

**Decision-Making Framework for the Selection and Design
Of Shading Devices**

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ABSTRACT

Most shading device systems installed in windows or glass walls are used only for protection from overheating and glare, neglecting other possible functions, such as increasing the daylight level in the space or collecting solar energy. The blinds are usually made of opaque or translucent materials, and if they are partially open/closed or completely closed, a direct view to the outside is blocked. A balance between a sufficient amount of daylight and protection from overheating of the space in summer is not often achieved due to inappropriate control of the blinds' tilt angle. There is also a need for specific guidance for the selection and design of shading device systems in the windows.

This research develops a general decision-making framework (DMF) that can be used by architects and manufacturers of shading devices. The general DMF is a guide for the user in analyzing shading device performance in the process of selection/design of the shading device. This research also develops a specific DMF to better understand and validate the general DMF. The specific DMF, based on illuminance and luminance, is used for an analysis of daylighting performance of shading devices to select the best possible existing system or new system among several alternatives. Architects or manufacturers of shading devices, as the users of the DMF, analyze various systems of blinds applied on a particular building and at a given location. The users of the DMF can apply either an experimental procedure or computer simulation that provides information about illuminance and

luminance levels in the space. Based on the analysis of the results of the experiments or simulations, the user of the DMF decides which blinds to select. The specific DMF proposes a methodology for both the analysis of the daylighting performance and for the process for making a decision based on the results of the analysis.

A case study is conducted in order to validate the DMF. Three types of shading devices are tested: an existing system, a patented system, and a new system, proposed by this research. The shading devices are installed in an office space located in Roanoke, Virginia. The software Autodesk VIZ 4 is used to simulate daylighting performance. The output information, such as illuminance and luminance levels in the space, is used as a basis for making the decision about which type of blinds to apply. A new system of shading device, which has a triangular cross section and is made of clear plastic with a silver coating on one side, shows better performance than the existing shading device and the patented shading device, given the research limitations.

By using the specific decision-making framework, a shading device manufacturer/designer is able to understand the shading device daylighting performance from his design-imposed criteria. Selection of the shading device, given the designer's daylighting objectives, is better achieved. Existing shading devices are also able to be analyzed from a building designer's perspective. This analysis is based on the designer-imposed daylighting criteria. The specific decision-making framework helps the designers of the buildings, together with the clients, select the most appropriate shading device based on daylighting performance. The decision-making framework is a model for development of decision-making software that will help designers of buildings, facades, and shading device systems in the selection/design of shading device systems in all phases of the design.

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1. INTRODUCTION

1.1 BACKGROUND

The shading device in a building is an important component of any conventional facade system, as well as the curtain wall system (both single-skin and double-skin facade). The shading device provides protection from direct sun and overheating in summer, thus reducing the cooling loads for the building. The shading device is also used for providing protection from glare and privacy.

Proper application of the shading device is especially important in curtain wall systems. Large glass areas are broadly used in contemporary architecture since glass provides direct visual contact between the inside and the outside, which has a significant psychological effect on building occupants. Glass also contributes to achieving a transparent look of the building.

Conventional curtain walls (single-skin facades) have been used to achieve these goals. But in the last 20 years double-skin facades have been gaining popularity because of their excellent thermal properties, ability to control solar radiation, energy-efficiency, high acoustical and daylighting performance, and opportunity to provide natural ventilation.

The shading device, as part of the fenestration system, is an important architectural element. The type and position of the shading device system are selected by the building designer, based on intuition rather than on the performance evaluation. The shading device can be installed in one of three basic positions:

- In front of the window, that is, in the exterior space
- Behind the facade, that is, in the interior space
- Between two glass panes in either:
 - a double insulating glass unit – in which the air cavity is a closed, non-ventilated system, or
 - the cavity between two glass layers in the double-skin facade – in a cavity that is from a few inches to 3 to 4 feet wide. The cavity can be either non-ventilated or ventilated by moving air naturally or mechanically.

The window, as a transparent facade element, transmits, reflects, or absorbs sunlight. The shading device, as a window component, should help in transmission, reflection, and absorbing the sunlight.

1.2 PROBLEM STATEMENT

- Existing shading devices currently available in the market have limited usage:
 - Shading devices are usually applied for protection from overheating in summer, for protection from glare, and for providing privacy.
 - Shading devices are rarely used as solar collectors. The shading device, which is installed in the cavity of a double-skin facade, can absorb solar energy and transfer energy to the air in the cavity. This warm air can be supplied to the HVAC system in winter or exhausted from the cavity to the outside space in the summer.
 - The shading device is rarely used as a thermal barrier. If the shading device blinds are insulated and in a closed position, blinds can be a very effective thermal protection during cold nights.
 - The shading device is not often used as part of a daylighting system. The shading device can redirect sunlight to spaces where daylight is needed, such as spaces that have a large distance from the window wall, and avoid the occurrence of glare.
- Another problem is that shading device slats are usually made of nontransparent materials. If the blinds are in a closed or partially closed/open position, the direct view to the outside is obstructed and transparency of the facade is not achieved.
- There is also a problem with appropriate control systems used to adjust the blinds' tilt angle. If the control of the blinds' adjustment is manual, problems occur if the occupants are absent from the room when the blinds need to be adjusted. Also, occupants very often close the blinds completely to protect space from overheating and glare, but at the same time the amount of daylight in the space is reduced and use of electric lighting is increased. As a result, the cooling loads are also increased. A balance between a sufficient amount of daylight and maximum overheating protection can hardly be achieved without the application of automatic control systems.
- There are no specific guidelines for architects in the selection of a shading device for a specific building.

- There are no specific guidelines for the design of new shading device systems – the manufacturers do not always apply a performance assessment in the process of designing a new system.

1.3 RESEARCH OBJECTIVES

The purpose of this research is to study and try to improve the performance of a shading device as part of a window system, by developing a decision-making framework (DMF). The building designer will use the DMF as an analysis tool in the process of the selection of existing shading device systems. The manufacturer will use the DMF in the process of the design of the new shading device system. Objectives of the research are as follows:

1. Develop the general decision-making framework for a shading device. The DMF is an analysis tool, which can be used in the selection and design of the shading device. The general DMF includes the following performance parameters: thermal, visual, acoustic, aesthetic, control, and cost.
2. Develop the specific decision-making framework that helps to validate the general decision-making framework. The specific decision-making framework includes only two performance parameters: illuminance and luminance.
3. Validate the specific decision-making framework for analysis in the process of selection and design of the shading device. Perform a case study for the different shading device systems to illustrate the specific DMF for illuminance and luminance.

1.4 RESEARCH METHODOLOGY

In order to accomplish research objectives, the following tasks are performed:

1. Develop the general decision-making framework for a shading device.

The tasks are to:

- Determine performance parameters for the shading device:
 - Categorize performance parameters for the shading devices.
 - Define subparameters related to the specific performance for each category of performance parameters.
 - Determine interactions and relationships among performance parameters.

- Determine variables that affect performance of the shading device:
 - Categorize variables that affect the shading device performance.
 - Determine subvariables for each category.
 - Determine relationships and interactions among variables that affect the shading device performance.
2. Develop the specific decision-making framework:
- Define and explain the two daylighting performance parameters: illuminance and luminance.
 - Define relationships among the illuminance and luminance.
 - Determine variables that affect the illuminance and luminance:
 - Categorize variables that affect illuminance and luminance.
 - Determine major variables as well as subvariables that affect illuminance and luminance for each category of variables.
 - Define relationships and interactions among these variables.
 - Identify measures for the variables and two performance parameters (illuminance and luminance) and sources of measures:
 - Identify measures for each variable and the two performance parameters: illuminance and luminance (that is, values and units, if applicable).
 - Identify sources of measures for each variable and for illuminance and luminance.
 - Create the specific DMF for the analysis in the process of selection and design of the shading device based on illuminance and luminance:
 - Define the decision problem.
 - Develop the influence diagram and the decision-making tree/chart.
 - Define the input and output parameters in the DMF and the relationship among them.
 - Describe the process of making a decision, based on the output data.
3. Validate the specific decision-making framework for the analysis in the process of selection and design of the shading device:

- Validate the specific DMF for selection of shading devices by performing a case study for the existing shading device systems and the patented shading device systems, and for the particular type of building and building location.
- Validate the specific DMF for design of shading devices by performing a case study for a new undeveloped shading device system. The new shading device is tested in order to analyze the effect of the shading device on the illuminance and luminance level in the space and to validate the specific DMF at the same time.

Validation is performed by using the software Autodesk VIZ 4, which calculates actual illuminance and luminance levels in the space as a result of the application of the specific types of the blinds in a proposed space.

1.5 RESEARCH CONTRIBUTION

The **primary** contribution of this research is the general decision-making framework (DMF). The general DMF is a guide for the user (building designer and/or manufacturer of the shading device) in analyzing the shading device performance in the process of the selection/design of the shading device. By developing the specific decision-making framework, the appropriate selection and the design of the shading device, based on illuminance and luminance, are achieved. This leads to the best possible daylighting performance of the shading device as a part of the window system, given the limitations of this research.

This research also has the following results that contribute to the current knowledge in the proposed area of study:

- The specific decision-making framework provides guidance for architects and clients for selection of the most appropriate shading device for the specific building type and location, based on the daylighting performance of the shading device.
- The specific decision-making framework provides guidance for the design of new shading device systems, which takes into consideration illuminance and luminance levels in the space.
- The decision-making framework is a basis for developing software for:
 - The selection of the best existing device among the several alternatives that can be used for the specific building, climate and site conditions.

- The selection of the best design among the several design alternatives of the new shading device system.

The software can be a helpful simulation tool in the conceptual design phase, as well as in the detail phase, of the building design and specifically the facade design.

1.6 RESEARCH LIMITATIONS

In the specific DMF, this research focuses only on the daylighting performance of the shading device and only on illuminance and luminance. A detailed investigation of other performance parameters for the shading device in the general DMF (such as thermal, acoustic, aesthetic, cost, and control) is subject for future research.

The research is conducted only for:

- An office building that contains VDT (video-display terminals)
- Horizontal Venetian blinds
- Roanoke, Virginia
- Climate conditions on March 21, June 21, December 21
- Two orientations: south and west
- Three times of the day – 11:00 a.m., 12:00 p.m., and 3:00 p.m. for south orientation, and 12:00 p.m., 2:00 p.m., and 4:00 p.m. for west orientation
- One fixed camera position at a task level, that is, one view of the three-dimensional space drawn by using Autodesk VIZ 4

Development of the computer simulation tool for the decision-making process for the selection/design of the shading device is a subject for future research.

This research focuses only on two daylighting performance parameters: illuminance and luminance in the specific DMF. The research does not analyze the occurrence of glare in the space.

The daylighting simulation is performed by using the software Autodesk VIZ 4, which has the capability to produce a three-dimensional image of the space and only illuminance and luminance levels. Autodesk VIZ 4 calculates reflection and transmission through transparent materials. Autodesk VIZ 4 works with surfaces so refraction and internal reflection are not fully represented. The new and patented blinds tested in this research are calculated as the hollow objects. Autodesk VIZ 4 has been validated only for accuracy of

direct illumination from IES sources. Autodesk VIZ 4 has not been validated for illuminance and luminance in complex environments by multiple reflections so the results of the simulation are biased. In this research, clear plastic is used as a material for the new and patented blinds. The Autodesk VIZ material library offers a ray-traced material--clear plastic--with 100% transmittance. Realistically, transmittance of plastic is between 82% and 92%, depending on the type and thickness of the plastic. Because of this limited modeling, results of the simulation are biased.

Software RADIANCE has also been considered as an option for the daylighting simulation, but the latest version of RADIANCE (version 3.5) runs under the UNIX operating system and is not user-friendly. The latest version of Desktop RADIANCE (DR) is version 2.0 beta, which has not been updated and has unfixed bugs. DR 2.0 beta runs under the Windows operating system. DR 2.0 was developed for Windows 95, Windows 98, and Windows 2000, and for AutoCAD R14 and AutoCAD 2000. Although the three-dimensional drawing of the building can be done in AutoCAD and then imported in DR 2.0, the blinds' geometry cannot be drawn in AutoCAD. An input for the blinds' geometry and materials should be done by adding the blinds to the text-based RADIANCE input files (for example, in MS-DOS). RADIANCE works with surfaces that are infinitely thin regardless of their real-life counterparts so the objects are hollow. Glass is also modeled as an infinitely thin, single-paned surface. By using a single surface in place of two, internal reflections are avoided. One transmitted and one reflected ray is produced. Simulation results are accurate for symmetric glass, but not for asymmetric (such as low-e glass). RADIANCE does not have a function for accurate calculation of transparent blinds. RADIANCE does not work well for glazing of a complex structure (with multiple reflecting elements in it). For transparent blinds, backward ray-trace software such as RADIANCE does not work. Forward raytracing should be used for the simulation of blinds. Blinds' modeling done by RADIANCE is accurate for a cloudy day but not for a sunny day. Calculations of the blinds by using RADIANCE is time-consuming and requires several Pentium Pro Linux workstations with a dual processor board.

Because of the previously mentioned reasons, RADIANCE is not used in this research.

1.7 DISSERTATION ORGANIZATION

This dissertation has six chapters that are organized in the following way:

Chapter 1 – Introduction: Gives the background information related to this research, defines the problems in the area of the study, and presents research objectives and methodology used to accomplish these objectives. Chapter 1 also explains contributions of the research and limitations of this study.

Chapter 2 – Literature Review: Gives an overview of the knowledge and results of the research in the areas that are related to this study. Chapter 2 reviews the daylighting performance parameters, and performance of the shading devices; standards, codes, and recommendations for lighting, shading, and controls; and existing and patented shading devices.

Chapter 3 – Decision-making Framework (DMF): Describes the structure of the DMF, how the DMF was developed from the general to detail level. Chapter 3 also explains qualitative and/or quantitative criteria for the variables and parameters and sources of measures for the variables and parameters in the specific DMF. In addition, chapter 3 gives the description of the decision-making process.

Chapter 4 – Validation of the Decision-making Framework: Describes the validation process and which tasks need to be performed in order to validate the specific DMF. This chapter also gives a description of the parameters of the case study used to validate the specific DMF.

Chapter 5 – Results of the Case Study: Describes different approaches that can be used to present the results of the case studies. In the second part of the chapter, an analysis of the results of the case study is given. The different ways of analysis of the results are presented.

Chapter 6 – Conclusions and Recommendations: Presents the results of the research and contributions of the research to the body of knowledge. Conclusions of this study are given and future research directions are recommended based on this investigation.

2. LITERATURE REVIEW

2.1 INTRODUCTION

The literature search is conducted to determine the current state of knowledge in the area of the study. The following areas are examined:

- Performance of shading devices
- Standards, codes, and recommendations
- Available shading device systems

The literature review on the performance of shading devices is conducted first because performance parameters that are used in the decision-making framework (DMF) need to be identified. The performance parameters are used as the criteria for the analysis of shading devices in the process of their selection or design for a particular building. After performance parameters are analyzed, standards, codes, and recommendations, which are related to daylighting and shading devices, are investigated. Standards are investigated to determine values for performance parameters that are used for evaluation of the shading device performance. At the end, the literature search on shading device systems is conducted to identify and classify both existing and the patented shading device systems.

Performance of shading devices is studied because the main criteria in the decision-making framework (DMF) are performance criteria, and particularly in the specific DMF, daylighting performance of shading devices. The terms “performance parameter” and “variable” are defined because the structure of the DMF includes performance parameters and variables related to a shading device. The literature review on the following daylighting parameters is presented: illuminance and luminance. Illuminance and luminance are used in the specific DMF for evaluation of daylighting performance of shading devices. Evaluation results are bases for selection of the preferred blinds for a particular building. Daylighting performance parameters are identified and defined, and the measurement procedure for each parameter is described. The literature search on available software for modeling daylighting performance is conducted because in this research software is used to calculate values of daylighting parameters. The two methods for daylighting modeling are investigated--radiosity and ray-tracing --to find which one is more appropriate to be used in the DMF. The SUPERLITE, RADIANCE, ADELIN, and Autodesk VIZ 4 software are analyzed to

determine features, advantages, disadvantages, and appropriateness of the software for this research. Based on this analysis, Autodesk VIZ 4 is selected as the preferred daylighting simulation software for this research.

A literature review of other research related to performance of a shading device is conducted to determine what results and findings have been achieved in this area of study. Thermal and daylighting performance of shading devices, as well as calculation methodologies, are explained based on the results of other research. These results and methodologies are used as a reference for the development of the methodology for testing daylighting performance of shading devices in this research.

A literature review on standards, codes, and recommendations for lighting, shading, and controls is conducted to determine the values for daylighting performance parameters used in the specific DMF. Standards for window size and daylighting are analyzed in order to recommend design principles to be used in the early stage of the design of the building to achieve better daylighting performance of the window assembly. Recommendations for window size are used as input for building variables in the DMF. A literature review on standards for lighting includes standards for illuminance and luminance because values of daylighting performance parameters given by standards are used as the reference in the DMF. These values are used in the process of evaluation of the shading device performance. Standards for shading are used in this research to make the user of the DMF aware of the necessity to apply shading systems on a particular building. Appropriate application of a shading device improves the daylight level in the space and provides protection from overheating and glare. Standards for controls are investigated to determine recommendations for the control systems that help in achieving energy savings for lighting.

A literature review on shading device systems was conducted because it was necessary to determine which existing systems are currently available on the market, as well as which shading device systems have been patented. An overview of the shading devices installed in the cavity between two panes of glass in the double insulating glass unit or in the cavity in the double-skin facade is given because the between-glass shading devices are waterproof and maintenance-free and can achieve the same performance as shading devices installed on the interior or exterior side of the window. Existing shading devices are classified based on the blinds' material (aluminum, wood, polycarbonate, and photovoltaic cells) and the

direction of the slats (horizontal or vertical). Patented shading device systems made of transparent materials are studied because this research objective is to provide transparency of the facade by designing a new transparent shading device. Two basic types of patented transparent shading device systems are analyzed -- moveable and fixed -- to find whether or not fixed blinds can achieve a required performance. Fixed blinds do not contain a control mechanism for adjustment of the blinds' position, thus fixed blinds are less expensive than moveable blinds. Blinds are also classified based on the shape of the cross section of the slat because blinds with different cross sections have different daylighting performance.

One of the reviewed existing systems and one of the reviewed patented systems are later tested in the process of validation of the specific DMF (refer to Section 4.3.10. Description of the shading device systems). Also, knowledge about the existing shading devices and the patented shading devices is a background for the development of the new shading device system, which is proposed by this research (see also Section 4.3.10.). The proposed new blinds are used to validate the specific DMF.

A literature review on basic optical physics (refer to Appendix A.1: Basic Optical Physics) was conducted because principles of optics, such as reflection, refraction, and total internal reflection, are used for the design of the new blinds proposed by this research.

2.2 PERFORMANCE OF SHADING DEVICES

In this chapter, a literature review on the performance of shading devices is introduced because selection of the shading device in the decision-making framework (DMF) is based on the analysis of the performance of the shading device. In the first part of this chapter, definitions of the terms “performance parameter” and “variable” are given because the structure of the DMF includes performance parameters and variables related to a shading device. In the second part of this chapter, daylighting performance parameters are explained because this research focuses only on daylighting performance of a shading device in the specific DMF. Also, available software used for the modeling of the daylighting in the space is investigated because the software for simulation of the blinds’ daylighting performance in the specific DMF must be selected. In the third part of this chapter, other research on the thermal and daylighting performance of a shading device is analyzed because the results of other research give information about the blinds’ performance, as well as calculation methodologies for the performance parameters. These results are strong background for the development of the methodology for investigating the blinds’ performance in the DMF and in this research.

2.2.1 PERFORMANCE PARAMETERS AND VARIABLES IN THE DECISION-MAKING FRAMEWORK

The structure of the decision-making framework created by this research includes performance parameters and variables related to the shading device. The performance parameter is a measurable factor that defines a shading device system and determines its behavior. Performance is the way in which the shading device functions. The performance parameter’s value varies based on the values of the input variables (independent, dependent, and shading device variables). The performance parameters considered in the general DMF include thermal, visual, acoustic and aesthetic performance, cost, and control strategy. The performance parameters of the shading devices analyzed in the specific DMF include illuminance and luminance.

“A variable is some property of an event in the world that has been measured. A variable is an aspect of a testing condition that can change or take on different characteristics with

different conditions.¹” In this research, all factors that affect performance of the shading device, that is, values of performance parameters, are called “variables.” For the purpose of this research, variables are organized in three categories:

- Independent: variables that are given to the user of the DMF and cannot be changed. The independent variables cause the values of the dependent variables and shading device variables.
- Dependent: variables that depend on the values of the other variables, that is, in this research, independent variables.
- Shading device variables: in this research, shading device values are given, that is, independent, in the process of selection of the shading device, or they are chosen, that is, dependent, in the process of the design of the shading device.

2.2.2. DAYLIGHTING PERFORMANCE PARAMETERS FOR SHADING DEVICES

In the general decision-making framework (DMF), six performance parameters are used to evaluate different shading device systems. To validate the general DMF, the specific DMF is created as a part of the general DMF. The specific DMF included only two performance parameters: illuminance and luminance. This research could have focused on any of the six performance parameters to develop the specific DMF. However, this research focuses only on the daylighting performance of the shading devices, specifically illuminance and luminance. Daylight has an important effect on the occupants of the buildings, the occupants’ behavior and well-being in the space. As one of the sustainable strategies, daylight contributes to energy savings by reducing the use of electric lighting and decreasing the cooling loads in the building. Daylighting has a significant aesthetic effect in the interior space. The appropriate use of shading device systems can improve the daylight level in the space. For these reasons, daylight performance parameters, (illuminance and luminance) are selected to be analyzed in the specific DMF.

In this chapter, daylighting performance parameters (illuminance and luminance) are explained in detail because they are used in the specific DMF for the evaluation of shading devices. Definitions, units, methods of calculation/measurement, and presentation of the parameters are shown to understand what the analyzed parameters include and how to

¹ McBurney, D.H. *Research Methods*. Brooks/Cole Publishing Company (1994)

measure the parameters in the specific DMF. In the second part of this chapter, software packages that are currently used for modeling of daylighting performance are described because it is necessary to select the method of testing the blinds' performance in the specific DMF. Based on the features, advantages, and disadvantages of the described software, Autodesk VIZ 4 is selected as the most appropriate software for this research.

2.2.2.1 Daylighting performance parameters

Daylighting performance parameters of the shading device system analyzed in this research include illuminance and luminance.

The main objective of the shading device system is to provide a sufficient amount and quality of daylight for the interior space, which reduces electrical energy for artificial lighting and decreases cooling loads.

Daylighting performance parameters of a shading device can be used to determine whether or not the shading device system achieves its proposed objectives. Performance parameters need to be defined and assigned a particular range of values, which can be compared to reference values, such as those proposed by the active standards and codes for daylighting.

The user of the DMF has a possibility to prioritize performance parameters in the decision-making process. Depending on the building type and climate, for instance, importance can be given to illuminance levels rather than protection from glare.

2.2.2.1.1 Illuminance

Illuminance is the performance parameter that is used to measure the quantity of light in the space. Illuminance levels in the space decrease asymptotically with increasing the distance from the window toward the depth of the space.

By definition, “illuminance is the density of luminous power”¹ or “the luminous flux incident on a surface per unit area.”² A unit is lux, that is, *lumen per square meter area*. A unit of luminous flux is lumen. According to the definition: “If we take a 1 candela source that radiates light equally in all directions and surround it with a transparent sphere of 1

¹ Stein, B. and Reynolds, J. *Mechanical and Electrical Equipment of Buildings*. John Wiley & Sons, (2000)

² *Daylight in Buildings: A Source Book on Daylighting Systems and Components*. LBNL (2000)

meter radius, then the amount of luminous energy (flux) emanating from 1 square meter of surface on the sphere (lumen) is 1 *lumen*.”¹

The IESNA² defines recommendations for the ranges of illuminance levels in the space based on:

- Task difficulty
- Eye of the observer
- Requirements for speed and accuracy
- Reflectance of the task background

For paper-based tasks, such as reading and writing, task illuminance levels can exceed recommended lighting levels by the factor 2 or more if glare does not occur and heat gain/cooling loads are not increased.

Daylight factor (DF) can be used to measure quantity of light. The daylight factor is defined as, “the ratio between the illuminance measured indoors at a reference point (for example, work plane) and the outdoor global illuminance on an unobstructed, horizontal surface.”³

$$DF = \text{indoor illuminance} / E_H$$

Where E_H – is unobstructed horizontal illuminance

DF – daylight factor given in percentage

The daylight factor can be used:

- For cloudy sky conditions
- For clear sky conditions with fixed distribution of light
- Where luminance distribution is known

The daylight factor cannot be used:

- For partly cloudy skies with constantly changing luminance
- For direct sun condition

¹ Stein, B. and Reynolds, J. *Mechanical and Electrical Equipment of Buildings*. John Wiley & Sons, (2000)

² Illuminating Engineering Society of North America

³ *Daylight in Buildings: A Source Book on Daylighting Systems and Components*. LBNL (2000)

The minimum daylight factor is recommended for the specific task. The minimum DF in any part of the interior space should be larger than 0.5%. Also, the ratio between the minimum and average daylight factors, which relates to the contrast ratios in the space, should be more than 30%. The daylight factor method can be used for the analysis of the daylight distribution for different fenestrations and facade orientations.

The daylight factor can also be calculated by applying the formula:

$$DF = SC + ERC + IRC^1$$

Where SC – sky component – portion of the total daylight at a point that is received directly from the area of the sky that is visible through the window

ERC – light reflected from the exterior obstructions onto the point under consideration

IRC – light reflected from interior and exterior surfaces at the point under consideration

Daylight can be graphically represented by plots of contours that show relative daylight levels in the space. If any of the variables change, such as fenestration dimensions, height of the working plane, and reflectance of surface, then daylight factor plots must be redrawn. If daylight factors are known, then work plane illuminance can be calculated by multiplying DF by the exterior sun or sky component.²

The ASHRAE/IES standard 90.1³ uses recognition of fatigue and task familiarity as factors in determining illuminance levels. This standard recommends use of daylight for the space illumination and use of task/ambient lighting design as the lighting strategy if high levels of task lighting are needed. The IESNA⁴ gives task illuminance recommendations based on the relationship between illuminance and luminance.

The required illuminance can be calculated by using the following formula:

$$L = E * RF / \pi$$

¹ Stein, B. and Reynolds, J. *Mechanical and Electrical Equipment of Buildings*. John Wiley & Sons, (2000)

² *Daylight in Buildings: A Source Book on Daylighting Systems and Components*. LBNL. (2000)

³ ASHRAE Standard 90.1 – Energy standard for buildings except low-rise residential buildings. American Society of Heating, Refrigerating and Air-conditioning. Atlanta (2001)

⁴ IESNA – Illuminating Engineering Society of North America

Where L – luminance unit=cd/m²
 E – illuminance unit=lux
 RF – reflection factor

2.2.2.1.2 Luminance

The distribution of light illuminance and luminance shows “how lighting varies from point to point across a plane of surface.”¹

By definition, luminance “is the luminous intensity per unit of apparent (projected) area of primary (emitting) or secondary (reflecting) light source.”² The unit of luminance is *candela per square meter* (cd/m²), which shows that luminance varies with both intensity and area.

By definition, luminous intensity is a “pressure and represents the force that generates the light that we see.”³ Intensity does not change with variations in the area or distance, but it depends on transmission factors. The unit of intensity is *candela* (cd).

A certain level of uniform light distribution across the task plane is desirable. The non-uniform distribution of illuminance and luminance can cause an uncomfortable lighting condition.

Uniformity of light distribution is measured by illuminance and luminance ratios, such as *maximum-to-average* or *average-to-minimum*. They are measured across a horizontal work plane at a height of 0.8 m above the floor. The IESNA recommends *maximum contrast ratios* among task, background, and remote surfaces.

Contrast is one of the most important factors that affects good visibility since the eye perceives only the contrast. Contrast (or luminance ratio) is a dimensionless ratio and can have values from 0 (no contrast) to 1.0 (maximum contrast). Contrast can be calculated by using the following formula:

$$C = |(L_B - L_T) / L_B|$$

Where C – is contrast
 L_B – is luminance of background

¹ *Daylight in Buildings: A Source Book on Daylighting Systems and Components*. LBNL (2000)

² Stein, B. and Reynolds, J. *Mechanical and Electrical Equipment of Buildings*. John Wiley & Sons, (2000)

³ Stein, B. and Reynolds, J. *Mechanical and Electrical Equipment of Buildings*. John Wiley & Sons, (2000)

L_T – is luminance of task

Since luminance can be calculated by multiplying illuminance and reflectance, contrast can be determined by applying the following formula:

$$C = |(R_B - R_T) / R_B|$$

Where R_B – is reflectance of the background

R_T – is reflectance of the task

If the contrast between the task and background is high, visibility is independent of illumination. For good visibility, a ratio of 3:1 between task luminance and background luminance is acceptable, while a ratio 1:1 is recommended.

The light illuminance profile throughout the space can be either measured or simulated, and contrast ratios can be calculated. The illuminance profile can be used to show how advanced shading device systems provide uniform distribution of light throughout the space compared to conventional windows. All daylighting strategies use luminance distribution from the sun, sky, and ground, as well as surrounding buildings. The window and shading device design affects the distribution of the daylight throughout the space.

Another important factor that affects good visibility is adaptation of the human eye to the changes of brightness levels. “The human eye detects luminance over an astonishing range of more than 100 million to 1, the lower level being accomplished after an adjustment period called *adaptation time*.”¹ The visibility increases with an enhanced adaptation level since visibility represents the ability to make a difference between various luminance levels. “At high adaptation levels, apparent brightness is lower than actual brightness, and vice versa.”² If the difference between the luminance of the task and the background is kept low, then the rapid changes in eye adaptation level would be avoided.

2.2.2.2 Available software for modeling daylighting performance

Available software for the modeling of daylighting performance is described in the following section because the most appropriate software to be used to simulate daylighting performance of blinds in this research needs to be selected. The two calculation methods are

¹ Stein, B. and Reynolds, J. *Mechanical and Electrical Equipment of Buildings*. John Wiley & Sons, (2000)

² Stein, B. and Reynolds, J. *Mechanical and Electrical Equipment of Buildings*. John Wiley & Sons, (2000)

radiosity and ray-tracing. Radiosity and ray-tracing are computer simulation techniques that are used for modeling of daylight distribution through the window with the shading device installed in it. The software SUPERLITE based on the radiosity method, as well as the software RADIANCE based on the ray-tracing method, are described. The software packages ADELIN and Autodesk VIZ 4 integrate the radiosity and ray-tracing methods. The four software programs are introduced in this section in order to compare them based on their features, advantages and disadvantages, and appropriateness for this research. A comparison of the software results in the selection of Autodesk VIZ 4 software to be used in the DMF.

Radiosity method

The **radiosity method** is a lighting simulation technique used for calculation of illuminance and luminance in the interior space. A calculation can be done for a set of points that are located at the centers of different surfaces. The advantage of the radiosity method (for example, compared to the ray-tracing method) is that the calculation of illuminance and luminance can be done independently of view before any rendering of the surfaces is done from the desired viewpoint.

The hypothesis and limitations of the radiosity method are as follows¹:

- Wall surfaces must be divided into small finite elements that have homogeneous photometric properties (for example, reflection coefficient).
- All elements must be perfect diffusers.
- A similar hypothesis should be used for all external obstructions that are located in front of the fenestrations.

The software **SUPERLITE**²³ developed by LBNL⁴ is based on the radiosity method. SUPERLITE is a simulation tool that calculates *illuminance levels* in the interior spaces that are the results of the use of daylight and electric lighting systems. This software can be used by lighting designers and researchers for analysis of illuminance distribution in architectural spaces. SUPERLITE is MS-DOS-based software. Output information provided by SUPERLITE software is as follows:

¹ *Daylight in Buildings: A Source Book on Daylighting Systems and Components*. LBNL (2000)

² Website: <http://eetd.lbl.gov/btp/superlite20.html>

³ This software was prepared as an account of work sponsored by an agency of the United States Government. Copyright © 1994 Regents of the University of California - Lawrence Berkeley National Laboratory

⁴ Lawrence Berkeley National Laboratories

- Hourly illuminance distribution on the work plane under given sky conditions for one day per month
- Daylight factor profiles
- Hourly energy consumption for general lighting needed to provide required illuminance level
- Annual relative daylighting hours
- Annual switch-on time of electric lighting

Advantages of SUPERLITE are as follows:

- SUPERLITE can be used for geometrically complicated architectural spaces
- SUPERLITE calculates daylight levels from both:
 - Diffuse sources of outdoor illumination, the sky, and the ground
 - Direct sunlight in the room
- SUPERLITE can use various window glazing as input:
 - Clear glass
 - Diffusing glass
 - Clear glass with a diffusing sheer curtain
- The solar and weather data can be supplied as input in three ways:
 - By supplying the appropriate sky conditions. The sky models that can be used by this software are:
 - o Uniform sky
 - o CIE standard overcast sky
 - o CIE standard clear sky, with or without direct sun
 - By specifying geographic data, such as:
 - o Latitude and longitude
 - o Time and date of the simulation under the given sky conditions
 - By specifying the solar position (altitude and azimuth angles) under given sky conditions.
- SUPERLITE also calculates the contribution of electric lighting to the illuminance of the space. A lighting fixture is given as candlepower distribution files.

- Illuminance levels, as a result of daylight, electric light, and reflected light, are calculated for nodal points on arbitrary work planes, whose orientation and location are defined by the user.
- Data are given numerically in terms of *illuminance levels* and *daylight factor* in tabular format.
- Since results can be obtained in very short time (for example, 5 minutes), SUPERLITE is useful in the preliminary design phase.

Disadvantages of SUPERLITE are as follows:

- SUPERLITE is not user-friendly software since it uses DOS operating system, and all input and output data can be accomplished only through the text files.
- SUPERLITE assumes that all reflection of light by surfaces is perfectly diffuse although some surfaces can be semi-specular.
- SUPERLITE assumes that the luminous flux that enters the room has a uniform spectral distribution and that flux reflection by surfaces is uniform over the entire visible spectrum.
- SUPERLITE assumes that scattering or absorption of light cannot take place other than at room surfaces.
- Number of surfaces, windows, and nodes is limited:
 - The maximum total number of surfaces is 30.
 - Each window consists of two surfaces.
 - Each room contains five windows.
- Colors of the surfaces are not taken into account (all surfaces are considered as black and white)
- Complex fenestration systems, such as Venetian blinds and light shelves, cannot be simulated.
- Partly cloudy sky conditions cannot be simulated.
- Electric lighting calculations cannot be thoroughly examined.

The update of SUPERLITE 1.0 is the software package SUPERLITE IEA 1.0 that is used as part of the ADELIN software. SUPERLITE IEA 1.0 has the following advantages (compared to SUPERLITE)¹:

- Modeling of multi-zones with radiative transfer
- Modeling of shading/obstructions
- Modeling of internal windows
- Input and output given in SI units
- Optimized running time
- Graphical input and output

SUPERLITE can be *useful* for this research since it calculates illuminance levels and analyzes illuminance distribution in architectural spaces. SUPERLITE also calculates and gives profiles of daylight factors. It can also be useful if quick analysis of daylight performance in the space is needed. The problem with SUPERLITE is that it cannot simulate Venetian blinds. This can be avoided by using the software SUPERLITE IEA 1.0 (which is part of the Adeline software) since it can model shading devices.

Ray-tracing method

The **ray-tracing method** is a lighting simulation technique that determines the visibility of surfaces by tracing imaginary rays of light from a viewer's eye to the objects of a rendered scene.² Light rays are traced until they reach the main daylight source, which can be:

- The sun position: clear and intermediate skies
- Sky vault: cloudy skies

Some software programs apply different simulation techniques to improve daylighting calculations, especially for clear sky (with sun) conditions. A forward ray-tracing technique is used by some software programs, such as Genelux, which traces rays from the light source to a scene.

The ray-tracing method has the following properties³:

¹Website: <http://radsite.lbl.gov/adeline>

² *Daylight in Buildings: A Source Book on Daylighting Systems and Components*. LBNL (2000)

³ *Daylight in Buildings: A Source Book on Daylighting Systems and Components*. LBNL (2000)

- The method accounts for every optical phenomenon that can be analytically expressed by physical equations.
- The method can consider specular materials (such as window panes and glossy surfaces).
- The method can simulate non-homogeneous textures and surface points.

The software **RADIANCE**^{1, 2} is based on the ray-tracing method. RADIANCE is used by architects and designers for calculation of light levels and rendering images, which can help in predicting the appearance of the space before its physical construction. RADIANCE is used for an accurate prediction of light behavior in the particular space. RADIANCE calculates radiance values, that is, the quantity of light that passes through the particular point in a particular direction. Light rays are traced from a measurement point, which is usually an observer viewpoint, backwards to the light sources. When the light path is found, then *luminance* associated with each ray can be calculated by using:

- The candle power distribution of the light source
- The reflective properties of the intervening surfaces

The user's *input* includes the following elements:

- Three-dimensional geometry of surfaces: it considers N-sided polygons, spheres, cones, cylinders, and rings.
- Characteristics of materials: predefined types of materials are used (such as plastics, metal, and glass), but their patterns and textures can be modified. Reflectance and transmittance properties of materials are also specified.
- Characteristics of light sources: light sources are simulated as emitting surfaces whose output distributions are taken either from photometric measurements or computed separately.

The *output* of a RADIANCE simulation is a photorealistic color image which contains a numeric prediction of light levels at any point in the scene.

¹ Website: <http://radsite.lbl.gov/radiance/HOME.html>

² RADIANCE is a highly accurate ray-tracing software system for UNIX computers that is licensed at no cost to users for non-commercial use; commercial use licenses, including distribution rights, are available for a fee. RADIANCE was developed with primary support from the U.S. Department of Energy and additional support from the Swiss Federal Government. It is copyrighted by the Regents of the University of California.

RADIANCE needs only one light source and one surface to calculate an image. First, color and optical properties of each surface are determined by the user. After that, the user defines:

- For electric light sources: photometric data
- For daylighting: latitude, longitude, calendar day, and time of day

When the final scene is calculated, the user must define viewpoint, exposure, and other image parameters in order to start software calculations. The calculation of light provided by RADIANCE consists of the following components:

- Direct component: consists of light which arrives at a surface *directly* from the light source
- Specular component: consists of light which arrives at a surface from other surfaces and being reflected off or transmitted through with directional preference
- Diffuse component: consists of light which arrives at a surface from other surfaces and being reflected off or transmitted through without directional preference

Advantages of RADIANCE are as follows:

- RADIANCE provides a digital view of an illuminated space, excluding the need for the physical model.
- RADIANCE can promote an energy-efficient lighting design by demonstrating the visual effect of electric lighting sources, daylighting, and control systems.
- In addition to a calculation of illuminance level in diffuse environments, RADIANCE considers reflections from shiny surfaces.
- RADIANCE calculates interreflections between surfaces and contributions from spatially distributed sources (for example, sky).
- Colors of the surfaces are considered.
- Accuracy of the results is higher.

Disadvantages of RADIANCE are as follows:

- RADIANCE is not a user-friendly program since it uses the UNIX operating system and text files, which means that numerical spatial coordinates of the shapes should be given.
- Problems with using the CAD program with RADIANCE include:

- The CAD file must be converted to a text file, which is then converted to the RADIANCE text file.
- The CAD file does not include information about materials, light sources, and geographic location.
- When CAD geometry is translated for RADIANCE, materials can be created and applied to surfaces.
- RADIANCE works with surfaces that are infinitely thin regardless of their real-life counterparts so the objects are calculated as hollow, not solid. Glass is also modeled as an infinitely thin, single-paned surface.
- RADIANCE does not have a function for accurate calculation of transparent blinds and glazing of a complex structure that has multiple reflecting elements in it.
- Since electric lighting fixtures must be placed in the scene, their photometric characteristics must be defined, and fixtures must be positioned correctly.
- There are difficulties with simulating reflection of intense light from curved specular surfaces (for example, parabolic light fixtures). In order to compute light from such a system, a forward ray-tracing technique should be used, that is, light is traced from the light source and is moved outward. A separate calculation is necessary for these distributions because RADIANCE uses a backward ray-tracing technique.
- Simulation running time is longer.

RADIANCE can be *useful* for this research since it calculates illuminance and luminance levels and gives a photorealistic color image with a numeric prediction of light levels, that is, it gives both numeric and graphical output. RADIANCE is appropriate for a high accuracy analysis of daylight performance in the architectural space.

The **ADELIN**¹ software is a simulation tool used by architects and engineers for lighting design in interior spaces. ADELIN² solves problems for both daylighting and electric lighting systems:

¹ Website: <http://radsite.lbl.gov/adeline/HOME.html>

² ADELIN is an integrated lighting design computer tool developed by an international research team within the framework of the International Energy Agency (IEA) Solar Heating and Cooling Programme Task 12. Copyright 2002 Fraunhofer-Institut für Bauphysik

- For daylighting: the standardized CIE sky distributions can be taken into consideration.
- For electric lighting: the luminous intensity distribution curves of any light source can be taken into consideration.

ADELIN helps architects and designers in the early design stage to predict the impact of daylighting on energy performance of the buildings. ADELIN uses the following input data:

- Geometric
- Photometric
- Climatic
- Optic
- Human response

Output of the lighting simulations is both numeric and graphic:

- Physically exact photorealistic images of the building
- Illuminance and luminance distributions
- Visual comfort evaluations

The design process executed by the application of ADELIN consists of the following steps:

1. Defining the objectives: for both lighting strategy and architectural purposes.
2. Input geometry: numerical model of the building is made by using the SCRIBE modeler. It produces two- and three-dimensional drawings of closed polygons. Every surface of the model can be assigned specific properties, such as color, roughness, reflectance, absorptance, and so forth. An interface program converts CAD input information on geometry and materials into a different input format used by SUPERLITE, RADIANCE, and SUPERLINK.
3. Input material properties: by using PLINK, which helps in assigning photometric characteristics to each component of the model. PLINK has a material database which, for example, consists of opaque surfaces (concrete, brick, wood, metal) and transparent and translucent surfaces (glass, plastic).
4. Defining climate: by using PLINK various climatic conditions can be used. The following climatic parameters can be used:

- Direct sunlight
 - Diffuse/global clear skies
 - Uniform/CIE standard overcast skies
 - Cumulative or “average” skies
5. Simplified analysis: performed by SUPERLITE, which gives results of *illumination level* and *daylight factors* on the work plane.
 6. Integrated energy analysis: performed by SUPERLINK and RADLINK, which provide evaluation of interaction between daylight, electric light, and the building dynamic thermal performance. Daylighting calculations done with SUPERLITE (for SUPERLINK) or RADIANCE (for RADLINK) are used as a basis for simulation. Energy performance results obtained by SUPERLINK/RADLINK programs can be used with building thermal simulation programs, such as DOE and TRNSYS.
 7. Detailed analysis: performed by RADIANCE, which gives three-dimensional images with a different lighting environment and provides quantitative analysis (for example, visual comfort evaluation).
 8. Illuminance analysis: two- or three-dimensional graphics give light distribution, and results are presented in the form of iso-lux or iso-daylight-factor curves. A two-dimensional building section can be used for the light penetration analysis.
 9. Luminance analysis: qualitative analysis of luminance distribution can be done by the program. Three-dimensional images are displayed based on the eye’s sensitivity. Luminance levels given in cd/m^2 can be determined for each point of the picture. Also, potential glare sources are identified.
 10. Comfort evaluation: visual comfort analysis can be performed by the program by calculating different glare indexes for a rendered image. This comparison includes determining values for:
 - CIE glare index (CGI)
 - Guth Visual Comfort Probability (VCP)

Advantages of ADELINe are as follows:

- ADELINe calculates:
 - Illuminance and luminance distribution
 - Illuminance levels and daylight factor (by SUPERLITE)

- Glare indexes and visual comfort probability for a rendered image
- Energy performance (by SUPERLINK)
- ADELINe provides a photorealistic image of the architectural space.
- ADELINe gives three-dimensional images of daylight level in the space (by using RADIANCE).
- ADELINe gives two-dimensional and three-dimensional graphics of the luminance distribution in the space.
- ADELINe integrates advantages of the ray-tracing technique (for example, RADIANCE) and the radiosity technique (for example, SUPERLITE)

Disadvantages of ADELINe are as follows:

- Building model is numerical (made by using the SCRIBE modeler).
- CAD input file cannot be used directly. It must be converted to the format that can be used by SUPERLITE, RADIANCE, and SUPERLINK.
- ADELINe does not simulate partly cloudy conditions.

ADELINe can be *useful* in this dissertation since it calculates illuminance and luminance distributions in the space, and it gives three-dimensional photorealistic images of the distributions. ADELINe is also useful because it identifies potential glare sources in the space. It also calculates glare indexes and visual comfort probability, which cannot be done by RADIANCE or SUPERLITE. ADELINe would be an appropriate software for this research since it integrates advantages of the ray-tracing and radiosity methods.

Autodesk VIZ 4¹ software integrates two lighting algorithms in order to accurately model lighting in the space:

- Ray-tracing
- Radiosity

In the Autodesk VIZ 4 software, radiosity is used for rendering diffuse-to-diffuse inter-reflections while ray-tracing is used for specular reflections. Autodesk VIZ 4 calculates illuminance and luminance levels in the space. The user's input includes the following elements:

- Three-dimensional geometry of the space and elements in the space

¹ Autodesk VIZ 4 Copyright 2004 Autodesk, Inc.

- Choice of materials which also defines their reflectance/transmittance properties
- Daylighting parameters: sun position and sky conditions

The output of Autodesk VIZ 4 is a photorealistic three-dimensional image of the space with illuminance and luminance levels defined by the range of colors.

Pseudo Color Exposure Control is actually a lighting analysis tool that provides you with an intuitive way of visualizing and evaluating the lighting levels in your scenes. It maps luminance or illuminance values to pseudo colors that show the brightness of the values being converted. From darkest to brightest, the rendering shows blue, cyan, green, yellow, orange, and red.¹

Advantages of Autodesk VIZ 4 are as follows:

- Autodesk VIZ 4 provides a realistic digital three-dimensional view of the space.
- Autodesk VIZ 4 takes into consideration daylighting and electric lighting in calculating illuminance and luminance levels in the space.
- Autodesk VIZ 4 considers color of the surfaces.
- Autodesk VIZ 4 is a user-friendly software.
- AutoCAD files are easily imported to Autodesk VIZ 4.
- The shading device can be easily simulated by making an input of a three-dimensional model of the blinds and defining materials.

Disadvantages of the Autodesk VIZ 4 software are as follows:

- Autodesk VIZ 4 does not calculate the glare.
- Simulation time is very long, even for the simple spaces.
- Autodesk VIZ 4 works with surfaces so refraction and internal reflection are not fully represented.²
- Autodesk VIZ 4 has been validated only for accuracy of direct illumination from IES sources. It has not been validated for illuminance/luminance in complex environments with multiple reflections.³

Autodesk VIZ 4 is useful for this dissertation since it calculates illuminance and luminance levels in the space and gives a three-dimensional photorealistic picture of the space with numerical values of light levels in the space.

¹ Autodesk VIZ 4 User Reference

² Based on the information obtained from Rod Recker, one of the developers of Autodesk VIZ.

³ Based on the information obtained from Rod Recker, one of the developers of Autodesk VIZ.

2.2.3. OVERVIEW OF THE ANALYSIS OF DAYLIGHTING AND THERMAL PERFORMANCE OF THE SHADING DEVICE

Other research conducted in the area of the performance of shading devices is explained in the next section. Most of the research is related to thermal and daylighting performance of various shading device systems. Some of the research introduces methodologies for calculation of daylighting and thermal performance without a need to perform the experiments. Objectives, methodology, results, and conclusions of each research project are described. Additional research in the area of the performance of the shading device is important for this dissertation because it helps in understanding various methodologies used in analyzing the performance of the shading device. Also, results of other research help in designing new shading device systems, and their applications provide a higher level of daylighting in the space.

Lee et al. (1998) conducted research whose objective was to prove that automated Venetian blinds have better thermal and daylighting performance than the static shading device, and they can achieve savings in both cooling loads and lighting energy. Lee et al. used an experimental approach by installing two identical automated Venetian blind systems in two rooms of an office building in Oakland, California. Both blind systems had a southeast orientation. The blinds were 0.5 in. wide, made of white aluminum, had a curved shape, and were installed inside the room. The blinds were not retractable and only the angle of the slats could be changed. The base case system and the prototype system of the blinds were compared, and cooling loads and lighting energy consumption were measured for both cases.

In the base case system, the blinds were set in one of three fixed, static positions: 0°, 15°, and 45° throughout the day. The base case system simulated manual control of the blinds. The base case system was tested for two cases: without daylighting control and with daylighting control. In the prototype system, the blinds were moveable (dynamic) and automatically controlled. Their position was changed every 30 seconds to block direct sun and maintain a designed daylight level in the interior. The dynamic system was tested with daylighting controls.

The results of the experiment that was conducted for one year show:

1. *For the base case and prototype with the same daylighting controls*

- The prototype system achieved reductions of:
 - 21% in cooling loads
 - 13% in peak cooling loads
 - 21% in lighting energy
 compared to the base case system with a 0° tilt angle of the blinds.
- The prototype achieved reductions of:
 - 13% in cooling loads
 - 13% in peak cooling loads
 - 22% in lighting energy
 compared to the base case system with a 15° tilt angle of the blinds.
- The prototype achieved reductions of:
 - 4% in cooling loads
 - 8% in peak cooling loads
 - 46% in lighting energy
 compared to the base case system with a 45° tilt angle of the blinds.

The solar gain was controlled almost equally by the partly closed base case blinds and by the prototype blinds. The prototype blinds maintained the higher level of illumination of the interior space for a longer period than the partly closed base case blinds.

2. *For the base case without daylighting control and prototype with daylighting control*

- the prototype system achieved reductions of:
 - 28±5% in cooling loads
 - 28±6% in peak cooling loads
 - 22-86% in lighting energy
 compared to the base case system with any tilt angle of the blinds.

Lee et al. concluded that:

- Prototype (dynamic) blinds have a performance comparable to the most open fixed blind (with a tilt angle of 0°), and better performance than the fixed blinds with 15° and 45° tilt angles for the full range of exterior illuminance during the year.

- Prototype (dynamic) blinds reduce the cooling loads and at the same time provide good control of direct sun and a sufficient amount of daylight. They are capable of optimizing balance between daylighting and solar heat gains. The base case (static) system could not achieve this balance.
- For manual operation of fully retracted blinds, lighting savings can be decreased, but cooling load would increase.
- For lower transmission glazing or for smaller glazing areas, cooling load and lighting energy savings can decrease slightly.
- In the cases of between-glass blinds and external dynamic shading devices, substantial cooling load reductions can be achieved with almost the same lighting energy savings.
- The dynamic system has several advantages compared to the fixed system:
 - It blocks direct sun.
 - It provides a view to the outside when there is no direct sun.
 - It provides controlled illumination of the interior space during the day.

Scuito (1998) explains the project SOLAR CONTROL that had a goal to investigate the performance of shading devices in order to improve knowledge in this area and provide support to the industry and final user. The objectives of the projects were to provide:

- Proposal of prenormative testing standards for shading devices: different types of shading devices, such as external, interpane and internal, isotropic, and nonisotropic, were determined for the assessment of their thermal, daylighting, and ventilation performance.
- Development of new validated algorithms of the shading devices' behavior in respect to solar and visible radiation and ventilation. The new algorithms should be integrated in existing simulation models.
- Development of new solar control systems that will be integrated into the building envelope.
- Preparation of the *Handbook of Design Guidelines and Shading Components* for European architects and building designers.

The following tasks were performed in order to accomplish the proposed objectives:

- Thermal and optical performance investigation: by conducting experimental measurements.
- Daylighting performance investigation: by conducting experimental measurements.
- Investigation on the shading devices' impact on natural ventilation of building spaces: by conducting experiment.
- Development and implementation of a smart control system that will manage both shading devices and lighting.
- Integration in design tools: the developed algorithms were validated by using experimental results. The algorithms can be used as reference models for the development of simplified models and can be incorporated in thermal/daylighting simulation models.
- Preparation of *Handbook of Design Guidelines and Shading Components* that includes information on:
 - Application of shading device systems
 - Smart solar control systems
 - Design and selection of shading components
 - Specific guidelines
 - Overview of shading devices and control systems
 - Illustrative applications

This project has two main contributions:

- Knowledge about the shading devices' performance will help manufacturers to improve the quality of the products.
- It will help architects to use a correct application of shading devices and control systems in new and existing buildings.

Klems and **Warner** (1997) did a study which used measured bidirectional transmittances and reflectance of Venetian blinds to produce:

- Directional-hemispherical properties for Venetian blinds
- Solar heat gain coefficients (SHGC) for the blinds combined with clear double insulating glass

Klems and Warner found that Venetian blinds do not fit well with calculation methods for heating and cooling loads of the buildings. They used a large-sample goniometer to measure Venetian blinds installed either at the interior of the window or between two panes of double insulating glass. The Venetian blinds were tested for three-slat positions:

1. Closed slats
2. At a 45° slat angle relative to horizontal
3. Open slats, that is, slats were horizontal

In a calculation method, Venetian blinds are considered as an effective layer with bidirectional transmittance, reflectance, and a directional absorptance that were measured by a goniometer. Klems and Warner found that:

- For closed blinds:
 - The reflectance of the closed blind is the same as the slat reflectance for most incident directions.
 - For an incidence angle larger than 45° for upward-going radiation, some light can be transmitted through the small gaps between the slats, and reflectance will decrease.
 - Transmission of light is very low in the case of downward-going radiation that strikes closed slats almost perpendicularly.
 - Light transmission by multiple reflections through the small gaps between slats becomes significant.
- For a 45° slat tilt angle:
 - Transmittance is very high for upward-going radiation, and reflectance is high for downward-going direction.
 - Transmittance of the radiation between the slats without striking them dominates in the case of upward-going radiation. Transmittance through multiple diffuse reflection from the slats dominates in the case of downward-going radiation.
- For incidence angles less than 25° , some radiation will be transmitted between the slats, and this transmittance will increase with a decreasing incidence angle.

In order to calculate solar heat gain coefficient (SHGC) of the window, directional-hemispherical transmittance and the directional absorptance are needed. Directional absorptance is derived from the transmittance and reflectance measurements. The SHGC

functions depend strongly on the incident angles. For between-glass blinds, SHGC has lower values in most directions because of the optical transmittance/reflectance and because some of the energy that flows inward is absorbed by the blinds.

The Klems and Warner study shows the following results:

- The present calculation methods of SHGC for unshaded glazing use the value for normal incidence.
- There is a time-dependence of beam SHGC for a given day.
- The diffuse term is important for low solar intensities.
- Effective SHGC of the windows varies with the time of the day, season, and orientation. These variations must be taken into account if we want to achieve accurate building thermal simulations, and if we need to compare a Venetian blinds system with other solar control systems.
- For south-oriented windows, the SHGC changes by more than a factor of two for different seasons, but it does not change significantly with time during the periods of high solar intensity.
- For west-oriented windows, the SHGC changes significantly with time during the afternoon when direct solar intensity is high, but it changes little for different seasons.
- Even Venetian blinds in an open/horizontal position can provide a certain level of solar protection in summer.
- Better solar protection can be provided by using adjustable blinds even though the level of protection depends on time and season.
- It is complicated to choose a single number for SHGC for all periods of significant solar gain.

Klems and Warner concluded that:

- The SHGC for windows incorporating Venetian blinds depends on the incident angle of beam solar radiation and that this dependence influences solar heat gain.
- The effective SHGC for diffuse radiation depends on sky conditions and ground reflectivity.
- Instead of using a single value for the SHGC, which leads to incorrect results, models that incorporate blind properties and rating schemes based on small sets of SHGC values might give better solutions.

- The methodology and results developed in this research, together with laboratory measurements on Venetian blinds, can provide a reasonable picture of the performance of complex, operable windows.

Pfrommer et al. (1996) developed a new calculation model called GLSIM-BLIND that simulates shading devices systems and can be integrated in thermal building simulation models. GLSIM-BLIND, which is basically a glazing simulator, performs these tasks:

- Calculates detailed radiation transfer through glazing and a blinds system.
- Produces input data for a building simulation program by simulating a shading device in one of two possible ways:
 - Accurately: at each simulation time-step.
 - Approximately: by using simplified daily effective shading factors for each radiation component.

A calculation model is able to model solar radiation transfer for both interior and exterior shading devices. The program also calculates annual or monthly effective total solar transmittance values or effective shading factors, which can be used in thermal calculations of heating and cooling loads or in simple building simulation programs. The calculation model can be used for different types of shading devices and for various control strategies. The algorithms can also be used in the early design phase for comparing and optimizing different blinds systems.

The model calculates radiation transmission through the blinds by considering:

- Direct transmittance: the unshaded transmission of the direct light beam.
- Direct-reflected transmittance: the direct reflected light beam from the slat surfaces, which can be diffuse, specular, or a combination of diffuse and specular.
- Diffuse transmittance: the unshaded transmission of the diffuse radiation.
- Diffuse-reflected transmittance: the reflected diffuse radiation at the slat surface.

The model calculates the inter-reflections between the slats and between the slats and glass panes. Interaction between the blinds and glass happens at two levels:

- Multiple-reflections occur between the glass panes and the blinds.
- The blinds change the light beam direction by modifying the incident angle at which solar radiation strikes the glass.

The calculation model considers the curvature of the slats. The influence of the slats' curvature decreases as the radius of the curvature increases:

- For large curvature radiuses (that is, the slat radius is larger than the slat width), the influence of the slat curvature can be neglected, which means that slats can be considered flat.
- For small curvature radiuses (that is, the slat radius curvature is smaller than the slat width), the influence of slat curvature needs to be considered.

GLSIM-BLIND offers a possibility for a dynamic treatment of blinds and a calculation of transmittance and absorptance values, depending on the incidence angle. On the other hand, by using effective blind properties instead of incidence-angle properties (dynamic blinds treatment), the amount of input data can be significantly reduced. This approach works for south-oriented windows, but for east- and west-oriented windows, a dynamic treatment of blinds should be applied. When the GLSIM-BLIND model was developed, it could be used only for simulation of the horizontal blinds. It could be used for different:

- Orientations of the window
- Window inclination angles
- Slat width, distance, color, and material

GLSIM-BLIND was developed for quick calculation so that analytical solutions were used rather than numerical procedures or ray-tracing techniques. GLSIM-BLIND is a pre-processing program which provides thermal simulation of a window with a blind systems without making any modifications to the thermal building simulation program to which GLSIM-BLIND is connected. The calculation model was verified by using the following methods:

- Through an analytical investigation during the model development.
- By comparing it with programs that use a different technique to calculate radiation transfer through a glazing/blinds system, such as the ray-tracing technique.
- By empirical validation since measured data were presented by other research projects.
- By comparing the results of diffuse transmittance calculated by GLSIM-BLIND with those calculated by RADIANCE (ray-tracing software).

Pfrommer et al. (1996) did not validate the calculation model by comparing the results with full-scale field measurements.

Kuhn et al. (2000) developed a methodology that makes a comparative evaluation of sun-shading systems together with associated control strategies. The methodology has been validated by using calorimetric measurements of the external and internal Venetian blinds. The new method is based on a calculation of total energy transmittance g , which quantifies the solar thermal gains through facades. Dependence of the g value on the sun incident angle is taken into consideration in this method. In the calculation method developed by Kuhn et al. optical properties (reflectance, absorptance, and transmittance) of Venetian blinds are found, for variable tilt angles of the slats and variable directions of incident irradiation, by using the ray-tracing procedure. A computer simulation optical measurement based on OptiCad was used. The calculation method was validated by using an experimental approach, that is, by testing three models of Venetian blinds:

- External Venetian blinds with metallic, light gray slats.
- Internal Venetian blinds with white slats, which are convex and perforated.
- Internal “daylighting” Venetian blinds with concave-shaped slats where the upper side is coated with mirror foil and the lower side is painted matt light gray.

The calculation method is validated in two steps:

1. Validation of the modeling of the solar transmittance of the blinds: calculated and measured values for solar transmittance for three systems of the Venetian blinds were compared. The conclusion is that the ray-tracing method is applicable to all products and allows a precise calculation of solar transmittance.
2. Validation of the calculation method for the total solar energy transmittance g : calculated and measured values of g were compared. There is a very good agreement between the modeled and calorimetrically measured values.

Kuhn et al. argue that the typical sky radiance distribution for the location of the building has to be considered. This means that typical weather and irradiation data need to be taken into account. The proposed calculation method consists of four steps:

1. Choosing a control strategy: Two basic strategies considered in this method are: “closed” strategy and “cut-off” strategy. In the “closed” strategy, slats are completely

closed when the facade is exposed to the direct sun. When the facade is in the shade or when there is no direct sun radiation, the blinds are fully retracted. This strategy has the advantage of good overheating and glare protection, and its disadvantage is not providing visual contact to the outside. In the “cut-off” strategy, the slats are in the tilted position when the facade is directly irradiated by the sun. In the “cut-off” position, the tilt angle of the slats depends on the incident angle of the sun. In the “cut-off” position, the slats are opened as much as possible without letting direct sun radiation into the interior. The advantages of the “cut-off” strategy are visual contact to the outside and good protection from overheating and glare.

2. Modeling total solar energy transmittance g that depends on the incident angle of the sun.
3. Calculation of sky radiance distribution.
4. Calculation of monthly effective total solar energy transmittance and monthly effective solar gain.

Incident solar energy and energy transmitted into the building are calculated for every hour of the year at a specific location for the building’s south-, east-, and north-oriented facades. The effective g -value for the month and location were defined, as well as the second effective g -value that takes into account only the time when the system is active. Kuhn et al. concluded that:

- The overall monthly effective total energy transmittance depends on the facade orientation.
- Solar gains through the north-oriented facade were high due to the diffuse radiation when the blinds are retracted, which shows that diffuse radiation has a strong impact on heat gains.
- The monthly effective total solar energy transmittance, when the system is not retracted, does not depend on orientation and is relatively constant during the year.
- The proposed calculation methodology can make a comparative evaluation of shading systems together with associated control strategies.
- Control strategies must be determined in the early design phase, and they must consider the needs of the future users of the building. The control strategies can vary for different shading systems.

- It is necessary to determine:
 - Angular distribution of incident radiation.
 - The angle-dependent value of total solar energy transmittance g .
- The level of overheating protection of the shading device depends on the building characteristics and must be determined for each building.

Datta (2001) conducted a study about the thermal performance of a building by using the TRNSYS simulation in which a shading model for windows was incorporated to test the effect of various shading devices on building performance. Simulations for three types of external fixed horizontal louvers oriented to the south were done for four different cities in Italy (Rome, Naples, Milan, and Palermo). The slats were defined by ratio s/l (s -vertical distance between slats, l -length of slat):

- Type 1 – $s/l = 1$
- Type 2 – $s/l = 2$
- Type 3 – $s/l = 0.92$

Also, different tilt angles of the slats (α) relative to the horizontal were considered: $\alpha = 30^\circ$, 45° , 60° , and 90° , that is, closed slats. The routine LOUVER.DLL, developed by the WIS group, was used to study the effect of shading by the slats on a south-oriented window. The solar and thermal performance of the shading device can be tested by the routine. The inputs for the model are:

- Length of the slats (l)
- Distance between the slats (s)
- Tilt angle of the slat (α)
- Absorption of both the front and back of the slats (assumed to be 0.2)

The routine generates primary and secondary transmittance of the shading device relative to the azimuth and altitude. This routine is linked to the TRNSYS program. Two parameters were tested by this study:

- The solar gains through the window
- The effect of the shading devices on the solar gains

The study provided the following results:

1. In Rome, the solar gains achieve the maximum without shading. If slats are closed, solar gains are not zero because east- and west-oriented windows are not shaded.
 - If type 1 and type 3 slats are closed, there is a large decrease in solar gains as a result.
 - If type 2 slats are closed, solar gains will increase.
 These results show the same pattern in all four cities.
2. In Milan, the annual energy (heating and cooling) loads are highest, followed by Rome, Naples, and Palermo, which is the result of the location of the cities.
3. The influence of shading devices on cooling and heating loads is small for a building zone in which windows are oriented to the north, west, and east.
4. In Milan, which has a colder climate, no shading gives the lowest energy load because heating loads are higher.
5. In Naples and Palermo, which have warmer climates, no shading will give the highest energy loads because cooling loads are higher in these climates.
6. The optimum shading devices for different climates are as follows:
 - Type 2 in Rome gives the lowest energy loads.
 - Type 2 with a slat angle of 60° in Milan and Rome.
 - Type 2 with a slat angle of 30° in Naples.
 - Types 1, 2, and 3 with a slat angle of 30° in Palermo.

Datta concluded that:

- External fixed horizontal louvers installed in south-oriented windows are effective in reducing both cooling loads in summer and total annual energy loads of the building.
- The optimum design and application of shading devices depend on location and climatic conditions.
- The shading factor varies with time of day and season (that is, it is different for summer and winter).

2.3 STANDARDS, CODES, AND RECOMMENDATIONS FOR LIGHTING, SHADING, AND CONTROLS

An analysis of standards is important for this dissertation because the standards are used in the specific DMF as the reference values for daylighting performance parameters. Values of illuminance and luminance in the space given by the standards are compared to actual values obtained by the application of shading devices on a specific building. Standards for window size, shading, and control systems are investigated because these standards not only help in the selection of the blinds but also in the early stage of the building design.

There are no specific standards for daylighting. The *IESNA Recommended Practice of Daylighting* and *Daylight in Buildings* are only two references specifically related to daylighting and used in this dissertation. But they both give recommendations rather than regulations for daylight application in buildings. The other codes and standards used as references are codes that set requirements for either energy-efficient design or electric lighting. They usually just refer to daylighting in relationship to two major requirements previously mentioned. “Conventional codes will either ‘prescribe’ minimum or maximum level for window properties (U-factor, g-coefficient, air leakage, etc.) or allow designer to meet performance goals.”¹

In countries with a climate that has predominantly overcast skies, particularly in Europe, codes and standards prescribe a minimum window size, a minimum daylight factor, and a position of a window to provide a sufficient illumination level in the space and view to the outside.

Meeting performance requirements is probably the most appropriate approach for shading devices. Energy consumption of the particular building with applied shading devices needs to be simulated to determine whether or not performance requirements are met. The manufacturer’s testing and calculations of shading device systems are not sufficient. In addition to this testing, code officials can require field testing to verify the performance of the system.

Two categories of codes and standards related to electric lighting are:

- Energy-saving codes
- Safety and construction codes

¹ *Daylight in Buildings: A Source Book on Daylighting Systems and Components*. LBNL (2000)

Energy-saving codes prescribe regulations for saving energy by efficient use of electric lighting. These codes establish:

- Maximum power allowed for lighting systems
- Minimum efficiency or efficacy (lumens per watt) values for lighting equipment

Safety and construction codes set regulations for the construction, installation, and maintenance of lighting equipment. In most cases, the lighting code is an element of the energy code that can be a part of a building construction code.

For example, the ASHRAE/IESNA Standard 90.¹ is an energy standard which sets minimum criteria and requirements for an energy-efficient design for buildings. It also emphasizes an efficient lighting design. The standard establishes mandatory requirements for controls and ballast and maximum lighting power density allowance, but it does not establish regulations for the quality and quantity of illuminance. The other example is the International Building Code 2000 which states: “Every space intended for human occupancy shall be provided with natural light by means of exterior glazed openings . . . or shall be provided with artificial light. . . . Exterior glazed openings shall open directly onto a public way or onto a yard or court . . .²

2.3.1 STANDARDS FOR WINDOW SIZE

Codes and standards regulate a minimum window area:

- The International Building Code 2000 states that a minimum window area should be at least 8% of the floor area in order to provide a sufficient amount of daylight.
- The ASHRAE Standard 90.1-2001 recommends the following window areas to achieve goals of an energy-efficient design:
 - The vertical window area should be less than 50% of the gross wall area for each space-conditioning category.
 - The skylight window area should be less than 5% of the gross roof area for each space-conditioning category.

¹ ANSI/ASHRAE/IESNA Standard 90.1 – 2001: Energy Standard for Buildings Except Low-Rise Residential Buildings.

² International Building Code 2000

In the same standard in the section titled “Building Envelope Trade-off Option”, the maximum vertical window area is limited to 40% of the gross wall area in each space-conditioning space.

- In the Energy Efficiency Standard for Residential and Nonresidential Buildings, the required window area is also a maximum 40% of the gross wall area or 6 feet times the display perimeter, whichever is greater.
- The recommended Practice of Daylighting IESNA RP-5-99 considers the human factor and the need for providing daylighting in the space. It therefore recommends a “minimum window size of 20-30% of the window wall area. In the case of housing, most national regulations require that a window be at least 10% of the room floor area.”¹

In conclusion, codes and standards either prescribe:

- A minimum window area relative to floor area or window wall area to provide a sufficient amount of daylighting.
- A maximum window area relative to the gross wall area to provide an energy-efficient design, that is, to limit heat loss and gain through the fenestration.

2.3.2 STANDARDS FOR DAYLIGHTING

Very few standards and recommendations exist that directly regulate just daylighting. One of these standards is called the “Recommended Practice of Daylighting”, which recommends the basic steps to be applied to achieve energy savings due to daylighting²:

- Plan interior spaces for access daylighting
 - Minimum window height of 1m is recommended for continuous windows used for providing daylight in the offices.
 - To provide sufficient daylight illumination of the space, a view of the sky in the upper half of the window, at 3m inside the window wall should not be obstructed by surroundings more than 50%.

¹ Recommended Practice of Daylighting IESNA RP-5-99

² Recommended Practice of Daylighting IESNA RP-5-99

- To provide adequate task illumination, the distance of the work station to the midpoint of the skylight projected on the floor should not be more than 0.75 times the height of the skylight above the floor.
- Sunlight should be minimized in the area near critical visual tasks. Excessive heat gain and glare, as a result of sun radiation, should be prevented by applying either exterior or interior shading devices:
 - Exterior shading devices seem to be the most effective for providing daylight and control of heat gain and glare.
 - Interior shading devices, usually moveable and controlled by occupants of the building, are required for sunlight control for low sun altitude angles. The problem with occupant-controlled shading devices is that most people keep shades lowered all the time, thus reducing penetration of daylight. In this case, additional openings, which will admit daylight and exclude sunlight from the task area, are required. An example of such a solution would be clerestories with fixed shading.
- Spaces should be designed to minimize glare. Glare can be reduced by:
 - Using high-reflectance, matte finish materials, which increase light reflection and reduce variations in illumination across a space.
 - Avoiding a specular element at window surrounds since they can reflect the sunlight, thus producing glare.
- Provide for daylight-responsive control of electric lighting:
 - Automatic or manual controls for dimming or switching an electric light in response to daylight conditions should be provided.
 - Luminaires on one circuit should cover areas with similar daylight conditions and activity patterns.

The *IESNA Lighting Handbook* gives a checklist of energy-saving guidelines regarding daylighting for existing and new buildings:

- Daylighting compensation: If daylighting is used for illumination of an interior space instead of electric lighting near the window, then electric light should be one circuit to control light by switching or dimming either manually or automatically.

- Daylight sensing: Daylight sensors and dimming systems are used for control of electric lighting and can contribute to energy savings.
- Daylighting control: Maximize effectiveness of existing fenestration-shading controls (interior and exterior) or replace with proper devices or shading media.
- Space utilization: “Use daylighting in transition zones, in lounge and recreational areas, and for functions where the variation in color, intensity, and direction may be desirable. Consider applications where daylight can be utilized as ambient lighting, supplemented by local task lights.”¹

The ASHRAE Standard 90.1 – 2001 does not regulate minimum visible light transmittance (VLT) criteria for fenestrations in the Prescriptive Building Envelope Option, but there are minimum VLT criteria for fenestration in the Building Envelope Trade-off Option: “The visible light transmittance (VLT) for fenestration in the base envelope design shall be the VLT factor (which value depends on the climate as well as on the type of the fenestration and glazing) times the SHGC (Solar Heat Gain Coefficient) criteria.”² If the building trade-off option is used, “Visible light transmittance shall be determined in accordance with NFRC 200. Visible light transmittance shall be verified and certified by the manufacturer.”³ For unlabeled vertical operable and fixed fenestrations, the ASHRAE Standard 90.1 assigns the U-factors, SHGC, and visible light transmittances. The values depend on the frame and glazing type, and values are given for both clear and tinted glass. Shading devices are not taken into consideration in VLT criteria for fenestration.

2.3.3 STANDARDS FOR LIGHTING

2.3.3.1 Standards for illuminance

The following standards that give regulations for required illumination in offices were analyzed in this research:

- International Standard ISO 8995, CIE S 008/E: Lighting of Indoor Work Places

¹ *IESNA Lighting Handbook* (8th edition)

² ANSI/ASHRAE/IESNA Standard 90.1 – 2001 – Energy Standard for Buildings Except Low-Rise Residential Buildings

³ ANSI/ASHRAE/IESNA Standard 90.1 – 2001 – Energy Standard for Buildings Except Low-Rise Residential Buildings

- ANSI/IES Standard RP-1-1982 Office Lighting
- IES Recommended Practice for Lighting Offices Containing Computer Visual Display Terminals (VDT) IES RP-24-1989

The International Standard ISO 8995, CIE S 008/E, gives recommended maintained illuminances over the task area on the reference surface, which can be horizontal, vertical, and inclined. These values will provide for visual safety at work and needed visual performance.

Table 2-1 gives the recommended values for maintained illuminance, glare limitation, and color quality in the various rooms, depending on the type of interior and task.

Table 2-1 *Schedule of lighting requirements – clause 5*

Type of interior, task, or activity	Maintained Illuminance (E _m) lux	Limited Unified Glare Rating (UGR _l)	Minimum Color Rendering Index (R _a)	Remarks
22. Offices				
Filing, copying, circulation, etc.	300	19	80	
Writing, typing, reading, data processing	500	19	80	For VDT – work, see clause 4.10
Technical drawing	750	16	80	
CAD workstation	500	19	80	For VDT – work, see clause 4.10
Conference and meeting rooms	500	19	80	Lighting should be controllable
Reception desk	300	22	80	
Archives	200	25	80	

The minimum required illuminance in normal lighting conditions is 20 lux, which is the lowest value on the scale of illuminances. The recommended scale of illuminances is: 20-30-50-75-100-150-200-300-500-750-1000-1500-2000-3000-5000 lux. The standard recommends a specific relationship between illuminance of the task and illuminance of the immediate surrounding areas to provide an appropriate and well-balanced luminance distribution in the field of view. Table 2-2 shows that task illuminance has higher levels than illuminance of immediate surroundings. Table 2-2 gives recommended minimum values.

Table 2-2 *Illuminance of immediate surroundings*

Task illuminance (lux)	Illuminance of immediate surroundings (lux)
≥ 750	500
500	300
300	200
≤ 200	Same as task illuminance

The illuminance of the task should be uniform. The uniformity of illuminance is defined as the ratio of the minimum to average value. The minimum recommended value of the uniformity of illuminance of:

- The task is 0.7
- The immediate surrounding is 0.5

Standard ANSI/IES RP-1-1982 – Office Lighting recommends:

- Illuminance categories based on the area/activity
- Ranges of illuminance categories and types of activity
- Minimum values of illumination for safety
- Weighting factors to be considered in selecting specific illuminance

Table 2-3 gives recommended illuminance categories and illuminance values for lighting design based on the area/activity for offices.

Table 2-3 *Recommended illuminance categories and illuminance values for offices*

Area/Activity	Illuminance Category	Illuminance (Lux)
Off-set printing and duplicating area	D	200-300-500
Reading	D E	200-300-500 500-750-1000
Drafting • Mylar High contrast • Vellum high contrast • Tracing paper high contrast • Prints: blueprints	E	500-750-1000
Drafting • Mylar low contrast • Vellum low contrast • Tracing paper low contrast • Prints: sepia prints	F	1000-1500-2000

Table 2-3 Recommended illuminance categories and illuminance values for offices

Drafting - Overlays Light Table	C	100-150-200
Spaces with VDT	D E	200-300-500 500-750-1000
Conference Rooms	D	200-300-500
Reception Areas	C	100-150-200
Libraries/Active Stacks	D	200-300-500

A comparison of Tables 2-1 and 2-3, that is, ISO and IESNA standards for illuminance levels for lighting in offices, shows that illuminance values for the same tasks are almost equal.

Table 2-4 gives illuminance categories and illuminance values for generic types of activities in interiors. Ranges of illuminances (in lux and footcandles) are given based on the type of activity/illuminance category. A reference work-plane is indicated for each type of activity/illuminance category.

Table 2-4 Illuminance categories and illuminance values for types of activities

Type of Activity	Illuminance Category	Range of Illuminance		Reference Work-plane
		Lux	Footcandles	
Public spaces with dark surroundings	A	20-30-50	2-3-5	General lighting throughout spaces
Simple orientation for short temporary visits	B	50-75-100	5-7.5-10	
Working spaces where visual tasks are only occasionally performed	C	100-150-200	10-15-20	
Performance of visual tasks of high contrast or large size	D	200-300-500	20-30-50	Illuminance on task
Performance of visual tasks of medium contrast or small size	E	500-750-1000	50-75-100	
Performance of visual tasks of low contrast or very small size	F	1000-1500-2000	100-150-200	
Performance of visual tasks of low contrast and very small size over a prolonged period	G	2000-3000-5000	200-300-500	Illuminance on task obtained by a combination of general and local (supplementary lighting)
Performance of very prolonged and exacting visual tasks	H	5000-7500-10000	500-750-1000	

Table 2-4 Illuminance categories and illuminance values for types of activities

Performance of very special visual tasks of extremely low contrast and small size	I	10000-15000-20000	1000-1500-2000	

Table 2-5 gives the minimum values for levels of illumination for safety of personnel, absolute minimum at any time and at any location, and on any plane where safety is related to seeing conditions. For various areas, different levels of illumination (such as slight and high) and values in either lux or footcandles are recommended.

Table 2-5 Levels of illumination for safety

Hazard Requiring Visual Detection Normal Activity Level	Slight		High	
	Low	High	Low	High
Areas	Conference rooms Reception rooms Exterior floodlighting Closets	Lobbies Corridors Concourse Restrooms Washrooms Telephone switchboard rooms Exterior entrance Exterior floodlighting	Elevators (freight) File rooms Mail rooms Offices Stairways Stockrooms Exterior entrance with stairs	Elevators Escalators Computer rooms Drafting rooms Offices Stairways Transformer vaults Engine rooms Electrical, mechanical, plumbing rooms
LUX (FOOTCANDLES)	5.4 (0.5)	11 (1.0)	22 (2.0)	54 (5.0)

Table 2-6 is used if the criteria illuminance is in the range of illuminance values. Table 2-6 gives weighting factors to be considered in selecting specific illuminance within the ranges of values for each category in Tables 2-3 and 2-4. Weighting factors depend on:

- Workers' ages
- Speed and/or accuracy
- Reflectance of task background

Table 2-6 Weighting factors

Task and workers characteristics	Weighting Factors		
	-1	0	+1
Workers' age	Under 40	40-55	Over 55
Speed and/or accuracy	Not important	Important	Critical

Table 2-6 Weighting factors

Reflectance of task background	Greater than 70%	30 to 70 %	Less than 30%

Table 2-7 shows the effect of weighting factors on general lighting. Illuminance values for illuminance categories A, B, and C weighting factors considered here are:

- Age of observer
- Importance of speed and accuracy
- Reflectance of the background on which task is seen

First, an illuminance category (A through I) is selected, based on the description of the task/activity. The category gives the range of three values of illuminance, then weighting factors are considered and illuminance values are determined.

Table 2-7 Effect of weighting factors on general lighting illuminance values for illuminance categories A, B, and C

Weighting Factors		Illuminance (lux)		
		Category		
Average age of occupants	Average room surface reflectance (%)	A	B	C
Under 40	Over 70	20	50	100
	30-70	30	75	150
	under 30	30	75	150
40-50	Over 70	30	75	150
	30-70	30	75	150
	under 30	30	75	150
Over 55	Over 70	30	75	150
	30-70	30	75	150
	under 30	50	100	200

The required illumination levels can be given, based on the task reflectance, and they can be categorized by the type of the task.¹ Such values are presented in Table 2-8.

Table 2-8 Requirements for illumination levels based on task reflectance and categorized by type of the task

Category of Visual Task	Required Illuminance E (lux)	
	RF = 50%	RF = 10%
Casual	62-125	300-625
Ordinary	125-625	625-3125

¹ Stein, B. and Reynolds, J. *Mechanical and Electrical Equipment of Buildings*. John Wiley & Sons (2000)

Table 2-8 Requirements for illumination levels based on task reflectance and categorized by type of the task

Moderate	625-1250	3152-6250
Difficult	1250-2500	6250-12500
Severe	>2500	>12500

Within one lighting zone, the ratio between maximum and minimum illuminance of light should be less than 3:1. This gives reasonable values for contrast ratios between the task and the background illuminance which determines three major zones:

- Task/background illuminance ratio = 3:1
- Task/background illuminance ratio = 6:1
- Task/background illuminance ratio = 9:1

A ratio larger than 9:1 between maximum and minimum illuminance points is not recommended, and in such a case the areas should be divided into more zones.

The daylight factor (DF) is used to quantify illumination levels in the space. The ratio between the minimum and average daylight factor, which relates to the contrast ratios in the space, should not be less than 30%, that is, $DF_{min}/DF_{avg} \geq 0.3$, while min DF should be at least 0.5% at any point of the space.¹ In some countries, minimum daylight factors are regulated by the codes. Denmark is an example where the minimum required DF for offices is 2%. Regulations for minimum DF in North America do not exist.

A special consideration should be given to the offices that contain computer visual display terminals (VDT). The IES Recommended Practice for Lighting Offices Containing Computer Visual Display Terminals (VDT) – IES RP-24-1989 gives recommendations for illuminance levels in such offices. Table 2-9 shows the relationship between various VDT average screen luminances and illuminance, which is required to produce luminance ratios of either 1:3 or 3:1 for a range of adjacent surfaces (paper or desk) reflectances.

¹ Stein, B. and Reynolds, J. *Mechanical and Electrical Equipment of Buildings*. John Wiley & Sons, (2000)

Table 2-9 Illuminance required to produce luminance ratios of 1:3 and 3:1 between various VDT screens and adjacent surfaces

1	2	3	4	5	6	7	8	9	10
VDT Average Screen Luminance (cd/m ²)	Adjacent Surface Luminance (cd/m ²) for 1:3	Adjacent Surface Luminance (cd/m ²) for 3:1	Adjacent Surface Reflectance (Percent)	Illuminance (lux) Producing Adjacent Surface Luminance Shown in Columns 2 and 3		300 Lux Falls Within Range of Required Illuminance	500 Lux Falls Within Range of Required Illuminance	750 Lux Falls Within Range of Required Illuminance	1000 Lux Falls Within Range of Required Illuminance
17	5.8	51	Paper 0.8	20	190				
			Paper 0.6	30	250				
			Desk 0.45	40	330	Yes			
			Desk 0.25	70	600	Yes	Yes		
51	17	153	Paper 0.8	60	560	Yes	Yes		
			Paper 0.6	80	750	Yes	Yes	Yes	
			Desk 0.45	110	1000	Yes	Yes	Yes	Yes
			Desk 0.25	200	1800	Yes	Yes	Yes	Yes
85	28.2	255	Paper 0.8	100	940	Yes	Yes	Yes	
			Paper 0.6	140	1250	Yes	Yes	Yes	Yes
			Desk 0.45	180	1670	Yes	Yes	Yes	Yes
			Desk 0.25	330	3000		Yes	Yes	Yes

Table 2-9 shows that:

- An illuminance range of 300-500 lux gives satisfactory adjacent surface luminances except for low values of the VDT screen luminance (17 cd/m²).
- To maintain a luminance ratio of 1:3 between the average luminance of the VDT screen and various adjacent surface luminances, the upper limit of illuminance must be set at 750 lux, which will work well except for low values of the VDT screen luminance (17cd/m²).
- For the high values of screen luminance (such as 85 cd/m²), the required illuminance may have values higher than 750 lux.

The IES also gives the following recommendations related to the lighting of offices with VDT screens:

- A limit of 750 lux for general lighting should be maintained in order to limit diffuse reflections from VDT screen surfaces.

- General luminance can be reduced to 200-300 lux if local task lighting is used.
- Task lighting should provide 300-450 lux illuminance on the work surface, assuming that general lighting provides illuminance of 200-300 lux.
- If the task is in category E, then the required illuminance provided by task lighting is 550-700 lux, assuming 200-300 lux illuminance from general lighting.
- Recommended illuminance range:
 - For paper-based category D visual task: 200-300-500 lux
 - For workers 55 or over: 500 lux
 - For workers under 55: the mid-range 300 lux
 - For category E visual task: 500-750-1000 lux
 - For workers 55 and over: 1000 lux
 - For workers under 55: mid-range 750 lux
- The VDT screen average luminance should be 85 cd/m² or greater.
- The illuminance should be provided by using supplemental local task lighting in which case the general lighting level may be reduced to 200-300 lux.

2.3.3.2 Standards for luminance

Standards recommend appropriate reflectances of room surfaces to increase the brightness in the space and to decrease the need for electric lighting for providing the required illuminance:

- The IESNA lighting handbook recommends: high reflectances of room surfaces – above 0.7
- The International Standard ISO 8995, CIE 008/E – Lighting of Indoor Work Places, recommends: a range of reflectances of room surfaces:
 - Ceiling: 0.6-0.9
 - Walls: 0.3-0.8
 - Working planes: 0.2-0.6
 - Floor: 0.1-0.5
- The Recommended Practice of Daylighting – IESNA RP-5-99 also recommends: higher reflectances of room surfaces – above 0.6.

- The ASHRAE/IESNA Standard 90.1 recommends: surface reflectances of 80% for ceilings, 50% for walls, and 20% for floors to be used in daylighting calculations.

Table 2-10 gives the required luminance ranges based on type of the task.

Table 2-10 Required luminance ranges categorized by type of the task¹

Category of Visual Task	Required Luminance (cd/m ²)
Casual	10-20
Ordinary	20-100
Moderate	100-200
Difficult	200-400
Severe	Above 200

Window luminance can be controlled in the following ways²:

- Window can be designed to provide view and daylighting separately.
- Daylighting systems located higher in the wall will distribute illumination farther from the window wall, that is, deeper into the interior space thus reducing glare.
- By using external shading devices.
- By using low-transmittance glazing (disadvantage: it will also reduce transmittance of visible light).
- By using high-reflectance and light-colored interior surfaces which will increase inter-reflections distributing daylight uniformly through the interior space.
- Light-colored window surroundings and mullions reduce luminance variations in the vicinity of a window and thus reduce glare.
- The task should be arranged so that the observer does not face the window directly.

The International Standard ISO 8995, CIE S 008/E gives recommendations for maximum luminance of electric light (luminaries), which may be reflected in VDT screens. These values are given in Table 2-11 based on the VDT screen quality.

¹ Stein B., Reynolds J. *Mechanical and Electrical Equipment of Buildings*. John Wiley & Sons, (2000)

² Recommended Practice of Daylighting – IESNA RP-5-99

Table 2-11 Average luminances of luminaries

Screen classes, see ISO 9241-7	I	II	III
Screen quality	good	medium	poor
Limit of average luminance of luminaries	$\leq 1000 \text{ cd/m}^2$		$\leq 200 \text{ cd/m}^2$

2.3.4 STANDARDS FOR SHADING

Both energy and lighting codes recommend application of shading devices to protect space from overheating and provide sufficient daylight and protection from glare. The International Energy Conservation Code 2000 in Chapter 4, which is related to the design of a building utilizing renewable energy sources, states: “Passive solar building designs shall provide documentation, acceptable to the code officials, that fixed external or other acceptable shading is provided to limit excessive summer cooling energy gains to the building interior.”¹ This code also recommends that:

- “The windows are provided with operable insulated shutters or other devices which, when drawn or closed, shall cause the window area to reduce maximum outward heat flows.”²
- “The window areas are shaded or otherwise protected from direct rays of the sun during periods when mechanical cooling is required.”³

The International Energy Conservation Code 2000 recommends that the effect of any permanent exterior solar shading device should be included in the calculation of a combined solar heat gain coefficient (the area-weighted average) of all glazed fenestration products.⁴

The section related to daylight in the International Standard ISO 8995, CIE S 008/E – Lighting of Indoor Work Places recommends: “Provide adequate sun control such as blinds or shades, so that direct sunlight does not hit workers and/or surfaces within their field of view.”⁵

The code also recommends: “To reduce glare from windows, screening shall be provided.”⁶

¹ International Energy Conservation Code 2000

² International Energy Conservation Code 2000

³ International Energy Conservation Code 2000

⁴ International Energy Conservation Code 2000

⁵ International Standard ISO 8995, CIE S 008/E – Lighting of Indoor Work Places

⁶ International Standard ISO 8995, CIE S 008/E – Lighting of Indoor Work Places

The section related to daylight in the IES Recommended Practice for Lighting Offices Containing Computer Visual Terminals (VDT)-IES RP-24-1989 recommends control of window maintenance by curtains, blinds, vertical louvers, or horizontal louvers that should have low transmittance. The standard also points at potential problems of eliminating daylight and visual access to the exterior by application of such devices for luminance control.¹

In the *IESNA Lighting Handbook*, blinds and louvers are also recommended as a control technique to limit light that enters the space and to keep brightness balance in the space.² Recommended Practice of Daylighting - IESNA RP-5-99 suggests various methods of solar shade controls:

- Using fixed shades that will exclude sunlight for all sun positions during which the space is occupied (the problem with this method is that sunlight can be excluded when it is desired).
- Using adjustable shading devices.
- Glare can be eliminated by using systems that diffuse the incident sunlight.
- Occupants should choose workstations.

The same standard recommends the use of separate systems for shading in the offices that contain VDT screens. Different shading systems can be applied in upper and lower window areas. Occupant-controlled shades can be used in the upper part of the window, and in this way potential glare problems in an open-plan area can be avoided. In top-lighting systems such as skylights, sunlight can be excluded by applying appropriate external shading devices and choosing the right orientation.

Standards also show potential problems of inappropriate use of blinds:

- Shades can protect space from direct and reflected glare, but at the same time they can also reduce illumination from daylight and can also affect the performance of photosensors in daylight-linked lighting control systems.
- The upper part of a window provides the most illuminance into the depth of the space, that is, farther from the window wall. Most of the blinds are lowered from the top of

¹ IES Recommended Practice for Lighting Offices containing computer visual terminals (VDT)-IES RP-24-1989

² *IESNA Lighting Handbook* – 8th edition

the window. As a result, Venetian blinds can reduce penetration of daylight if they are in the lowered position.

- Blinds can modify input for the photosensors and affect daylight-linked fluorescent dimming systems.
- Blinds can also redirect light to the ceiling and give inaccurate information about workplane illuminance.
- In larger spaces in which dimming systems are controlled by one photosensor various applications of blinds can cause:
 - Excessive illumination: if blinds exclude daylight near the photosensor when daylight adequately supplements electric sources.
 - Inadequate illumination: if blinds are lowered in areas away from the photosensor to control glare.
- Occupants usually adjust blinds for the worst-case conditions keeping blinds lowered most of the time, thus reducing admission of daylight into the space and effectiveness of daylight-linked electric lighting control systems.
- If blind slats are made of translucent material, glare can occur when blinds are illuminated by the sun.¹

The IESNA Recommended Practice of Daylighting suggests various systems that can be used for sun control and providing daylight:

- Sidelight system: simple window with blinds which can control admission of sunlight, reduce glare from the sky, and redirect daylight to the ceiling.
- Sidelight system: split window with upper and lower blinds which provides a different kind of glare control for the upper and lower parts of a window. In this way, daylight is provided in the areas farther from the window wall even if the blinds in the lower window part are lowered. There are shades that can be raised from the bottom to the top of the window so the upper part is the last part that will be obstructed.
- Sidelight system: split window with reflective louvers which admit daylight from the upper part of the window while screening it to protect space from glare. For example, curved specular louvers used in the classrooms increase illumination levels near the rear of the space by ~100% (from 250 lux to 500 lux) under clear sky conditions and

¹ Recommended Practice of Daylighting - IESNA RP-5-99

~25% under overcast skies. At the same time, louvers reduce illuminance levels in the areas near the window by ~30% under both clear and overcast skies.

2.3.5 STANDARDS FOR CONTROLS

Standards and codes prescribe or give recommendations for daylighting and electric lighting controls to achieve energy savings for lighting. For example, the ANSI/ASHRAE/IESNA Standard 100-1995 – Energy Conservation in Existing Buildings requires: “Light shall be turned-off in areas adequately and properly illuminated by daylight. Standard light switches may be replaced with automated controls, such as photocell switches or automatic dimming systems.”¹ The same standard uses the power adjustment factor (PAF)² for calculation of lighting power control credit, which can be subtracted from connected lighting power. For automatic control devices, such as various types of daylight-sensing controls (DS), power adjustment factors (PAF) should be used, as given in Table 2-12.

Table 2-12 Power adjustment factor (PAF)

Automatic Control Device(s)	PAF
(1) Daylight-sensing controls (DS), continuous dimming	0.30
(2) DS, multiple-step dimming	0.20
(3) DS, ON/OFF	0.10
(4) DS continuous dimming and programmable timing	0.35
(5) DS multiple-step dimming and programmable timing	0.25
(6) DS ON/OFF and programmable timing	0.15
(7) DS continuous dimming, programmable timing, and lumen maintenance	0.40
(8) DS multiple-step dimming, programmable timing, and lumen maintenance	0.30
(9) DS ON/OFF, programmable timing, and lumen maintenance	0.20
(14) Occupancy sensor and DS, continuous dimming	0.40
(15) Occupancy sensor and DS, multiple-step dimming	0.35
(16) Occupancy sensor and DS ,ON/OFF	0.35
(17) Occupancy sensor, DS, continuous dimming, and lumen maintenance	0.45
(18) Occupancy sensor, DS, multiple-step dimming, and lumen maintenance	0.40
(19) Occupancy sensor, DS, ON/OFF, and lumen maintenance	0.35

¹ ANSI/ASHRAE/IESNA Standard 100-1995 – Energy Conservation in Existing Buildings

² PAF – a modifying factor that adjusts the effective connected lighting power (CLP) of a space to account for the use of energy-conserving lighting control devices.

The standard also requires the following¹:

- If the sufficient amount of daylight is available, daylight-sensing controls shall be capable to reduce electrical power consumption for lighting (continuously or in steps) to 50% or less of maximum power consumption.
- Daylight sensing controls shall control all luminaries to which the PAF is applied and which direct a minimum of 50% of their light output into a daylight zone.
- The occupancy sensors, which are located in daylighted spaces, should be installed in conjunction with a manual ON switch or a photocell override for ON.

The 2001 Energy Efficiency Standards for Residential and Nonresidential Buildings set up mandatory requirements for lighting control devices similar to the ASHRAE Standard 100-1995: “Automatic Daylighting Control Devices shall be capable of reducing the light output of the general lighting of the controlled area by at least one half while maintaining a uniform level of illuminance throughout area.”² The same standard recommends reduction of wattage of any luminaries if, for daylighting control credits, the luminaire is controlled by the daylighting control and the luminaire is located in the daylit area.³ The wattage of the luminaire is reduced through controls by the number of watts times the applicable lighting power adjustment factor (given in Table 2-13). The values of lighting PAF are categorized by the glazing type, particularly the Visible Light Transmittance (VLT), and by the window/wall ratio (for windows) or the skylight/roof ratio (for skylights).

The ASHRAE Standard 90.1 – 2001 recommends the use of continuous daylight dimming systems in all spaces. Such systems should be activated at the illumination level of:

- 50 fc for nonresidential and residential conditioned spaces
- 30 fc for semi-heated spaces⁴

The standards also prescribe maximum areas controlled by a particular lighting control system:

¹ ANSI/ASHRAE/IESNA Standard 100-1995 – Energy Conservation in Existing Buildings

² 2001 Energy Efficiency Standards for Residential and Nonresidential Buildings

³ 2001 Energy Efficiency Standards for Residential and Nonresidential Buildings

⁴ ASHRAE Standard 90.1 – 2001

Table 2-13 Lighting power adjustment factors

Combined controls Occupant sensor with a separate sensor for each space used in conjunction with lumen maintenance controls Occupant sensor with programmable multiscene dimming system Occupant sensor with a separate sensor for each space used in conjunction with daylighting controls and separate sensor for each space	Any space $\leq$ 250 square feet and enclosed by opaque floor-to-ceiling partitions		0.25
	Hotels/motels, restaurants, auditoriums, theaters		0.35
	Any space $\leq$ 250 square feet within a daylit area and enclosed by opaque floor-to-ceiling partitions		0.10 (may be added to daylighting control credit)
Automatic Daylighting Controls (Stepped/Dimming)			
	WINDOWS Window Wall Ratio		
Glazing Type	$< 20\%$	20% to 40%	$> 40\%$
VLT $\geq 60\%$	0.20/0.30	0.30/0.40	0.40/0.40
VLT ≥ 35 and $< 60\%$	0/0	0.20/0.30	0.30/0.40
VLT $< 35\%$	0/0	0/0	0.20/0.40
	SKYLIGHTS Percentage of Gross Exterior Roof Area		
Glazing Type	$< 1\%$	1% to 3%	$> 3\%$
VLT $\geq 60\%$	0/0.30	0.15/0.40	0.30/0.40
VLT ≥ 35 and $< 60\%$	0/0.20	0/0.30	0.15/0.40
VLT $< 35\%$	0/0.10	0/0.20	0/0.30

- The ANSI/ASHRAE/IESNA Standard 100-1995 requires a minimum number of lighting control points for a particular area: “Each space enclosed by walls or ceiling-height partitions shall be required to have one control point and in addition one control point for each task location or one control point for each group of task location within an area of 450 ft² or less.”¹
- The 2001 Energy Efficiency Standards for Residential and Nonresidential Buildings requires that each daylit area greater than 250 ft² must have:
 - At least one control that controls only luminaries in the daylit area.
 - At least one control that controls at least 50% of the luminaries in daylit area.
 - Controls that control the luminaries in each vertically daylit area separately from the luminaries in each horizontally daylit area.

¹ ANSI/ASHRAE/IESNA Standard 100-1995

- The *IESNA Lighting Handbook* recommends that the lighting zones adjacent to the window should have a maximum depth of 4 m if the daylight is provided to the spaces from a side window. If occupant-operated shading devices are used, the standard recommends smaller control zones to provide effective daylighting. For daylighting and task-tuning control strategies, small control zones such as 10-40 m² (100-400 ft²) are recommended.¹

The standards and codes also recommend lighting control techniques to be used:

- The ANSI/ASHRAE/IESNA Standard 100 – 1995 gives a table for determining the type and number of controls for an electric lighting system. The minimum number of controls required shall not be less than one for each 1500 W of controlled lighting power. Table 2-14 shows the types of lighting controls and the equivalent number of control points they represent.²

Table 2-14 *Control types and equivalent control points*

Type of Control	Equivalent Number of Control Points
Manually operated on-off switch	1
Occupancy sensor	2
Timer – Programmable from the space being controlled	2
Three – level, including OFF, step control, or pre-set dimming	2
Four-level, including OFF, step control, or pre-set dimming	3
Automatic or continuous dimming	3

- The 2001 Energy Efficiency Standards for Residential and Nonresidential Buildings requires that automatic daylighting control devices shall control only luminaries within the daylight area. The same standard also requires that for daylighting control credits, the luminaire should be located within the daylit area and controlled by the daylight control.³

¹ *IESNA Lighting Handbook* – 8th edition

² ANSI/ASHRAE/IESNA Standard 100 – 1995

³ 2001 Energy Efficiency Standards for Residential and Nonresidential Buildings

- The *IESNA Lighting Handbook* recommends that the luminaries nearest the window should be circuited and controlled separately from the luminaries in the interior of the spaces. Each separate office with daylighting should have at least two-level switching to provide control of lighting by the occupants. Since daylighting illumination levels vary continuously, the dimming system is the most appropriate control strategy. The dimming system provides a smooth and continuous variation in needed illuminance levels in the space. If the interior illumination is controlled by a single photosensor, then the space controlled should have the same daylight illumination continuously and the same general task activity.¹
- The Recommended Practice of Daylighting – IESNA RP-5-99 recommends integration of daylight and electric light to provide a sufficient amount of lighting during the daytime. The particular differences between the daylight and electric light system that need to be considered are:
 - Each system provides light and different spectral and color-rendering characteristics.
 - Daylight varies with time and sky conditions, while electric light does not vary.
 - Directionality of daylight in the space is different from the directionality of electric light in the space.

Since the illumination level decreases with increasing distance from the window wall, electric light may be needed to supplement daylight in the depth of the space. Occupants near the windows may have a sufficient amount of daylight to perform their tasks, but occupants who are distant from the windows might need electric light in addition to daylight. If daylight levels are too low, then electric light needs to provide the required illuminance level for the entire space.

The ASTM E-1662 is standard classification for serviceability of an office building for a sound and visual environment. In section A.3, the Sound and Visual Environment standard gives a Scale A.3.5 for Adjustment of Lighting by Occupants. Two scales are shown:

- Occupant requirement scale
- Facility rating scale

¹ *IESNA Lighting Handbook* – 8th edition

The occupant requirement scale has levels from 1 to 9 and is defined by:

- Adjusting for type of work
- Occupant lighting control
- Task lighting requirement
- Window covering adjustment

The occupant requirement does not set up any requirements at level 1. The occupant requirement at level 9 is as follows:

- “Adjusting for type of work: Operations require that illumination levels in open plan can be readily adjusted on short notice to provide for very different types of work.
- Occupant lighting control: Require occupant control of general lighting levels in small groups, that is, zones of less than 15 workstations in open plan.
- Task lighting requirement: Task lighting is required for all or most occupants.
- Window covering adjustment: Window coverings must allow adjustments to daylight and control of glare.”¹

The facility rating scale has levels from 1 to 9 and is defined by:

- Control of ceiling lights
- Relocation of ceiling lights
- Window coverings
- Power for task lights

The facility rating level 9 set up the following requirements:

- Control of ceiling lights: In open plan areas, lights are switched on/off and dimmed by occupants in zones of less than 15 workstations. Enclosed rooms have switches and dimmers.
- Relocation of ceiling lights: Ceiling light fixtures plug into a power source like office equipment does. They hang or lay in a ceiling grid so they can easily be relocated within a ceiling grid without technical expertise.
- Window coverings: Window coverings are operable by occupants or automated to respond to prevailing external conditions.

¹ ASTM Standard E-1662 Standard Classification for Serviceability of an Office Facility for Sound and Visual Environment

- Power for task lights: Each occupant can add task lights along with his personal computer, printer, and other accessories.

Facility rating level 1 set up the following requirements:

- Control of ceiling lights: There is no local control of ceiling lights. Switching is controlled by the building operator or a designated person.
- Relocation of ceiling lights: Ceiling light fixtures can be relocated only by major reconstruction of the ceiling.
- Window coverings: There are no window coverings or coverings are not operable.
- Power for task lights: There are insufficient power/plugs or capacity for task lights.

2.4. OVERVIEW OF SHADING DEVICE SYSTEMS

In this chapter, the literature review on existing and patented shading devices is given. The literature search on shading device systems is conducted to get an overview of the available systems and their performance. The literature review also provides a background for the design of a new system of blinds proposed by this research. One existing system and one patented system, reviewed in this section, are used in the validation process of the DMF in this research.

In the first part of the chapter, the existing between-glass blinds are analyzed to understand their design, structure, and performance. The patented transparent shading devices are introduced in the second part of the chapter because the reviewed patented system provide protection from direct sun and glare. The patented transparent systems also offer a sufficient amount of daylight in the space by applying the principles of optical physics in the blinds' design. The knowledge of transparent blinds helps in understanding the principles of their design, which is used in this research for the design of the new blind system.

2.4.1. EXISTING SHADING DEVICE SYSTEMS

A literature search on existing shading devices was conducted to get an overview of the systems currently available on the market. The literature review focuses on between-glass shading devices that consist of blinds sealed between two panes of glass. The blinds can be either fixed or operable, controlled manually or automatically. The between-glass blinds are analyzed in this research because of their advantages compared to interior and exterior blinds. Since the louvers are installed between glass panes, they are waterproof compared to exterior blinds and also maintenance-free compared to both exterior and interior blinds.

Several products of between-glass blinds are available on the market:

- **Unicel Vision Control**¹ – (see Figures 2-1, 2-2, 2-3). Hollow chambered louvers are sealed between double insulated glass. A primary seal is polyisobutylene that has high resistance to ultraviolet radiation, and the secondary seal is made of polysulfide. The air space between the two panels of glass is dehydrated by desiccant. The air space is 2" wide and louvers are 1 3/8" wide, made of extruded aluminum. Louvers

¹ Website: <http://www.visioncontrol.qc.ca/product.html>

can be installed either horizontally or vertically. If louvers are wider than 48", a vertical spacer is needed. Blades can rotate 180° and can be operated as follows:

- Manually: by a hand crank or thumbwheel
- Automatically: by the motor, which can be operated electrically by a programmable logic controller. The timer and sun-sensors can be incorporated in this system.

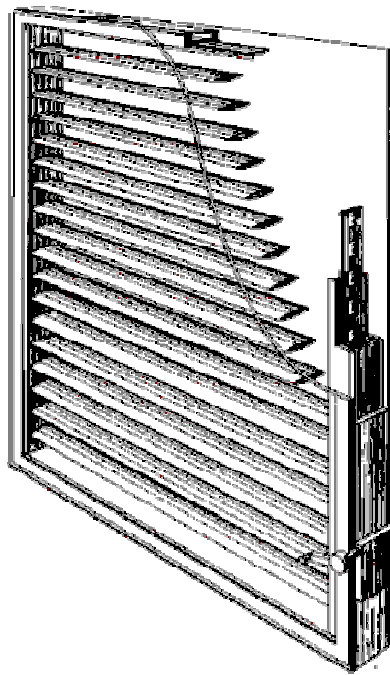


Figure 2-1 Isometric view of horizontal blinds

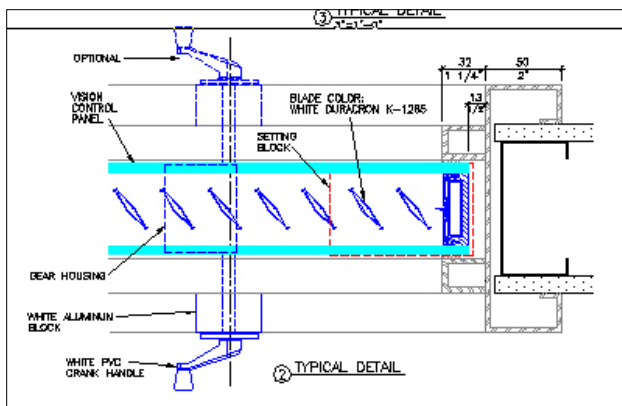


Figure 2-2 Vertical blinds – horizontal section

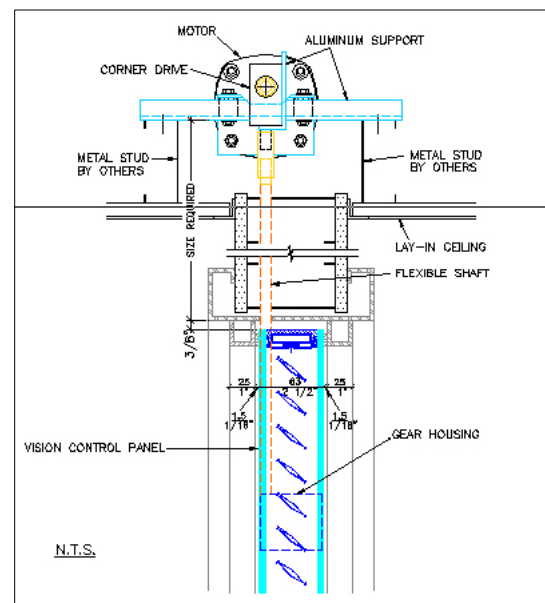


Figure 2-3 Horizontal blinds – vertical section

- **Hunter Douglas** (see Figure 2-4) offers two types of between-glass blinds: 5/8" wide and 0.008" thick and 1" wide and 0.006" thick made of aluminum. Blinds can be installed horizontally or vertically. Vertical blinds rotate 180°. They can be operated magnetically, which means that a permanent magnet moves the shading device from a closed position in one direction to a closed position in the opposite direction. This system does not require holes in glass panels.²

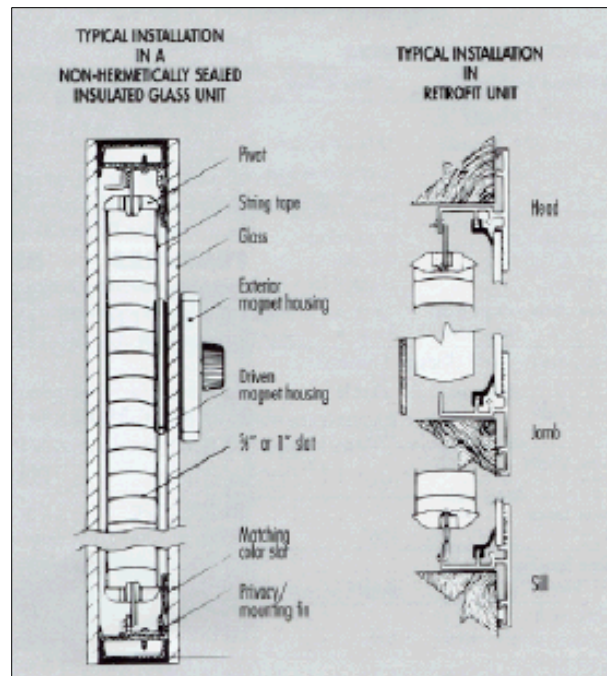


Figure 2-4 Hunter Douglas horizontal blinds
– vertical section

In Table 2-15, the maximum sizes for Hunter Douglas blinds are given.³

Table 2-15 Maximum sizes for between-glass blinds

Size Maximums for Between-Glass Blinds				
Min. Air Gap	Slat Width	Max. Blind Width	Max. Blind Height	Max. Area
1 3/8"	1"	96"	96"	40 sq feet

² Website: <http://www.blindsgalore.com/blindsgalore/content/commercial/BETWEEN.htm>

³ Website: <http://www.cssautomation.com/horizontal/between%20glass/default.html>

- **Concord Shading Systems**⁴ (see Figures 2-5 and 2-6) offer either motorized horizontal or vertical blinds. Horizontal blinds can be 1" and 2" wide made of wood or aluminum, while 1/2" wide blinds can be made only of aluminum. Vertical blinds are made of PVC or aluminum. The automatic operation of louvers is possible by using a comfort control system that monitors sun radiation intensity by using sun-sensors. The control system also moves (raises, lowers, or tilts) the shading device based on sun conditions.

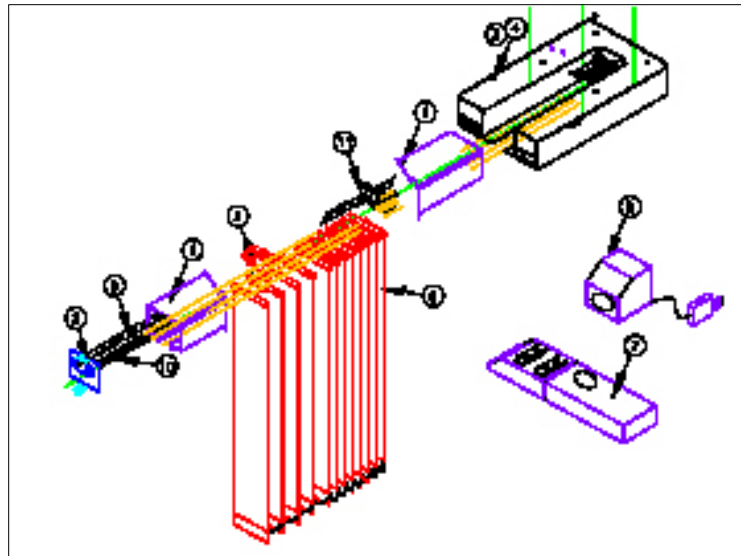


Figure 2-5 Concord vertical blinds

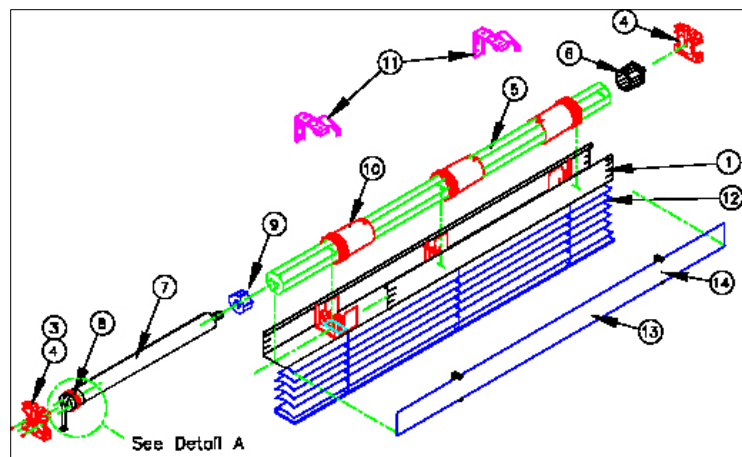


Figure 2-6 Concord horizontal blinds

⁴ Website: <http://www.concordshading.com/>

- **Photovoltaic shading devices**⁵ (see Figure 2-7) provide solar control and capture sun energy at the same time. The blinds are fixed between two panes of glass. Adjustable solar blinds are also available. The photovoltaic slats consist of tandem amorphous silicon cells deposited on glass. Syglas, German company, makes two systems, one of which is used for the roof systems and another for the vertical facades. A current of 24V is used for stand-alone systems and a current of 60V is used for grid-connected systems. Nominal power of photovoltaic slats is about 40 W/m².

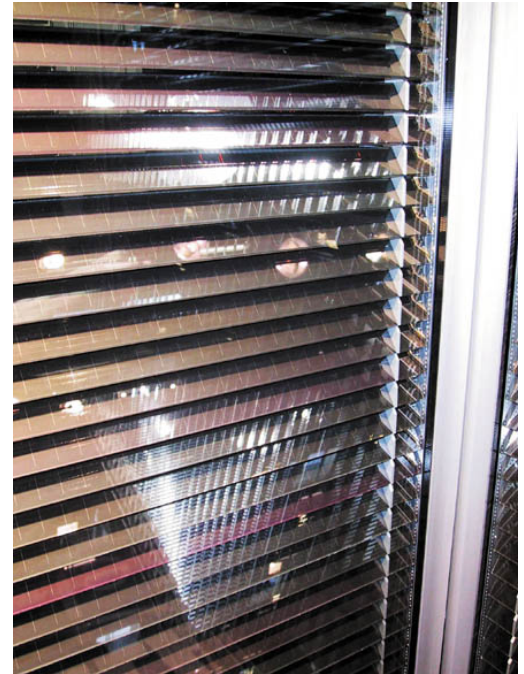


Figure 2-7 Syglas photovoltaic horizontal blinds

- **Okasolar**⁶ (see Figure 2-8) reflective louvers are installed between insulating glass units. The louvers protect the interior from sun radiation in summer but provide diffused natural light. In winter, radiation is reflected by the louvers to the ceiling so that a large amount of sun energy and daylight can enter the building, achieving goals and advantages of passive solar design strategy. Okasolar units are made of clear float glass, but louvers with a concave and convex shape are made of a highly reflective, light gauge steel strip with a high performance Trital coating. Louvers are fixed at a predetermined angle and spacing to respond to different seasonal conditions. Since louvers absorb a certain amount of sun radiation, increased thermal stress can occur. The outside glass pane therefore needs to be toughened or heat-strengthened, and it can have a sun control coating to reduce transmittance. The unique shape and position of the louvers permit light transmission. Multiple reflection of light can also occur between adjacent louvers so that some light will be reflected to the outside and some will be transmitted into the interior.

⁵ Website: http://www.photon-magazine.com/products/products_01-03_syglas.htm

⁶ Website: <http://www.daylight.uk.com/okasolar.htm>

Direct light transmission varies from 3% to 58% and diffused light transmission from 13% to 28%. The louvers have a reflective surface coating so that most of the sun radiation is reflected, and absorption of sun radiation and its conversion to long wave heat radiation are minimized. The thermal insulation of okasolar glass panels is $U=2.7 \text{ W/m}^2\text{K}$. By using a low-e coating and an argon filling in the air space, the U-value can be decreased to the value of $1.8 \text{ W/m}^2\text{K}$. Figure 2-8 shows the section through the okasolar glazing and how it works for different seasons. In summer, all sun radiation is reflected; in transition seasons (fall and spring), sun radiation is reflected into the interior; and in winter, sun radiation is also reflected into the interior space.

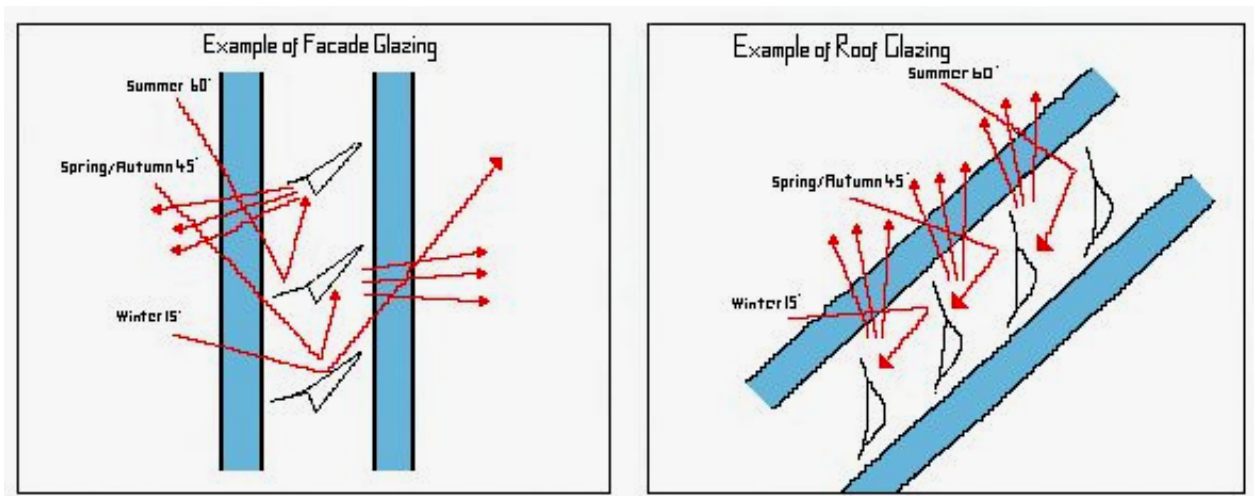


Figure 2-8 Okasolar shading device – cross section

Transparent blinds, such as Optix (see Figure 2-9) made by Graber,⁷ consist of 2" wide slats made of polycarbonate. They have an L -shape with one side completely transparent and the other side frosted or translucent. The three available blind positions are:

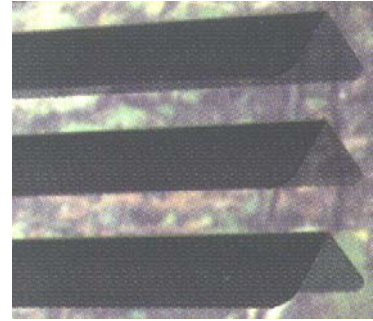
- Tinted view: the transparent side of the slats is in the vertical and closed position, providing a view and reducing glare and UV rays transmission.



Figure 2-9 Transparent Optix blinds

⁷ Website: <http://www.springs.com/ourproducts/windows/graber/index.html>

- Open: the slats are in the semi-open position allowing a higher percentage of direct natural light transmission and providing a view.



- Privacy: the slats are tilted in the opposite direction to the tinted view position; the frosted part of the slat is in the vertical and closed position, providing privacy and obstructing a view to the outside.

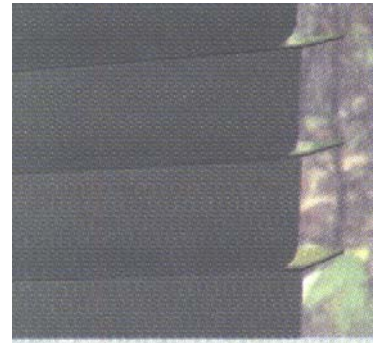


Figure 2-9 *Transparent Optix blinds*

Completely transparent blinds 1" or 2" wide are also available and recommended if privacy is not necessary and a view is desired. Transparent blinds can be installed horizontally and vertically. They reduce 30% to 50% of light and glare and eliminate almost 100% of the sun's ultraviolet rays. This shading device can be operated manually or automatically.

2.4.2. PATENTED SHADING DEVICES SYSTEMS

The patented shading devices made of transparent materials, such as glass or plastics, are especially interesting for application since they provide a possibility for complete transparency of the windows or glass facade. The patented systems have been investigated to get an understanding of their performance and the application of the principles of the optical physics in the design of the blinds. This understanding is important for the research because the objective is to improve the daylight level in the space by using shading devices. One of the patented systems (see Figure 2-34) is simulated by using Autodesk VIZ 4 to validate the decision-making framework (DMF). Also, an understanding of the design principles explained in the patented solutions helps in the design of the new transparent shading device, which is proposed by this research. Several patented shading device systems are explained in this section.

Wirth et al. (1998) state that planar absorbing, specularly reflecting, or diffusely reflecting layers can protect against solar overheating. By using physical phenomena, such as absorption, reflection, total internal reflection, refraction, diffraction, and so forth, directional selectivity can be achieved. Wirth et al. focus on the use of total internal reflection in glass or plastics for solar control. For a particular incidence of angles, that is, angles greater than or equal to the critical angle, the total internal reflection from a smooth glass surface will reject 100% of the solar radiation while absorption will not occur. A tool for two-dimensional ray-tracing is called SysSim (Schmidt, 1997), which obtains angular transmission and calculates reflected and transmitted intensities.

The two basic types of shading devices are:

1. Moveable (dynamic)
2. Fixed (stationary)

2.4.2.1. Moveable shading devices

Components of shading devices are moveable, and usually they rotate around either a horizontal or vertical axis, depending on the position of the slats. Venetian blinds assemblies with rotatable horizontal slats consist of an array of rectangular symmetric prisms. These prisms are made of dielectric transparent material and are arranged on a rotatable slat. Because of refraction, the slats are not transparent, that is, the view will be distorted, but it is possible to have a view between adjacent slats.

U.S. Patent no. 4,517,960 by Bartenbach Christian (1983) is an invention of a protection device against sunlight. The shading device consists of:

- A plurality of slats that are made of a light-permeable, refracting material. The slats have a flat non-reflective base surface on a side oriented to the sun and a prismatic structure on the opposite side oriented away from the sun (see Figure 2-10).
- The prismatic structure consists of prismatic rods that have a triangular cross section. The prismatic rods are parallel to the longitudinal axes and have two non-reflective surfaces that work only by total internal reflection (see Figure 2-11).
- The slats are arranged in a side-by-side relationship in a window opening. The slats are mechanically coupled to one another, and all the slats are simultaneously moved at the same time and for the same angle around the longitudinal axes.

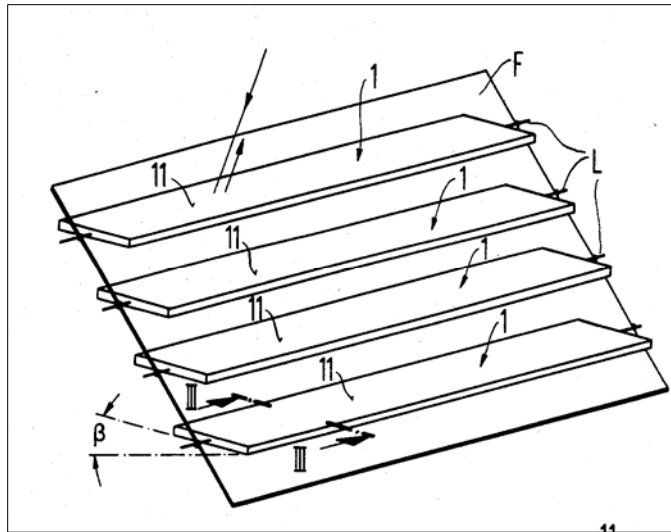


Figure 2-10 Isometric view of the shading device

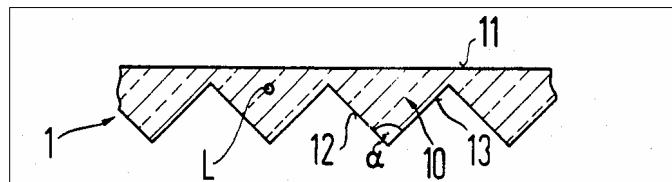


Figure 2-11 Cross section through the prismatic slat

Inclination of the slats can be changed during the day and year, depending on the angle of the sun rays.

The invented shading device has the following advantages:

- It improves light transmittance.
- It provides effective protection from the sunlight.
- It does not require adjustment of the slat inclination during the day for the south orientation since the required screening conditions are fulfilled during several days.
- It requires little adjustment throughout the year for the south orientation. For instance, only four adjustments of the angle of inclination of the slats are needed. These four adjustments will cover the entire range of the change in the altitude angle in accordance with the time of year (in meridian plane 47°) with a screening range of 12° in the same plane.

The slats can be adjusted to let sun rays enter the interior space and be used for heating the space in winter.

The transparency of the shading device can be improved in two ways:

- By improving the transparency of the obstructed (slat) area or
- Reducing the obstructed (slat) area

The transparency of the obstructed area can be improved by adding another prism array. The slats become transparent since the additional prism restores the direction of the light rays that pass through the slat and are not internally reflected.

U.S. Patent no. 3,438,699 by B.I. Seeger (1969) is an example of such a shading device.

The shading device consists of:

- Multiple slats assembled in a configuration similar to Venetian blinds. The slats can be either horizontal or vertical, and they are collectively moved depending on the sun angle (see Figure 2-12). Each slat consists of two prisms which are oriented opposite of each other. Together they form a rectangular cross-sectioned slat, being 0.1707"

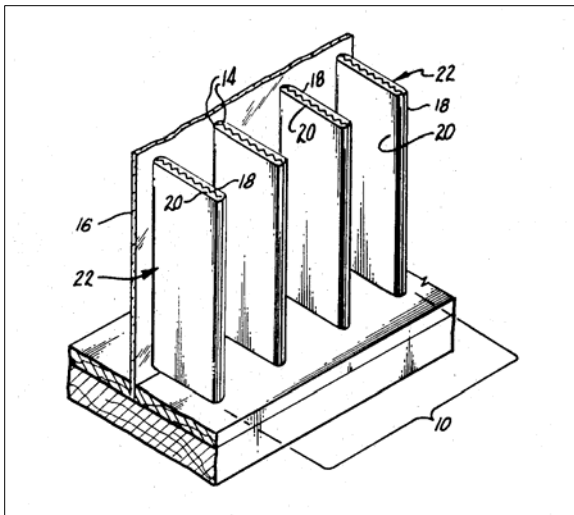
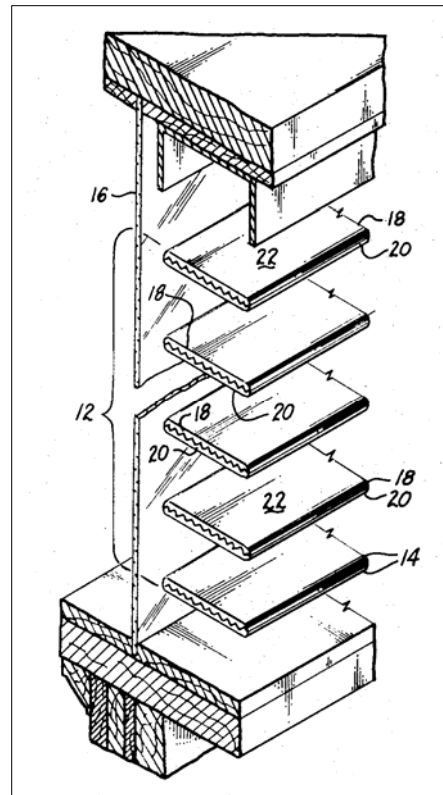


Figure 2-12 Isometric view of the prismatic shading device



thick, and 2" wide, and as long as one dimension of a sunlight area (see Figure 2-13). The ridges of prisms are immersed in a thin medium, such as air or a vacuum, which has an index of refraction lower than the prism material. The materials used for slats are highly transparent to all light, such as a transparent polymethyl methacrylate material, which has an index of refraction 1.49.

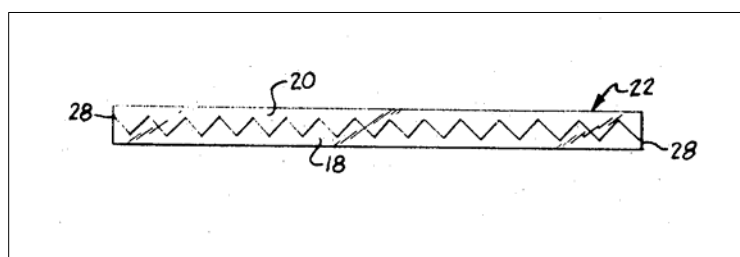


Figure 2-13 Cross section through the prismatic shading device

Figure 2-14 shows the refraction and total reflection of the sun rays for different incident angles:

- Ray A has an incident angle 0° , that is, it is perpendicular to the surface, and it will be totally internally reflected, protecting the interior space from overheating and glare.
- Ray B is twice refracted and emerges parallel to its original direction. An occupant has a clear and undistorted view along the line of such a ray. Ray B is not a glare ray and it supplies the desired light to the interior space. Ray B forms a “clear view range.”
- Ray C is refracted at the first outside surface and after that there are several successive total internal reflections at the parallel surfaces of the slat. Rays C forms an “opaque view range.”

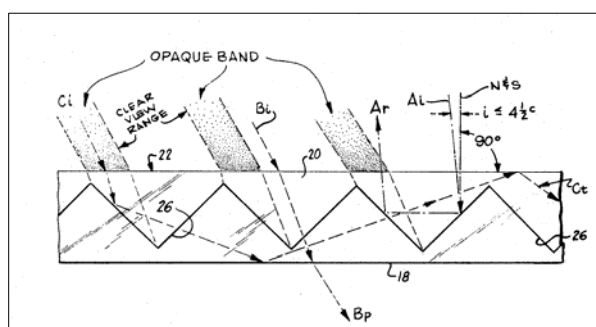


Figure 2-14 Detailed cross section through the prismatic shading device

This shading device totally reflects all glare rays. Indirect glare rays are totally reflected while other light rays that have less energy are provided to the space beyond the location of the slats by:

- Construction of the slats proposed by this invention.
- Using transparent materials with indices of refraction equal to or greater than $\sqrt{2}$.
- Control of their collective rotation.

The other strategy for improving the transparency of a shading device is reducing the slat area. A different functional arrangement of the slats is needed for achieving this goal. Assuming a mean solar profile angle between 45° and 60° , only a retro-reflecting slat will provide protection at nearly a horizontal orientation. Figure 2-15 shows a slat with a retro-angle of 45° .

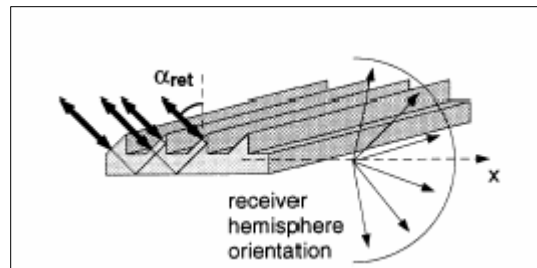


Figure 2-15 Cross section through the retro-reflecting slat

U.S. patent no. 4,773,733 by Murphy (1988) shows several types of prismatic transparent shading devices. The goals of these inventions are:

- To block direct sun rays to enter the space.
- To permit passage of indirect sun rays into the space.
- To permit a view through the shading device from the interior to outdoor space.
- To provide a shading device that will give even illumination of the space without blocking vision through the shading device.
- To protect/minimize heat gain from direct sun rays.
- To provide a shading device that can be applied to vertical, as well as horizontal, and roof/sloped openings.

The shading device has a form of Venetian blinds comprised of prismatic, reflective slatted panels that are rotatable depending on the sun's movement.

Figure 2-16 shows a perspective view of a shading device that consists of:

- A plurality of slatted panels that can be rotated, depending on the sun's movement (20, 22, 24).
- A pair of rope ladders (30, 32) that have their upper end suspended over and around tilt pulleys (34, 36).
- Tilt pulleys that are attached to a tilt rod (38), which is connected to a motor (40).
- A reversible motor that is operated under the control of the electronic circuitry.

The pull handle (44) operates a pair of ropes (46, 48). The pull handle can be operated by occupants of the building, that is, shading elements can also be moved manually. Figure 2-17 is a cross section through the shading device. It shows how an arrangement of the slats reflects the direct sun rays while permitting a view from the outside through the space between the adjacent slats.

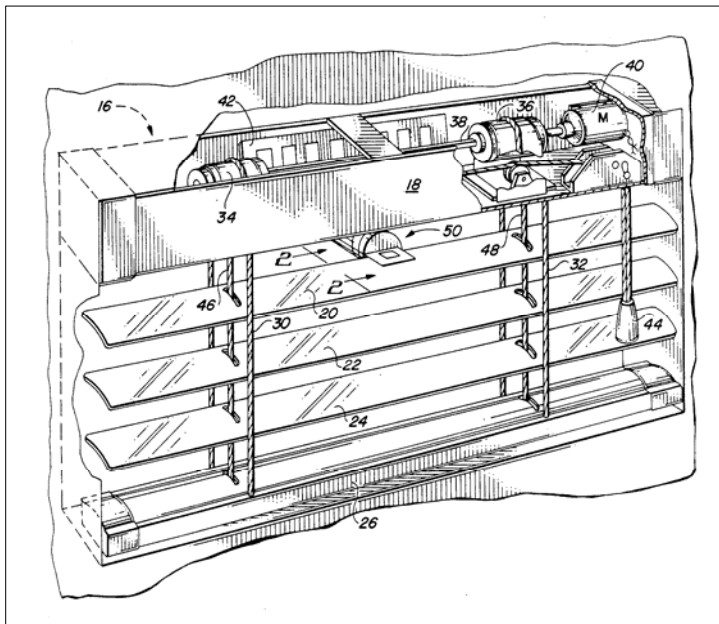


Figure 2-16 Isometric view of the prismatic shading device

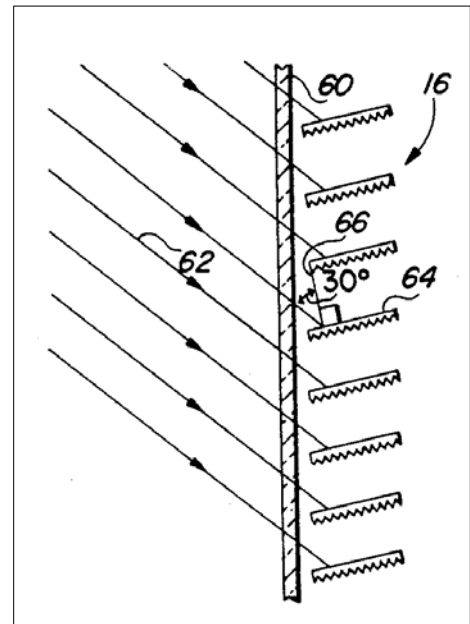


Figure 2-17 Cross section through the prismatic shading

Figure 2-18 shows different positions of the slats for different incident angles of the sunlight rays, always keeping the angle of 30° between the incident sun ray and imaginary normal line to the slat's front face. Figure 2-18a shows the position of the slats for the very

low sun, such as the early morning sun striking east-oriented windows or late afternoon striking west-oriented windows. Figure 2-18c shows the position of the shading elements for a high position of sun, that is, summer at noon for south-oriented windows.

The slats in Figures 2-18b and 2-18c have almost a horizontal position, providing an unobstructed view from the interior through the spaces between the slats. The slats in Figure 2-18a do not provide a view to the outdoors between the slats.

The prismatic slats are made from a light transmissive material having an index of refraction of approximately 1.5, such as glass, acrylic, and polycarbonate. The slats have two faces:

1. The front face (flat, curved, or stepped) that is oriented to sun.
2. The rear face that is oriented away from the sun. The rear face has reflective prisms for total internal reflection of sun rays that strike the front face of the slat at a 30° angle from a normal to the front face. These prisms are either linear prisms or triangular pyramidal prisms.

In the case of using a three-faced linear prism, the first and the second face are oriented in such a way so that a plane bisecting the angle between the first and the second faces is parallel to the refracted direct sun rays that pass from the front to the rear face of the slat. The ideal central focal angle is 30° , but it can lie within the range of 20° to 40° ,

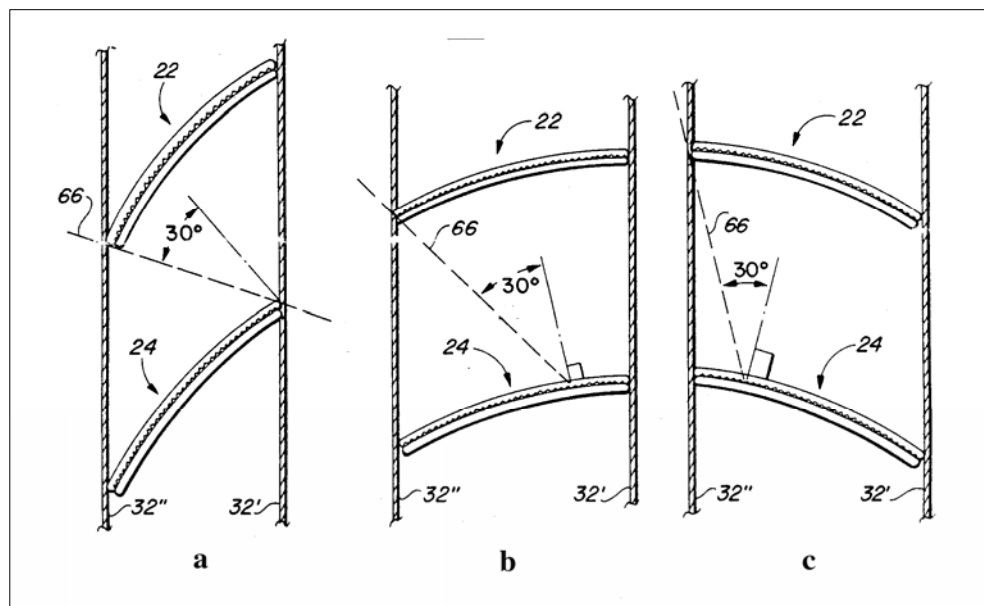


Figure 2-18 Different tilt angles of the shading elements

preferably 25° to 35° to the normal relative to the front face of the slat. The third face of each three-faced linear prism is set at a 20° angle to the normal, avoiding interference with the reflected direct sun from the first and second faces.

Each prismatic surface of the slat is inclined at a certain angle, relative to the front face of the slat, and each prismatic surface consist of two or more prisms that reflect direct sunlight rays back to the space through the front face of the slat. The incident light angle and the angle of the reflected light, which leaves the slat, are equal.

Figure 2-19 shows a partial cross section through the three-faced prism at the rear side of the slat. One of the three-faced linear prisms has two faces of equal width, and a 90° angle between them and third face that has a lesser width than the first and second face. A direct sunlight ray strikes the front flat slat surface at a 30° incident angle, and it is refracted at the 20° angle. The second surface (74) is set at the angle of 45° to the refracted ray so that the total internal reflection will occur. The reflected ray (86) is reflected again at the first surface (72), and then refracted as it exits from the slat to air, again at the angle of 30° .

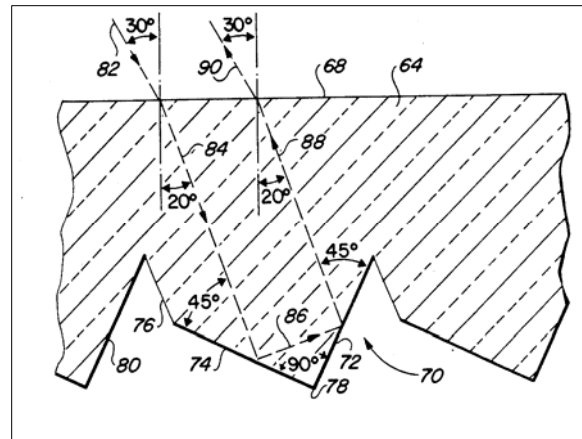


Figure 2-19 Partial cross section through the three-faced prism

Figure 2-20 shows a partial cross section through a reflective slat that has the curved front face and the prismatic rear face with 3-faced linear prisms. Since the front face is curved, the design of linear prisms becomes more complicated because they need to have different angles relative to the normal to the front face. If we assume that the incident angle of sunlight that strikes the front face is approximately 30° , we will notice that the angle of the rays at the left part (the closest to the outside) of the slat will be less than 30° , and the angle of the rays that strikes the right side of the slat is more than 30° . If we want to achieve a total

internal reflection under the same conditions in each of the prisms on the rear slat side, each of them will have different orientations, that is, an angle relative to the normal. Refracted rays in the panel have a different angle of refraction because of the curved front face. By adjusting the orientation of the prism, the total internal reflection angle of the light beam can be kept the same in all prisms. Angles between the first and the second face of three-faced prisms in each prism is 90° , and the angle between the second and the third face is always 135° .

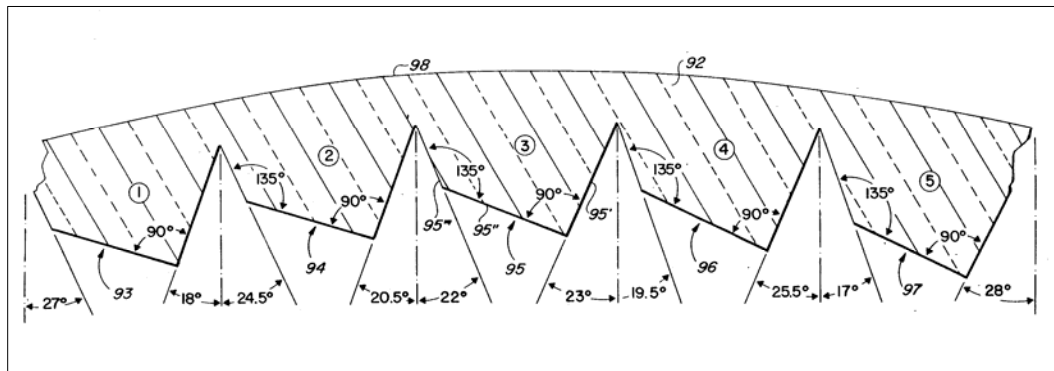


Figure 2-20 Cross section through the prismatic shading device with a curved front face

Figure 2-21 shows a partial cross section through the slat that has the stepped front face and 3-faced linear prisms on the rear face of the slat. The advantage of this invention is that all light that perpendicularly strikes the stepped front face of the panel will be transmitted rather than reflected or refracted. In this way, the loss of indirect sun rays due to reflection off the front face is minimized. The rear face of the slat consists of the 3-faced linear prisms. The first and the second face of each prism are perpendicular to each other, and the plane bisecting the angle between the first and the second surface is parallel to the incident sun rays. The third face of the prisms is also parallel to the sun rays, achieving the same effect as in the shading device shown in Figure 2-19. The sunlight ray (152) strikes the front surface of the slat perpendicularly, and after being transmitted, it has been totally internally reflected at the first and second surface of the prism. It leaves the slat again, transmitted from the slat to air in the direction parallel to the incident ray direction.

Figure 2-22 shows the cross section through a slatted prismatic panel that has a flat front face and a stepped rear face in which each step consists of several two-faced linear prisms.

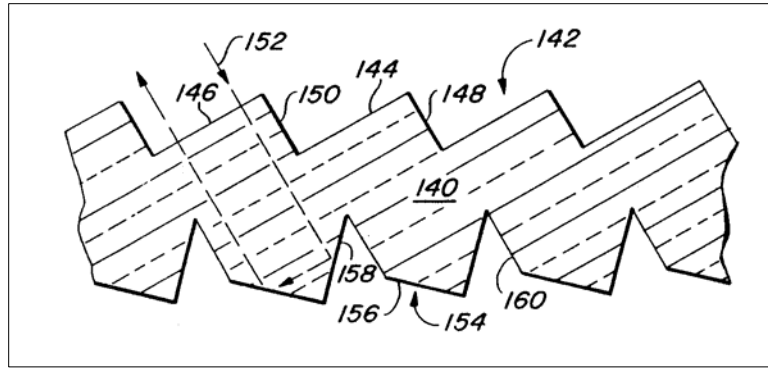


Figure 2-21 Cross section through the prismatic shading device with the stepped front face

The geometry of refraction and internal reflection, which is used in this invention, is the same as the one used in the shading device shown in Figure 2-19. An incident ray strikes the front face of the slat at a 30° angle relative to the normal and is refracted at a 20° angle for an index of refraction of 1.5. The refracted ray is totally internally reflected at the first and the second face of the two-faced prisms on the rear side of the slat, and the second reflected ray has an angle of 20° relative to the normal. The ray is refracted at the front surface of the slat and leaves the slat at an angle of 30° .

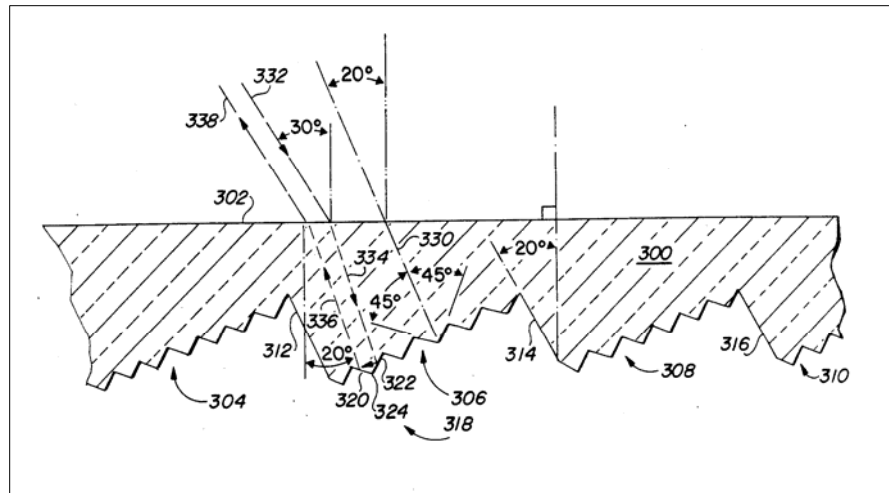


Figure 2-22 Cross section through a prismatic shading device with a stepped rear face

Figure 2-23 shows a partial cross section through a prismatic slat that has stepped both the front and the rear face. Each rear step consists of several two-faced linear prisms.

Principles of light transmission and total internal reflection used in the slat shown by Figure 2-21 are also applied for this slat. The first face of each front step makes an angle of 30° to the normal, and the second face is perpendicular to the first face making an angle of 60° to the normal. The rear face steps consist of two faces: one flat making a 30° angle to the normal, and the other face that comprises several two-faced linear prisms. A plane bisecting angle between the two faces of each prism makes a 30° angle with the normal. The incident light angle is 30° relative to the normal, but it strikes the front face of the slat perpendicularly. This means that all light will be transmitted and will not be reflected or refracted. Transmitted light will be twice totally internally reflected at two surfaces of the rear prisms, and will leave the slat at the angle of 30° to the normal, that is, parallel to the incident sunlight ray.

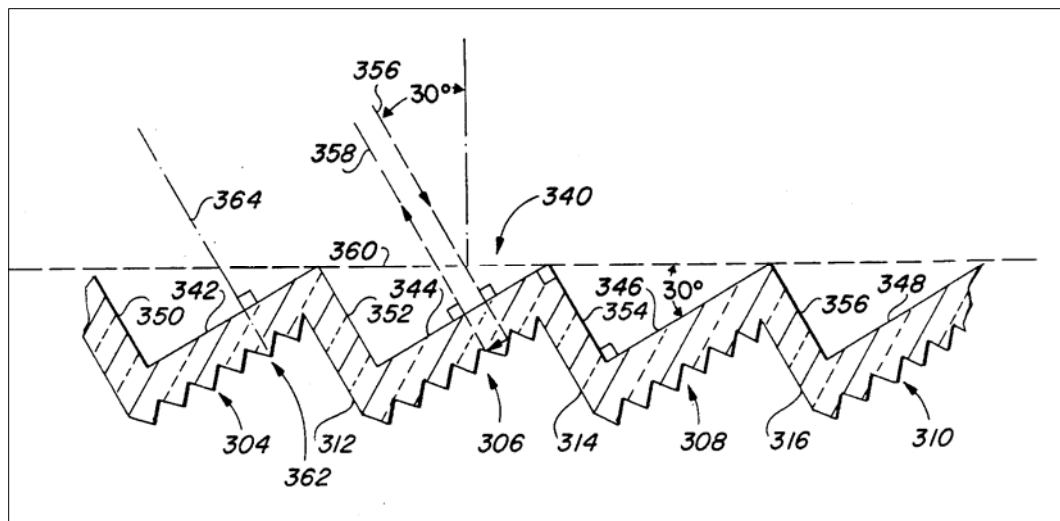


Figure 2-23 Cross section through the prismatic shading device with a stepped front and rear face

This invention can be improved by adding a diffusion panel to each slatted panel. The diffusion panel is attached to the rear face of the slat, and it is used for diffusing direct sunlight that is transmitted through each slatted panel. It is not reflected by the prisms at the rear face of the slat. Also, diffusion panels are used to diffuse transmitted indirect sunlight rays to more evenly illuminate the interior space. In winter, diffusion panels disperse direct rays transmitted through the slatted panels. The diffusion panels can be made of either translucent material or transparent material with an irregular surface. An insulated air space

between the rear face of the slatted panel and the diffusion panel is created. This shading device can improve the insulating properties of the facade/window when it is completely closed. The shading device can reduce heat gain during summer, as well as heat loss during winter nights. The diffusion panels can be colored or tinted to change the color of the transmitted light.

Figure 2-24 shows a cross section of a prismatic reflective slat and the diffusion panel. A sun-position sensor is attached to the slat, and it is used for controlling the tilt angle of the slatted panel.

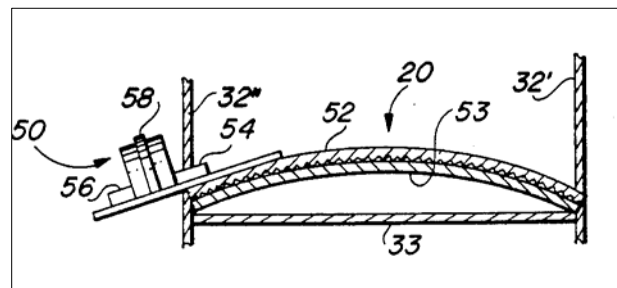


Figure 2-24 Cross section of a prismatic reflective slat and the diffusion panel

Figure 2-25 shows a cross section through a slatted panel that has a curved front face and a prismatic rear face with a diffusion panel attached to the rear side of the slat.

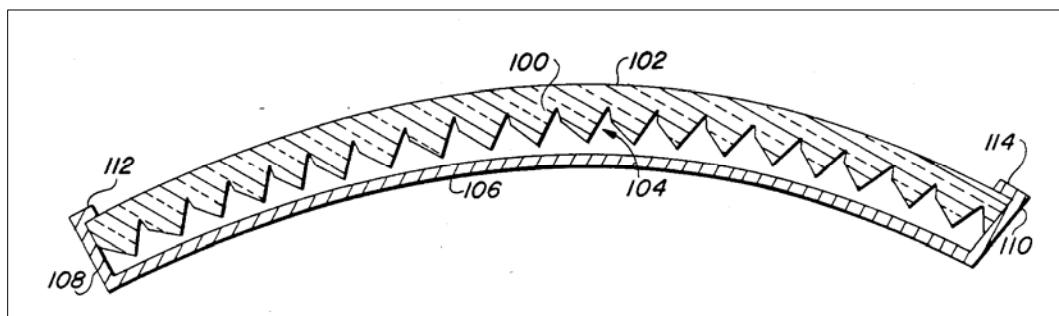


Figure 2-25 Cross section through slatted panel with a curved front face and a diffusion panel

Figure 2-26a shows a partial cross section through the prismatic slat panel that has a flat front surface and a diffusion panel attached to the slat rear face.

Figure 2-26b shows a partial cross section through the composition of the slat panel and the diffusion panel. The slat panel has stepped both the front and the rear face.

U.S. patent no. 4,993,469 by Julius Moench (1991) is a device for the protection from the sun. It has vertical Venetian blinds consisting of transparent prismatic slats. The slats rotate around their vertical axis and move from an open to a closed position (see Figure 2-27). Vertical Venetian blinds consist of:

- A plurality of slats: for blocking the sunlight rays.
- Supporting means: for supporting each of the slats in a vertical position.
- Supporting means: includes mounting means for mounting drive shaft therein.
- Mounting means: including bearing means.
- Moving means: for moving the slats along the supporting means between a closed and an open position.
- Rotating means: for rotating each of the slats about a vertical axis.
- Coupling means: for coupling/uncoupling adjacent pairs of the slats in response to the movement of the slats along supporting means.
 - Coupling means: includes a plurality of spacer bars.

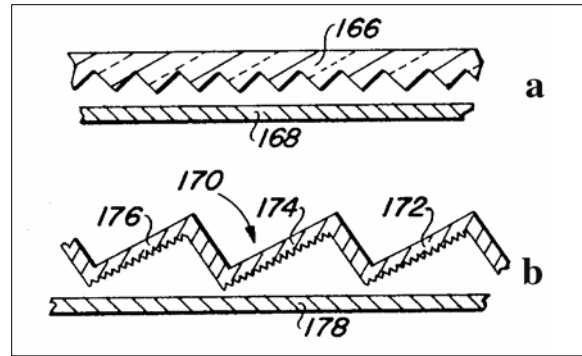


Figure 2-26 Prismatic shading devices with diffusion panel

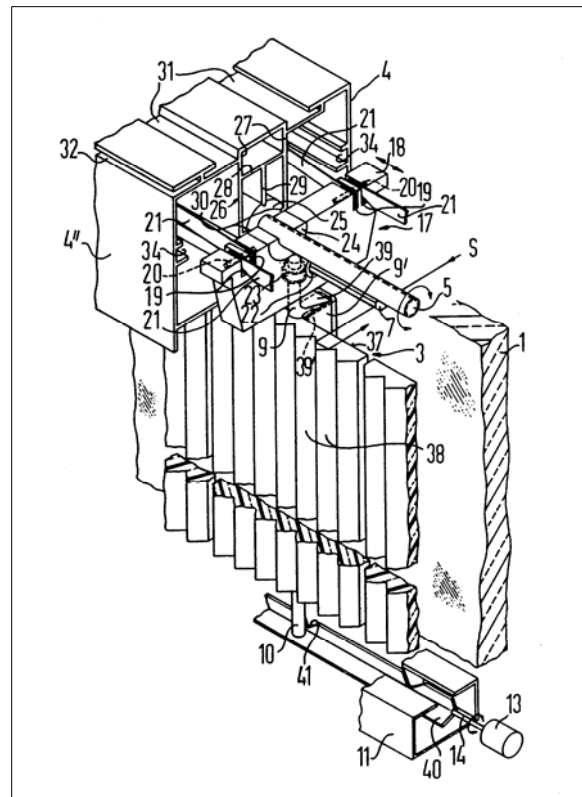


Figure 2-27 Prismatic shading devices with vertical slats

- Each spacer bar: is pivotally attached to one slat.

Each slat is made of refractive material, such as plastic, and has two surfaces: one flat and the other consisting of prisms that are used for retro-reflection of the sunlight rays. The opposite side, that is, the flat side, is oriented perpendicularly to the sun rays. The slats must be adjusted, that is, rotated periodically, depending on the sun position in order to maintain a condition of retro-reflection of the sunlight rays. To control the rotation and movement of the slats, a light sensor is installed to track the sun position and send this information to the control unit, which registers the change of the sun incident angle and sends the signal to an electric motor to rotate the slats for a specific angle. The tilt rod can rotate slats for approximately 180° - 90° in a clockwise direction and 90° in a counterclockwise direction.

2.4.2.2. Fixed shading devices

The fixed shading device can be used to provide protection from direct sun rays and overheating for several hours per day. It also gives protection for several months for seasonal overheating protection, such as in the summer, or the whole year for complete solar control. The shape and position of the shading element must be carefully designed and calculated to meet these goals. The correct slat tilt angle must be chosen in accordance with the latitude and altitude angle, as well as the index of refraction of the slat material. The slope of the slat is designed to meet the requirements of total internal reflection.

Wirth et al. (1998) proposed the design of the slat that consists of concentric cylindrical shell segments because two reflections are not enough to achieve the desired efficiency of the shading device. The shading element with a cylindrical shell array provides multiple, successive, total internal reflections (see Figure 2-28). The number of shell segments in the slat is limited by production capabilities. The remaining part of the slat can be left transparent or covered with a reflecting layer. This invention can be used seasonally or as an all-year solar control for orientations that provide a normal incidence angle, such as tilted, south-

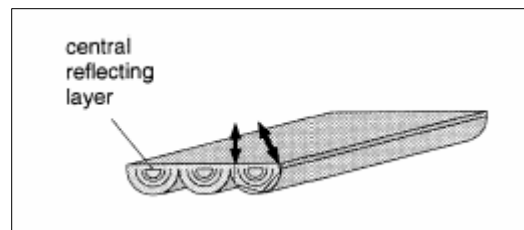


Figure 2-28 Shading device with a cylindrical shell array

facing roofs or vertical east/west facing windows. Optical properties of the shading element can be changed by adding a complementary structure and by establishing optical contact between adjacent shells. A switching mechanism can be used to turn a mirror of a wide shading element into a transparent slab (see Figure 2-29). One such mechanism is a thermally induced phase change of a substance from a liquid to a gas with an index of refraction approximately 1.0. This solution leads to thermally self-regulating overheating protection.

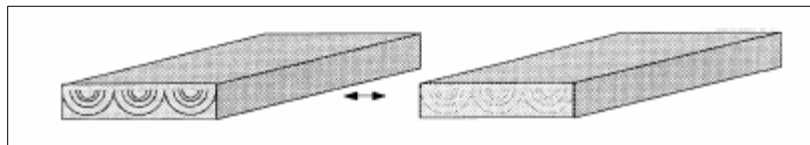


Figure 2-29 *Switching of a cylindrical shell array to a transparent slab*

U.S. Patent no. 2,812,691 by Robert A. Boyd (1957) is an invention that utilizes daylight for illumination of the building through the openings in the roof. The goal of this invention is to design a skylight that will reject direct sunlight from high altitude angles and transmit sunlight from low altitude angles and light from the northern sky (see Figure 2-32). This sun control concept may be applied to the design of the fixed shading devices for the vertical openings.

Control of lighting through the skylight can be achieved by using four air glass interfaces between the sun (or sky) and the interior of the building (see Figure 2-30):

- *Face 1*: the interface nearest to the light that can have a smooth surface or a series of longitudinal ribs extended in a north-south direction.
- *Face 2*: the intermediate interface that can have parallel prism-shaped ribs expanding in an east-west direction.
- *Face 3* (intermediate interface) and *face 4* (interface nearest to the interior): interfaces that have ribs and/or prisms or are opalescent to diffuse transmitted light for even illumination of the interior.

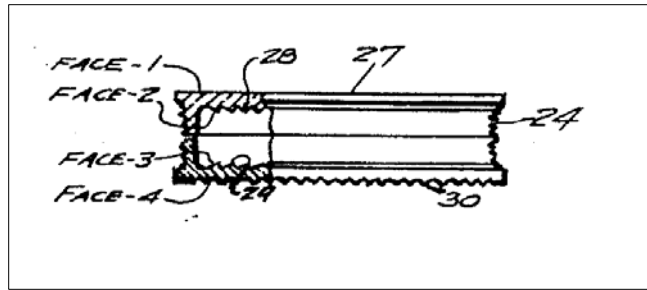


Figure 2-30 Cross section of the hollow block showing four faces

The greater portion of the horizontal surface lighting is a result of light from the sun, and the lesser portion is due to the northern sky so that sun control is necessary.

Figure 2-31 is a partial cross section through faces 1 and 2, and it shows the path of the light for high sunlight altitude angles. The sunlight is refracted by face 1 and then totally internally reflected at face 2. A light ray L_1 , which has an altitude angle a_1 , is refracted at face 1. It is transmitted to and reflected from surface 31 to surface 32, refracted through surface 32 to surface 31 of the adjacent prism, refracted through surface 31 to surface 32, reflected from surface 32 to face 1, and refracted out to the atmosphere.

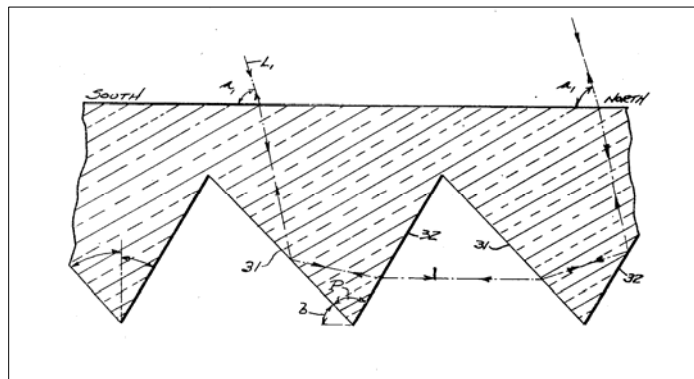


Figure 2-31 A partial cross section through faces 1 and 2 of the prism

Figure 2-32 shows the cross section through faces 1 and 2, as well as the sunlight path through the prisms for different sun altitude angles. Sunlight L_2 , which has a low altitude angle a_2 , such as in winter, is refracted at face 1 and then refracted out at face 32, that is, into

the interior space. A ray L_3 , coming from the northern sky at an altitude angle a_3 , is refracted at face 1 and at surface 31 toward the interior.

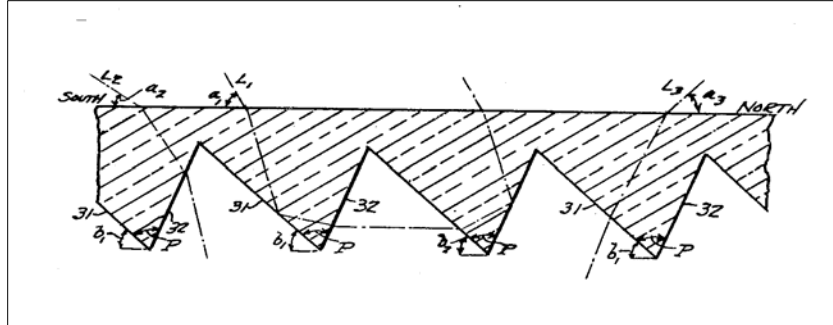


Figure 2-32 Cross section through faces 1 and 2 of the prism and path of the various light rays

In Robert Boyd's invention, angle P between the surfaces of the prism is 75° , and an angle b between the south-oriented surface of the prism and glass surface, that is, a horizontal plane, is 40° for the latitude of $42^\circ N$. The maximum rejection of direct sunlight is achieved for sun altitude angles between 52° and 71° . With increasing angle b , the area or the zone of rejection of light rays with large altitude angles is shifted to include large altitude angles. With decreasing angle b , the area of light ray rejection may be changed to include smaller altitude angles.

Faces 3 and 4 can have a diffusing structure to diffuse light transmitted by faces 1 and 2. The diffusing structure can consist of multiple depressed pyramids (see Figure 2-33).

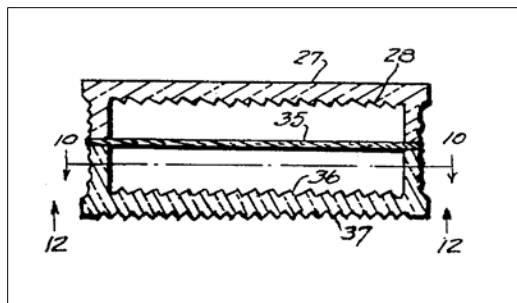


Figure 2-33 Cross section of the hollow block with the diffusion panel

Robert Boyd's invention works best for the glass having an index of refraction of 1.52 so that the proposed angles of refraction and reflection can be achieved. For best results, the skylight should be positioned in such a way that prisms are oriented in an east-west direction.

U.S. Patent no. 6,367,937 by Helmut Koster (2002) is an invention of sun protection installation, comprising of sun protection lamellae, each having a toothed upper side. The goals of this invention were:

- To develop a sun shading device that has a step-shaped surface that can:
 - Reflect sun radiation back to the outside space by one single reflection for high sun incidence angles, such as in the summer.
 - Illuminate interior space for low sun incidence angles, such as in the winter.
- To develop a reflective lamellae that will not produce glare in the interior and outside space.
- To provide a shading device that will avoid multiple reflections that lead to overheating of lamellae and therefore to heating of the interior space.

Each slat of the shading device consists of:

- The first portion of the teeth that is close to the outside space. The first portion works in favor of thermal comfort by reflecting sun radiation in summer.
- The second portion of teeth that is close to the interior space. The second portion works in favor of visual comfort by reflecting light into the interior.

Each individual tooth has two sides:

- A side exposed to sun radiation
- A shaded side

Glare is avoided since the tooth side exposed to the sun takes a deflection function, while the shaded tooth side takes a dimming function. The shaded tooth side rather than the irradiated side is seen from the interior space, and the shaded side becomes darker since it is not irradiated by the sun. The slats can have either a reflective surface or a white surface or a diffused surface. No glare effect will occur when looking at the lamellae.

The tooth angle α_1 should be larger than 30° in the first portion and increasing relative to the second portion (see Figure 2-34). By using the different angles α_1 of individual teeth in the first portion of the slat, the glare is reduced because retro-reflection is scattered and is reflected.

The advantage of the shading device designed by Koster is that if it is in the horizontal position, it provides good transparency and light diffusion through the space between the slats while direct sunlight is reflected back to the outside space. The slats in this shading device are fixed, but they can also be moveable. In summer when sun incident angles are high, the slats can be bent inwardly (see Figure 2-38) so that direct sun rays can be reflected.

Figure 2-34 shows a perspective section through three sun protection lamellae. Each lamella consists of four teeth each of which has two sides:

- One faces the sun which makes angle α_1 equal to or larger than a 30° with horizontal axis.
- The other one faces the shaded side that makes angle α_1 approximately 60° .

Three general cases are shown in Figure 2-34:

1. In summer, a high sun incident angle is represented by sun ray 25, which is reflected back to the outside space by one single reflection.
2. In summer, a high sun incident angle is represented also by sun ray 26. Light is secondly reflected by the shaded side of the first tooth, and then reflected again from

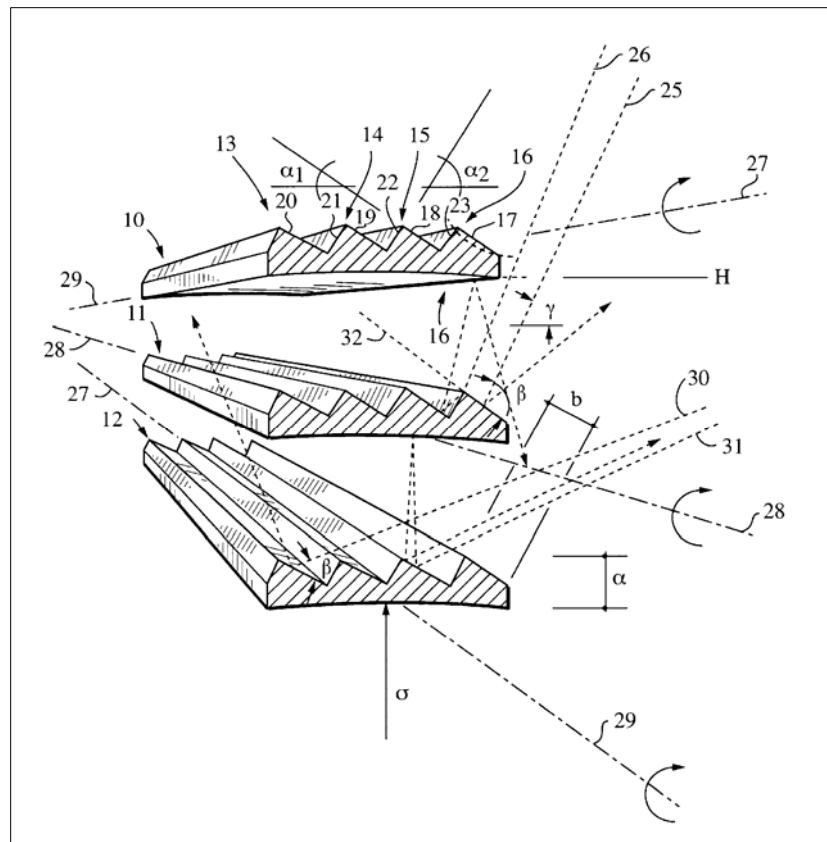


Figure 2-34 Perspective section through three sun protection lamellae

the underside part of the upper lamella to the outside space.

3. In winter, a low sun incident angle is represented by rays 30 and 31, which are reflected from the sun irradiated sides of the teeth, depending on the incident angle. These rays are reflected either to the ceiling of the interior space (ray 30) or to the underside part of the upper lamella and then reflected back to the outside space (ray 31).

It is possible to avoid multiple reflections:

- In summer, by rotating the slats about their horizontal axis to the inside until there is no impact on the shaded side of the tooth.
- In winter, by rotating the slats about their horizontal axis to the outside so that angle β will become steeper, and the lamella's second part teeth will be oriented to the sun. In this case, all light will be reflected back to the outside space.

Generally, with increasing angle β , sun radiation is reflected back to the outside by the first two teeth of the lamella. By decreasing angle β , sun radiation is reflected by the lamella's second part teeth into the interior improving the illumination of the space. Angle α_2 is the angle that the shaded tooth side makes with the horizontal, and it should be selected based on the highest sun incident angle expected on the teeth.

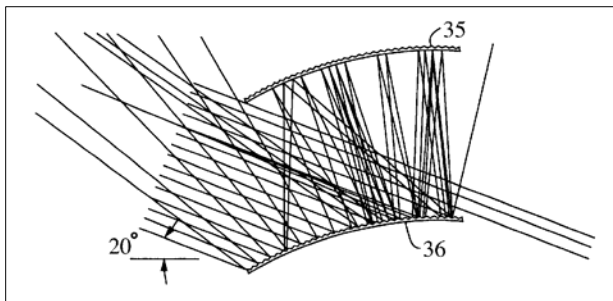


Figure 2-35 Pair of arched lamellae and their optical behavior for a 20° sun angle

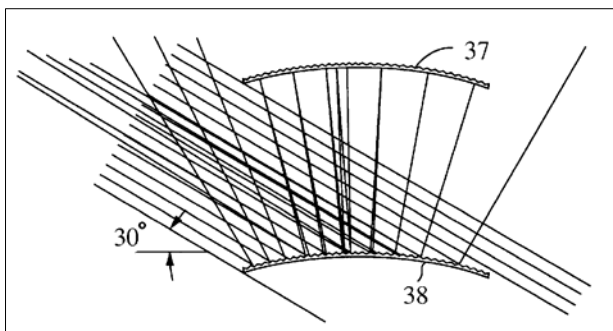


Figure 2-36 Pair of arched lamellae and their optical behavior for a 30° sun angle

Figures 2-35, 2-36 and 2-37 show pairs of arched shading device slats and their optical behavior for different sun angles. Figures 2-35 and 2-36 show the optical behavior of the slats for angles of incidence of 20° (see Figure 2-35) and 30° (see Figure 2-36). Sunlight rays are reflected at the slat surfaces by either one or multiple reflections back to the outside space or into the interior space at a very steep angle, that is, to the ceiling. Figure 2-37 shows the optical behavior of the slats for the angle of incidence of 60°. Sunlight rays are reflected back to the outside by one single

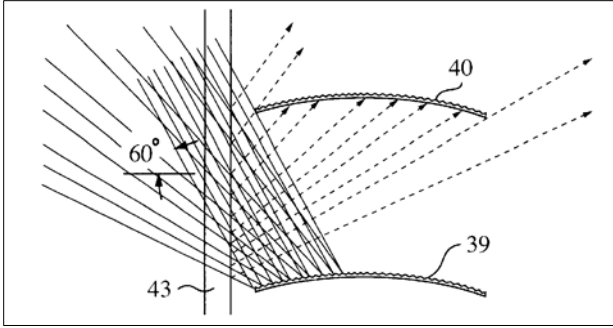


Figure 2-37 Pair of arched lamellae and their optical behavior for a 60° sun angle

show the path of the light, that is, the light which is by scattering reflected to the underside of the upper lamella (40).

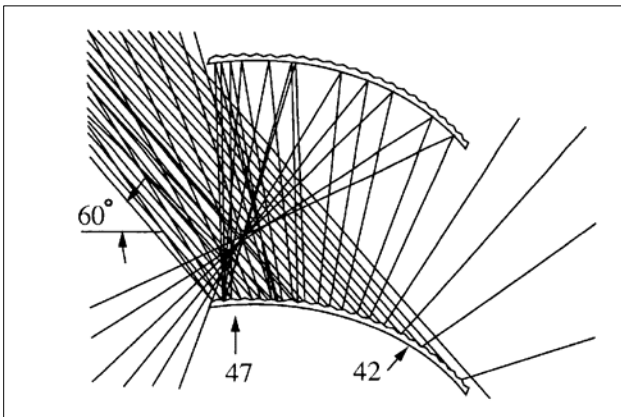


Figure 2-38 Pair of arched lamellae rotated inside and their optical behavior for a 60° sun angle

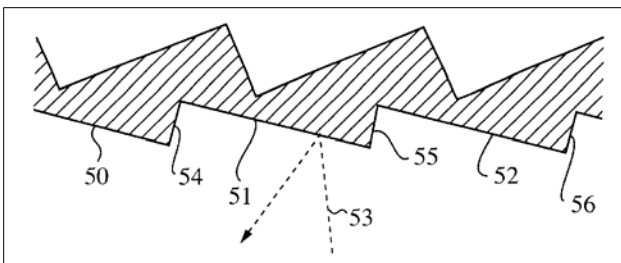


Figure 2-39 Cross section through a lamella with teeth both on the upperside and underside

reflection. The advantage of this shading device is that the glare in the interior space is avoided. In Figure 2-37, glass pane (43) retro-reflects sun radiation, which can cause the glare in the interior when looking at the window. This glare can be avoided by arching the slats and using different angles α_1 of individual teeth, which will cause scattering of the light. Dashed lines

Figure 2-38 shows the shading device in which the slats are rotated around their horizontal axis to the inside. The sunlight angle is 60°. The first part of the slat (47) reflects sunlight rays back to the outside either by one or multiple reflections while the second part of the slat (42) reflects the sun rays into the interior space either to the ceiling or into the depth of the room.

Figure 2-39 shows the partial cross-section of the slat that has teeth both on the upperside and underside. The sunlight ray (53) is reflected twice, the first time from the upperside of the lower lamella and then by the underside of the upper lamella back to the outside. Multiple reflections are avoided and therefore overheating of the slats will not occur.

Figure 2-40 shows a shading device where the slats consist of two parts:

- The first part (60) that is close to the outside space consists of teeth.
- The second part (61) that is close to the interior space is concavely shaped.

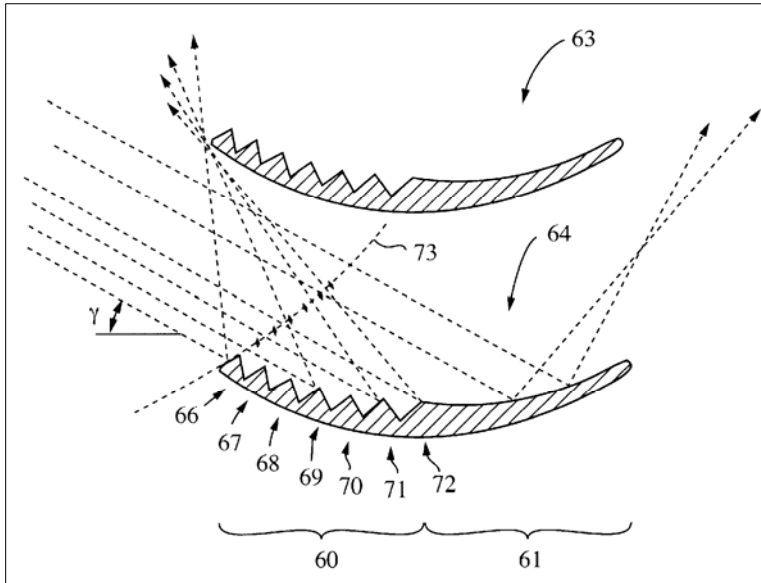


Figure 2-40 Cross section through a concavely arched lamella with toothed first portion

The parabola curve (73) defines the angular position of the first part of teeth that are exposed to sun radiation. The parabola's focus is in the starting point of the first part of the upper lamella. This shading device has a concave shape, but a convex curve is also possible. In this case, the sun angle γ is 30° and is determined by the goal that only a single reflection of sunlight to the outside space can occur. For

the sun angles γ less than 30° , light rays are retro-reflected by at least two reflections from the upperside of the lower lamella to the underside of the upper lamella into the outside space. The second part of the lamella (61) will deflect all sunlight rays into the interior space, improving the space illumination.

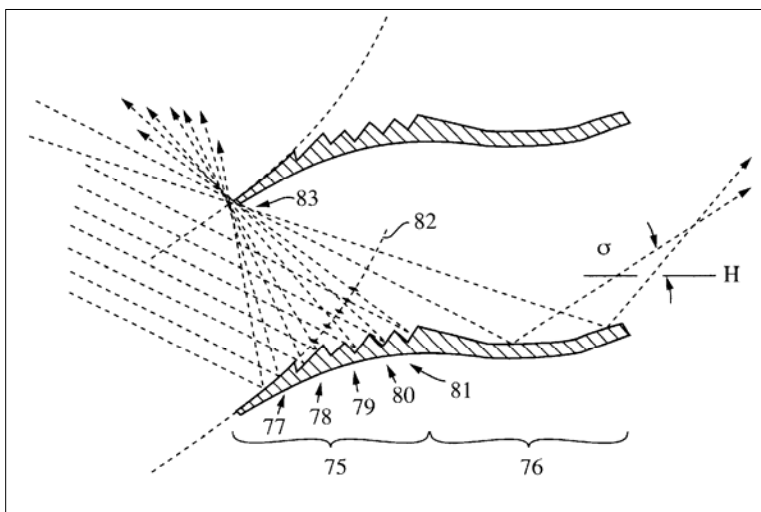


Figure 2-41 Cross section through a lamella with a convexly shaped, toothed first portion and a concavely shaped second portion

Figure 2-41 shows a shading device which has an "S" shaped lamella comprising of:

- The first portion (75) that is convexly arched with teeth. The position of the sun irradiated teeth is defined by the parabola curve (82). The angle of the shading part of the teeth is steep so they are

not exposed to any radiation.

- The second portion (76) that has a concave shape and reflects all the sun rays into the interior space.

Figure 2-42 shows a shading device where the convexly shaped lamellae consist of three parts:

- The first part (86) consists of the teeth where the sun exposed side is aligned into points F_1 and F_2 . This portion of the lamella reflects sunlight rays back to the outside space.
- The second part (87) is convexly shaped without teeth and reflects light at very low angles to the interior space.
- The third part (88) consists of the teeth where the sun irradiated side is aligned with point F_3 . This portion of the lamellae reflects light at a very steep angle to the interior space, that is, toward the ceiling, improving the illumination of the space.

The angle of impact α_1 of the individual teeth increases within the first portion (86) toward the second portion.

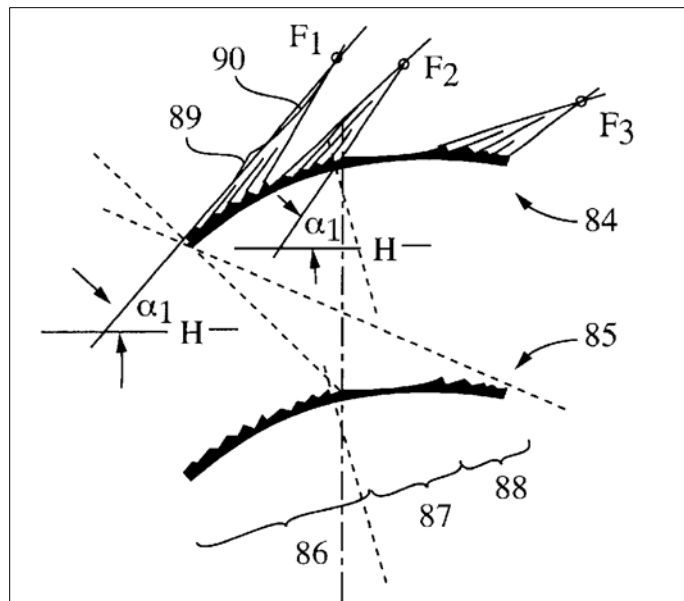


Figure 2-42 Cross section through the lamellae with three convexly shaped portions

Figure 2-43 shows a shading device that has a different shape of the lamellae for the upper (a) and the lower (b) window area. These two lamellae types can be stacked together, as in Venetian blinds. Figure 2-43c shows how lamellae for the upper window part (a) and the lamellae for the lower window part (b) can be laid into each other. Figure 2-43a shows the shape of the lamellae for the upper window area that consist of three parts:

1. The first part (91) is close to the outside space and comprises the teeth that reflect light to the outside. It has two teeth that have sun irradiation sides concavely shaped.
2. The second part (92) is convexly shaped, and it reflects sunlight at low angles to the interior space.
3. The third part (93) has one tooth that reflects sunlight at a high angle to the interior space.

This lamella works well for the upper window part since light is reflected at the second portion of the lamella at a very low angle. In this way, it helps illumination of the interior space. Figure 2-43b shows lamella for the lower window part. The lamella consists of two portions:

1. The first portion (95) has one more tooth compared to the lamella for the upper window part. It reflects direct sunlight back to the outer space.
2. The second portion (96) has the same shape as the third portion in the lamella for the upper window area. The second portion reflects light at a very high angle to the ceiling, avoiding occurrence of the glare.

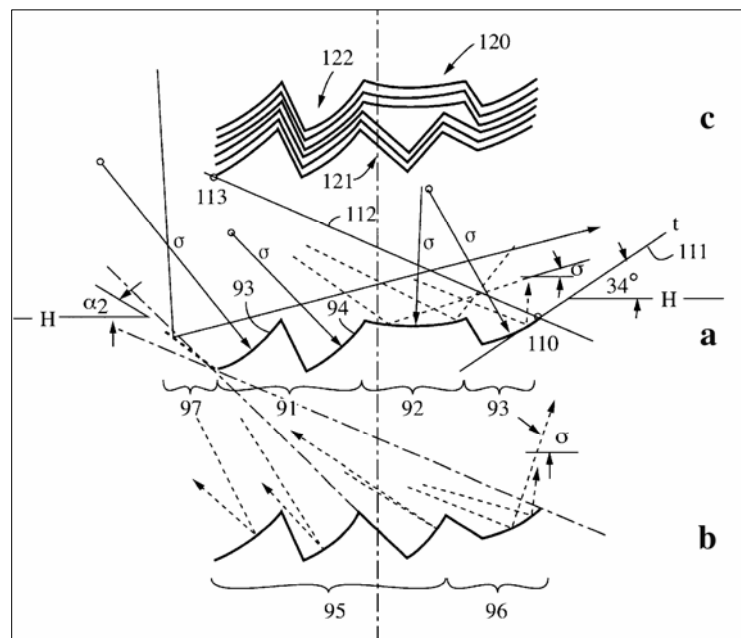


Figure 2-43 Cross section through the lamellae with parallel upperside and underside

Figures 2-44 through 2-47 show another shading system invented by Helmut Koster. This system has the similar geometry to that of the system shown in Figure 2-43a. Light-deflecting lamellae shown in the following figures are fixed, and a different performance is

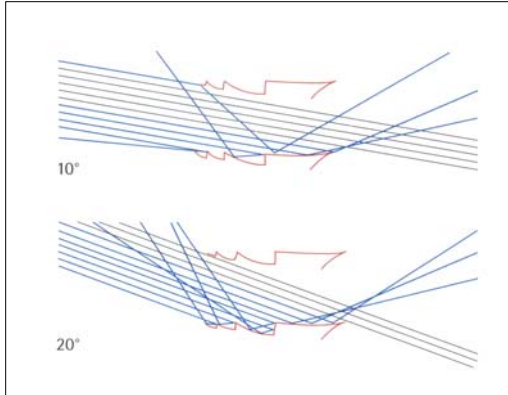


Figure 2-44 Cross section through the light-deflecting lamellae and underside

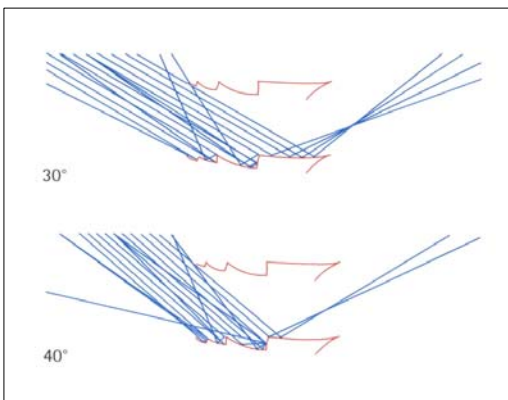
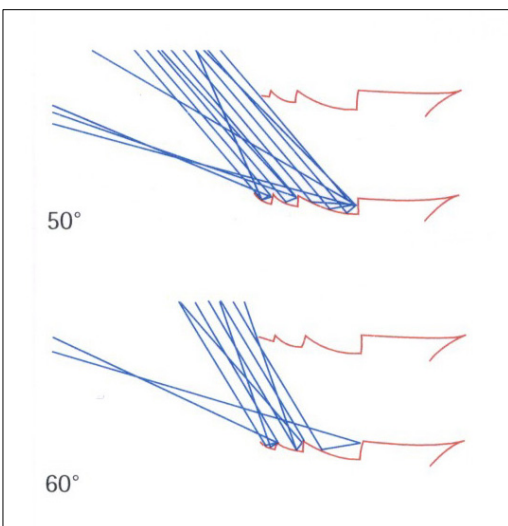


Figure 2-45 Cross section through the light-deflecting lamellae



achieved for different sun angles, that is, for different seasons:

Figure 2-44 shows the optical behavior of the lamellae for the sun angles of 10° and 20° (winter).

Direct sunlight either:

- directly enters into the interior space, or
- is reflected by the front toothed portion to the outside, or
- is reflected by the second concavely shaped part to the ceiling of the interior space.

Figure 2-45 shows the optical behavior of the lamellae for the sun angles of 30° and 40° (winter/transition period). Sunlight rays are either:

- reflected back to the outside space by the first toothed portion of the lamellae, or
- reflected into the interior space toward the ceiling by the second portion of the lamellae.

Figure 2-46 shows the optical behavior of the lamellae for the sun angles of 50° and 60° (transition period/summer). All the sun rays are reflected back to the outside space by the first toothed portion of the lamellae.

Figure 2-47 shows the optical behavior of the lamellae for the sun angles of 70° and 80°

Figure 2-46 Cross section through the light-deflecting lamellae

(summer). Most of the sun rays are reflected back to the outside space but some of them are reflected to the interior space either by the first toothed portion of the lamellae or by the second concavely shaped part of lamellae.

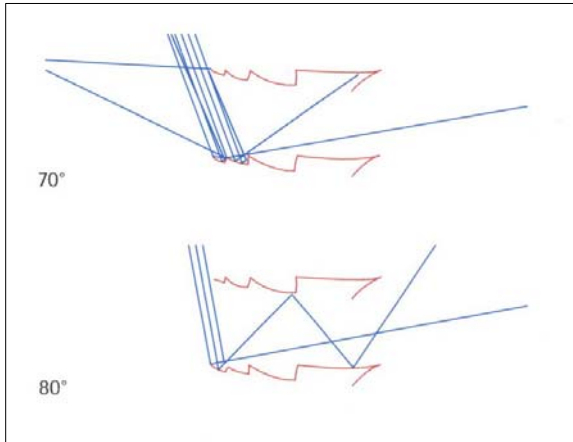


Figure 2-47 Cross section through the light-deflecting lamellae

- Ray 102 is reflected by the third portion (93) and second (92) portion of the upper window part lamellae (see Figure 2-43a for the parts of the lamellae).
- Ray 103 is reflected by the second portion (92) of the upper window lamellae (see Figure 2-43a for the portions of the lamellae).
- Rays 104 and 105 are reflected by the second portion (96) of the lower window area (see Figure 2-43b for the portion of the lamellae).

Figure 2-48 shows the cross section of the room and how the room is illuminated by the second portion of the shading device lamellae in the lower (100) and the upper (101) part of the window. The portions of the lamellae that are close to the interior space provide visual comfort. In a controlled way, light rays are reflected to the ceiling and into the depth of the interior space and no glare will occur. Rays shown in Figure 2-48 are reflected by the lamellae shown in Figures 2-43a and 2-43b:

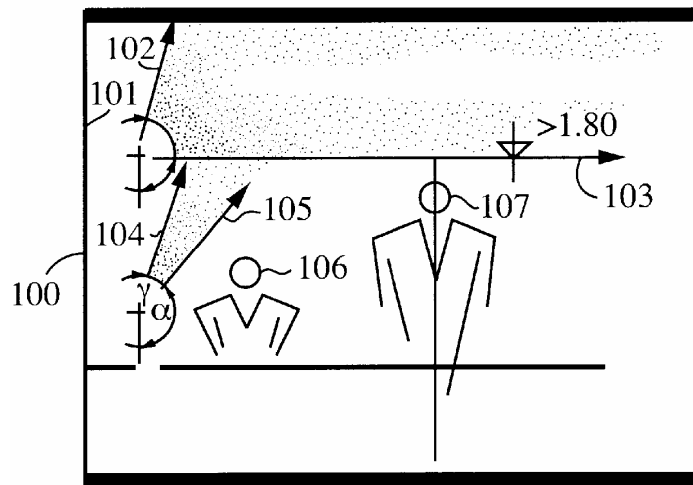


Figure 2-48 Cross section through a window with different light reflections

Manufacture of the lamellae

The lamellae may be produced by using the following methods:

- The aluminum extrusion molding and polishing method
- The roller process
- Casting and co-extruding the lamellae in a transparent material
- Plastic material extrusion, including reflective film covering
- Thermal methods

In the roller process:

- First step: the lamellae are stamped from a flat sheet by using a calendar roll.
- Second step: the stamped flat sheet is cut up into small lamellae.
- Third step: the lamellae are shaped to a curved (concave or convex) form by a rolling form process.

Applying a transparent coating on the toothed side of the lamellae improves the manufacturing process and also the performance of the lamellae. The spaces between the teeth can be filled with a transparent adhesive or cast material (for example, polyurethane or acrylic). If the lamellae are made of transparent materials, the reverse side can be made reflective by metallizing. One of the manufacturing methods is the thermal method, such as deep drawing or pressing a plastified film in a tool. In the step either before or after this process, the film is coated with a reflective foil.

Dimensions of the lamellae

The shading devices' lamellae *width* is:

- 20–100 mm if installed behind the window in the interior space
- 10–25 mm if installed in the space between two panes of glass in the insulating glass

It is beneficial to make the tooth shape of the surface extremely small so that the edge *lengths* for the teeth are less than 1.0 mm (up to even less than 0.1 mm). The *thickness* of such a lamella is between 0.3 and 2.0 mm in the cross section. The teeth that have a length less than 0.5 mm have advantages of:

- Being hardly visible for human eyes, which helps in achieving the goal of a window's transparency.
- Dust cannot be gathered in the valleys between the teeth.

2.5. SUMMARY

The literature review on daylighting performance parameters for shading devices helps in defining performance parameters, which are included in the specific decision-making framework, such as illuminance and luminance. Interactions among the performance parameters are described, and the quantitative and/or qualitative ways of measuring parameters are explained. A review of available computer techniques used for simulation of illuminance and luminance is also given. The most appropriate simulation techniques, such as ray-tracing and radiosity, are explained, as well as software that use either of these techniques. The advantages and disadvantages of the software are explained, as well as the appropriateness of the computer simulation techniques for this research.

The review of research related to thermal and optical performance of shading devices is done to determine results achieved in that area. Various methodologies for testing thermal and optical performance of the shading device are identified, as well as calculation procedures that are the result of the research. A review of such research shows:

- Contributions in the area of creating design guidelines for the shading device
- Calculation of thermal properties, solar heat gain coefficient (SHGC), radiation transmission gains, and directional-hemispherical properties
- Calculation of optical properties by using a ray-tracing procedure in relationship with the application of the shading device systems in the facade.

The literature review on active standards, codes, and recommendations related to the area of this study is necessary to determine values of performance parameters that are used as the reference values in the decision-making model. The ASHRAE, ASTM, IESNA, ISO, and ANSI standards are analyzed to get information about:

- Codes and standards for the window size to provide sufficient illumination levels.
- Standards and recommendations for daylighting.
- Standards for lighting (illuminance values, luminance values, reflectance of surfaces in relation to luminance).
- Standards and recommendations for shading device systems.
- Standards for control systems for daylighting and electric lighting.

The existing shading device systems overview shows products that are currently available on the market and also patented systems. Existing systems available in the market are

investigated to understand which shading device can be currently applied on the building. Various between-glass blinds are presented, based on material and geometry of the slats, blinds' positions, as well as the ways of the operation. Research on patented shading devices is done for various systems that use principles of optics to provide thermal protection and light distribution in the space. The possible different shapes of the slats are shown in each of the patents and explained as a result of applying principles of optical physics. Both fixed and operable shading device systems are explained. Manufacturing methods used for the slats production are investigated. A review of transparent patented blinds is useful since one patented system is simulated in this research as a part of the case study. Also, principles of the transparent blinds design, which are learned from the potential solutions and principles of optics (refer to Appendix A.1: Basic Optical Physics), are used in the design of the new shading device system proposed by this research.

3. DECISION-MAKING FRAMEWORK (DMF)

3.1. INTRODUCTION

This chapter explains the accomplishment of this research's main objective: the development of the decision making-framework (DMF) as an analysis tool to be used in the process of selection and design of a shading device. The development of the DMF starts with the design of a general DMF, which includes the variables and performance parameters (thermal, visual, acoustic, aesthetic, cost, control systems). The development of the general DMF is necessary because it includes several specific DMFs that can be developed in detail in the future. The structure of the general DMF consists of variables (independent, dependent, and shading device variables) and performance parameters that are used as criteria for the blinds' evaluation. The simplified diagram (see Figure 3-1) that shows these major elements of the general DMF is presented and explained in this chapter to get an understanding of the basic structure of the DMF. By expanding the simplified diagram of the DMF, the general DMF is created. The general DMF is developed further by creating subcategories for each variable and performance parameter. The structure of the general DMF also includes relationships and interactions among the variables and performance parameters. Understanding the structure of the DMF is very important because it helps the user of the DMF to make the appropriate decisions about the values of the variables and performance parameters when analyzing and selecting the shading device system. After the structure of the general DMF is described, the process of making the decision about the blinds' selection/design by using the general DMF is explained at the conceptual level.

Since the general DMF is complex, the research takes only one aspect of the DMF to create a specific DMF as a "plug-in" for the general DMF. In this research, the DMF, which is based on two daylighting performance parameters of a shading device (illuminance and luminance), is developed as one specific DMF (see Section 3.3). The daylighting performance is selected for this research because daylighting provides a significant positive effect on human beings, it has a visual quality in the space, and it contributes to energy savings. A shading device impact on illuminance and luminance levels is analyzed because the appropriate use of a shading device can improve daylighting in the space.

The structure of the specific DMF, based on daylighting performance, is created by identifying variables (independent, dependent, and shading device variables) and performance parameters (illuminance and luminance), as well as relationships and interactions between them. The design of the structure of the specific DMF is crucial because it helps the user of the DMF to understand which variables to analyze in the process of the design of the building and the selection/design of a shading device.

This chapter also explains ways of quantitative and qualitative measurement for each variable and performance parameter in the specific DMF. The user of the DMF needs to know how to measure or select the values of the variables and parameters in the DMF to be able to complete the decision-making process.

After the structure of the specific DMF is explained, the process of making the decision by using the specific DMF is described. The user of the specific DMF needs to understand not only the structure of the specific DMF, but also how to use the input and output information of the specific DMF to make the decision about the selection/design of a shading device. In the decision-making process of the analysis of the shading device, the user of the specific DMF goes through the following four steps:

- Identifying input parameters
- Testing the shading device daylighting performance
- Obtaining output parameters
- Making the decision

In this section, each of the four steps is explained in detail to provide the concept for making the decision. In this way, the user of the specific DMF would be able to apply the step-by-step procedure/concept for making the decision about the preferred blinds for a particular building.

3.2. GENERAL DECISION-MAKING FRAMEWORK (DMF)

The result of accomplishing the first research objective is the general *decision-making framework* (DMF) that:

- Includes possible variables (independent, dependent, and shading device variables), as well as performance parameters.

- Defines relationships and interactions among these variables and performance parameters on a general level.

A simplified diagram of the general DMF is shown in Figure 3-1. Independent, dependent, and shading device variables are input for the analysis of the performance of the shading device. Based on the actual performance of the shading device, which is the output of the analysis, a decision about either selection or design of the shading device is made.

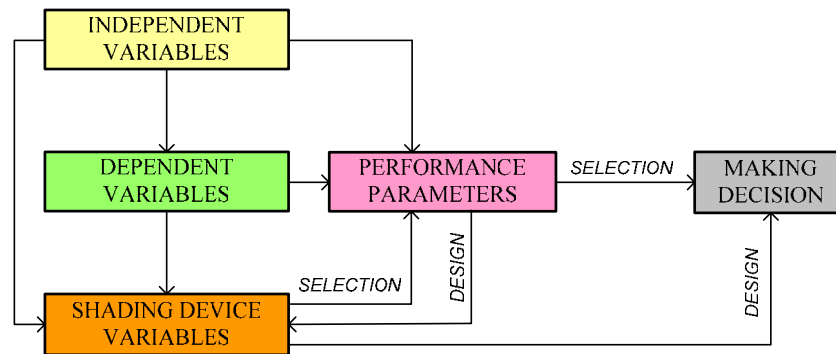


Figure 3- 1 *Simplified diagram of the decision-making framework*

By expanding the simplified diagram and adding more details, that is, defining subcategories for each major variable and performance parameter, the general, complex DMF for the shading device selection and design is developed. The general DMF shown in Figure 3-2 defines possible variables and performance parameters and interactions between them that are relevant in the decision-making process for the selection/design of the shading devices.

3.2.1. DESCRIPTION OF THE STRUCTURE OF THE GENERAL DECISION-MAKING FRAMEWORK

The general decision-making framework includes:

- Independent variables
- Dependent variables
- Shading device variables
- Performance parameters

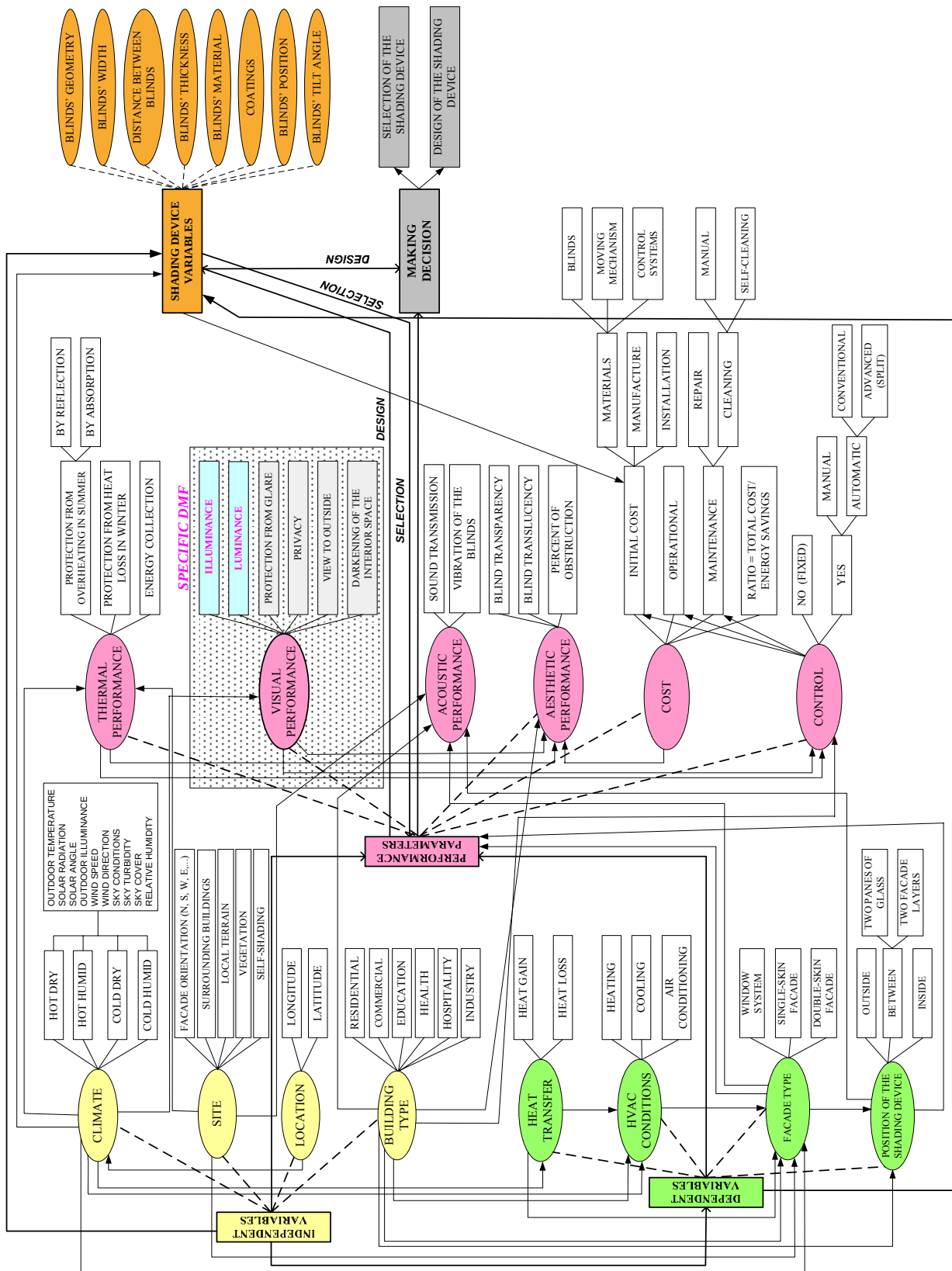


Figure 3-2 General decision-making framework

3.2.1.1. INDEPENDENT VARIABLES

Independent variables are given to the user of the decision-making framework, and the user cannot change these variables. Values of the independent variables do not depend on the decision of the user of the DMF. Independent variables include the following subcategories: climate, location, site, and building type. For each subcategory, variables are defined at a more detailed level.

3.2.1.1.1. Climate

Different types of climate can be considered in the general DMF; for example, the United States has four major climate zones: hot dry, hot humid, cold dry, and cold humid. For each of these climates, characteristics need to be determined. The climate characteristics include: outdoor temperature, solar radiation, solar angle, outdoor illuminance, wind speed, wind direction, sky condition, sky cover, sky turbidity, and relative humidity. The climate characteristics depend on the location of a building, that is, latitude and longitude. Climate as an independent variable directly affects the following dependent variables: type of heat transfer, HVAC conditions, and facade type. Also, climate has a significant influence on the shading device variables and on the shading device performance, particularly on the thermal and visual performance. Climate also affects the operational cost of the shading device and control strategy for the blinds' adjustment.

3.2.1.1.2. Location

The building location is given to the designer of the building. Location is defined by latitude and longitude. Location is directly linked to the following independent variables: climate and site. Based on the building location, the climate of the region, as well as the microclimate of the particular building's site, can be determined. Location indirectly affects dependent variables, such as heat transfer, HVAC conditions, and facade type, and also performance parameters, such as thermal and visual performance and control strategy.

3.2.1.1.3. Site

The building site is an independent variable since it is given to the designer. The designer has two choices: to select the position of the building on the site or to accept the predefined

position of the building, as in the case of the dense, urban setting. The site variables include: orientation of the facade of the analyzed building, existing surrounding buildings, local terrain, existing vegetation, and self-shading properties of the analyzed building. The site is connected to the two independent variables: climate and location. The site has direct influence on facade type and on the performance parameters, such as thermal and visual performance and operational cost and control strategy for the blinds' adjustment. Also, shading device variables are dependent on the site characteristics.

3.2.1.1.4. Building type

In the general DMF, the building type is also considered an independent variable since the designer does not make a decision about the building type. The building type defines a function of the building, for example, residential, commercial, education, health, and so forth. The building type directly influences the following dependent variables: heat transfer, HVAC conditions, facade type, and position of the shading device, as well as the shading device variables. The building type also affects the performance of the shading device, including the following performance parameters: thermal, visual, acoustic and aesthetic performance of the blinds, cost of the blinds, and control strategy for the blinds' position adjustment.

3.2.1.2. DEPENDENT VARIABLES

The designer of the building, facade, and the shading device system defines dependent variables. The dependent variables' values are selected by the user of the DMF. Dependent variables shown in the general DMF include the following subcategories: heat transfer, HVAC conditions, facade type, position of the shading device relative to the facade, as well as possible variables for each subcategory.

3.2.1.2.1. Heat transfer

The user of the DMF defines dominating heat transfer conditions in the building, such as heat gain or heat loss. Heat transfer depends on the independent variables: climate, location, and building type. Heat transfer affects the two dependent variables: HVAC conditions and

facade type, as well as the shading device variables. Values of the performance parameters for the shading devices depend on the heat transfer conditions.

3.2.1.2.2. HVAC conditions

By selecting the HVAC conditions, the user of the DMF makes a decision whether or not there is a need for heating, cooling, or air conditioning--or a combination of any of these systems. The selection of the HVAC conditions is made based on the heat transfer in the building. Also, the decision about the HVAC conditions is influenced by the independent variables, such as climate and building type. Selected HVAC conditions affect the selection/design of the shading device variables. The HVAC conditions have an impact on the shading device performance, specifically thermal performance and control strategy for the blinds' adjustment.

3.2.1.2.3. Facade type

The user of the DMF selects the facade type and defines whether or not a shading device is installed only in the window, in the single-skin facade (such as a conventional curtain wall), or in the double-skin facade¹ (such as a double envelope). The selection of the facade type is affected by the independent variables: climate, site, and building type. The facade type strongly influences the shading device variables. Depending on the facade type, the blinds' geometry, materials, and position are chosen. The facade type affects another dependent variable: position of the shading device relative to the window. Also, the facade type has an effect on the shading device performance, particularly thermal, visual, aesthetic performance, and cost. For example, if the double-skin facade is chosen, the blinds can be installed between the two facade layers and function as a solar collector, that is, the blinds will have a good thermal performance.

3.2.1.2.4. Position of the shading device relative to the facade

The user of the DMF makes a decision about the position of the shading device relative to the facade. The user determines whether the shading device is installed outside, in front of the facade, inside the facade, in the interior space, between two panes of glass in the double

¹ Refer to Appendix A.3: Double-skin facade overview.

insulated glass unit, or in the cavity between two facade layers in the double-skin facade. The position of the shading device is dependent on the following independent variables: climate, site, and building type. The position of the shading device also depends on the dependent variables, such as heat transfer, HVAC conditions, and facade type. The position of the shading device relative to the window strongly influences the shading device variables, especially the blinds' geometry and material. For example, blinds installed outside of the window will be made of different material than blinds installed inside because outside blinds must have good weather protection and must be wind-resistant. The position of the shading device affects the performance parameters for the shading devices, particularly thermal, visual, and aesthetic performance, as well as the cost, especially the maintenance cost. For example, it is more expensive to clean outside blinds than inside blinds.

3.2.1.3. SHADING DEVICE VARIABLES

The general DMF includes the following shading device variables: the blinds' geometry, width and thickness, distance between the blinds, applied materials and coatings, the blinds' position (vertical/horizontal), and the blinds' tilt angle. Shading device variables can be either independent or dependent.

Shading device variables are independent in the process of the selection of the existing shading device system because the building designer cannot change the variables. Shading device variables are already defined by the manufacturer and given to the designer of the building. The performance of the shading device, such as thermal, visual, acoustic, aesthetic, cost, and control strategy, is directly affected by shading device variables in addition to the influence of the independent and dependent variables. To test the performance of the existing shading device experimentally or by computer simulation, the user of the DMF uses shading device predefined variables.

Shading device variables are dependent in the process of the design of the new shading device system because the designer of the shading device decides about the variables. In the process of the design of the new shading device, the values of the required performance for the new shading device (thermal, visual, acoustic, aesthetic, cost, and control systems) are given to the designer of the shading device. The user of the DMF makes a decision about the values of the shading device variables based on the values of:

- Performance parameters required values
- Independent variables (such as climate, site, building type)
- Dependent variables (such as heat transfer, HVAC conditions, facade type, and position of the shading device)

As a result of this consideration, the new shading device's actual performance should achieve the performance required by the standard.

3.2.1.4. PERFORMANCE PARAMETERS FOR THE SHADING DEVICES

Performance parameters for the shading devices, which are considered in the general DMF, are as follows (including possible subparameters for each performance parameter): thermal, visual, acoustic and aesthetic performance, cost of the shading devices, and control strategy for the blinds' position adjustments. The performance parameters' values depend on the independent, dependent, and shading device variables. There are also interactions among the performance parameters.

3.2.1.4.1. Thermal performance of the shading device

Thermal performance of the shading device includes:

- Protection from overheating in summer--by reflection or absorption
- Protection from heat loss in winter
- Collection of sun energy

Thermal performance strongly depends on the independent variables: climate, site, and building type. Thermal performance is also influenced by the dependent variables, such as heat transfer, facade type, and position of the blinds relative to the window. Shading device variables directly affect the values of the thermal performance parameters. For example, climate zone and type of building directly determine heat transfer and HVAC conditions. Based on these decisions, the required thermal performance of the shading device can be defined. In a hot climate, the office building's shading device will be required to provide protection from overheating. The blinds' geometry, materials, position, and tilt angle will be chosen to achieve the required protection from overheating.

The existing shading device systems protect the interior space from overheating in summer or in hot climates, usually by using the principles of reflection of the sun energy.

The measure of the blinds' thermal performance can also be the level of protection from heat loss that the blinds provide during winter nights or in cold climates. Another subparameter that measures the shading device's thermal performance is the collection of sun energy. The blinds can absorb solar energy instead of reflecting it, and they can collect this energy for application in the building's mechanical systems.

There is a strong relationship between the thermal performance parameters of the shading device and the other performance parameters in the DMF, such as visual performance and control systems. For example, the shading device can be designed to provide maximum overheating protection but also can allow the sufficient daylight level in the space. To achieve this goal, control systems should provide the optimum blinds' position and tilt angle.

3.2.1.4.2. Visual performance of the shading device

Visual performance of the shading device includes:

- Providing sufficient illuminance in the space
- Providing sufficient luminance in the space
- Protection from glare
- Providing privacy
- Providing desired darkening of the interior space
- Providing direct visual contact to the outside space

The independent variables (for example, climate, and site) influence the visual performance of the shading devices, particularly illuminance, luminance, and protection from glare. The building type strongly affects the following visual performance parameters: providing privacy, darkening of the interior space, and direct visual contact to the outside space. For example, providing privacy and darkening of the space is often desirable in residential buildings, but not necessarily in office buildings. The visual performance of shading devices depends on the dependent variables, such as facade type and the position of the shading device relative to the window. The blinds' geometry, dimensions, material, position, and tilt angle, that is, shading device variables, have significant impact on the blinds' visual performance. Also, the interaction and dependence among the following performance parameters come into play: thermal, visual, aesthetic, and control. When selecting or designing the blinds, the user of the DMF needs to understand that good visual

performance can be achieved only with the thoughtful control strategy of the blinds' adjustment. The user of the DMF also must consider the impact of such a shading device system on the appearance of the facade, that is, on the aesthetic performance. An understanding of all these interactions in the DMF and careful selection among alternative existing shading devices or design of the new blinds lead to improved visual performance of the blinds.

3.2.1.4.3. Acoustic performance of the shading device

Acoustic performance parameters of the shading device include:

- Sound transmission
- Vibration of the blinds

The acoustic performance of the shading device is significantly affected by the building location and site. For example, a higher level of noise occurs in urban areas, therefore, the blinds have to be selected or designed to reduce this noise. Considering acoustic performance, the building type also affects the selection/design of the shading device. Different levels of acoustic comfort are required in different types of buildings, and a specific shading device can help in achieving the acoustics requirements. The two dependent variables, facade type and position of the shading device relative to the window, also influence the acoustic performance of the shading devices. For example, the blinds installed outside can vibrate because of wind, resulting in increased noise level. For that reason, structure of the outside blinds should be designed properly to avoid the problem of vibration. The acoustic performance of the blinds is connected to the thermal performance, cost, and control. For example, the blinds that protect space from heat loss during cold nights can also protect the space from noise because blinds can be made of materials that have good thermal and acoustical properties. Control strategy is very important when considering the blinds' acoustic performance because completely closed blinds provide the lowest sound transmission, but at the same time they block the daylight. The user of the DMF needs to find the appropriate control strategy to balance the sound transmission and penetration of the daylight, as well as protection from heat loss or gain. The shading device variables directly affect the acoustic performance. The blinds' material, shape, dimensions, and position need to be selected to achieve the best possible protection from noise.

3.2.1.4.4. Aesthetic performance of the shading device

The shading device is an important architectural element, which can have a significant impact on both the exterior and interior appearance of the facade. To achieve an aesthetically pleasing look of the shading device and facade, the following aesthetic performance parameters need to be considered:

- Blinds' transparency
- Blinds' translucency
- Percent of window area obstructed by the blinds

The shading device's aesthetic performance is affected by the independent variables, such as climate, site, and building type. For example, the appearance of the surrounding buildings also affects the appearance of the analyzed building, and, consequently, the appearance of the shading device. Different aesthetic requirements will be imposed for the shading devices installed on different building types. For example, the blinds can have a different look if they are installed on an office building compared to a hospital or industrial building. The aesthetic performance of the shading device is influenced by the dependent variables: facade type and position of the shading device relative to the window. There is a strong relationship between the aesthetic performance parameters and thermal, visual, and acoustic performance, as well as cost of the blinds and applied control systems. For example, the blinds' transparency and percent of window area obstructed by the blinds depend on the requirements for:

- The protection from overheating
- The desired daylight level in the interior space

The values of the shading device variables, that is, choice of the blinds' geometry, dimensions, material, and position/tilt angle, directly affect the blinds' transparency/translucency and percent of the window area obstructed by the blinds.

3.2.1.4.5. Cost of the shading device

Cost of the shading device¹ consists of:

- Initial cost
- Operational cost
- Maintenance cost

¹ Refer to Appendix A.5: Shading Device Cost.

- Ratio between total cost (initial, operational, maintenance) and energy savings achieved due to use of the shading devices

The initial cost of the shading device consists of the cost of material, cost of manufacture of the system, and cost of installation of the shading device on the facade. The initial cost includes not only the cost of the blinds, but also the cost of the moving mechanisms and control systems if the blinds are adjustable. The operational cost includes the operating cost of the shading device itself, as well as the cost of the heating, cooling, and lighting of the space, which is a result of the application of the shading device on the building. The cost of maintenance includes the cost of cleaning of the shading device and the cost of the repair of the shading device. The cost of the shading device is influenced by independent variables, such as climate, location/site, and building type. The cost of the shading device is also directly affected by the remaining performance parameters in the general DMF: thermal, visual, acoustic, aesthetic, and control systems.

3.2.1.4.6. Control strategy for the shading device

The shading device can be either fixed or adjustable. If the shading device is adjustable/moveable, its position can be changed depending on the sun position and sun radiation intensity. If the shading device is adjustable, it can have three basic positions: open, partially open/partially closed, and completely closed. If adjustable, the shading device can be automatically controlled to provide its predicted and designed functions and its positions. The two automatic control strategies are conventional and advanced (split). The control strategy for the blinds' adjustment depends strongly on climate, particularly sun radiation, sun angle, and sky conditions. The control strategy also depends on the building type because different building types require different values of the performance parameters for the shading device and, therefore, different positions and tilt angles of the blinds. The control strategy is also affected by the dependent variables, such as facade type, heat transfer, and HVAC conditions. The shading device variables, particularly geometry of the blinds, dimensions, and materials, determine the control strategy. A strong relationship exists between the control strategy for the blinds' adjustment and the remaining performance parameters. For example, the required thermal, visual, and acoustic performance, as well as

the cost of the shading device, are the major factors in designing the control strategy for the blinds' adjustment.

3.2.2. MAKING THE DECISION IN THE GENERAL DECISION-MAKING FRAMEWORK

The process of making a decision about selection or design of the shading device by using the general DMF includes the following steps (see Figure 3-3):

- Identifying input for the DMF
- Testing the shading device
- Obtaining output results
- Making the decision

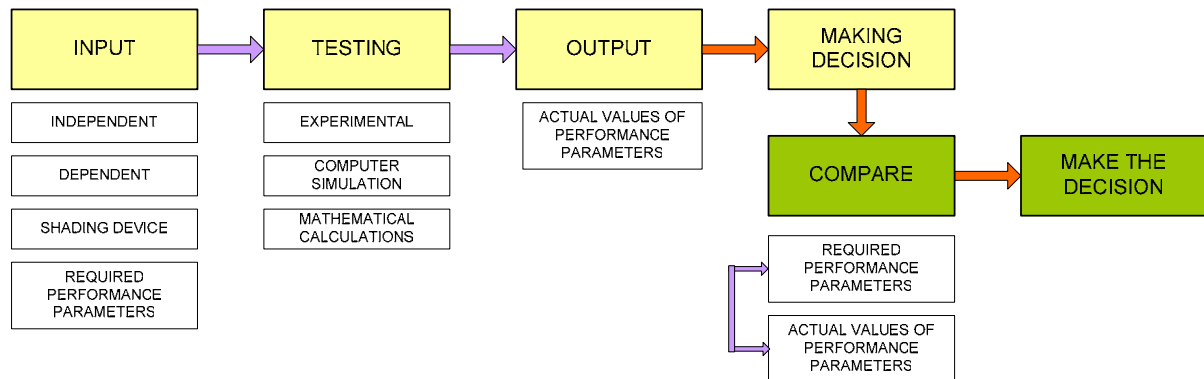


Figure 3-3 Decision-making process in the case of the general decision-making framework

Step 1: Identifying input for the DMF

In the first step, the user of the general DMF prepares the input for the DMF. In this step the user does the input for:

- Independent variables, by identifying and inputting the values of:
 - climate characteristics based on the given climate zone
 - longitude and latitude based on the building location
 - site characteristics
 - building type
- Dependent variables, by identifying:
 - type of heat transfer in the building

- type of HVAC conditions
- facade type
- position of the shading device relative to the window
- Shading device variables, by identifying: the blinds' geometry, dimensions, and materials for each type of shading device that will be analyzed in the general DMF.
- Required values of the performance parameters, which are used as criteria for testing the shading devices in the general DMF. These values include the values of the required thermal, visual, acoustic, and aesthetic performance parameters, as well as acceptable cost of the shading device and required control strategy/systems. These values can be:
 - Taken from active standards, codes, and recommendations related to the specific performance parameter, or
 - Recommended by the decision-making framework itself.

Step 2: Testing the shading device

In the second step of the decision-making process, testing of the various shading device systems is performed. For each type of shading device, separate testing is performed to analyze: thermal, visual, acoustic, and aesthetic performance, and cost and effect of the applied control strategies. Depending on the nature of the performance parameter, the following methods can be used to obtain the actual values of the performance parameters: experimental testing, computer simulations,¹ and mathematical calculations.

Step 3: Obtaining output results

In the third step of the decision-making process, the output results of testing of the shading devices, that is, actual values of thermal, visual, acoustic, and aesthetic parameters, cost of the shading device systems, and effect of the control strategy, are collected for each type of shading device. The results are organized in an understandable and useful format and prepared for analysis.

¹ An example of testing shading devices' daylighting performance (illuminance and luminance) by using computer simulation is given in Chapter 4: Validation of the Specific DMF.

Step 4: Making the decision

In the fourth step of the decision-making process, the decision about the selection of the preferred blinds for the particular building is made. This step consists of two stages. In the first stage, output results of testing are compared to the required values of performance parameters for the shading devices. If the shading device's actual performance meets the requirements of the standards and/or the DMF, then the particular shading device can be considered for further analysis and application on the building. In the second stage, the alternative shading devices are compared to each other. The actual values of the performance parameters for each blinds' system are compared, and the shading device with the best overall performance is selected for use on the specific building. The six criteria (thermal, visual, acoustic and aesthetic performance, and cost and effect of the control systems) are used to measure the blinds' performance. Therefore, it is a complex task to prioritize the criteria in making the decision. The user of the DMF needs to place weighting factors for each of these performance parameters, giving them importance based on the requirements of the project. Also, it is difficult to find a common measure for the six performance parameters since each of them is represented by a different measurement.

A possible approach for evaluating the blinds' overall performance is to convert the values of each performance parameter to the scale, for example, 0 to 100, where 0 is the worst performance and 100 is the best performance, and then compare the performance parameters. However, averaging the values of the performance parameters in this manner gives approximate results, and leads to quick--and not always--accurate decisions. Therefore, the recommendation is to create the decision matrix that considers separately each performance parameter for each shading device system (see Table 3-1). The user of the DMF analyzes the matrix, understanding the advantages and disadvantages of each system. The user then makes the decision about the blinds' selection by applying a thorough and careful analysis of the decision matrix.

Table 3-1 A decision-making matrix

TYPE OF SHADING DEVICE	PERFORMANCE PARAMETERS					
	THERMAL	VISUAL	ACOUSTIC	AESTHETIC	COST	CONTROL STRATEGY
Shading device 1						
Shading device 2						
Shading device 3						

The general DMF shows the complexity of the problem and need to focus research on only one performance parameter and to investigate in detail other possible factors that affect this particular performance parameter. The visual performance of the shading device is highlighted in Figure 3-2, which shows that this research focuses only on daylight illuminance and luminance as performance parameters relevant in the selection/design of the shading device.

3.3. THE SPECIFIC DECISION-MAKING FRAMEWORK BASED ON DAYLIGHTING PERFORMANCE

The specific DMF, based on the daylighting performance of a shading device, is created by taking one aspect (daylighting) of the general DMF and developing it in detail because the general DMF was very complex. The specific DMF is developed to better understand the general DMF. The methodology developed for two daylighting performance parameters, illuminance and luminance, that is, the specific DMF, provides the concept for a shading device analysis. The same concept also can be applied for other performance parameters (thermal, cost, control, and so forth) that are part of the general DMF. Values of input parameters (independent and dependent variables and performance parameters defined by the standards), output parameters, and ways of testing a shading device would vary depending on the performance parameters (for example, thermal, cost, and so forth) analyzed in the DMF. The analysis of the output results and the process of making the decision would be the same for each parameter. Therefore, the DMF based on illuminance and luminance is a prototype

of the specific DMF developed for understanding the general DMF. The prototype can be used for the creation of remaining specific DMFs.

The result of accomplishing the second research goal is the specific DMF shown in Figure 3-4 that includes:

- Possible variables (independent, dependent, and shading device variables) developed in detail.
- Performance parameters for a shading device system: illuminance and luminance level. Performance parameter values are affected by independent, dependent, and shading device variables.
- Relationships and interactions between variables and performance parameters.

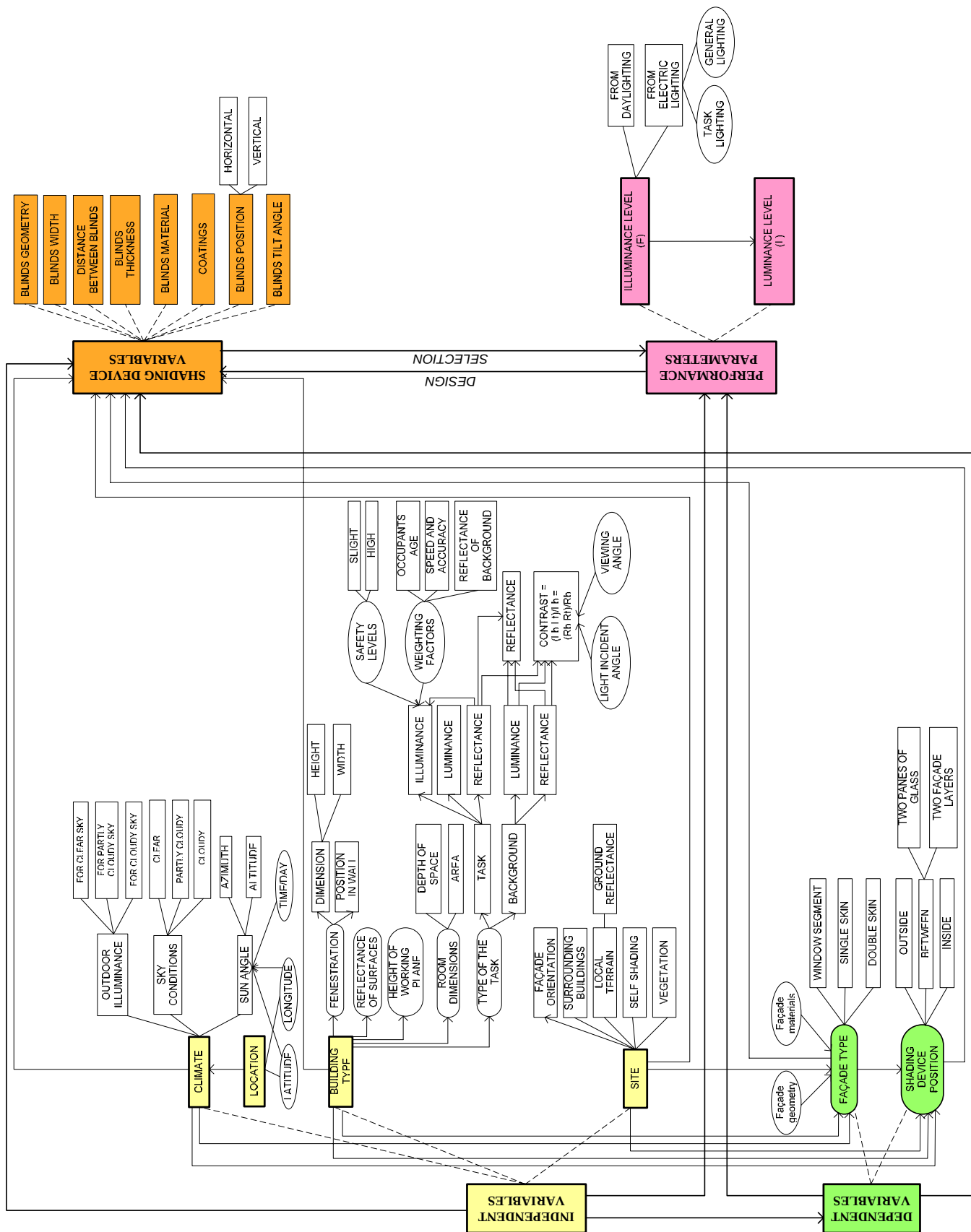


Figure 3-4 Specific decision-making framework based on the shading device daylighting performance

3.3.1. DESCRIPTION OF THE STRUCTURE OF THE SPECIFIC DECISION-MAKING FRAMEWORK

3.3.1.1. INDEPENDENT VARIABLES

Independent variables are variables independent from the designer's choice. Independent variables considered in this research include: climate, site, and building type.

3.3.1.1.1. Climate

Climate is determined by the building location (longitude and latitude). Climate parameters that influence daylighting performance of the shading device are:

- Outdoor illuminance
- Sky conditions
- Sun angle

Outdoor illuminance

The outdoor illuminance level varies continuously and depends on the geographic location and time. The outdoor horizontal and vertical illuminance can be calculated by using empirical formulas or statistical data for a particular building location. The outdoor illuminance determines the available illuminance level from daylighting in the interior space.

Sky conditions

Sky conditions are the most important factors that influence the outdoor illuminance level. The three basic sky conditions are:

- Clear sky
- Partly cloudy sky
- Solid overcast sky

Clear sky

For clear sky conditions, a horizontal and vertical illuminance must be calculated separately. There is no relationship between the horizontal and vertical surface illuminance,

as in the case of a solid overcast sky, because the illuminance of a vertical surface depends also on the azimuth angle of the sun. The exterior *horizontal* illuminance on a cloudless day consists of:

- Diffuse illuminance from the entire sky
- Direct sunlight

The total illuminance is the sum of the diffuse and direct illuminance, and it depends on the sun altitude angle. Various empirical formulas are used to calculate the exterior horizontal illuminance. The *vertical* surface illuminance depends both on the sun azimuth and altitude angles. The vertical illuminance consists of two components:

- Sky only
- Direct sun only

Partly cloudy sky

Since a partly cloudy sky varies continuously, it is impossible to calculate sky luminance by using mathematical formulas. Statistical data on sky luminance for a partly cloudy sky are available for most locations, and these data should be used in a software that gives hour-by-hour energy calculations. The illuminance from a partly cloudy sky is higher than that from a clear sky by 10% to 15% because of the additional reflected sunlight from cloud edges.

Solid overcast sky

A solid overcast sky is also called a CIE sky and is defined by the Commission Internationale de l'Eclairage as a standard design sky that has non-uniform brightness distribution, increasing from horizon to zenith in approximately the ratio of 1:3. The term "cloudy sky" used in this research and in the DMF corresponds to the CIE overcast sky definition.

Sun angle

The sun azimuth and altitude angles depend on the building location (longitude and latitude), as well as time of the year and time of the day. These angles directly influence the values of outdoor illuminance levels. They also affect the blinds' tilt angle in the process of control of the shading devices and illuminance level in the space.

3.3.1.1.2. Site

The building site influences microclimate and daylighting performance of the shading device system. Site parameters that need to be considered in relation to the illuminance and luminance are:

- Existing surrounding buildings
- Local terrain
- Influence of the site on facade orientation
- Existing vegetation
- Self-shading of facade

Existing surrounding buildings and local terrain can increase illumination levels in the interior space by reflection, or they can function as a shading/obstruction, thus reducing the illuminance level. Depending on the terrain configuration, as well as surrounding structures and proposed building function, facade orientations can be determined. Ground reflectance directly affects luminance distribution while surrounding building structures influence the illuminance level in the space, as well as luminance distribution. Facade orientation affects the illuminance level in the space. Also, the blinds' position (horizontal or vertical) depends on the facade orientation. Existing vegetation provides shading of the building and facade, protecting the space from overheating in the summer but also decreasing illuminance and luminance levels in the interior space. Self-shading of the facade depends on the geometry of the building and facade. If the facade is designed to be tilted at a particular angle relative to the vertical plane or if the facade has offsets, self-shading can be achieved. Self-shading can be very beneficial for protection from overheating in the summer, but it also contributes to the lower light levels in the interior space. The site directly affects the level of outdoor illuminance, and, in this way, indirectly influences the interior illuminance level.

3.3.1.1.3. Building type

The building type is considered an independent variable in the context of the shading device performance. A building can have one of the following functions:

- Residential
- Commercial

- Education
- Health
- Hospitality
- Industry, and so forth

The building type directly affects dependent variables such as:

- Facade type (window-segment, single-skin or double-skin facade)
- Shading device position (outside the window, inside the window, between two panes of glass or between two facade layers)

These variables also have an influence on the daylighting performance of the shading device.

The building type determines the following dependent variables that influence daylighting performance:

- Fenestration dimensions and position in the wall: choice of the window width and height depends on the type of the building, and it significantly affects illuminance and luminance levels in the space--the larger the window, the higher the level of daylight in the space. The position of the window in the wall is also an important factor. For example, if the window is located in the upper part of the wall, closer to the ceiling, it will provide higher illuminance levels deep in the space compared to the window located at the lower part of the wall.
- The building type affects the choice of materials for the interior surfaces and the choice of furniture, which determine the values of reflectance of these surfaces. Reflectance of the surface directly influences luminance levels in the space.
- The height of the working plane is determined by the building type and type of task, and it affects the values of the illuminance and luminance levels.
- Room dimensions: room depth affects the illuminance and luminance level in the interior space because the level of daylight decreases with increasing the distance from the exterior wall and window. Also, the area of the room is influential in determining the light levels in the space--the larger the area of the space, the lower the daylight levels for the same size of the windows.
- The type of the task performed in the building determines the recommended illuminance and luminance levels in the space (based on active standards). Based on the type of the task, the luminance of the task and luminance of the background are

determined in order to achieve recommended luminance (contrast) ratios, which directly affect luminance levels. The type of the task also defines the reflectance of the task and reflectance of the background, which are used for calculation of contrast and which directly affect luminance levels in the space.

The above explained variables are selected by the user of the DMF based on the building type.

3.3.1.2. DEPENDENT VARIABLES

Dependent variables are defined by the user of the DMF, which can be either the designer of the building or the designer of the shading device system. Dependent variables are also affected by the independent variables, such as climate, site, and building type. The following dependent variables related to the daylighting performance of the shading device are considered in the specific DMF:

- Facade type
- Position of the shading device in the facade

3.3.1.2.1. Facade type

The choice of the facade type depends on climate, site, and building type, and it is the designer's choice in the decision-making process. The designer also considers the aesthetic criteria while designing the facade. The designer's choice can be:

- Window in any type of wall
- Single-skin facade
- Double-skin facade

The application of the shading device in the window depends on the facade geometry and applied materials. In the case of the window in any type of the facade, the shading device can be designed to cover all the window area, and blinds can have various tilt angles to provide designed illuminance levels from daylight in the interior space. In the case of single-skin and double-skin facades, transparency of the facade segments is determined by the designer. Not only the window but also other facade segments can be transparent and require application of the shading device systems. To provide the desired light levels in the space, the blinds' tilt

angle can vary within the height of the window or the transparent facade segment. The facade type and its geometry directly influence the illuminance and luminance level.

3.3.1.2.2. Shading device position in the facade

The position of the shading device in the facade is the designer's choice and is dependent on the following independent variables:

- Climate
- Site
- Building type

The position of the shading device also depends on dependent variables, such as heat transfer and designed HVAC conditions, which are also the designer's choice. The position also depends on the desired aesthetic performance of the facade and the shading device installed in it. Possible positions of the shading device in the facade are:

- Outside: in front of the facade
- Inside the facade: in the interior space
- Between:
 - two facade layers in the double-skin facade
 - two panes of the double insulated glass unit

Depending on the position of the shading device in the facade, daylight illuminance and luminance levels can vary within the interior space. The position of the shading device also affects shading device variables, such as the blinds' geometry, width and thickness, distance between the blinds, and the blinds' material.

3.3.1.3. SHADING DEVICE VARIABLES

Shading device variables, such as the blinds' geometry, width, thickness, distance between the blinds, and the blinds' materials, affect daylight performance, that is, influence daylight illuminance and luminance in the space. Considering the influence of the shading device variables on the daylighting performance, there are two possible approaches in the DMF:

- In the case of the selection of the existing shading device: the designer of the building makes a decision about the choice of the shading device based on its actual

daylighting performance, which is compared to the performance requirement defined by the standard or by the DMF. In this case, shading device variables are predefined by the manufacturer.

- In the case of the design of the new shading device: the designer of the shading devices designs the blinds' geometry, width, thickness, distance, and material in accordance with the required shading device performance defined by the standards or DMF.

It means that the design/selection of shading device variables is directly affected by the performance parameters, such as required daylight performance (illuminance and luminance level in the space), and indirectly by independent and dependent variables defined by the DMF.

3.3.1.4. PERFORMANCE PARAMETERS FOR A SHADING DEVICE

In the general DMF, visual performance of the shading device is considered and the visual performance consists of the following parameters:

- Illuminance level
- Daylight factor
- Luminance level
- Protection from glare
- Privacy
- View to outside
- Darkening of the interior space

However, in this research, the specific DMF focuses on only two performance parameters, illuminance and luminance levels in the space, as a result of the application of the shading device system. The specific DMF develops these two performance parameters in detail.

3.3.1.4.1. Illuminance

Illuminance is the performance parameter that measures the quantity of the light in the space.¹ Illuminance of the interior space can be provided from daylighting and electric lighting. The goal is to use daylight to provide the maximum (if not all required) illuminance level possible, and then the rest of the illuminance should be provided by artificial (electric) general or task lighting. Illuminance provided by daylighting depends on:

- Independent variables, such as climate, site, and building type
- Dependent variables, such as facade type and position of the shading device in the facade
- Shading device variables

Sky conditions and the sun angle affect the level of outdoor illuminance, which affects the illuminance level from daylighting in the interior space. The daylight reflected from the ground and surrounding buildings can increase the illuminance level in the interior space. The illuminance level in the space also depends on the position and dimension of the windows, as well as room dimensions, particularly the depth of the space. Since the illuminance from daylighting asymptotically decreases with increasing the distance from the window wall, the optimal depth of the room should be defined to achieve the maximum penetration of the daylight in the space. The lighting zones in the room need to be determined since the illuminance level from daylighting varies throughout the space, and the amount of electric lighting added to provide the required illuminance will also vary.

Shading device variables have a great impact on the illuminance level in the interior space. The blinds' geometry, as well as width and distance between the blinds, can be designed to redirect daylight to the ceiling and the depth of the space. Material for the blinds should have good reflective properties to reflect daylight into the interior space and increase the illuminance level. Depending on the design of the shading device system, coatings can be applied on the blinds' surfaces to meet various requirements. If coatings are reflective, they can increase reflectance of the daylight into the space and thus improve the illuminance in the interior.

¹ Refer to Section 2.2.2.1.1: Illuminance

3.3.1.4.2. Luminance

Luminance is the performance parameter that measures the quantity of light reflected off a surface in a particular direction.¹ The luminance level depends on independent variables such as:

- Climate
- Site
- Building type

The luminance level is also affected by dependant variables that are either the designer's choice or are determined by independent variables. The dependent variables that are the designer's input and that influence luminance distribution are:

- Facade type
- Shading device variables

Shading device variables influence the illuminance level in the space and consequently the luminance level. The blinds' position affects uniformity of the light distribution. For example, the vertical position of the slats provides uniform luminance distribution although vertical blinds are usually applied on the east- and west-oriented facades to protect space from direct sun and overheating. On the south-oriented windows, the vertical position of the blinds might not be a good choice for solar protection.

Dependent variables that are determined by independent variables and affect light distribution throughout the space are:

- Room dimension: the designer's input based on the building type
- Type of the task: determined by the building type

Based on the type of the task, the luminance of the task and luminance of the background can be chosen to achieve recommended contrast (luminance) ratios and thus good visibility. Also, reflectance of the task and reflectance of the background are used for computing a contrast ratio that affects the luminance distribution.

¹ Refer to Section 2.2.2.1.2: Luminance

3.3.2. QUANTITATIVE/QUALITATIVE CRITERIA FOR THE VARIABLES AND SOURCES OF MEASURES IN THE SPECIFIC DMF

The structure of the specific DMF is created by identifying variables and performance parameters and by defining their relationships and interactions. After the specific DMF's structure is designed, quantitative and qualitative criteria for variables in the specific DMF, as well as sources of measures for the variables, are determined. Identifying the ways and sources of measures for the variables in the specific DMF gives the user of the specific DMF an understanding of how to deal quantitatively and qualitatively with the variables. The user has options to:

- Calculate values manually or automatically by using the software (outdoor illuminance, sun angle).
- Select the values from the database (sky conditions, building type, shading device position relative to the facade, values of illuminance and luminance given by the standard).
- Use/draw a three-dimensional model (for example, site, building, shading device)

The source of measure depends on the nature of the variable, and this DMF clearly defines the appropriate way of measurement for each variable and parameter. The ways of measurement of variables are explained in the next section.

3.3.2.1. INDEPENDENT VARIABLES

3.3.2.1.1. Climate

Sources of the measures for climate parameters are either statistical data obtained by measurements at the particular weather station or calculations performed by the computer software.

Outdoor illuminance level can be determined by:

- Experimental measurement using photometric sensors
- Use of statistical climatic data for a particular location
- Mathematical calculations

The value of outdoor illuminance is an input for either experimental testing or computer simulation of indoor illuminance and luminance levels. In this research Autodesk VIZ 4 is

used for simulation of daylighting. VIZ 4 automatically calculates outdoor illuminance based on the sky condition and sun angle, which depends on the building location, date, and time.

Sky conditions: for a particular location, sky conditions can be determined, and then values of sky luminance and outdoor horizontal and vertical illuminance can be calculated based on sky conditions. For example, in the case of clear sky conditions, illuminance data for a particular location and climate are not always available, but solar radiation data are available. It is therefore necessary to calculate illuminance by multiplying the solar radiation value by the following conversion coefficients:

- For total radiation, sun and sky = 119 lm/W
- For diffuse (sky) radiation only ~ =14 lm/W
- For direct solar radiation only ~ =105 lm/W¹

In the case of cloudy sky conditions, the sky luminance (L_A) can be calculated by using the following formula:

$$L_A = L_Z * (1+2*\sin A)/3$$

where

L_A = luminance at angle A above the horizon

L_Z = luminance at the zenith

A = altitude angle above the horizon²

The exterior horizontal illuminance (E_H) is not dependant on the solar azimuth and can be calculated by using the following formula:

$$E_H = 300 + 21,000 \sin (A)$$

where

E_H = exterior horizontal illuminance (lux)

A = sun altitude angle (°)³

If the exterior horizontal illuminance (E_H) is known, then the vertical surface illumination can be calculated by using the following formula:

$$E_V = E_H/2.5$$

where

E_H = horizontal surface illumination

E_V = vertical surface illumination¹

¹ Stein, B. and Reynolds, J. *Mechanical and Electrical Equipment of Buildings*. John Wiley & Sons, (2000)

² Stein, B. and Reynolds, J. *Mechanical and Electrical Equipment of Buildings*. John Wiley & Sons, (2000)

³ Stein, B. and Reynolds, J. *Mechanical and Electrical Equipment of Buildings*. John Wiley & Sons, (2000)

The other approach is to use statistical data for the sky conditions. Statistical data specify the number of clear, partly cloudy, and cloudy days for each month individually and per year for a particular location. In this research the statistical data are used.

Sun angle: Depending on longitude, latitude, time of the year and time of the day, the sun angle can be found mathematically for a particular location.² Also, the sun angle can be measured by using the sun angle sensor. In this research, Autodesk VIZ 4 is used to automatically calculate the sun angle depending on the geographic location, date, and time.

3.3.2.1.2. Building type

The source of measure for the building type is a database of various possible building types. For example, the database consists of a list of building types, such as residential, commercial, educational, health, industrial, hospitality, and so forth. Each of the building types is linked to the second level databases that consist of the list of the spaces that create such a building. For example, a list of the spaces for the commercial building includes lobby, reception area, conference rooms, office space, space for copier machines, and so forth. The database of the spaces in the particular building is linked to a database of possible tasks that can be performed in the particular space. For example, in the office space, possible tasks are reading, writing, use of computer, and so forth. (see Figure 3-5). Based on the types of the tasks, the optimal values for illuminance and luminance in the space are determined by using the active standards and codes.

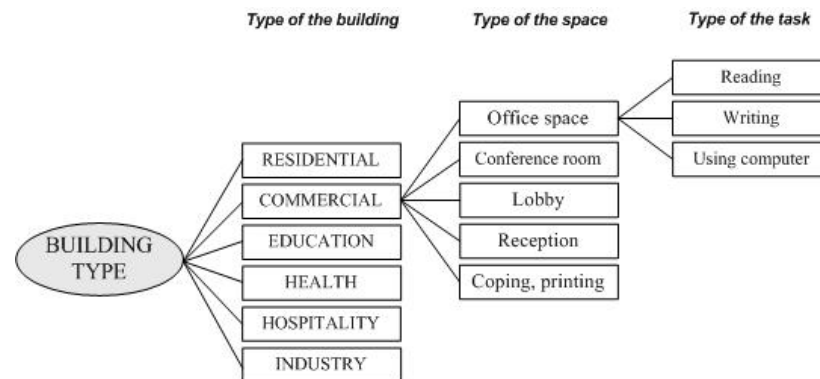


Figure 3-5 Databases for the independent variable: building type

¹ Stein, B. and Reynolds, J. *Mechanical and Electrical Equipment of Buildings*. John Wiley & Sons, (2000)

² Refer to Appendix A.4.1: Sun position calculation

Dependent variables that are affected by the specific building type are determined by the designer of the building in accordance with current standards and codes:

- ***Fenestration dimensions and position*** recommended by various standards¹ are reviewed and defined as minimum or maximum values:

- Minimum window area = 8% to 10% of floor area
- Maximum window area = 40% to 50% of the gross wall area
- Minimum window area = 20% to 30% of the window wall area
- Minimum window's sill height = 1m

Based on these recommendations, one window dimension is chosen to meet both minimum and maximum requirements. The criteria/recommendations for sizing the windows can be used in the conceptual phase, prior to performing experimental testing or computer simulation of the daylighting performance of the shading device system. The window positions are chosen based on the building type, the building's geometry, and aesthetics requirements, but they are also based on recommendations for providing daylighting in the space.

- ***Reflectances of room surfaces*** are chosen by the designer in accordance with standards.² For example, values of the reflectances for the interior surfaces should be in the following recommended ranges:

- For the ceiling: 0.6-0.9
- For the walls: 0.3-0.8
- For the working planes: 0.2-0.6
- For the floor: 0.1-0.5

This means that the designer of the building chooses materials for interior surfaces with reflectance properties that will meet recommendations of the standards.

- ***Height of working plane*** is chosen based on architectural standards and building codes and in relation to the tasks that are performed in the building. In this research the height of the working plane of 30" is chosen based on the standard.
- ***Room dimensions*** are determined to provide sufficient daylight.

¹ Refer to Sections 2.3.1: Standards for window size, and 2.3.2: Standards for daylighting

² Refer to Section 2.3.3.2: Standards for luminance

The sources of measures are the standards¹ that introduce, for example, three criteria relevant in defining the depth of the room:

- Maximum depth, that is, distance from the vertical source of daylight, of 4 m
- Ratio window height/room depth = 1: 2.5
- Area of daylighting control zones of 10 – 40 m²

The room depth for this research is chosen to meet all three criteria.

- The **types of tasks** are dependant on the building type. The types of tasks performed in the building are defined and categorized in a database.

3.3.2.1.3. Site

Sources of measures for the site are databases developed for each site parameter.

The site as an independent variable consists of the following parameters that influence illuminance and luminance levels in the interior space:

- The position of surrounding buildings relative to the analyzed building, as well as their applied facade materials, affects the illuminance and luminance level. Reflectances of the facade surfaces of the surrounding buildings are quantified in order to use them as an input for calculation of indoor illuminance. Sources of measurement for the building position, geometry, and facade materials are three-dimensional drawings of the surrounding buildings/site with defined and attached materials. Based on the chosen materials, the values of the reflectances are determined. The other approach for determining reflectance of the facade materials is to use databases of the materials that define their reflective properties. In this research, the surrounding buildings are not considered in the validation of the DMF due to the limitation of the software and hardware used in the research to process the large amount of input information. Adding three-dimensional drawings of the existing surrounding buildings to the drawing of the analyzed building dramatically increases the size of the file and needed time for the simulation.
- Local terrain: configuration of local terrain should be considered in determining the position of the building on the site. Sources of measures for the site configuration can be either a database of possible configurations or three-dimensional drawings of the

¹ IESNA *Lighting Handbook* – 8th edition

actual building site, which provides more accurate information. Values of ground reflectance are determined to find the contribution to the illuminance level in the space. The source of measure is a database of reflectance values of various ground and pavement materials.

- Influence of the site to the facade orientation: sources of measures are three-dimensional drawings of the site that define geometry, dimensions, and materials for both local terrain and surrounding buildings. These sources of measure influence the proposed building position on the site and, consequently, the orientation of the facades.
- Existing vegetation: the source of measure of existing vegetation is a three-dimensional drawing of the site with precisely defined types of vegetation/tree, height and diameter of the tree, as well as the position of the tree on the site.
- Self-shading of facade: the source of measurement for the self-shading parameter is a three-dimensional drawing of the building that determines its geometry and particularly geometry and materials of the facade with a precisely defined slope of the facade and facade offsets.

3.3.2.2. DEPENDENT VARIABLES

3.3.2.2.1. Facade types

Two possible sources of measures for the facade types are:

- A database of various types of facades depending on their structure, applied materials, and geometry. The designer of the building or the shading device chooses one of these types that is applicable for the building and uses it as an input in the DMF.
- A three-dimensional drawing of the facade that defines geometry, structure, and materials of the facade. The drawing is done by the designer of the building or the shading device, which means that the designer does the input for the facade type.

3.3.2.2.2. Shading device position relative to the facade

The source of measure for the position of the shading device is a database of various positions. The database includes three basic positions of the shading device relative to the

facade cross section: outside, between, and inside the window. The designer's choice on the shading device position is used as an input for determining daylighting performance of the shading device. The other approach for measuring the shading device position is a three-dimensional drawing that precisely defines the position of the shading device in the window.

3.3.2.3. SHADING DEVICE VARIABLES

The decision-making model can be used in two cases:

1. Selection among alternative existing shading device systems
2. Design of a new shading device system

In the case of the selection among alternative existing shading device systems, the shading devices' variables, such as the blinds' geometry, width, thickness, and materials, are already known and given by the manufacturer, that is, they function as independent variables in this decision-making model. These values are used as input for a simulation performed by the computer software.

The source of measure is a database of the existing shading device systems with information provided by the manufacturer. If some of the shading device systems are not included in the database, then the designer of the building has the opportunity to add the system that is supposed to be applied at the building to the database. The designer needs to use a three-dimensional drawing of the shading device system that precisely defines its geometry and materials.

In the case of the design of the new shading device system, the approach would be reversed from the selection process of the existing shading device system. The required performance parameter values are accepted and defined as they are given by the standards or decision-making model. The performance parameters are input for the designer of the shading device in the decision-making process, which are related to the variables for the shading device. Based on the required values of the performance parameters and the designer's knowledge and experience, the blinds' geometry, width, thickness, distance between the blinds, and position of the shading device are defined and the blinds materials are chosen. The source of measure is a three-dimensional drawing of the shading device system with precisely defined parameters, such as geometry and materials.

3.3.2.4. DAYLIGHTING PERFORMANCE PARAMETERS: ILLUMINANCE AND LUMINANCE

3.3.2.4.1. Illuminance

Two types of illuminance levels that need to be quantified in the analysis of the shading device are:

- The actual value that is the result of application of the shading device in the building.
- The value recommended by active standards, codes, and recommendations.

These two values are compared in the DMF in order to decide which type of blinds can be used in the building. Two methodologies can be used for testing the shading device performance: experimental and computer. The chosen methodology affects the selection of the source of measure of the actual illuminance level in the space:

- If the shading device performance is tested experimentally, then the physical, experimental measurements are the source of information about the illuminance levels in the space.
- If the shading device performance is tested by using the software, then the output of the simulation gives results and information about the actual illuminance.

In this research computer simulation is used to measure actual illuminance in the space.

The sources of measures for the required illuminance level in the space are active standards, codes, and recommendations. The standards¹ give the values of the needed illumination level based on:

- Type of the task (see Table 3-2)
- Illuminance category of the task (see Table 3-2)
- Levels of illumination for safety (see Table 3-3)
- Weighting factors: age of occupant and reflectance of surfaces (see Table 3-4)
- Task and background reflectance (see Tables 3-5 and 3-6)

These five criteria must be considered when choosing the value of the illuminance requested for a particular space.

The user of the DMF chooses illuminance values relevant for a particular task and space from the standards. For example, if Tables 3-2 through 3-6 are recommended values of

¹ Refer to Section 2.3.3.1: Standards for illuminance

illuminance that need to be considered, then the following procedure can be applied to choose the illuminance value:

- From Table 3-2, choose the illuminance category based on the type of the task performed in the space, and then choose the range of illuminance for that task.
- From Table 3-3, find out what level of illumination for safety in a particular space is required and compare this value with the one chosen in the previous step to see if an adjustment of the required value is needed.
- In the next step, weighting factors must be investigated and the requested illuminance level adjusted, if needed, based on the occupant's age, room surface reflectances, and illuminance category with values given in Table 3-4.
- Another factor that needs to be considered is task reflectance, which also affects illuminance levels. Values are chosen from Table 3-5 based on the illuminance category.
- In the final step, the relationship between task illuminance and illuminance of immediate surroundings is considered, as given in Table 3-6 and the required illuminance value adjusted if needed.

If there are differences among the values of illuminance taken from the standards, then the highest illuminance should be accepted in the DMF as a reference value.

Table 3-2 *Illuminance categories and illuminance values based on types of activities*

Type of Activity	Illuminance Category	Range of Illuminance		Reference work-plane
		Lux	Footcandles	
Public spaces with dark surroundings	A	20-30-50	2-3-5	General lighting throughout spaces
Simple orientation for short temporary visits	B	50-75-100	5-7.5-10	
Working spaces where visual tasks are only occasionally performed	C	100-150-200	10-15-20	
Performance of visual tasks of high contrast or large size	D	200-300-500	20-30-50	Illuminance on task
Performance of visual tasks of medium contrast or small size	E	500-750-1000	50-75-100	
Performance of visual tasks of low contrast or very small size	F	1000-1500-2000	100-150-200	

Table 3-2 Illuminance categories and illuminance values based on types of activities

Performance of visual tasks of low contrast and very small size over a prolonged period	G	2000-3000-5000	200-300-500	Illuminance on task, obtained by a combination of general and local (supplementary lighting)
Performance of very prolonged and exacting visual tasks	H	5000-7500-10000	500-750-1000	
Performance of very special visual tasks of extremely low contrast and small size	I	10000-15000-20000	1000-1500-2000	

Table 3-3 Levels of illumination for safety

Hazard Requiring Visual Detection Normal Activity Level	Slight		High	
	Low	High	Low	High
Areas	Conference rooms Reception rooms Exterior floodlighting closets	Lobbies Corridors Concourse Restrooms Washrooms Telephone switchboard rooms Exterior entrance Exterior floodlighting	Elevators (freight) File rooms Mail rooms Offices Stairways Stockrooms Exterior entrance with stairs	Elevators Escalators Computer rooms Drafting rooms Offices Stairways Transformer vaults Engine rooms Electrical, mechanical, plumbing rooms
LUX (FOOTCANDLES)	5.4 (0.5)	11 (1.0)	22 (2.0)	54 (5.0)

Table 3-4 Effect of weighting factors on general lighting illuminance values for illuminance categories A, B, and C

Weighting Factors		Illuminance (lux)		
		Category		
Average age of occupants	Average room surface reflectance (%)	A	B	C
Under 40	Over 70	20	50	100
	30-70	30	75	150
	under 30	30	75	150
40-50	Over 70	30	75	150
	30-70	30	75	150
	under 30	30	75	150
Over 55	Over 70	30	75	150
	30-70	30	75	150
	under 30	50	100	200

Table 3-5 Requirements for illumination levels based on task reflectance and categorized by type of the task

Category of Visual Task	Required Illuminance E (lux)	
	RF = 50%	RF = 10%
Casual	62-125	300-625
Ordinary	125-625	625-3125
Moderate	625-1250	3152-6250
Difficult	1250-2500	6250-12500
Severe	>2500	>12500

Table 3-6 Required illuminance of immediate surroundings based on the task illuminance

Task Illuminance (lux)	Illuminance of Immediate Surroundings (lux)
≥ 750	500
500	300
300	200
≤ 200	Same as task illuminance

3.3.2.4.2. Luminance

As is the case for illuminance, both the actual value of luminance at specific points in the space and values required by standards need to be quantified. The actual luminance value, which is the result of the application of the specific shading device system, can be measured experimentally by:

- Luminance meters which gives values in cd/m^2
- Lux meters which gives values in lux
- Video-based photometers

The actual luminance levels can also be measured by using software such as Autodesk VIZ 4. Also, if illuminance levels are measured or simulated and reflectances of surfaces are known, then luminance can be calculated, based on the relationship between illuminance and luminance.¹ In this research the actual luminance level is calculated by using Autodesk VIZ 4.

¹ Refer to Section 2.2.2.1.1: Illuminance

Sources of measures for required luminance levels in the space are active standards, codes, and recommendations.¹ Standards require consideration of several factors when choosing the luminance level in the space:

- Reflectance of room surfaces²
- Type of task (see Table 3-7)
- Luminance ratios (see Table 3-8)

Each of these criteria needs to be met when selecting the value of the required luminance:

- If reflectance of the surface and required illuminance in the space are chosen, then the required luminance is calculated.
- Based on the type of task, the value of the required luminance is chosen from Table 3-7.
- Standards recommend maximum luminance (contrast) ratios among task, background, and remote surfaces. This ratio should be used when considering the luminance of the task and background (see Table 3-8).

If there are different values of luminance taken from the standards, then the highest recommended value for a particular space and task conditions should be chosen.

Table 3-7 Required luminance ranges categorized by type of the task

Category of Visual Task	Required Luminance (cd/m ²)
Casual	10-20
Ordinary	20-100
Moderate	100-200
Difficult	200-400
Severe	Above 200

¹ Refer to Section 2.3.3.2: Standards for luminance

² Refer to Section 2.3.3.2: Standards for luminance

Table 3-8 *Maximum luminance ratios for offices containing VDTs*

Between paper-based visual tasks and adjacent VDT screen	3 to 1
Between a visual task (paper or VDT) and adjacent dark surroundings	3 to 1
Between a visual task (paper or VDT) and adjacent light surroundings	1 to 3
Between a visual task (paper or VDT) and more remote dark surroundings	10 to 1
Between a visual task (paper or VDT) and more remote lighter surroundings	1 to 10

3.3.3. DESCRIPTION OF DECISION-MAKING PROCESS IN THE SPECIFIC DMF

The decision-making process includes the creation of the structure of the DMF and identifying the ways of measure of the variables and performance parameters in the DMF. It also includes the process of testing the shading device, obtaining output results, analyzing the results, and making the decision about the preferred blinds, based on the analysis of the results of the blinds' performance. The next section gives a general description of the basic steps in the process of making the decision in the case of the specific DMF based on illuminance and luminance. This description of the decision-making process helps the user in understanding which methodology should be employed to make the decision. A more detailed description of the decision-making process is given in Chapters 4 and 5 (validation and analysis of results) by using the case study.

The decision-making process for the analysis of the shading device systems consists of the following steps:

- Identifying input variables and performance parameters
- Testing the shading device systems
- Obtaining output performance parameter values
- Making the decision

The decision-making process steps are shown in Figure 3-6.

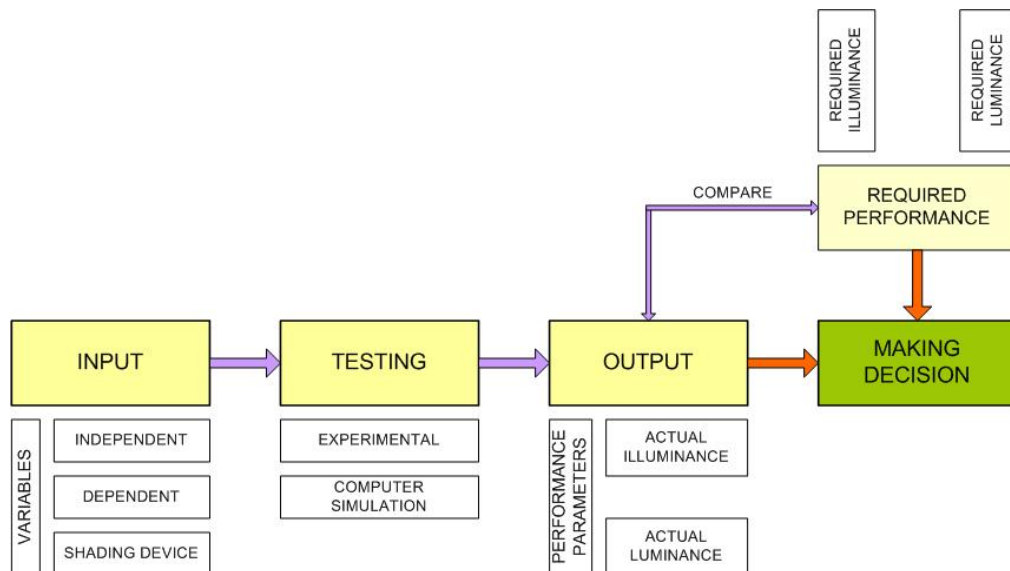


Figure 3-6 Decision-making process steps in the specific DMF

3.3.3.1. Input parameters

In the first step of the decision-making process, the user of the specific DMF identifies input parameters. In the case of the selection/design of the shading device, input parameters are categorized as independent, dependent, and shading device variables,¹ which are assigned particular quantitative or qualitative values.² Once the user of the DMF decides the values of the independent and dependent variables, the values can be considered constant for a particular site and building type. The only independent variables that change their values are the date and time of analysis, which affect the sun angle and sky conditions. Since these variables significantly affect daylighting performance of the shading device and control strategies, various conditions need to be tested.

The objective in this decision situation is to select the best possible shading device among several alternatives, that is, various shading device systems. In this situation, each of these alternatives must be tested separately. As a result, input for the shading device variables must be prepared individually for each system.

3.3.3.2. Testing

In the second step of the decision-making process, testing of the shading device system is performed. Testing is done either:

- Experimentally or
- By using computer simulation software³

Input parameters prepared in the first step are used for testing the daylighting performance of the various shading device systems. For each type of shading device, testing is repeated for different dates during the year, with at least one day for each season and different times for each of those days. The choice of testing time depends on the facade orientation and type of building, that is, times when the space is used.

Testing is repeated individually for each type of shading device to find out how application of these shading device systems in the building affects illuminance and luminance levels in the space. If the blinds are adjustable, then the shading device system is

¹ Refer to Section 3.3.1: Description of the structure of the specific decision-making framework

² Refer to Section 3.3.2: Quantitative/qualitative criteria for the variables and sources of measures in the specific DMF

³ For advantages and disadvantages of each approach refer to Sections A.6: Experimental procedures to measure daylighting performance parameters, and 2.2.2.2: Available software for modeling daylighting performance

tested for various blind tilt angles, from completely open to partially open/partially closed, and finally to completely closed. This testing is helpful in establishing a control strategy for a shading device for different sun and sky conditions to keep the required illuminance and luminance level in the space.

3.3.3.3. Output parameters

The output of both experimental and computer testing are actual values of illuminance and luminance levels in the space, as a result of the application of the specific shading device system in the building.¹ In the third step of the decision-making process, the output information is gathered, organized, and prepared for analysis.

3.3.3.4. Making the decision

In the first step of the decision-making process, before making the final decision, the actual daylighting performance (output information) and the required performance established by the standards or DMF are compared. Two approaches for making the decision are:

- In the case of selection of the best shading device among the existing shading device systems
- In the case of the design of the new shading device

In the first case, daylighting performances (illuminance and luminance) of shading devices are compared to each other and to the required performance. First, the shading device's actual performance is compared to the required performance. If the daylighting performance of a specific shading device meets the requirements of the standards, then the shading device can be applied at the building. If several shading device systems are considered for application, then the system, which gives the highest illuminance and luminance level--but less than the maximum values recommended by the standard, is chosen. The decision made in the final step in this case is to choose the shading device with the best daylighting performance to be applied on the particular building. If none of the shading device systems meets the requirements of the standard, the decision is not to apply any of the tested systems on the building. Figure 3-7 graphically presents the final step of the process,

¹ Refer to Section 3.3.2.4: Daylighting performance parameters: illuminance and luminance

which is making the decision, for example, about which shading device systems to select for the building.

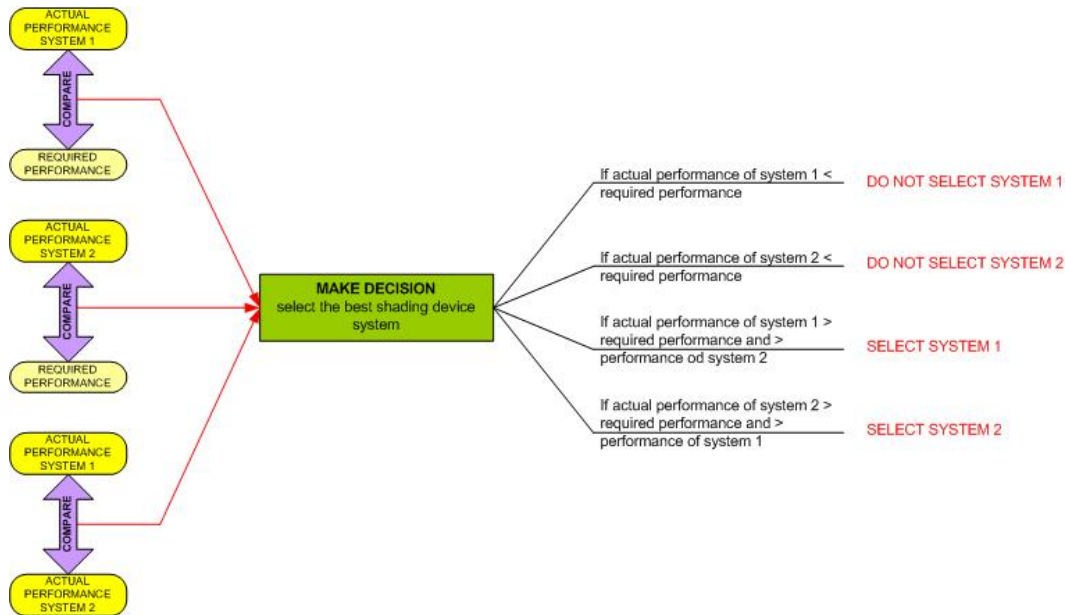


Figure 3-7 Decision-making final step in the case of selection between two existing shading device systems

In the case of designing the new shading device system, the required performance is the guide for the designer in creating the new system and deciding about the shading device variables. Once the design of the new shading device system is completed, its daylighting performance is tested and compared to the required performance values. If the daylighting performance of the new shading device system meets the requirements proposed by the standard, then the new shading device design is satisfactory. If the actual values of illuminance and luminance are below those required by the standard, then the new shading device needs to be redesigned. The shading device input variables need to be changed in order to improve performance of the shading device and meet the requirements of the standard.

The decision that can be made in the final step in the case of the design of the new shading device system is either:

- A new system must be redesigned (if its performance does not meet the requirements of the standard), or
- A new system design is satisfactory (since its daylighting performance meets the requirements of the standard) and it can be produced.

Figure 3-8 is a graphical representation of the final step of the process for making a decision on whether to redesign or produce a new system of shading device.

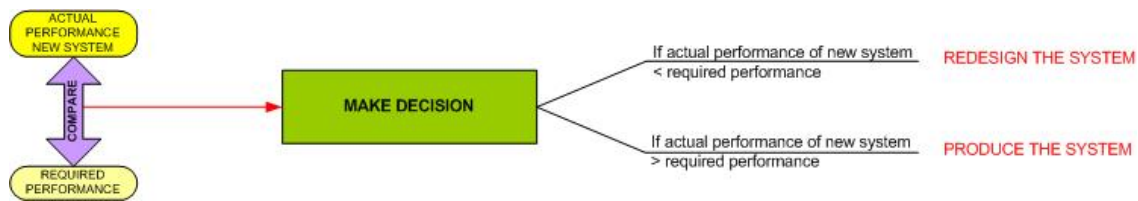


Figure 3-8 Decision-making final step in the case of testing the new shading device system

3.4. SUMMARY

This chapter describes the structure of the DMF and steps of the decision-making process. The structure of the DMF can be explained at two levels:

- The general level, that is, the general DMF. The general DMF includes major categories of variables that affect shading device performance, and also performance parameters considered in the process of the selection/design of the shading device system.
- Detail level, that is, the specific DMF. The specific DMF includes only variables that affect the shading device daylighting performance, and they are categorized, structured, and explained in detail. The specific DMF includes only two daylighting performance parameters: illuminance and luminance.

The general DMF consists of independent, dependent, and shading device variables, and performance parameters, such as thermal, visual, acoustic, aesthetic performance, cost, and control strategy. The structure of the general DMF also includes relationships and interactions between the variables and performance parameters.

The specific DMF consists of independent, dependent, and shading device variables, and also daylighting performance parameters, such as illuminance and luminance, including interactions between the variables and performance parameters.

In the specific DMF, variables and performance parameters are measured by using either qualitative or quantitative criteria. Sources of measure differ based on the characteristics of variables and performance parameters. Databases of information, a three-dimensional model of the site, a building and shading device, and active standards, codes, and recommendations are the most common sources of measures for variables. Sources of measures for performance parameters in the specific DMF are:

- Active standards: for required illuminance and luminance levels in the space.
- Experimental testing or computer simulation: for actual daylighting performance of the shading device.

The basic steps of the decision-making process are:

- Identifying input parameters, such as independent, dependent, and shading device variables.
- Testing the shading device system, by conducting an experiment or performing computer simulation.
- Obtaining output information, such as an actual illuminance and luminance level in the space at which the shading device is applied.
- Making the decision about the shading device application/production.

4. VALIDATION OF THE SPECIFIC DECISION-MAKING FRAMEWORK

4.1. INTRODUCTION

This chapter takes the specific DMF, developed and explained in Chapter 3, and validates it. Validation of the DMF proves that the proposed methodology for the analysis of the shading device performance and making the decision about the preferred blinds for a particular building works. In the first part of this chapter, the validation process is described so that the user of the DMF gets an understanding of how to use the DMF. The basic principles of the decision-making process introduced in Chapter 3 (see Section 3.3.3: Description of decision-making process in the specific DMF) are explained in this section on a more detailed level. This is necessary to understand how to use the DMF in a particular case of selection of the preferred blinds among several alternatives. The tasks of the validation process presented in this section are: input for the specific DMF, simulation of daylighting performance, presentation of the output, analysis of results, and making the decision. For each task, subtasks are defined in the process of making the decision about the blinds' selection/design. A step-by-step explanation of the tasks and subtasks represents the methodology for the testing/analysis of the blinds. This methodology is used in this dissertation to validate the DMF, but the same methodology can also be applied by the user of the DMF in any case study.

In order to validate the specific DMF, the case study is performed for an office building located in Roanoke, Virginia. Three different types of blinds are simulated to select the most appropriate blinds for the building. The case study includes variables and parameters that are part of the specific DMF structure and shows how the values for the variables and parameters are selected. Based on the input of the values described in this section, the user of the DMF understands how to make input for the DMF in the particular case. This chapter describes the following parameters of the specific DMF used in the case study: a proposed building, building facade, facade orientations, building location, time frame, sun angle, outdoor illuminance, sky conditions, shading device system, blind tilt angle and blind position, and performance parameters (illuminance and luminance). This chapter also explains the method of analysis used in the specific DMF and in this case study, because the user of the DMF needs to understand how Autodesk VIZ 4, which is used as a daylighting modeling software,

simulates blinds on a particular building at a given location. The input and output of Autodesk VIZ 4 is described because it helps in understanding how to organize input information for the software. It also helps in understanding how to prepare an analysis of the output from the simulation performed by Autodesk VIZ 4. At the end of this chapter examples of three specific DMFs for the three types of shading devices used in this case study are represented graphically. These examples give an idea of the application of the specific DMF in the real world.

In this chapter, the validation process for the specific DMF and the case study's parameters are described. The tasks of the validation process, such as making an input for the specific DMF, performing simulations of daylighting performance of the shading devices, presenting the output of the simulations, analyzing the results of simulations, and making the decision, are explained in detail. In the second part of the chapter, a description of a case study used in the validation process is given.

4.2. VALIDATION PROCESS DESCRIPTION

The specific decision-making framework (DMF) is validated in order to evaluate the possibility for its application. The validation process consists of the following tasks:

- Input for the specific DMF
- Simulation of the daylighting performance
- Presentation of the output
- Analysis of results
- Making a decision

4.2.1. TASK 1 – INPUT FOR THE SPECIFIC DMF

In the first step of the validation process, an input for the specific DMF, which includes independent, dependent, and shading device variables, and also the performance parameters required by the standard, is done by the user of the DMF. Table 4-1 presents an overview of the input information for the specific DMF and the sources of input in the validation process.

Table 4-1 Input for the specific decision-making framework in the validation process

INPUT		SOURCE OF INPUT
Independent variables	date	User's input
	time of the day	User's input
	location	User's input
	sun angle	Software - automatically
	sky conditions	User's input based on statistical data
	building type	Database
	site	3D drawing done by AutoCAD and Autodesk VIZ 4. Material properties included in the drawing.
Dependent variables	building space	Database of standards + 3D drawing done by AutoCAD and Autodesk VIZ 4. Material properties included in the drawing.
	facade type	3D drawing done by AutoCAD and Autodesk VIZ 4. Material properties included in the drawing.
	position of the shading device	3D drawing done by AutoCAD and Autodesk VIZ 4
	windows	Database of standards + 3D drawing done by AutoCAD and Autodesk VIZ 4. Material properties included in the drawing.
Shading device variables		3D drawing done by AutoCAD and Autodesk VIZ 4. Material properties included in the drawing.
Recommended daylighting performance		Database of active standards, codes, and recommendations

Independent variables

- **Climate**
 - Based on the *building location* (longitude and latitude), climate characteristics can be determined by using software such as Climate Consultant. However, the Autodesk VIZ 4 software is used for daylighting simulation to perform validation of the results in this research. Autodesk VIZ 4 requires as an input sun and sky

conditions, which are done automatically by the software if geographic location, date, and time are defined by the user of the DMF.

- The simulations can be done for different climate zones (that is, four climate types/four building locations in the United States).
- *Dates and times*, for which the simulations are performed, are defined by the user of the DMF. The simulations can be done for various days during the year, for example, one day per each season. Also, simulations can be performed for different times of the day depending on the facade orientation and frequency of the space usage.
- Based on the building location and date and time of the day and also by using the appropriate daylighting simulation software (DSS), such as Autodesk VIZ 4, the user of the DMF defines the *sun angle* for which the daylighting simulation is performed.
- The user of the DMF chooses the *sky condition*. Autodesk VIZ 4 offers three values for the sky condition: clear, partly cloudy, and cloudy.

- ***Building type***

The type of building is given or chosen by the user of the DMF. The user defines:

- The building type: it is possible to test different types of buildings, but this research is limited to an office building that contains computers. The building type is chosen by the user from the database of building types.
- Various spaces in the buildings (for example, office space/work stations, copy rooms, assembly rooms, conference rooms, and so forth.). Based on the selected building type, another database that contains names of the spaces is activated, and the user chooses the rooms that occur in the building.
- The possible types of tasks that can be performed in each selected room. This information is also derived by the user from the database of the possible tasks linked to the specific type of room.

- ***The site***

The chosen building location/site is defined by a three-dimensional drawing of the surrounding buildings, local terrain, and existing vegetation. The local terrain properties, such as the ground reflectance, are chosen from the database by the user of

the DMF. The self-shading properties of the facade and facade orientations of the proposed building are determined by a three-dimensional drawing.

Dependent variables

Dependent variables are defined by the designer of the building or the designer of the new shading device system who is also a user of the DMF. The user's input for the dependent variables in this specific DMF is the three-dimensional drawing done by using AutoCAD and Autodesk VIZ 4. The user draws:

- A 3D model of the building in which the user defines:
 - Geometry:
 - o Shape and dimension of the spaces/rooms, based on the building type and types of tasks that are performed in the spaces, as well as active standards.
 - o Geometry and type of facade, based on the building type and aesthetic requirements.
 - o Dimensions and positions of the windows, based on the building type and active standards.
 - o Position of the shading device relative to the window.
 - o Shape, dimensions, and position of furniture that are used in a particular space that also defines height of the working plane.
 - Materials:
 - o Choice of materials for the interior surfaces which automatically determines the values of reflectances of the surfaces (the materials are attached to the surfaces).
 - o Choice of materials for furniture that also determines values of reflectance of their surfaces.
 - o Choice of materials for the window frames and the glazing.

Shading device variables

Shading device variables are defined by the user of the DMF (designer of the building or designer of the shading device). The user draws a 3D model of the shading device in which he defines:

- Geometry:
 - Shape and dimensions of the blinds
 - Distance between the blinds
 - Blinds' tilt angle. (The blinds' tilt angle is fixed in the particular 3D model. If the blinds are adjustable--for each new tilt angle of the blinds--a new 3D model must be created).
- Materials:
 - Choice of the materials for the blinds with the materials' properties (the materials are attached to the blinds' surfaces)

If the existing blinds are tested, then the 3D model can be provided by the manufacturer. If such information is not given, the user of the DMF needs to prepare input for the shading device variables. In the case of testing the new system of blinds, the designer of the new system must determine the shading device characteristics and input them into the DMF.

Performance parameters

The user of the specific DMF prepares information for illuminance and luminance values that are requested for the particular space. The values are chosen from a database of active standards, codes, and recommendations. Selection of the values is based on the types of tasks performed in the proposed rooms, as well as adjustment factors (such as level of safety, weighting factors, reflectances of the task and other surfaces).

4.2.2. TASK 2 – SIMULATION OF DAYLIGHTING PERFORMANCE

Daylighting simulations are performed for the particular building type, the facade type, and different shading device types at the chosen location. The simulations are performed by using the simulation software Autodesk VIZ 4. For each type of shading device and its fixed position relative to the window, multiple simulations are performed since the analysis is done for different dates and different times per day, as well as for various sky conditions. If blinds are adjustable/moveable, the number of simulations is multiplied by the number of various blind tilt angles. The daylighting simulations are performed for the different types of shading devices based on:

- Blinds' material (for example, aluminum, plastics, glass, wood, and considering the material's transmittance and reflectance)
- Blinds' geometry (shape, thickness, width, distance between the blinds)
- Blinds' tilt angle
- Shading device position relative to the window

If any of first two parameters (material and geometry) are changed, the shading device is considered to be a new, different type compared to the previous model. Changing the blinds' tilt angle and position relative to the window does not make a new type of shading device since it is still the same product, but just at a new position. The variables that are changed in the simulation process are as follows:

- Climate parameters:
 - Sun angle
 - Sky conditions
- Time parameters:
 - Date
 - Time of the day
- Shading device variables:
 - Blinds' geometry
 - Blinds' material
 - Blinds' tilt angle
 - Shading device position relative to the window

The software Autodesk VIZ 4 simulates the actual illuminance and luminance levels as a result of the application of the specific type of shading device. This software presents them in a three-dimensional realistic picture of the space. Measurements of daylighting parameters are read at different points of the space from the pictures.

4.2.3. TASK 3 – PRESENTATION OF OUTPUT

Variables are changed in the specific DMF in order to present different simulation situations. A combination of all these variables requires thousands of simulations and gives as an output a large quantity of data that need to be represented in a simple, organized, and understandable format. The output of the simulation are values of the illuminance and

luminance level calculated for different combinations/values of the input variables. Since the values are given in the format of the three-dimensional image (see Figures 4-1 and 4-2), the values are read at different points in the space and recorded in the format of matrixes of the data.¹

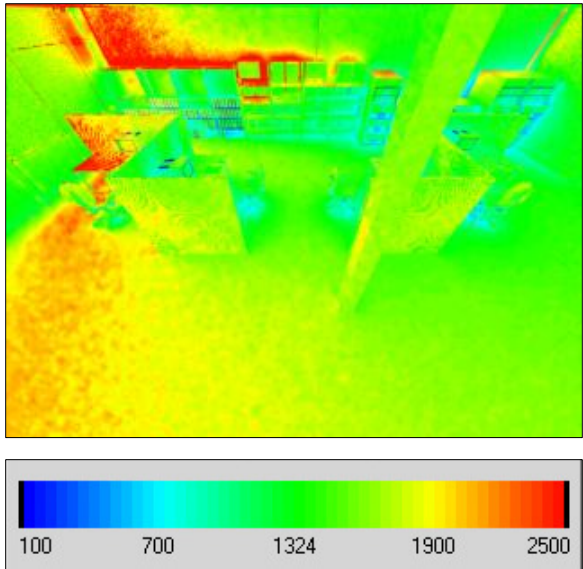


Figure 4-1 Output of the simulation's three-dimensional image of the space - illuminance (in lx)

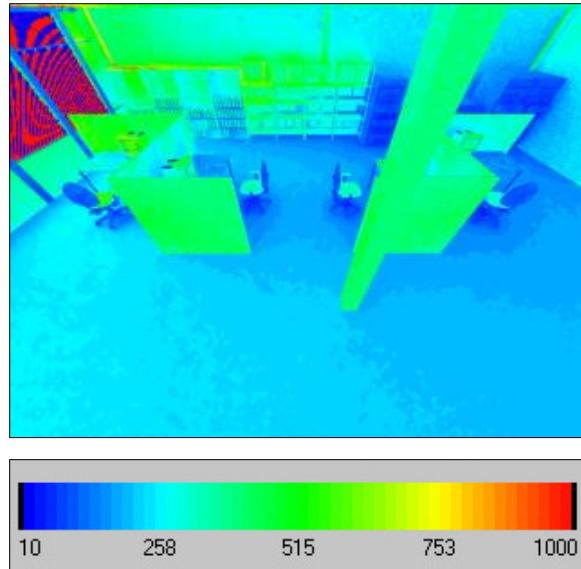


Figure 4- 2 Output of the simulation's three-dimensional image of the space – luminance (in cd/sq m)

These results are then presented in the format of charts that compare daylighting performance of different types of blinds and different sky conditions. For example, one chart shows illuminance level values on the vertical axis and different sky conditions (clear, partly cloudy, and cloudy) on the horizontal axis. In the chart, three lines represent the performance of the three types of blinds.² One of these charts representing the performance for the particular orientation of the facade and the specific measurement point in the space is interpreted in Figure 4-3 below.³

¹ Refer to Appendix B.1. Matrixes of data, and to Section 5.2.1. Description of the matrixes of data

² Refer to Appendix B.2: Charts and tables – for the user of the DMF, and to Section 5.2.2. Description of the charts of results used in the specific DMF

³ For a detailed description of the charts' elements, refer to Section 5.2.2: Description of the charts of results used in the specific DMF, and see Figure 5-1

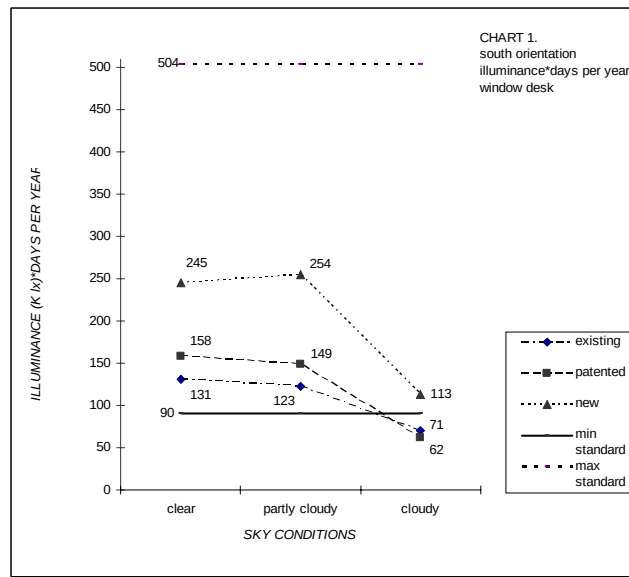


Figure 4-3 Results in the format of the chart

4.2.4. TASK 4 – ANALYSIS OF RESULTS

Once the output data, that is, actual illuminance and luminance values, are presented in the format of the charts, the results of the simulations are analyzed. The performances of different types of shading devices are then compared, and a decision as to which shading device should be selected to be applied for the particular building is made. The user of the specific DMF considers the following criteria in the analysis of the specific chart:

- Which shading device type gives the highest illuminance (or luminance level) in the space? An analysis is done separately for each sky condition.
- Does each type of shading device meet requirements of the standards for the illuminance (or luminance) level? An analysis is done separately for each sky condition.
- How do sky conditions affect the illuminance (or luminance) level in the space relative to the various types of shading devices? The analysis is done for each type of shading device.

The number of analyzed charts depends on the number of:

- Facade orientations
- Performance parameters

- Measured point in the space

For example, if two facade orientations, two performance parameters, and two points in the space are considered, there are eight charts of results made as a combination of these six variables. The user of the specific DMF analyzes all eight charts following the previously explained criteria.

4.2.5. TASK 5 - MAKING THE DECISION

In the final step of the validation process, the decision about the selection/application of the shading device is made, based on the analysis of the results of the simulation performed in the previous step. An analysis of the charts shows which shading device systems fit in the range of values for illuminance and luminance recommended by the standards. If some of the systems of shading devices do not have values of the daylighting performance that fit in the range of values recommended by the standard, then this system is excluded from the comparison with the other systems. The analysis also shows which type of shading device gives the highest levels of illuminance and luminance in the space. The decision is to select the shading device that meets both criteria. This approach is suitable in the process of selection of the best existing shading device system among several alternatives.

A possible approach in making the decision consists of several steps (for details, see Section 5.3.1.4: Analysis of results, obtained by converting the values of the data to the scale 0-1):

- Creating a chart with performance parameter values for all types of shading devices that are analyzed.
- Converting values of illuminance and luminance to the values in a range 0 to 1.
- Adding converted values and dividing the sum with the number of different decision situations for each performance parameter.
- Using weight factors in making the decision.

4.3. CASE STUDY'S PARAMETERS DESCRIPTION

In order to validate a specific DMF, a case study is performed. In this chapter, the following parameters of the case study are described:

- Proposed building
- Building facade
- Facade orientations
- Building location
- Ground reflectance
- Time frame for the simulations
- Sun angle
- Outdoor illuminance
- Sky conditions
- Shading device systems (existing, patented, and new)
- Blinds' tilt angle
- Shading device position
- Performance parameters
- Analysis method

The site parameters, such as existing surrounding buildings and existing vegetation, are not considered in this case study in order to decrease the time of the simulation. The objective is to validate the specific DMF, that is, to prove that the methodology works for the analysis of blinds. Exclusion of the two site parameters (existing building and vegetation) does not affect the concept of testing the blinds.

4.3.1. DESCRIPTION OF THE PROPOSED BUILDING

A proposed office building is used in this study. In order to decrease the time of simulation, that is, rendering three-dimensional images of the analyzed space, an analysis is done for the rectangular office space 60' wide, 40' deep, and 10' high (see Figure 4-4).

The office space is divided in separate work spaces by cubicles. Each cubical space contains an office desk, a chair, and a computer. Shelves and cabinets line the interior walls (see Figures 4-5, 4-6, 4-7 and 4-8). Only four cubicles are presented in the model of the proposed space in order to decrease the time of the simulation, and, at the same time, provide

enough results for the analysis of the blinds' performance. Similar office furniture would be repeated in the remaining space.

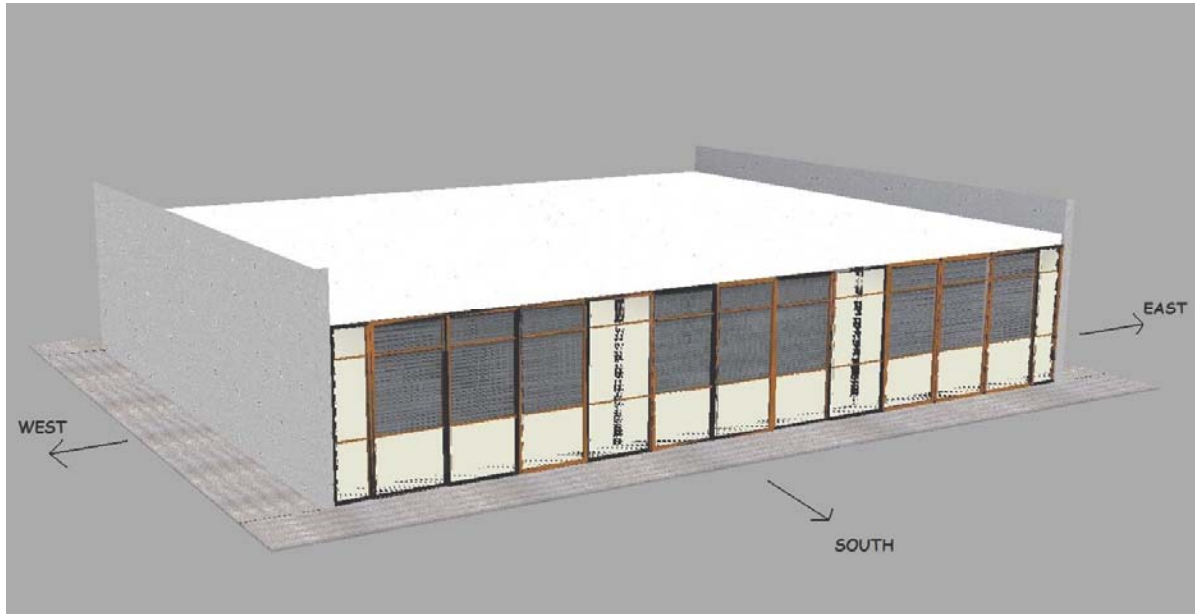


Figure 4-4 *Perspective view of the office building*

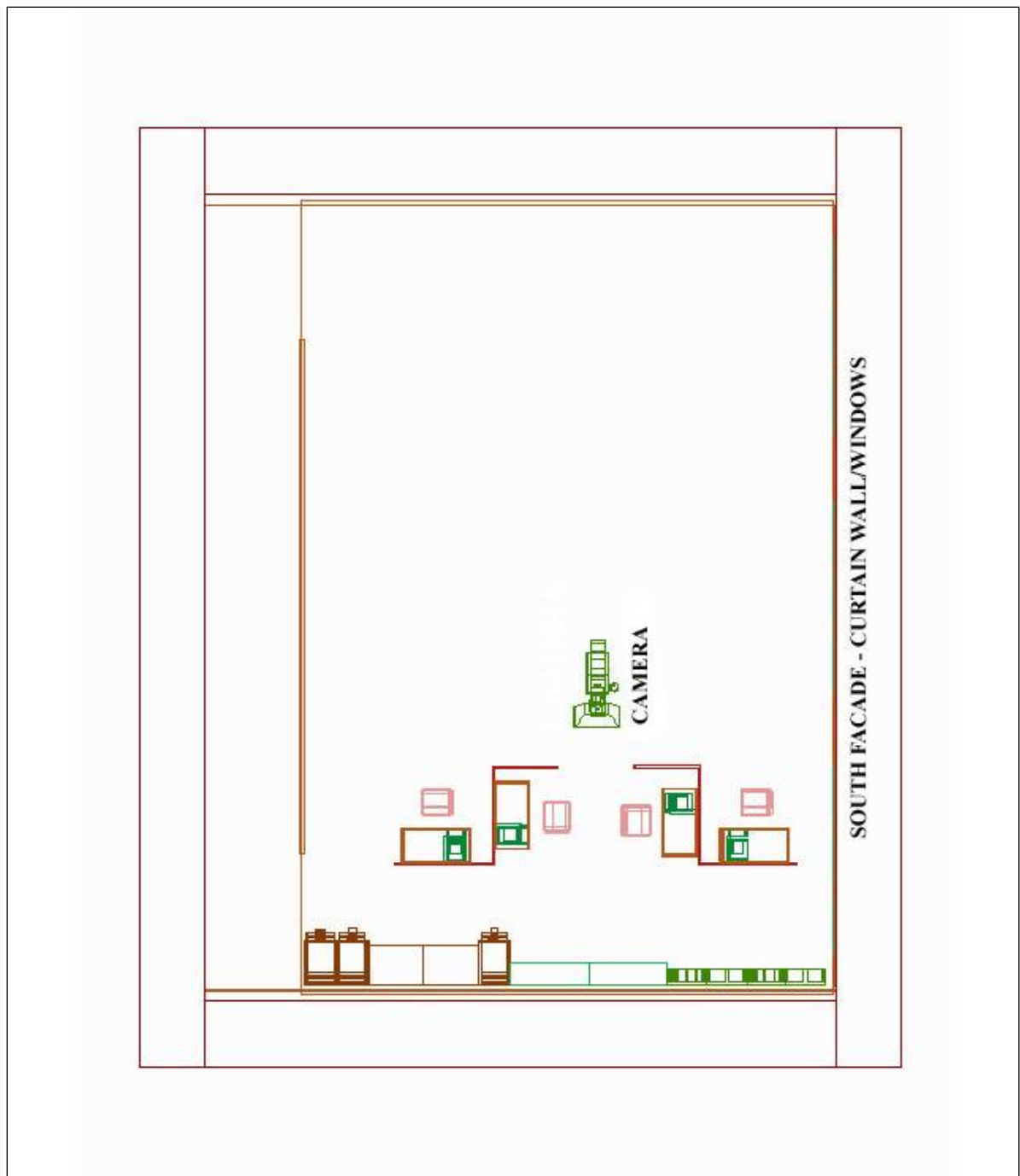


Figure 4-5 Floor plan of the office space

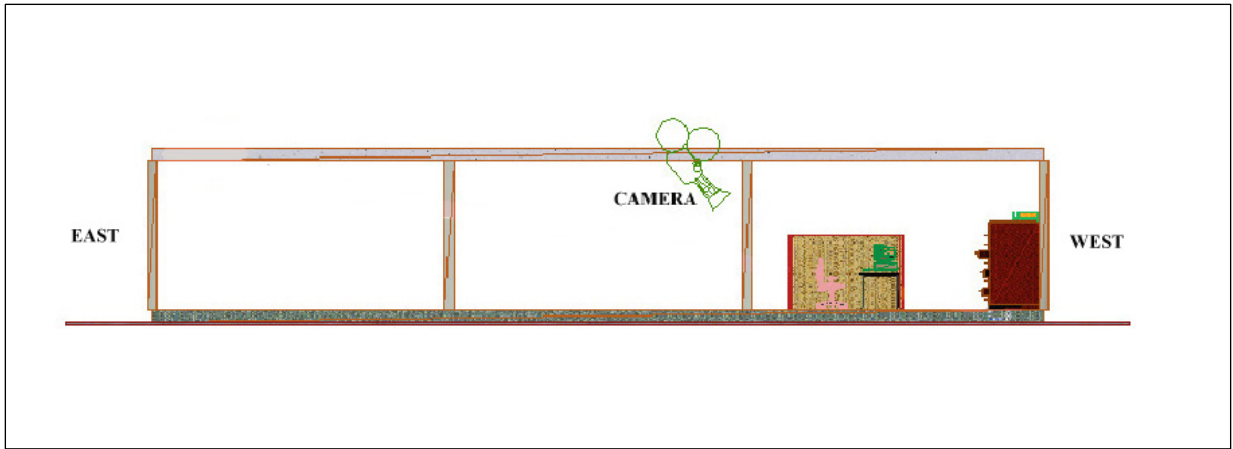


Figure 4-6 Longitudinal section the office space

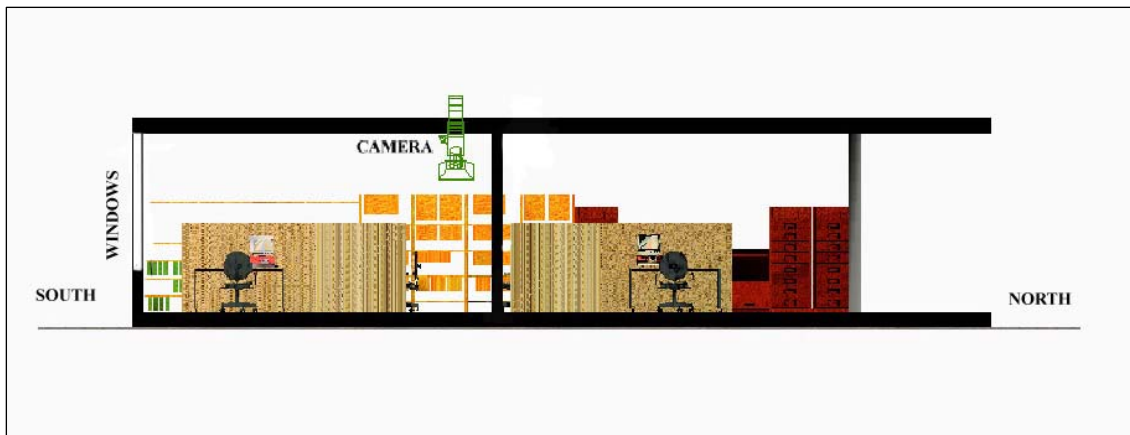


Figure 4-7 Cross section of the office space

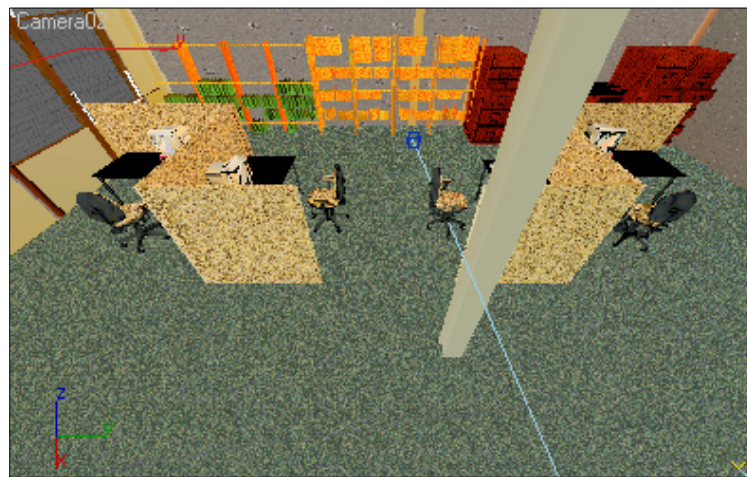


Figure 4-8 Perspective view of the interior space

Reflectances of the interior surfaces are based on the choice of materials, and they are shown in Table 4-2.

Table 4-2 Reflectances of the interior surfaces

ELEMENT	MATERIAL	REFLECTANCE (%)
Ceiling	Light grey paint	84
Walls	Light grey paint 2	55
Floor	Green carpet	42
Columns	White wood	77
Interior finish of curtain wall	White wood	77
Curtain wall mullions and transoms, window frame	Metal - bronze	48
Interior doors	Wood bass	99
Interior cubical partitions	Beige fabric	82
Office cabinets	Wood burl oak	53
Office desks	Wood-oak plywood	64
Office shelves	Wood bass	99
Office chairs	Beige fabric	82
Window glass	Clear Glass	0

4.3.2. DESCRIPTION OF THE BUILDING FACADE

The south-facing curtain wall has a 600 sq. ft. area and has a completely glazed outside layer. The transparent/window area is 315 sq. ft., and one window assembly consists of two parts: lower (4.5' x 5') and upper (4.5' x 1.75'). It is located 3' above the floor. The opaque parts of the facade have wooden boards as an interior finish and an area of 345 sq. ft. (see Figure 4-9). The window-to-wall ratio is 0.47 while the window-to-floor ratio is 0.13.



Figure 4-9 South-oriented facade

4.3.3. DESCRIPTION OF THE FACADE ORIENTATION

The simulations of the shading devices are done for two facade orientations: south and west. The sun angles are the same/symmetrical for the east- and west-oriented facade so the east facade is not simulated. The north orientation of the facade is also not considered in this research because there is no need for protection of the interior space from the glare and overheating on the north, that is, there is no need for blinds. Also, the north light gives the most uniform indoor illuminance. To simplify the validation process, the same building design is used for the simulation for the south and west. The building is just rotated 90° clockwise in order to switch from a south to west orientation (see Figure 4-10).

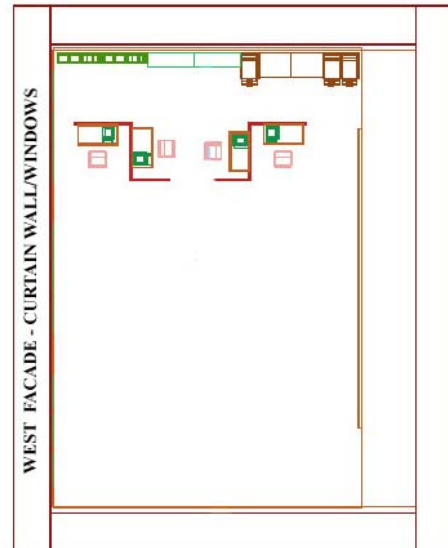
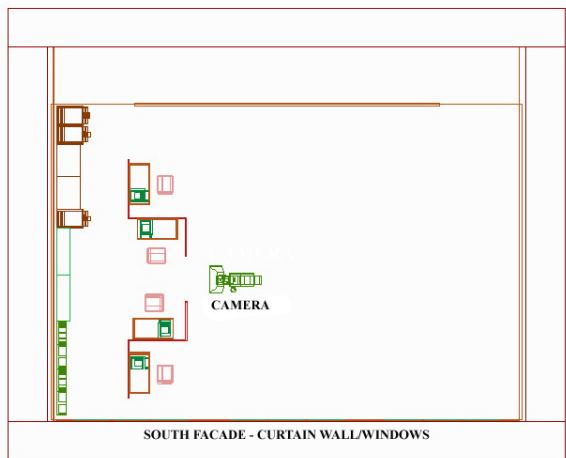


Figure 4-10 Facade orientations - south and west

4.3.4. DESCRIPTION OF THE BUILDING LOCATION

The proposed building is located in Roanoke, Virginia: latitude 37°N and longitude 80°W and a moderate climate. The building site conditions are also proposed in the case study to simplify the geometry of the site and the size of the input for Autodesk VIZ 4, resulting in a reasonable simulation time.

4.3.5. DESCRIPTION OF THE GROUND REFLECTANCE

A sidewalk is designed around the building to simulate the ground, which reflects the daylight into the interior space. The sidewalk is 5' wide and is made of grey concrete with a reflectance of 53%.

4.3.6. DESCRIPTION OF THE TIME FRAME

Simulations of the shading devices are done for one day per each season: December 21, March 21, and June 21. Since the sun angles are the same on March 21 and September 21, simulations for September 21 are not performed. Usually an office building is occupied from 9:00 a.m. until 5:00 p.m. For the south-oriented facade, the sun angles at 9:00 a.m. and 3:00 p.m. are the same so simulations are performed just for 3:00 p.m. Simulations are done three times per day:

- For the south-oriented facade: 11:00 a.m., 12:00 p.m., 3:00 p.m.
- For the west-oriented facade: 12:00 p.m., 2:00 p.m., 4:00 p.m.

4.3.7. DESCRIPTION OF THE SUN ANGLE

Values of the azimuth and altitude sun angles used for the simulations in this case study are identified automatically for various dates and times and for the given location (Roanoke, Virginia) by using Autodesk VIZ 4.

4.3.8. DESCRIPTION OF THE OUTDOOR ILLUMINANCE

Values of outdoor illuminance levels used for the simulations in this case study are identified automatically for various dates and times, various sky conditions, and for the given location (Roanoke, Virginia) by using Autodesk VIZ 4.

4.3.9. DESCRIPTION OF THE SKY CONDITIONS

Simulations of shading devices are done for three sky conditions: clear, partly cloudy, and cloudy sky. For each date and time of the simulation, the shading devices are tested for all three possible sky conditions. The blinds' tilt angles are changed depending on the sky conditions.

4.3.10. DESCRIPTION OF THE SHADING DEVICE SYSTEMS

In this research, three shading device systems are simulated in order to validate the DMF:

- Existing system
- Patented system
- New system

4.3.10.1. Existing system



Figure 4-11 Existing shading device system – vinyl light grey blinds

Mini Venetian blinds,¹ as an existing shading device system available on the market, are chosen for the simulation (see Figure 4-11). The slat has the curved, concave shape in the cross section. The distance between the blinds is 1". Since the lower window area dimensions are 4.5' by 5' (54"x 60") and the upper window area dimensions are 4.5' by 1.75' (54" x 21"), there are 60 slats in the lower window part and 20 slats in the upper window part. The blinds' width has the range of values from 20" to 72" and the drop is up to 64". The thickness of the blinds is 0.008". The blinds are made of grey vinyl with a reflectance of 40% (maximum 46%) and they are opaque, that is, nontransparent for light. The blinds are in the horizontal position relative to the window,

and they are installed on the inside of the window, that is, in the interior space. The slats are operable, that is, their tilt angle can be adjusted, based on sun and sky conditions and the occupant's need for privacy. In this case study, three basic positions of this type of shading device are tested (see Figure 4-12): completely open (0° tilt angle), partially open/partially closed (45° tilt angle), and completely closed (90° tilt angle).

¹http://kaysnet.com/gus/product.asp?brand=kays&cat%5Fid=15&zone%5Fid=&prod%5Fid=192565&offer%5Fid=&extra=&mcs_sid=4V1HU0F0FQV48NSMDSG5DPQF4TTJ27C2&fh_secondid=192565&fh_search=min i+vynil+blinds

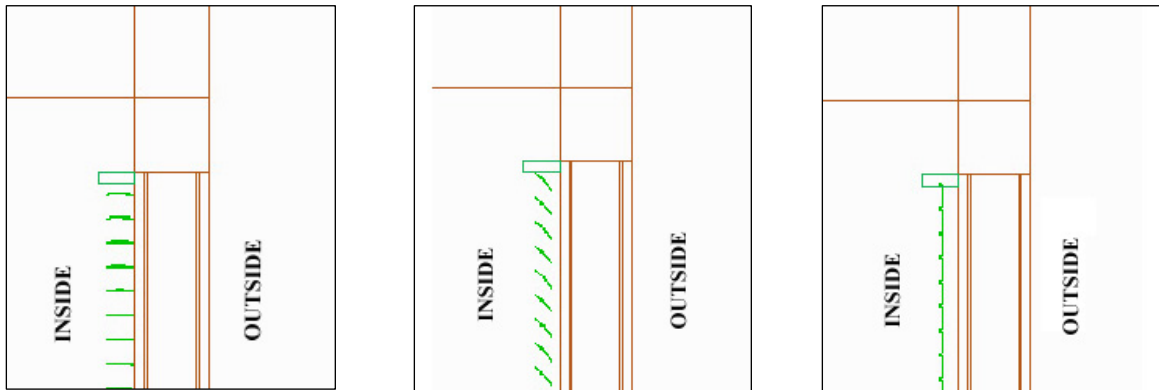
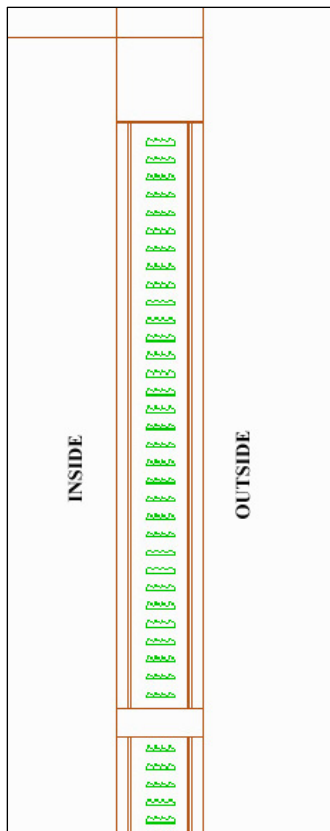


Figure 4-12 Various tilt angles for the existing blinds - 0°, 45°, 90°

4.3.10.2. Patented system



The shading device patented by U.S. Patent no. 6,367,937¹ is simulated as an example of a patented system. The blinds have a tooth-shaped upper surface, and they have a slightly curved, concave bottom surface (see Figure 4-14). The blinds' width is 53" in this case study. The width of the slat is 1" and its thickness is 3/16". The distance between the slats is 0.625" so there are 94 slats in the lower window part and 32 slats in the upper part. The slats are made of clear plastic with a transmittance of 100%. The blinds are always in a horizontal, fixed, completely open position (0° tilt angle), and are installed in the cavity between two panes of glass (see Figure 4-13).

Figure 4-13 Cross section through the patented shading device

¹ Refer to Chapter 2, Section 2.4.2: Patented Shading Device Systems – US Patent no. 6,367,937 (p. 90–92) and to Koster, H. **Sun protection installation comprising sun protection lamellae having a toothed upper side.** US Patent 6,367,937 (2002)

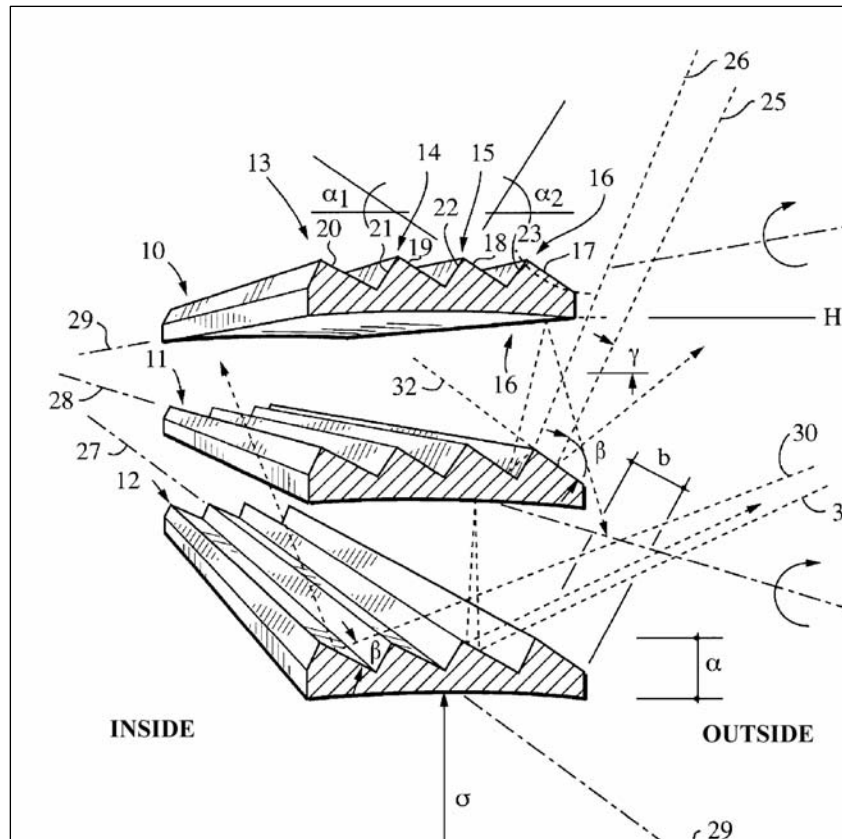


Figure 4-14 Perspective view of the patented shading device

4.3.10.3. New system

A new shading device system is proposed by this research. The slat has a right triangle shape in the cross section and the hypotenuse dimension is 1", while the triangle legs are 0.707" (see Figure 4-15). The distance between the slats is 1", so there are 58 slats in the lower window part and 20 slats in the upper window part. The width of the blinds is 53" in this case study. The slats are made of clear plastic with a transmittance of 100%. A silver reflective film, which has a

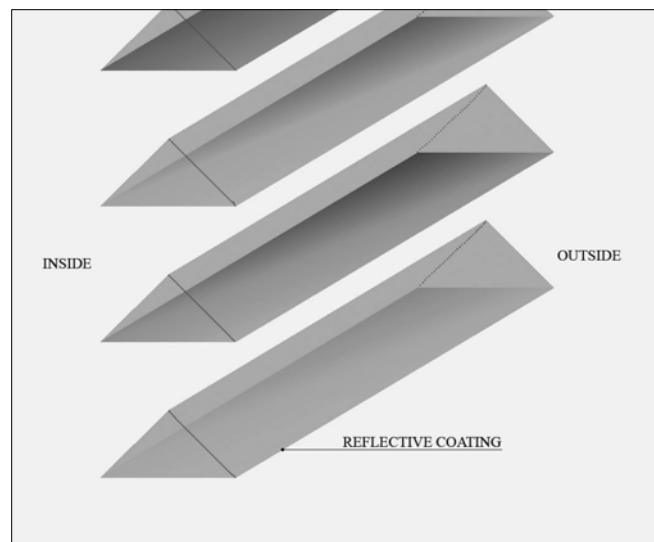


Figure 4-15 Perspective view of the new shading device

thickness of 0.5 microns, and a reflectance of 94%, is applied on the hypotenuse outside surface. The blinds are in the horizontal position relative to the window and installed between two panes of glass. In the process of the design of new blinds, the principles of optical physics¹ are used, and the properties of transparent materials² are considered.

The blinds are simulated for three tilt angles in this research (see Figure 4-16):

- 0° tilt angle (completely open blinds): the hypotenuse is parallel to the horizontal, and the triangle legs are oriented upwards.
- 45° tilt angle (partially open/partially closed blinds): the angle between the hypotenuse and the horizontal is 45°, and the triangle legs are oriented to the outside.
- 90° tilt angle (completely closed blinds): the angle between the hypotenuse and the horizontal is 90°, and the triangle legs are oriented to the outside.

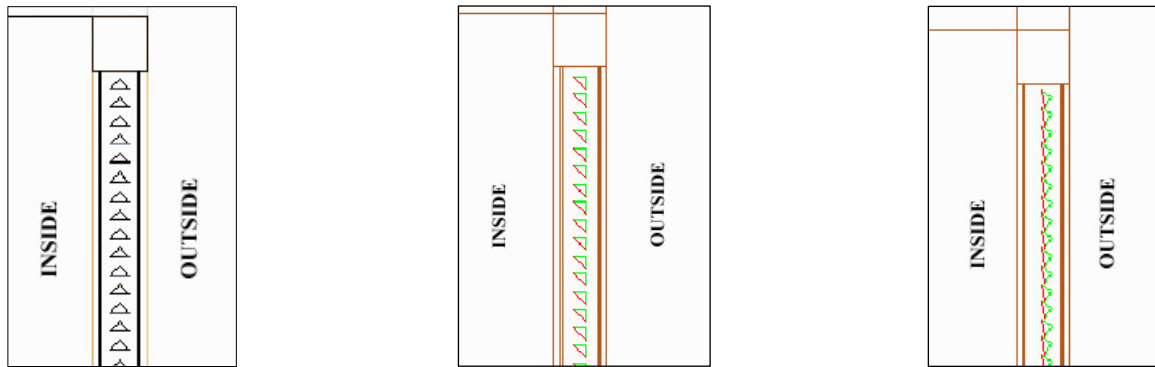


Figure 4-16 Various tilt angles for the new shading device - 0°, 45°, 90°

4.3.11. DESCRIPTION OF THE BLIND TILT ANGLE PARAMETER

The blind tilt angle is one of the most influential variables in the performance of the shading device. In this case study, all shading device systems are simulated for a completely open position, which corresponds to the 0° tilt angle of the blinds. In addition to completely open position simulations, the existing system and new system are simulated for a completely closed position (90°) and a partially open/partially closed position (45°). The sky conditions

¹ Refer to Appendix A.1: Basic optical physics

² Refer to Appendix A.2: Transparent materials used for manufacture of the shading device slats

significantly affect the light levels in the space and control strategy for adjusting the blinds' tilt angle. The shading devices are simulated for the various blinds' tilt angles in relation to the sky conditions:

- Existing and new shading devices are simulated for a 0° tilt angle for the partly cloudy and cloudy sky. The light levels for these two sky conditions are lower than that for the clear sky, and the blinds need to be open. Simulations for a 45° blind tilt angle are performed in the case of the clear and partly cloudy sky. For these two sky conditions, on particular dates and times, the light level can be higher than requested, and the blinds need to be partially closed. Simulations for a 90° tilt angle are done for clear sky conditions. There can be a need for completely closed blinds to protect the space from uncomfortably high light levels for clear sky conditions. These light levels' values are beyond the values of levels recommended by the standard.
- The patented shading device system has a 0° tilt angle all the time, that is, it is at the fixed position by the design so simulations are done for a completely open position of the blinds for all sky conditions.

Additional simulations that combine all three blind angles (0°, 45°, 90°) and three sky conditions are done for the existing and new shading device system for particular relevant dates and times. For example, both systems are tested for three blinds' angles and sky conditions on December 21, March 21, and June 21, at 12:00 p.m. for a south-oriented facade, and at 4:00 p.m. for a west-oriented facade.

4.3.12. DESCRIPTION OF THE SHADING DEVICE POSITION

Theoretically, the shading device has one of three basic positions: inside, between, and outside the facade (see Figure 4-17). However, blinds are almost always installed in the position that is predetermined by the design. In this study, the existing blinds are installed on the interior side of the window, and patented and new blinds are installed between two panes of glass. To get a better understanding of the effect of the blinds' position on the light levels in the space, additional simulations for different positions of the shading device are performed:

- Existing shading device system: for exterior and between position
- New shading device system: for exterior and inside position

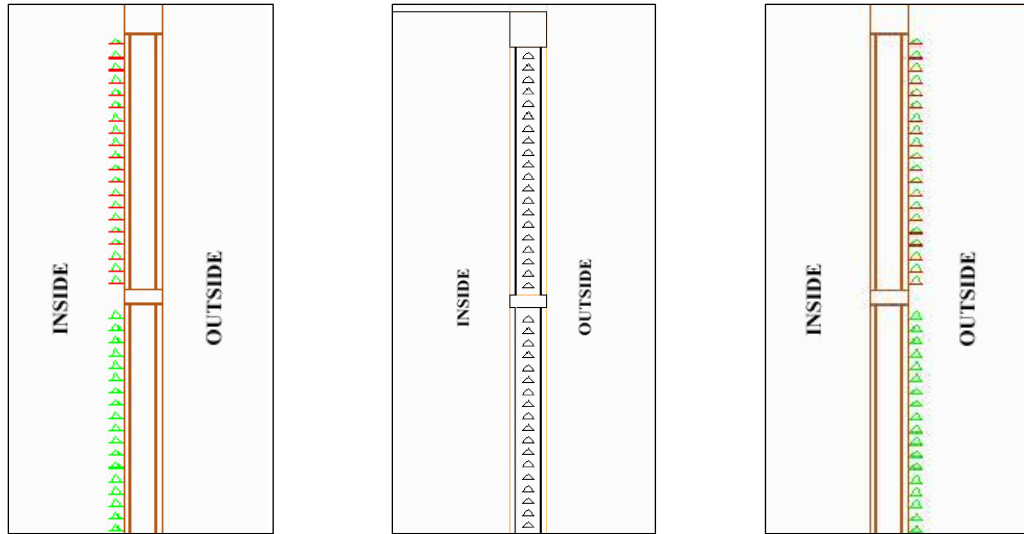


Figure 4-17 Shading device position relative to the window – an example of the new system

4.3.13. DESCRIPTION OF THE PERFORMANCE PARAMETERS

Two performance parameters are measured by the simulations: illuminance and luminance. Both illuminance and luminance are determined for two points in the space:

- Office desk at the distance of 96" from the window; height of the top of the surface is 30"
- Office desk at the distance of 343" from the window; height of the top of the surface is 30"

The distance between two measured points is 247".

The required values of illuminance and luminance in this office space are taken from the standard. The following ranges of values are used:

- For illuminance: minimum 750 lx and maximum 4200 lx
- For luminance: minimum 100 cd/sq. m. and maximum 850 cd/sq. m.

4.3.14. DESCRIPTION OF AN ANALYSIS METHOD

The Autodesk VIZ 4 software is a tool for a three-dimensional simulation of the space, which gives photorealistic images as an output. Autodesk VIZ 4 also has a feature that simulates lighting and gives photometric values of illuminance and luminance levels in the space.

The values of the sun angles (azimuth and altitude), as well as sun intensity, depend on geographic location, time, and date. Autodesk VIZ 4 calculates daylight that comes from skylight that is scattered through the atmosphere.

In VIZ 4, the sky is modeled as a dome of infinite radius placed around the scene. Daylight computes the illumination of a point in the scene with reference to all directions around the point where the sky is visible. The sky brightness is not constant over the sky dome, but rather it changes depending upon the position of the sun.¹

Three possible sky conditions (clear, partly cloudy, cloudy) define how much light is scattered throughout the sky. The user of the specific DMF needs to do input for Autodesk VIZ 4 in order to simulate daylighting:

- Building geometry: walls, columns, ceilings, floors, facade/windows, doors (see Figures 4-5, 4-6, 4-7, 4-8, 4-9)
- Furniture specific for the particular type of the space (see Figures 4-5, 4-6, 4-7, 4-8)
- Choice of materials for interior surfaces and furniture, which automatically defines reflectance properties of materials. Material is taken from the Autodesk VIZ 4 library with pre-defined optical properties (see Table 4-2).

To simulate daylight and get a photorealistic image of light levels in the space, it is necessary to define the camera position in the space. In this research the camera position is fixed for all simulations and renderings to get the same view of the space in each simulation (see Figures 4-5, 4-6, 4-7). The camera position is selected to get the view of the top surface of the two office desks. The values of illuminance and luminance are calculated for the two points at the top of the office desks. The camera position affects the output of simulations, that is, the limits of the 3D image of the space with calculated illuminance and luminance levels.

The following parameters are fixed in the Autodesk VIZ 4 file:

- Building geometry
- Surface materials
- Furniture
- Camera position and field of view

¹ Autodesk VIZ 4 User Reference

The following parameters need to be varied to get different performance parameter values (illuminance and luminance) by using Autodesk VIZ 4:

- Shading device:
 - Type – geometry: shape, width and thickness of slats, distance between slats
 - Blinds' material
 - Blinds' position relative to the window
- Outdoor conditions (see Figure 4-18)
 - Sun angle: changes based on time (hours, minutes, seconds), date (month, day, year) and location (longitude and latitude). The user of the DMF and Autodesk VIZ 4 changes in this case study just time and date since location is fixed (Roanoke, Virginia)
 - Sky conditions: clear, partly cloudy, cloudy

In order to start simulations after completing the input, the user of the DMF and Autodesk VIZ 4 defines rendering parameters such as:

- Radiosity
- Environment

In radiosity, the processing parameter rollout initial quality is set to 75%, and possible rendering options are set to render direct illumination¹ and regather indirect illumination² (see Figure 4-19). The radiosity process is re-run each time the user changes the shading device parameters or outdoor conditions. The user defines the exposure control in the Environment dialog box. The pseudo color exposure control is used to determine light levels in the space (see Figure 4-20).

Figure 4-18 Input in Autodesk VIZ 4 for sun angle, time, date, location, facade orientation, and sky conditions



¹ Direct illumination - a longer render that calculates shadows by the standard renderer so they are better quality (Autodesk VIZ 4 User Reference)

² Regather indirect illumination – the longest and best render that calculates shadows from the light sources and corrects artifacts and shadow leaks.

Pseudo Color Exposure Control is actually a lighting analysis tool that provides you with an intuitive way of visualizing and evaluating the lighting levels in your scenes. It maps luminance or illuminance values to pseudo colors that show the brightness of the values being converted. From darkest to brightest, the rendering shows blue, cyan, green, yellow, orange, and red.¹ (see Figures 4-20 and 4-21)

After radiosity and environment parameters are set, the scene is rendered. The output of the rendering is a three-dimensional photorealistic image of the space with either illuminance or luminance levels represented by the colors. The illuminance and luminance values can be read from the scale shown in the Pseudo Color Exposure Control dialog box.

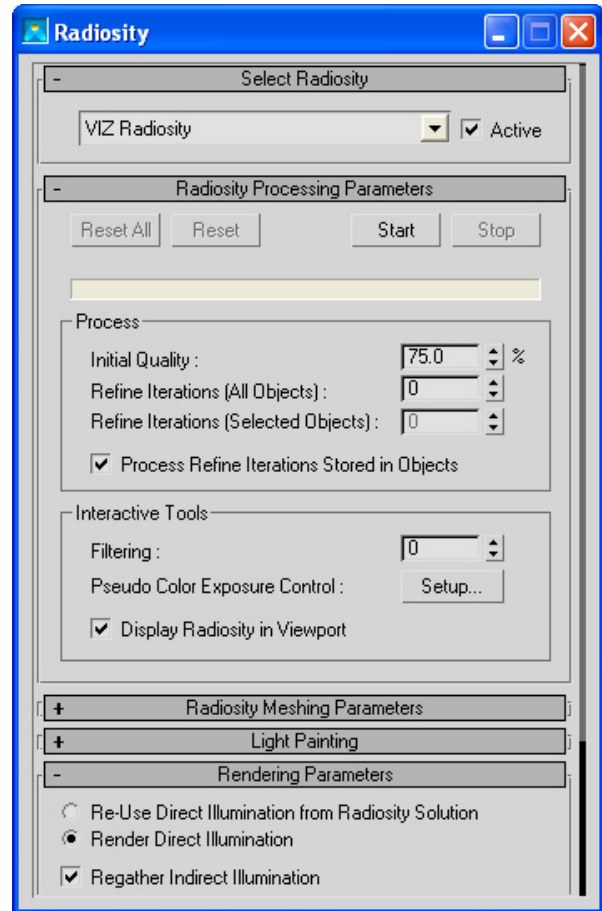


Figure 4-19 Radiosity dialog

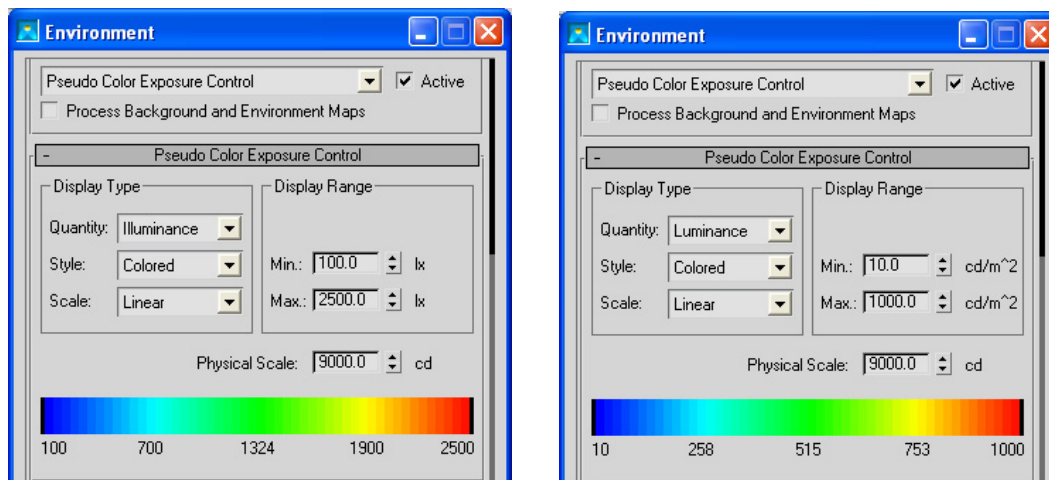


Figure 4-20 Environment dialog – pseudo exposure control

¹ Autodesk VIZ 4 User Reference

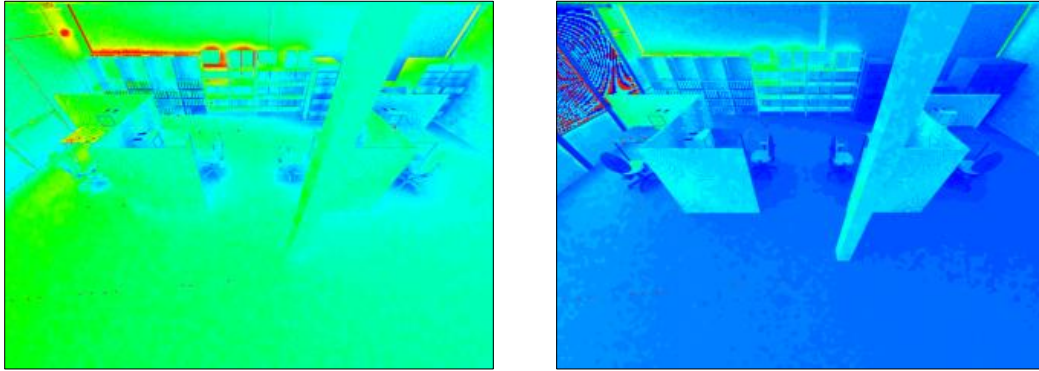


Figure 4-21 Output of the simulations – illuminance and luminance

4.3.15. THE SPECIFIC DMF FOR THREE TYPES OF SHADING DEVICES USED IN THE CASE STUDY

The specific decision-making frameworks are created for each type of blinds to identify an input for the simulations. Independent and dependent variables and required performance parameters in the DMF are the same in all three cases. The exception is the dependent variable that defines the blinds' position relative to the window, which changes based on the type of shading device. Shading device variables are also changed based on the type of blinds. The overall specific DMF for existing blinds is shown in Figure 4-22. Since the three specific DMFs in this case study have the same structure, with the exception of the shading device variables, three partial DMFs are created that include only the shading device variables. Figure 4-23 shows the partial DMF for the existing blinds. This partial DMF includes values of the shading device variables specific for the existing blinds analyzed in the case study. Figure 4-24 shows the partial DMF, which consists of the shading device variables specific for the patented blinds. Figure 4-25 shows the partial DMF for new blinds, which consists of values for the shading device variables specific for the new blinds.

In these DMFs, the values of independent, dependent, and shading device variables, as well as performance parameters (ranges of illuminance and luminance values required by the standards), are identified, based on the parameters described in this chapter.¹ For example, the user of the DMFs can refer to Sections 4.3.1 through 4.3.9 for the description of independent and dependent variables and their measures. The values of independent and dependent variables, which were identified in Sections 4.3.1 through 4.3.9, and the required

¹ Refer to Section 4.3: Case study parameters description

performance parameters described in Section 4.3.13 are directly used as an input for the specific DMFs shown in Figure 4-22.

For example, the values of the independent variables are found in the following ways:

- Climate characteristics are calculated based on building location (Roanoke, Virginia), that is, latitude and longitude. The values of sun azimuth and altitude angles are calculated for these latitude and longitude values for three days: December 21, March 21, and June 21 at noon. Also, levels of outdoor illuminance are calculated for the same days and for three sky conditions: clear, partly cloudy, and cloudy. The values are shown in the overall specific DMF (see Figure 4-22).
- An office building is selected as a building type in this case study. Based on this building type, subvariables are defined by the user of the DMF:
 - Minimum fenestration dimensions are calculated based on the requirements of the standards. In the overall specific framework (see Figure 4-22), three required dimensions of the window are shown. They were a guide in designing the window.
 - Based on the requirements of the standards, reflectances of interior surfaces and furniture are determined. The user of the DMF then selects the materials and furniture whose reflectance has the value of reflectance required by the standard.
 - Based on the building type, the types of tasks that will be performed in the specific spaces are identified. For each type of task, the values of the minimum and maximum illuminance and luminance required by the standard are determined. Also, the building is divided into two daylighting zones, based on the required minimum illuminance and luminance values. Based on the type of building and type of task, the height of a working plane is selected.
 - Based on the building type and requirements of the standards and recommendations for daylighting, the room dimensions are defined. Two criteria for the room depth and one criterion for floor area are shown in the overall specific DMF (see Figure 4-22). The lowest value of the calculated maximum room's depths was chosen.

- For the proposed site, the user of the DMF selects the value of sidewalk reflectance and facade orientation that are analyzed in this case study: south and west.

The values of the dependent variables are selected by the user of the DMF:

- The facade type used in this case study is a single-skin curtain wall, and values of its subvariables are shown in the overall specific DMF (such as fully glazed outside surface, transparent windows, and opaque-other facade segments).
- The position of the shading device in this overall specific DMF for the existing shading device is in the interior space.

The shading device variables are described in Sections 4.3.10 through 4.3.12. Section 4.3.10 focuses on each specific type of blinds used in this case study. The values of the shading device variables given in Section 4.3.10 are the input for the partial DMFs shown in Figures 4-23, 4-24, and 4-25. For example, the shading device variables are highlighted in Figure 4-22 showing that these values are changed for each particular blind type. For that reason, three partial DMFs are created, and they include only shading device variables for three types of blinds (see Figures 4-23, 4-24, and 4-25). Figure 4-23 shows the partial DMF for the existing blinds. The values of the blinds' geometry, dimensions, materials, position, and tilt angle are taken from the manufacturer's data. Figure 4-24 shows the partial DMF for the patented blinds. The values of the blinds' geometry, dimensions, material, and position are taken directly from the patent and shown in this partial DMF. Figure 4-25 shows the partial DMF for new undeveloped blinds. The user of the DMF is also the designer of the new blinds in this case study. The user of the DMF makes the decision about the blinds' geometry, dimensions, materials, reflective coating, position, and tilt angles.

All these previously described variables are input for computer simulation performed by the Autodesk VIZ 4 software (see Figure 4-22). The output of simulation, which in this case study is actual performance (actual illuminance and luminance level), is compared to the required performance (illuminance and luminance required by the standard). Based on this comparison, the user makes the decision whether or not to select the particular blinds (see Figure 4-22).

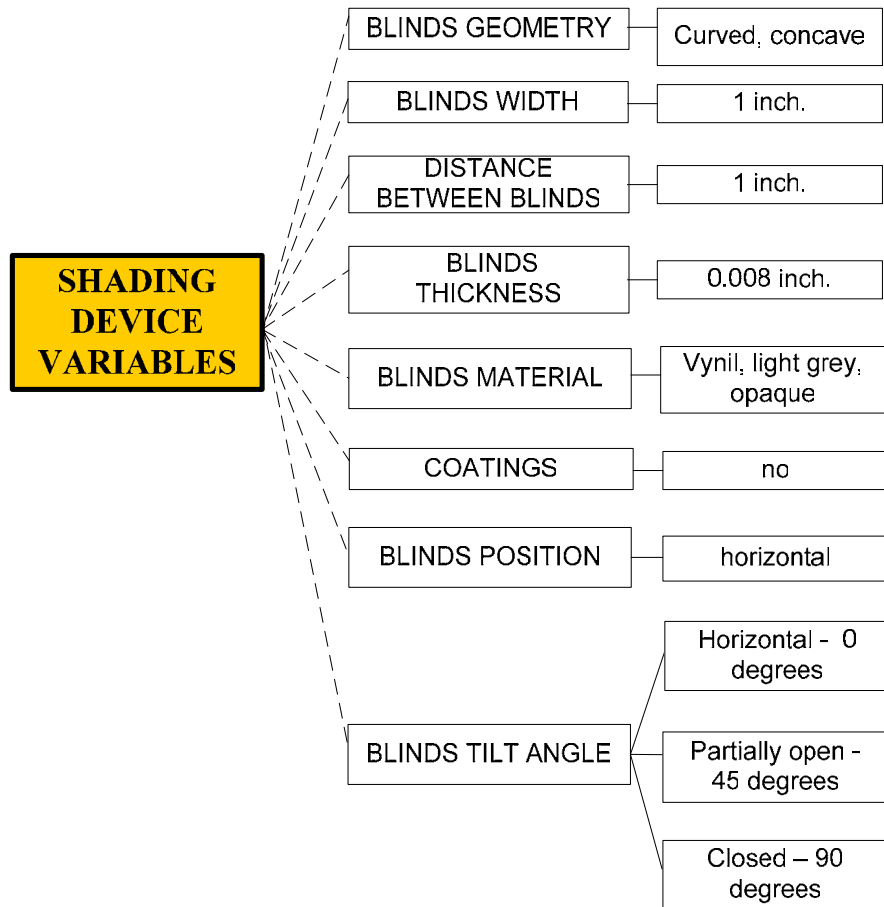


Figure 4-23 Partial specific DMF for the existing blinds

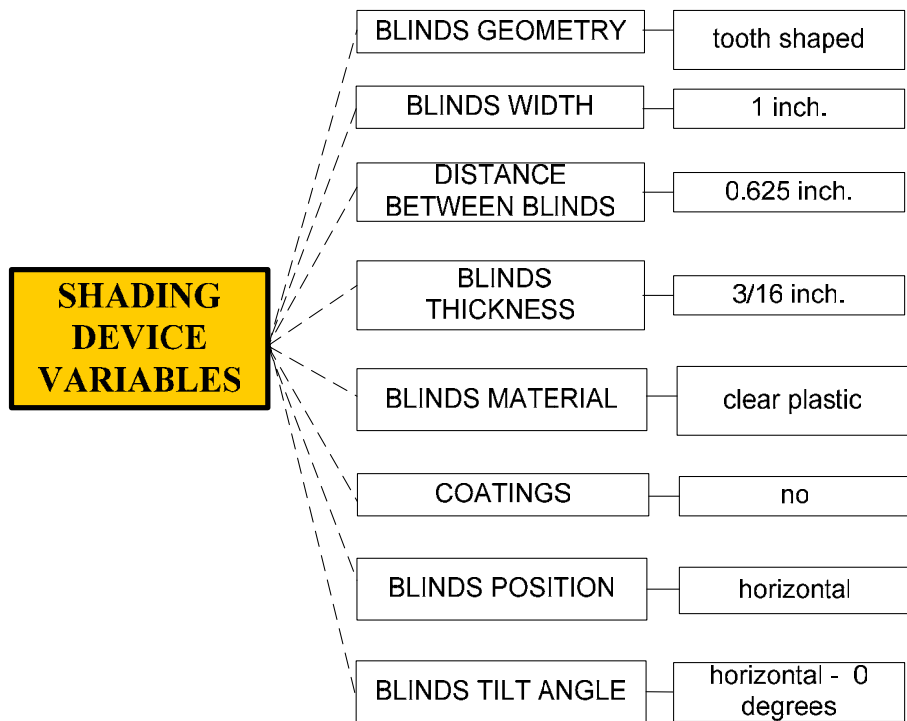


Figure 4-24 Partial specific DMF for the patented blinds

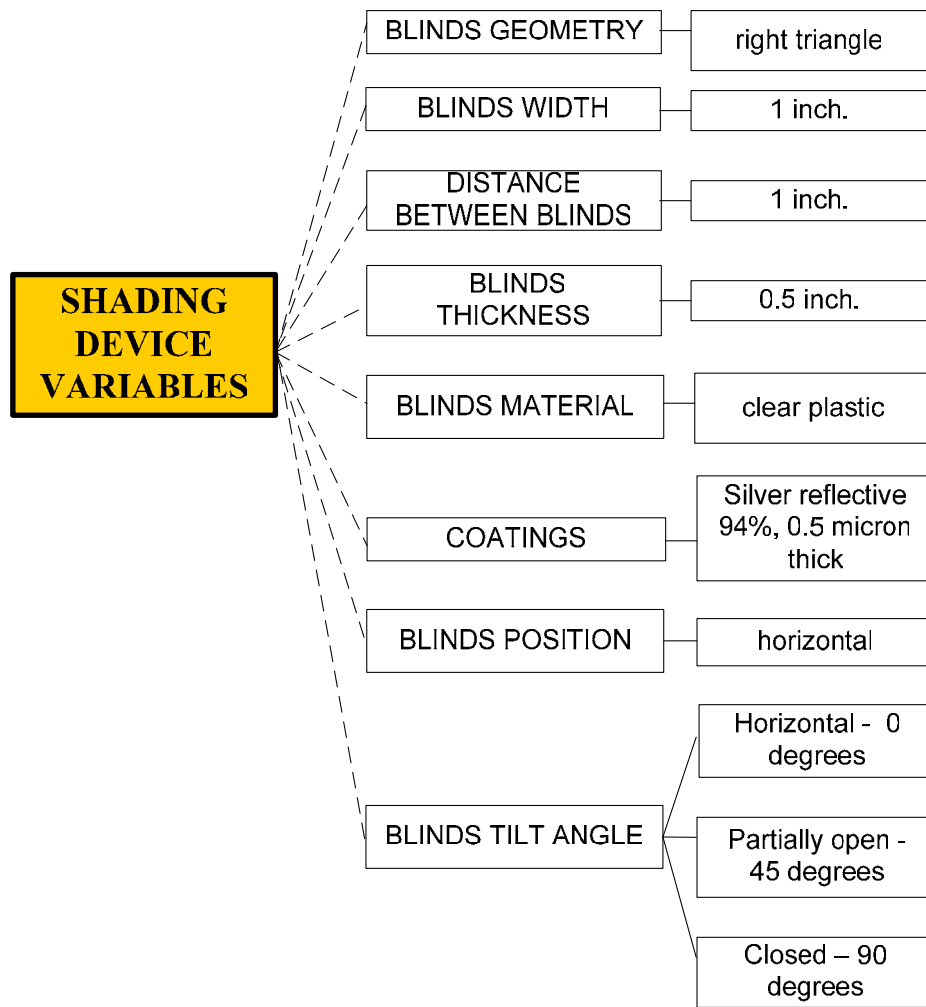


Figure 4-25 Partial specific DMF for the new blinds

4.4. SUMMARY

This chapter describes the process used for the validation of the specific DMF and a case study conducted in order to validate the process. The validation process consists of the following tasks:

1. Making an input for the specific DMF (independent, dependent, and shading device variables, and the required performance parameters).
2. Simulation of daylighting performance based on the input information. Simulations of illuminance and luminance in the space are performed by using the software Autodesk VIZ 4.
3. Presentation of the output of the simulations in the format of the three-dimensional photorealistic images. Values of illuminance and luminance in the space are read from these images and represented in the format of the matrixes of data and the charts.
4. Analysis of results by comparing the performance of the various types of shading devices.
5. Process of making the decision, based on the analysis of the results of daylighting performance of shading devices.

A case study is conducted to validate the specific DMF. An office building that contains computers is used in the case study. The building is located in Roanoke, Virginia, which has a moderate climate. A simple office space that contains cubicles is simulated for south and west facade orientations for one day per each season and three times per day. A conventional curtain wall (single-skin facade) is used in this case study, and three different shading device systems (existing, patented, and new) are tested for various blind tilt angles and sky conditions. The Autodesk VIZ 4 software is used for the simulation of the daylighting performance of shading devices. The output of the simulations are actual values of illuminance and luminance in the space, represented by three-dimensional pictures.

5. RESULTS OF THE CASE STUDY

5.1. INTRODUCTION

The final step of the specific DMF consists of the analysis of the results of the simulations, which is the basis for making the decision about the selection of the preferred blinds. This chapter explains the execution of the final tasks of the validation process described in Chapter 3 (see Section 3.3.3.4: Making the decision).

In the first part of this chapter, possible ways of organizing and presenting the output data, which are the results of simulation done by Autodesk VIZ 4, are described. The results are presented in the format of:

- Matrixes of data: because matrixes of data include all simulation results as the results are obtained, without averaging the results. Matrixes of data combine parameters that are the input for the simulation (blinds' parameters: type, position, tilt angle, performance parameters; and date, time, and sky conditions). For each combination of the input parameters, the obtained result is recorded in the matrixes of data, which represent the most accurate and precise way of presentation of the output of simulation.
- Charts of results, based on the matrixes of data and developed to be used by the user of the specific DMF: Matrixes of data consist of a large number of output results, which lead to a complicated and time-consuming analysis of results to be performed by the user of the specific DMF. To simplify the analysis of the results, the results from the matrixes of data are averaged and presented as the values of illuminance*days/year and luminance*days/year for each type of blinds and three sky conditions. In this way the results are decreased to a reasonable number that can be quickly, easily, and accurately analyzed.
- Charts of the results, based on the matrixes of data, developed for the detailed analysis of the shading devices' performances and discussed specifically in this dissertation. The process of averaging values of data to get values of illuminance*days/year (or luminance*days/year) leads to a simplified analysis of the performance of the blinds. The values given per year rather than per day (or season) cannot show performances of shading devices for different dates and times per day.

- That is the reason why detailed charts that include and analyze all variables that affect daylighting performance of shading devices are developed. These charts are more appropriate for an in-depth analysis of the blinds' performance compared to the charts developed for the user of the specific DMF because charts consider the time and date effect on the blinds' performance, as well as the blinds' position and tilt angle.
- Tables that use the conversion of actual illuminance/luminance values to the scale 0-1. This approach can be used by the user of the specific DMF because conversion of the values simplifies the analysis of simulation results. By conversion of values to the scale 0-1, illuminance and luminance values are averaged resulting in only two values for daylighting performance (one for illuminance and one for luminance) for each type of blinds. The comparison of the reduced number of averaged results is less complicated for the user of the specific DMF as is the case with the use of the simplified charts of results (see Section 5.2.2: Description of the charts of results used in the specific DMF).
 - Charts that represent the daylight autonomy (DA) of the shading device systems. This approach can possibly be used by the user of the specific DMF because the DA per year averages the values of illuminance and luminance per year. These values are expressed in a percentage of time per year for which the required illuminance/luminance level is provided by daylight only. The DA/year is given for each type of blind and at two measurement points in the space for this case study. In this way, the comparison of the blinds' performance expressed in the DA per year is simplified for a quick and accurate analysis by the user of the specific DMF.

The second part of the chapter focuses on the analysis of the results of the case studies obtained by the simulations. The analysis process, considered criteria, and results are explained for:

- The charts used by the user of the specific DMF: charts represent illuminance*days/year and luminance*days/year.
- The charts used only in this dissertation: charts represent illuminance and luminance for the different combination of six variables.
- Charts used by the user of the specific DMF: charts represent daylight autonomy.

In this way, the methodology for the analysis of the results for each presentation of results is explained to the user of the specific DMF. The user can then follow the given procedure and complete the analysis for his case studies in the same manner.

5.2. PRESENTATION OF RESULTS OF SIMULATION

When the initial simulation was designed, many variables caused approximately 46,600 simulations to consider all the cases. This number was too demanding to deal with. A systematic look at the variables was done to reduce the amount of simulations to a reasonable number while giving enough information to interpret the results. This resulted in a final number of simulations run to be 470. The process of reducing the number of simulations is described in this section.

5.2.1. DESCRIPTION OF THE MATRIXES OF DATA

Results of the computer simulations of daylighting are presented in the format of the matrixes by using Microsoft Excel software. The first developed matrix consists of the combination of possible variables that affect shading device daylighting performance:

- Climate: hot-dry, hot-humid, temperate, and cool
- Facade orientation: south, west, and east
- Shading device parameters:
 - Type:
 - o Existing:
 - plastic, curved shape, 1" wide
 - plastic, curved shape, 1/2" wide
 - o Patented,
 - plastic, tooth-shaped top surface, square cross section of the slat
 - plastic, tooth-shaped top surface, concave cross section of the slat
 - plastic, tooth-shaped top surface, convex cross section of the slat
 - o New design proposed by this research
 - Position relative to the window
 - o exterior
 - o interior
 - o between two panes of glass

- Blinds' tilt angle: 0°, 45°, and 90°
- Time parameters:
 - Dates: December 21, March 21, June 21, and September 21
 - Times: three times per day for each facade orientation:
 - o south at 9:00 a.m., 12:00 p.m., and 3:00 p.m.
 - o west at 12:00 p.m., 2:00 p.m., and 4:00 p.m.
 - o east at 8:00 a.m., 10:00 a.m., and 12:00 p.m.
- Sky conditions: clear, partly cloudy, and cloudy
- Daylighting performance parameters:
 - Illuminance
 - Luminance
- At two measurement points in the space: top surface of two office desks: one close to the window and another close to the interior partition wall.

The combination of these parameters gives a matrix that consists of 93,312 cells and 46,656 simulations. Table 5-1 represents an example of the matrix for one location/climate, one orientation and for December 21, only, that is, a partial matrix.

Since the simulation of the daylighting performance of the shading device is a time-consuming process, and the objective of the research is to validate the specific DMF, the second matrix of data, which eliminates irrelevant parameter values from the first matrix, was developed. Several preliminary simulations were performed to determine which values of the parameters can be excluded. The analysis of the results of these simulations shows that:

- Only one building location needs to be simulated since the simulation process in the specific DMF is the same for any other location. Roanoke, Virginia, has a temperate climate and is chosen for the building location in this case study.
- Since the results of the daylighting performance depend on the sun angle, and values of altitude and azimuth sun angles are the same (relative to the south direction) for the east and west facade orientation, simulations are performed just for the west facade orientation in addition to the simulations for the south orientation.

blinds type	blinds position	blinds tilt angle	21-Dec																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																						
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Table 5-1 First matrix of data - partial presentation

- Only three types of shading devices are simulated¹:
 - Existing system: plastic light grey blinds, concave-convex shape, 1" wide
 - Patented system: plastic, tooth-shaped top surface, square cross section of the slat
 - New system: The shading device proposed by this research: plastic transparent blinds with a silver reflective coating, triangular cross section, 1" wide
- Three blind tilt angles need to be simulated:
 - 0° (completely open blinds)
 - 45° (partially open/partially closed blinds)
 - 90° (completely closed blinds)
- Since the sun angles (azimuth and altitude) are the same on March 21 and September 21, simulations need to be done only for the March 21 (in addition to December 21 and June 21).
- Simulations need to be done three times per day:
 - For south orientation: at 11:00 a.m. (instead of 9:00 a.m., as proposed in the first matrix, because the sun angles at 9:00 a.m. and 3:00 p.m. are the same for the particular day), 12:00 p.m., and 3:00 p.m.
 - For west orientation: at 12:00 p.m., at 2:00 p.m., and at 4:00 p.m.
- Since sky conditions significantly affect daylight levels in the space and control strategy for the blind tilt angle adjustment, three sky conditions must be considered: clear, partly cloudy, and cloudy.
- Two daylighting performance parameters need to be measured: illuminance and luminance. Each parameter is measured at two points of the space: at the top of the surface of the office desks, one close to the window and another close to the interior partition wall.

A combination of all these parameters gives the second reduced matrix, which consists of 5,832 cells and 2,916 simulations. This matrix is shown partially in Table 5-2 (for December 21 at 11:00 a.m.).

¹Refer to Section 4.3.10: Description of the shading device systems

Blinds type	Blinds position	Blinds angle	21-Dec 11:00 a.m.											
			clear sky						partly cloudy sky					
			illumina- nce (lx)		lumina- nce (cd/sq m)		illumina- nce (lx)		lumina- nce (cd/sq m)		illumina- nce (lx)		lumina- nce (cd/sq m)	
			inside wall	window	inside wall	window	inside wall	window	inside wall	window	inside wall	window	inside wall	window
existing	exterior	0												
		45												
		90												
	between	0												
		45												
		90												
	interior	0												
		45												
		90												
patented	exterior	0												
		45												
		90												
	between	0												
		45												
		90												
	interior	0												
		45												
		90												
new	exterior	0												
		45												
		90												
	between	0												
		45												
		90												
	interior	0												
		45												
		90												

Table 5-2 Second reduced matrix of data - partial presentation

Since it is not necessary to perform all these simulations to validate the specific DMF, the goal is to decrease the number of simulations to those that in the best way represent how the specific DMF works. To achieve this goal, the following variables are reduced:

- Blinds' position: the blind position relative to the window is not considered a variable. The blinds' positions are fixed for each particular type of blinds. The existing blinds are installed only at the inside of the window. However, in this research, the existing blinds are simulated not only for the interior but also for the between-glass and outside positions. The patented blinds' design proposes between-glass positions of the blinds. The new blinds are installed between two panes of glass. However, the new blinds are also simulated for the position inside and outside the window. The obtained results of simulation can help in understanding the effect of the blinds' position on the illuminance and luminance level for each type of blinds. The results are also used for comparison of the three blinds' performance in the different positions. For example, performance for the three blinds in the outside position is compared to understanding which blinds provide the highest illuminance level in the space.
- Blinds' tilt angle: simulations are done for the blinds' tilt angles that are relevant for the particular shading device type and sky conditions. For example, if the existing blinds' tilt angle is 45° , the illuminance level in the space is not sufficient for cloudy sky conditions. Blinds should be completely open for cloudy sky conditions to provide maximum possible daylight in the space. These are the reasons that simulations are done just for the specific blind tilt angles:
 - For the existing and new shading device:
 - o For clear sky: 45° and 90°
 - o For partly cloudy sky: 0° and 45°
 - o For cloudy sky: 0°
 - For the patented shading device: the blinds are fixed (non-operable) at the horizontal position so they are tested at a 0° angle for all sky conditions.

The existing and new shading devices are additionally tested for all three blind tilt angles (0° , 45° , and 90°) for particular dates, times, and sky conditions:

- The existing shading device:

- o For the south orientation on March 21, June 21, and December 21 at 12:00 p.m., for all sky conditions, for interior position of blinds and all three blinds' tilt angles.
- o For the west orientation on March 21, June 21, and December 21 at 4:00 p.m., for all sky conditions, for the interior position of blinds, and all three blinds' tilt angles.
- The new shading device:
 - o For the south orientation on March 21, June 21, and December 21 at 12:00 p.m., for all sky conditions, for the between-position of blinds, and all three blinds' tilt angles.
 - o For the west orientation on March 21, June 21, and December 21 at 4:00 p.m., for all sky conditions, for the between-position of blinds, and all three blinds' tilt angles.

The number of needed simulations was decreased to 468 by reducing these variables, and it gives the matrix of data, which consists of 936 cells. This number of 468 simulations gives an excellent picture of the overall blinds' performance. The matrix is used for the final presentation of simulation data in the case study. The partial matrix for December 21 at 11:00 a.m. is given in Table 5-3.

Blinds type	Blinds position	Blinds angle	21-Dec 11:00 a.m.											
			clear sky						partly cloudy sky					
			illumination (lx)			luminance (cd/sq m)			illumination (lx)			luminance (cd/sq m)		
			window	inside wall	outside wall	window	inside wall	outside wall	window	inside wall	outside wall	window	inside wall	outside wall
existing	exterior	0												
		45												
		90												
	between	0												
		45												
		90												
patented	interior	0												
		45												
		90												
	between	0												
		45												
		90												
new	exterior	0												
		45												
		90												
	between	0												
		45												
		90												
	interior	0												
		45												
		90												
		0												
		45												
		90												

Table 5-3 Third reduced matrix of data - partial presentation

5.2.2. DESCRIPTION OF THE CHARTS OF RESULTS USED IN THE SPECIFIC DMF

Matrixes of data and the charts are used by the user of the specific DMF (either a building designer/architect or manufacturer/designer of the shading device) for making decisions. This format of data shows the average annual illuminance-days and luminance-days for each type of blinds for three different sky conditions, as well as the range of values recommended by the standard. In this way, the presentation of data is simplified and made more applicable and helpful for the user of the specific DMF.¹ By comparing the values of illuminance-days and luminance-days for three types of blinds, the user of the specific DMF can conclude which type of blinds provides the illuminance (or luminance) levels required by the standard for the longest period of time (that is, number of days per month or year). The shading device system that shows the best daylighting performance for the longest time, that is, the highest values of illuminance-days/year and luminance-days/year, should be applied to the building given economic viability.

Table 5-4 shows the number of days per month for various sky conditions, as well as the number of clear, partly cloudy, and cloudy days per year in Roanoke, Virginia. Table 5-5 shows the illuminance (or luminance) values at one point in the room (either close to the window or close to the interior partition wall) for each type of blinds, for three sky conditions, and for each month in the year, as well as annually. Illuminance (or luminance) values in these tables are taken from the matrixes of data (see Appendix B.1: Matrixes of data) for March 21, June 21, and December 21, and for a specific blinds' position and tilt angle:

- For existing blinds: interior position and 45° angle for clear and partly cloudy sky conditions and 0° for cloudy sky conditions.
- For patented blinds: between-position and 0° angle for all sky conditions, determined by the design.
- For new blinds: between-position and 45° angle for clear and partly cloudy sky conditions, and 0° angle for cloudy sky conditions.

The average values are found by summing the values for a particular month for three hours per day and for particular sky conditions. For example, the average illuminance value

¹ Refer to Tables 5-4 – 5-8, Figure 5-1 and Appendix B.2: Charts and tables – for the user of the DMF

**Table 5-4 Sky conditions -
number of days in Roanoke, Virginia**

month	clear	partly cloud	cloudy
january	8	8	15
february	8	7	13
march	8	9	14
april	8	9	13
may	7	11	13
june	7	12	11
july	7	13	11
august	8	12	11
september	10	9	11
october	13	7	11
november	9	8	13
december	9	8	14
annual	102	113	151

Table 5-5 Illuminance at the point close to the window (lx)

	EXISTING BLINDS			PATENTED BLINDS			NEW BLINDS		
month	clear	partly cloud	cloudy	clear	partly cloud	cloudy	clear	partly cloud	cloudy
january	1433	889	394	1700	1147	333	2444	2022	628
february	1300	1028	439	1600	1273	400	2456	2211	706
march	1167	1167	483	1500	1400	467	2467	2400	783
april	1189	1178	517	1456	1400	467	2378	2367	828
may	1211	1189	550	1411	1400	467	2289	2333	872
june	1233	1200	583	1367	1400	467	2200	2300	917
july	1211	1189	550	1411	1400	467	2289	2333	872
august	1189	1178	516	1456	1400	467	2378	2367	828
september	1167	1167	483	1500	1400	467	2467	2400	783
october	1300	1028	439	1600	1273	400	2456	2211	705
november	1433	889	394	1700	1147	333	2445	2022	628
december	1567	750	350	1800	1020	267	2433	1833	550
annual	15401	12851	5699	18500	15660	5001	28701	26800	9099

Table 5-6 Illuminance x days at the point close to the window (lx*days)

	EXISTING BLINDS			PATENTED BLINDS			NEW BLINDS		
month	clear	partly cloud	cloudy	clear	partly cloud	cloudy	clear	partly cloud	cloudy
january	11467	7111	5917	13600	9173	5000	19556	16178	9417
february	10400	7194	5706	12800	8913	5200	19644	15478	9172
march	9333	10500	6767	12000	12600	6533	19733	21600	10967
april	9511	10600	6717	11644.44	12600	6067	19022	21300	10761
may	8478	13078	7150	9877.778	15400	6067	16022	25667	11339
june	8633	14400	6417	9566.667	16800	5133	15400	27600	10083
july	8479	15457	6049	9877.778	18200	5135	16023	30333	9593
august	9513	14136	5681	11644.44	16800	5136	19024	28400	9103
september	11670	10503	5313	15000	12600	5137	24670	21600	8613
october	16903	7196	4825	20800	8913	4402	31925	15478	7759
november	12901	7112	5126	15300	9173	4335	22001	16178	8160
december	14100	6000	4900	16200	8160	3733	21900	14667	7700
annual	131388	123287	70567	158311	149333	61878	244921	254478	112667

**Table 5-7 Annual illuminance
x days (lx*days/year)**

	clear	partly cloud	cloudy
existing	131388	123287	70567
patented	158311	149333	61878
new	244921	254478	112667
min standa	90000	90000	90000
max standa	504000	504000	504000

**Table 5-8 Annual illuminance
x days (K lx*days/year)**

	clear	partly cloud	cloudy
existing	131	123	71
patented	158	149	62
new	245	254	113
min standa	90	90	90
max standa	504	504	504

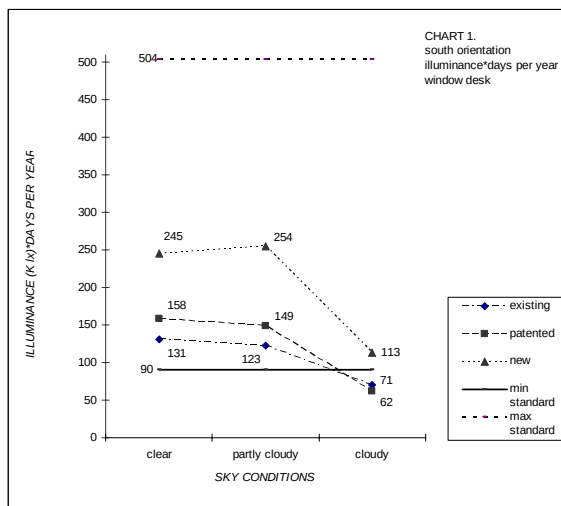


**Figure 5-1 Relationship between illuminance
*days/year levels and sky conditions for three
types of blinds**

for existing blinds for December is found by summing the values obtained on December 21 at 11:00 a.m., 12:00 p.m., and 3:00 p.m. for clear sky conditions at one point of the room, and dividing this value by 3.

Since the illuminance/luminance values are calculated only for March, June, and December by using Autodesk VIZ 4, the values for other months are found by interpolation of the known values. Table 5-6 shows the average illuminance-day (or luminance-day) values for each type of blinds for three sky conditions and for each month in the year, as well as annual values. The values in this table are calculated by multiplying the average values for illuminance (or luminance) (from Table 5-5) and the number of days for various sky conditions (from Table 5-4) for each type of blinds. The values are found for each month and the total for the year by adding values for 12 months.

Table 5-7 presents the annual values of illuminance-days (or luminance-days) for each type of blinds and for three sky conditions. It also gives the minimum and maximum values that are recommended by the standard:

- For the minimum value of illuminance-days – 90000 (lx*days): the value is calculated by using the following formula:

$$[\text{min illuminance (by standard)}] \times (\text{average number of days/month for sky conditions}) \times 12 \text{ month} = (750 \text{ lx}) \times (10 \text{ days}) \times 12 = 90000 \text{ lx*days}$$
- For the maximum value of illuminance-days – 504000 (lx*days): the value is calculated by using the following formula:

$$[\text{max illuminance (by standard)}] \times (\text{average number of days/month for sky conditions}) \times 12 \text{ month} = (4200 \text{ lx}) \times (10 \text{ days}) \times 12 = 504000 \text{ lx*days}$$
- For the minimum value of luminance-days – 12000 [(cd/sq m)*days]: the value is calculated by using the following formula:

$$[\text{min luminance (by standard)}] \times (\text{average number of days/month for sky conditions}) \times 12 \text{ month} = (100 \text{ cd/sq m}) \times (10 \text{ days}) \times 12 = 12000 \text{ (cd/sq m)*days}$$
- For the maximum value of luminance-days – 102000 [(cd/sq m)*days]: the value is calculated by using the following formula:

$$[\text{max luminance (by standard)}] \times (\text{average number of days/month for sky conditions}) \times 12 \text{ month} = (850 \text{ cd/sq m}) \times (10 \text{ days}) \times 12 = 102000 \text{ (cd/sq m)*days}$$

The annual values for illuminance/luminance are taken from Table 5-6.

Table 5-8 presents the same values as Table 5-7 just given in K lx*day for a more convenient presentation of the data in the line chart. The chart shows the comparison of the annual daylighting performance among three types of blinds for clear, partly cloudy, and cloudy sky (see Figure 5-1). The sky conditions are shown on the horizontal (x) axis, and the vertical (y) axis shows the values of the annual illuminance-days (in K lx*days) or luminance-days (in cd/sq m)*days). There are eight sets of these five tables and the chart in Appendix B.2, and each set represents a combination of the following parameters:

- Performance parameters: illuminance/luminance
- Orientation of the facade: south/west
- Point at which the measurements are taken: close to the window/close to the interior partition wall

5.2.3. DESCRIPTION OF THE CHARTS OF RESULTS USED IN THE DISSERTATION

A set of charts is made¹ to simplify an analysis of the data provided by simulation and presented in the matrixes of data in Appendix B.1. These charts are used to present the results of the simulation for the purpose of the research and this dissertation, but they are not tools to be used by the decision-maker in the DMF. The charts show the effect of six variables on the illuminance and luminance level in the space. Eight sets of charts are based on the combination of the following parameters (similar to the charts shown in Appendix B.2):

- Performance parameters: illuminance or luminance
- Facade orientation: south or west
- Point in the space at which measurement is made: close to the window or close to the interior partition wall (see Table 5-9)

Sets 1, 2, 5, and 6 consist of nine sheets, and sets 3, 4, 7, and 8 consist of seven sheets based on the combination of six variables (see Appendix B.3). Sets 1, 2, 5, and 6 present results of simulation for the south-oriented blinds. However, sheets 4 and 7 in these four sets present a comparison of the results of simulations for south and west orientation of the blinds. Sets 3, 4, 7, and 8 present the results of simulation for the west-oriented blinds. Sheets 4 and 7 are

¹ Charts are made by using the software Microsoft Excel.

excluded from sets 3, 4, 7, and 8 to avoid repetition of information already given in sets 1, 2, 5, and 6. For that reason, sets 3, 4, 7, and 8 consist of seven sheets. The purpose of these charts is to analyze the effect of the following six variables on the illuminance or luminance level in the space: time, date, sky conditions, orientation of the facade, blinds' position, and blinds' tilt angle.

Table 5-9 *Overview of the eight sets of charts*

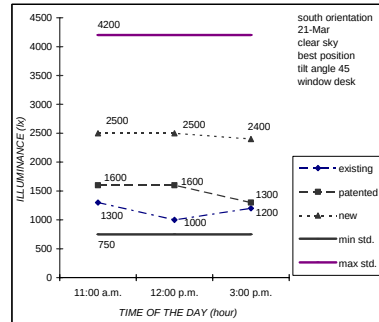
SET NO.	PERFORMANCE PARAMETER	FACADE ORIENTATION	MEASUREMENT POINT
1	illuminance	south	window
2	illuminance	south	interior
3	illuminance	west	window
4	illuminance	west	interior
5	luminance	south	window
6	luminance	south	interior
7	luminance	west	window
8	luminance	west	interior

These parameters are always shown on the horizontal (x) axis of the chart as categories. The values of the illuminance or luminance levels are given in lux or cd/sq m on the vertical (y) axis. The charts always show a comparison among the three types of blinds--existing, patented, and new--based on one major variable. Another purpose of using these charts is to analyze the effect of two other minor parameters on the illuminance or luminance level. The major variable is always shown on the x axis of the chart, and it represents a variable whose effect is analyzed in the charts on the particular sheet. The minor variables' effect can also be analyzed from the charts in the particular sheet by comparing the charts in the particular row or column of the charts in the sheet. The values of one minor variable are changed in each column. For example, sheet 1 (see Figure 5-2) shows the effect of the time as a major variable on the illuminance level in the space for the south orientation of the blinds and at the point close to the window. The values of time are shown on the x axis (11:00 a.m., 12:00 p.m., and 3:00 p.m.). The values of the date, which is a minor variable in sheet 1, are different for each column of the charts (I column – March 21, II column – June 21, and III

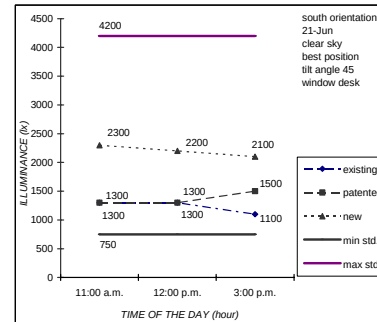
column – December 21). A comparison of the charts in the three columns for the particular sky condition shows the effect of the date on the illuminance level in the space. The values of sky condition, which is also a minor variable, change for each row of charts in sheet 1 (I row – clear sky, II row – partly cloudy sky, III row – cloudy sky). A comparison of charts in the three rows for the particular date shows the effect of the sky condition on the daylight level in the space. The rest of the parameters in sheet 1 (facade orientation, blinds' position, and blinds' tilt angle) are fixed.

	existing	patented	new
BEST POSITION	inside	between	between

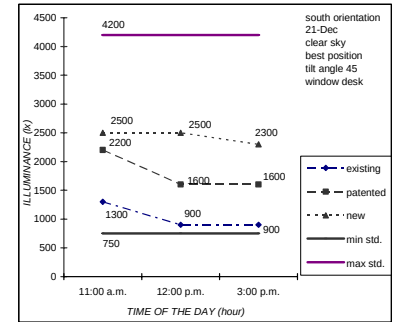
illumiance		11:00 a.m.	12:00 p.m.	3:00 p.m.
south orientation	existing	1300	1000	1200
21-Mar	patented	1600	1600	1300
clear sky	new	2500	2500	2400
best position	min std.	750	750	750
tilt angle 45	max std.	4200	4200	4200
window desk				



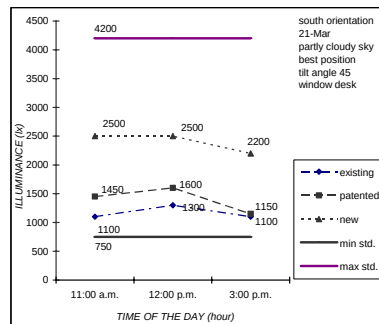
illumiance		11:00 a.m.	12:00 p.m.	3:00 p.m.
south orientation	existing	1300	1300	1100
21-Jun	patented	1300	1300	1500
clear sky	new	2300	2200	2100
best position	min std.	750	750	750
tilt angle 45	max std.	4200	4200	4200
window desk				



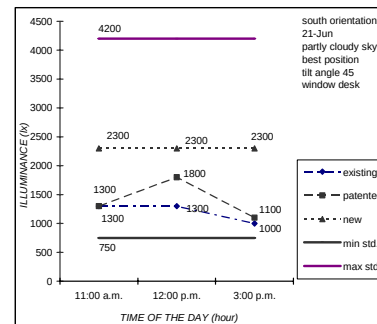
illumiance		11:00 a.m.	12:00 p.m.	3:00 p.m.
south orientation	existing	1300	900	900
21-Dec	patented	2200	1600	1600
clear sky	new	2500	2500	2300
best position	min std.	750	750	750
tilt angle 45	max std.	4200	4200	4200
window desk				



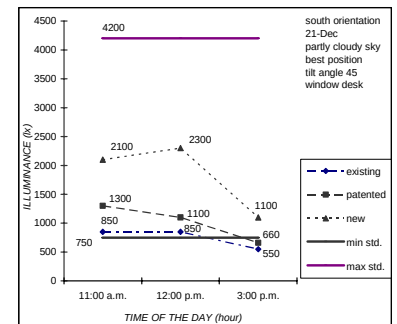
illumiance		11:00 a.m.	12:00 p.m.	3:00 p.m.
south orientation	existing	1100	1300	1100
21-Mar	patented	1450	1600	1150
partly cloudy sky	new	2500	2500	2200
best position	min std.	750	750	750
tilt angle 45	max std.	4200	4200	4200
window desk				



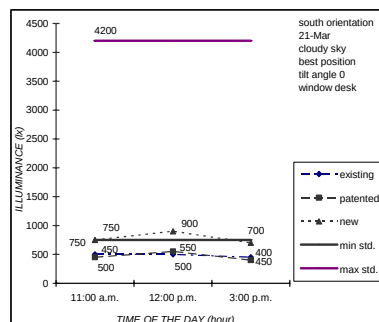
illumiance		11:00 a.m.	12:00 p.m.	3:00 p.m.
south orientation	existing	1300	1300	1000
21-Jun	patented	1300	1800	1100
partly cloudy sky	new	2300	2300	2300
best position	min std.	750	750	750
tilt angle 45	max std.	4200	4200	4200
window desk				



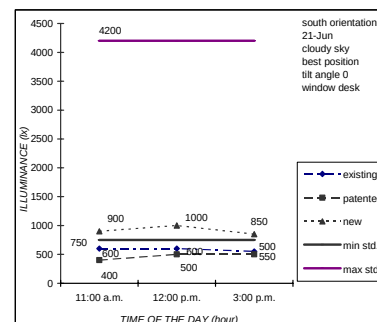
illumiance		11:00 a.m.	12:00 p.m.	3:00 p.m.
south orientation	existing	850	850	550
21-Dec	patented	1300	1100	660
partly cloudy sky	new	2100	2300	1100
best position	min std.	750	750	750
tilt angle 45	max std.	4200	4200	4200
window desk				



illumiance		11:00 a.m.	12:00 p.m.	3:00 p.m.
south orientation	existing	500	500	450
21-Mar	patented	450	550	400
cloudy sky	new	750	900	700
best position	min std.	750	750	750
tilt angle 0	max std.	4200	4200	4200
window desk				



illumiance		11:00 a.m.	12:00 p.m.	3:00 p.m.
south orientation	existing	600	600	550
21-Jun	patented	400	500	500
cloudy sky	new	900	1000	850
best position	min std.	750	750	750
tilt angle 0	max std.	4200	4200	4200
window desk				



illumiance		11:00 a.m.	12:00 p.m.	3:00 p.m.
south orientation	existing	500	450	10
21-Dec	patented	300	400	10
cloudy sky	new	550	600	500
best position	min std.	750	750	750
tilt angle 0	max std.	4200	4200	4200
window desk				

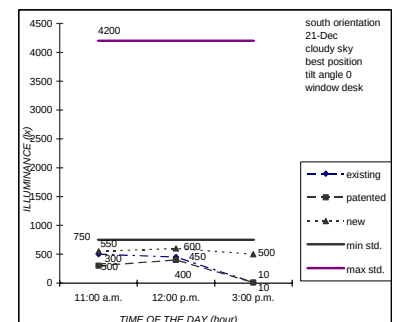


Figure 5-2 An example of sheet 1 – south orientation, illuminance at the point close to the window

The following chart is taken from sheet 1 (see Figure 5-3) to explain the structure of the chart. The values of illuminance represented in the chart are the results/output of simulations performed for the three types of blinds (existing, patented, and new) and three times per day (11:00 a.m., 12:00 p.m., and 3:00 p.m.). Time is the major variable considered in these charts, and the values of the times are given on the horizontal (x) axis. The values of illuminance (in lx) are given on the vertical (y) axis.

ILLUMINANCE- effect of the time -for different dates-for different sky condition

	existing	patented	new
BEST POSITION	inside	between	between

illuminance
south orientation
21-Mar
clear sky
best position
tilt angle 45
window desk

	11:00 a.m.	12:00 p.m.	3:00 p.m.
existing	1300	1000	1200
patented	1600	1600	1300
new	2500	2500	2400
min std.	750	750	750
max std.	4200	4200	4200

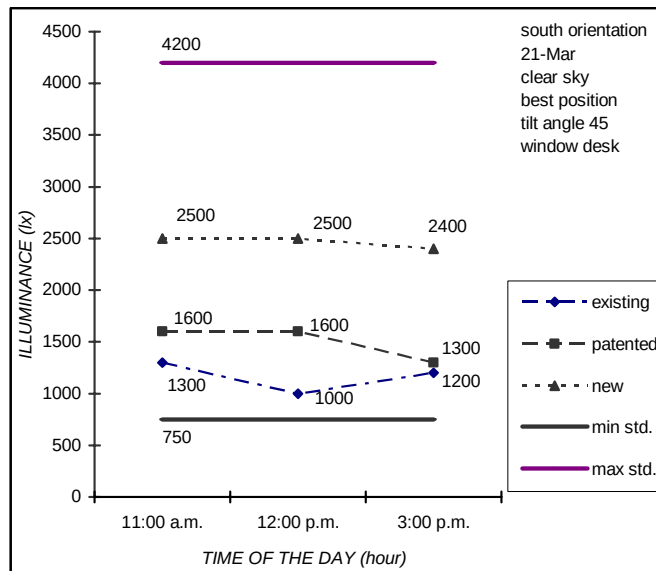


Figure 5-3 An example of the chart from sheet 1 – south orientation, illuminance at the point close to the window

The results, obtained by simulation, show values of actual illuminance in the space at the specific time and for each particular type of blinds. Each line in the chart represents performance of the specific type of blinds. There are two additional horizontal lines in the chart that show values of illuminance recommended by the standard: the line at 4200 lx level

represents maximum illuminance, while the line at 750 lx level represents the minimum illuminance recommended by the standard. A comparison of the three lines for the actual performance of blinds and the two lines for the recommended performance gives these conclusions:

- Which blinds perform the best, that is, which give the highest illuminance level in the space?
- Does the value of illuminance for specific blinds meet the requirements of the standard, that is, does the line of blind performance lie between the two lines that represent values recommended by the standard?

The legend given on the right side of the chart shows the line types used to represent the performance of different types of blinds, as well as the line types for the minimum and maximum values of illuminance by the standards. In the upper right corner of the chart, the values of the variables that are fixed for this particular chart are shown. The table which precedes the chart shows the same values of illuminance, which are given in the chart. The actual values of illuminance that are the output of the simulation are given in this table. The values in the columns represent the values for different times, while values in the rows represent the performance of different blinds, as well as values of illuminance given by the standard.

The remaining eight sheets are presented and analyzed in the same manner as sheet 1:

- Sheet 2 (see Appendix B.3, p. 417): shows the effect of the date, but also how sky conditions and times affect the blinds' performance (illuminance/luminance level) because these two variables are changed. The rest of the variables (facade orientation, blinds' position, and blinds' tilt angle) are fixed.
- Sheet 3 (see Appendix B.3, p. 418): shows the effect of sky conditions, but also how the date and time affect the blinds' performance (illuminance/luminance level) because these two variables are changed. The rest of the variables (facade orientation, blinds' position, and blinds' tilt angle) are fixed.

An analysis of sheets 1-3 shows that the time of day slightly affects the illuminance/luminance level, while sky conditions and the date significantly affect the illuminance/luminance level in the space. That is the reason why these two variables (sky conditions and date) are used as the variables for which values are changed in the analysis of

the effect of the facade orientation, the blinds' position, and blinds' tilt angle on the illuminance level in the space (sheets 4, 5, and 6).

- Sheet 4 (see Appendix B.3, p. 419): shows the effect of the facade/blinds' orientation and also the effect of the date and sky conditions on the blinds' performance (illuminance/luminance level). The rest of the variables are fixed (time – 12:00 p.m. for south, blinds' position, and blinds' tilt angle).
- Sheet 5 (see Appendix B.3, p. 420): shows the effect of the blinds' position, as well as the effect of the date and sky conditions on the illuminance/luminance level in the space. The rest of the parameters are fixed (time – 12:00 p.m. for south, the facade orientation, and blinds' tilt angle).
- Sheet 6 (see Appendix B.3, p. 421): shows effect of the blinds' tilt angle, as well as the effect of the date and sky conditions on the illuminance/luminance level in the space. The rest of the variables are fixed (time – 12:00 p.m. for south, the facade orientation, and blinds' position).

Sheets 7, 8, and 9 show again the effect of the sky conditions as the most affecting variable, but in the context of the date (that is varied) and three other variables: facade orientation, blinds' position, and blinds' tilt angle.

- Sheet 7 (see Appendix B.3, p. 422): shows the effect of the sky conditions and also the facade orientation and date on the illuminance/luminance level in the space. The rest of the variables are fixed (time – 12:00 p.m. for south, blinds' tilt angle, and blinds' position).
- Sheet 8 (see Appendix B.3, p. 423): shows the effect of the sky conditions, as well as the date and blinds' position on the illuminance/luminance level in the space. The following variables are fixed: facade orientation, time – 12:00 p.m. for south, and blinds' tilt angle.
- Sheet 9 (see Appendix B.3, p. 424): shows effect of the sky conditions and also the date and blinds' tilt angle on the illuminance/luminance level in the space. The following variables are fixed: facade orientation, time – 12:00 p.m. for south, and blinds' position.

Table 5-10 presents the overview of the variables used in sheets 1-9, such as major, minor, and constant variables, which are shown for each sheet individually.

Table 5-10 Overview of the variables used in sheets 1-9

SHEET NO.	MAJOR VARIABLE	MINOR VARIABLE	CONSTANT VARIABLES
1	Time	Sky conditions Date	Facade orientation Blinds' position Blinds' tilt angle
2	Date	Sky conditions Time	Facade orientation Blinds' position Blinds' tilt angle
3	Sky conditions	Date Time	Facade orientation Blinds' position Blinds' tilt angle
4	Facade orientation	Sky conditions Date	Time Blinds' position Blinds' tilt angle
5	Blinds' position	Sky conditions Date	Time Facade orientation Blinds' tilt angle
6	Blinds' tilt angle	Sky condition Date	Time Facade orientation Blinds' position
7	Sky conditions	Date Facade orientation	Time Blinds' position Blinds' tilt angle
8	Sky conditions	Date Blinds' position	Time Facade orientation Blinds' tilt angle
9	Sky conditions	Date Blinds' tilt angle	Time Facade orientation Blinds' position

5.2.4. DESCRIPTION OF THE APPROACHES TO POSSIBLY BE USED IN THE SPECIFIC DMF

Three simplified approaches are created for the presentation of the results of the simulation in the specific DMF. The approach explained in the previous section (see Section 5.2.2: Description of the charts of results used in the specific DMF) is selected as the preferred approach in the specific DMF. However, two alternative approaches that analyze the output data, in a simplified way, are also results of the research and are explained in the next section. The two alternative approaches can also be used in the specific DMF, and then give the same level of accuracy in the selection of the preferred blinds compared to the selected approach.

The first alternative approach for the presentation of the data in the specific DMF uses the method of conversion of values of output data to the scale 0-1 (see Section 5.2.4.1: Conversion of values of data to the scale 0-1). By obtaining the average converted values of daylighting performance parameters (illuminance and luminance) for each analyzed shading device, a comparison of the performance of the shading devices is simplified and accurate enough to make the selection of preferred blinds.

The second alternative approach for the presentation of data in the specific DMF uses daylight autonomy (DA) as the criterion for a comparison of the blinds (see Section 5.2.4.2: Using daylight autonomy). Daylight autonomy represents a percentage of time per year for which the shading device provides a minimum daylight level in the space without use of electric lighting. Output data (illuminance values) are used for the calculation of DA for each shading device. Daylight autonomy is a simple methodology for a comparison of shading devices, but, at the same time, accurate enough to provide a correct selection of the blinds.

5.2.4.1. CONVERSION OF VALUES OF DATA TO THE SCALE 0-1

A simplified analysis of data can be used in the following way:

- Values of illuminance (or luminance) for existing, patented, and new shading devices-- for two points in the space and for south and west orientation--are taken from the matrixes of data (from Appendix B.1). Values are taken by considering the following principles:
 - Regarding the blinds' tilt angle:

- o Values for existing and new shading devices are taken for a 45° tilt angle for clear and partly cloudy sky conditions, and for a 0° tilt angle for cloudy sky conditions.
- o Values for patented shading devices are always taken for a 0° tilt angle since the system is fixed at that angle by the design.
- Regarding the blinds' position relative to the window:
 - o Values for the existing shading devices are taken for its interior position.
 - o Values for the patented and new shading devices are taken for their position between two panes of glass.

Table 5-11 shows the values of illuminance/luminance obtained in this way. Table 5-11 presents just a part of the original table (for December 21 at 11:00 a.m.).¹

Table 5-11 Values of illuminance/luminance taken from matrixes of data

	21-Dec											
	11:00 a.m.											
	clear sky				partly cloudy sky				cloudy sky			
	illuminance		luminance		illuminance		luminance		illuminance		luminance	
	window	inside wall	window	inside wall	window	inside wall	window	inside wall	window	inside wall	window	inside wall
EXISTING	1300	650	150	110	850	500	100	90	500	400	10	10
PATENTED	2200	650	200	100	1300	600	160	120	300	400	10	10
NEW	2500	1300	400	150	2100	800	220	130	550	400	10	10

- In the next step, the values of illuminance (or luminance) given in Table 5-11 are converted to the values on the scale 0-1 in the following way:
 - For illuminance levels: a range of values of 100-2500 lx is converted to a range 0-1, where 100 lx equals 0 and 2500 lx equals 1.
 - For luminance levels: a range of values of 10-1000 cd/sq m is converted to a range 0-1, where 10 cd/sq m equals 0 and 1000 cd/sq m equals 1.

Table 5-12 shows the conversion factors for both illuminance and luminance, depending on the ranges of values.

¹ For the rest of the results, refer to Appendix B.4.1: Conversion of values.

Table 5-12 Conversion table

Ranges of illuminance in lx	Ranges of luminance in cd/sq m	Conversion factors
<100	<10	0
100-400	10-134	0.125
401-700	135-257	0.25
701-1000	258-381	0.375
1001-1300	382-505	0.5
1301-1600	506-628	0.625
1601-1900	629-753	0.75
1901-2200	754-876	0.875
2201-2500	877-1000	1.00

Each value of illuminance (or luminance) from Table 5-11 is converted to the corresponding value from the scale 0-1, and Table 5-13 shows these values. Table 5-13 presents just part of the original table (for December 21 at 11:00 a.m.).¹

Table 5-13 Values of illuminance/luminance converted to scale 0-1

	21-Dec											
	11:00 a.m.											
	clear sky				partly cloudy sky				cloudy sky			
	illuminance		luminance		illuminance		luminance		illuminance		luminance	
	window	inside wall	window	inside wall	window	inside wall	window	inside wall	window	inside wall	window	inside wall
EXISTING	0.5	0.25	0.25	0.125	0.375	0.25	0.125	0.125	0.25	0.125	0.125	0.125
PATENTED	0.875	0.25	0.25	0.125	0.5	0.25	0.25	0.125	0.125	0.125	0.125	0.125
NEW	0.875	0.5	0.5	0.25	0.875	0.375	0.25	0.125	0.25	0.125	0.125	0.125

- The next step consists of summing converted values of illuminance and luminance separately, and for each type of blinds individually, by taking values from Table 5-13.
- The summed value is divided by the number of the cells in the row (where row corresponds to the values for one type of blinds). This result is an average

¹ For the rest of the results, refer to Appendix B.4.1: Conversion of values.

illuminance (or luminance) for a specific type of shading device, expressed on the scale 0-1 (see Table 5-14).

Table 5-14 *Values of illuminance/luminance summed and divided by number of cells*

type of blinds	average illuminance	average luminance	illuminance divided by number of cells	luminance divided by number of cells
EXISTING	21.75	9	0.4	0.17
PATENTED	21.75	10	0.4	0.185
NEW	29.87	12.5	0.55	0.23

- The average value of illuminance (or luminance) given on the scale 0-1 is converted to the actual values of illuminance in lx (or luminance in cd/sq m), and this result represents the average illuminance (or luminance) value for a particular type of shading device (see Table 5-15).

Table 5-15 *Average values of illuminance/luminance converted to actual values*

type of blinds	average illuminance in scale 0 - 1	average illuminance converted to lx	average luminance in scale 0 - 1	average luminance converted to cd/sq m
EXISTING	0.4	1060	0.17	168
PATENTED	0.4	1060	0.185	183
NEW	0.55	1300	0.23	227

- Values given in Table 5-15 are used for a comparison of the three different types of shading devices. They are used for making the decision about the selection of the system that has the best average daylighting performance.

5.2.4.2. USING DAYLIGHT AUTONOMY

Another way of presenting the data and comparing the performance of different types of blinds is calculating daylight autonomy for each type of blinds. Daylight autonomy is the percentage of time per year for which a shading device provides the minimum amount of daylight in the space without need for electric lighting, provided the amount also does not exceed the maximum values recommended by the standard. Daylight autonomy is found for different facade orientations and blind tilt angles. Table 5-16 presents illuminance data obtained by simulations for:

- Three types of blinds (existing, patented, new)
- Three dates (June 21, December 21, March 21)

- Three sky conditions (clear, partly cloudy, cloudy)
- Two points in the space (close to the window, close to the interior partition)
- Particular time (for example, 12:00 pm.)
- Particular facade orientation (for example, south)
- Particular blinds' tilt angle (for example, 0°)

Table 5-17 shows the number of clear, partly cloudy, and cloudy days for each month that is simulated, taken from statistical data for Roanoke, Virginia. Tables 5-16 and 5-17 are used for the calculation of daylight autonomy by using the following process:

- The values of illuminance from Table 5-16 are analyzed to see which of them fit in the range of values recommended by the standard (range of 750-4200 lx). The actual value of illuminance meets the requirements of the standards in specific sky conditions and on particular days. The number of days per month, for which the required value is obtained, is divided by the total number of days in the month to get daylight autonomy per month for that type of shading device. For example, the actual illuminance values for the existing shading device in June--at the measurement point close to the window--are obtained by looking at the values from Table 5-16 for:
 - Clear sky – 1300 lx
 - Partly cloudy sky – 2200 lx
 - Cloudy sky – 600 lx

The existing shading device meets the requirements of the standard for the clear and partly cloudy sky conditions, but not for the cloudy sky conditions. By looking at Table 5-17, one can see 7 clear days and 12 partly cloudy days in June in Roanoke, Virginia. It means that the existing shading device provides an optimum illuminance level for 19 days in June or 63% of the time per month. These values are shown in Table 5-18. If the values of actual illuminance are out of the range of values recommended by the standard, that is, less than 750 lx and more than 4200 lx, then the number of days for which these values of illuminance are obtained is multiplied by 0. For example, Table 5-16 shows that actual illuminance--for both existing and new blinds for a clear and partly cloudy sky on December 21 at 12:00 p.m. at the south-oriented facade--is 10000 lx, which is much beyond 4200 lx that is the maximum value recommended by the standard. On the other hand, the actual

illuminance for the existing blinds is 450 lx and for the new blinds is 600 lx for a cloudy sky on December 21 at 12:00 p.m. at the south-oriented facade. These values are below 750 lx, which is the minimum value recommended by the standard. In both cases, the values of actual illuminance are assigned value 0 because the values are out of the range of the values recommended by the standard, that is, out of the comfort zone. As a result, the values of daylight autonomy per month, as shown in Table 5-18, are 0 for the existing blinds and new blinds on December 21 at the point close to the window (see Section 5.3.3: Analysis of charts – daylight autonomy, p. 252).

- Table 5-18 shows the values of the daylight autonomy for each type of shading device, for each month, and at two measurement points in the space. The values of daylight autonomy per month are added up and divided by the number of months to get the average value of daylight autonomy per year, which is shown in Table 5-19.
- Values of daylight autonomy per year from Table 5-19 are represented in the chart (see Figure 5-4), which compares the performance of three types of blinds for a particular orientation and blinds' tilt angle. Horizontal axes show the measurement points in the space (window, interior), and vertical axes show the values of daylight autonomy in percentages.

In this case study, only results at 12:00 p.m. at the south-oriented facade and at 4:00 p.m. at the west-oriented facade are considered for calculating daylight autonomy due to the structure of simulation data described in Chapter 4. Since time of the day only slightly affects the illuminance/luminance levels in the space, values obtained at 12:00 p.m. and 4:00 p.m. are taken as the average illuminance values for the particular date at the south and west orientation.

Table 5-16 Values of illuminance taken from the matrixes of data

BLIND TILT ANGLE 0	ILLUMINANCE - JUN 21- AT 12:00 P.M.						ILLUMINANCE - DECEMBER 21- AT 12:00 P.M.						ILLUMINANCE - MARCH 21- AT 12:00 P.M.					
	CLEAR SKY		PARTLY CLOUDY SKY		CLOUDY SKY		CLEAR SKY		PARTLY CLOUDY SKY		CLOUDY SKY		CLEAR SKY		PARTLY CLOUDY SKY		CLOUDY SKY	
	WINDOW	INTERIOR	WINDOW	INTERIOR	WINDOW	INTERIOR	WINDOW	INTERIOR	WINDOW	INTERIOR	WINDOW	INTERIOR	WINDOW	INTERIOR	WINDOW	INTERIOR	WINDOW	INTERIOR
	EXISTING	1300	1300	2200	1500	10000	600	550	10000	1300	10000	400	450	1000	2250	1300	500	450
PATENTED	1300	1300	1800	1700	1000	550	500	550	1100	850	400	450	1600	900	1600	550	500	500
NEW	2500	1700	2500	2200	1000	650	1000	10000	10000	1800	10000	600	500	1900	2500	1600	900	600

Table 5-17 Sky conditions – number of days for each sky condition

month	JUNE			DECEMBER			MARCH		
	clear	partly cloud	cloudy	clear	partly cloud	cloudy	clear	partly cloud	cloudy
EXISTING	7	12	11	9	8	14	8	9	14
PATENTED	7	12	11	9	8	14	8	9	14
NEW	7	12	11	9	8	14	8	9	14

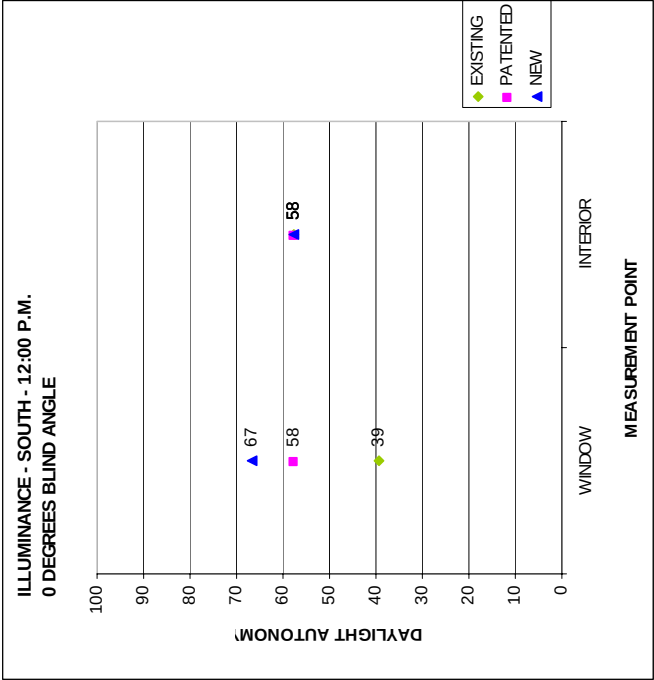
Table 5-19 Daylight autonomy per year

	PER YEAR	
	WINDOW	INTERIOR
	EXISTING 39	58
PATENTED	58	58
NEW	67	58

Table 5-18 Daylight autonomy per month

	ILLUM - JUNE		ILLUM - DECEMBER		ILLUM - MARCH	
	WINDOW	INTERIOR	WINDOW	INTERIOR	WINDOW	INTERIOR
EXISTING	63	63	0	55	55	55
PATENTED	63	63	55	55	55	55
NEW	100	63	0	55	100	55

Figure 5-4 Comparison of daylight autonomy for three types of blinds



5.3. ANALYSIS OF RESULTS OF THE CASE STUDY

Different ways of presenting the results of the simulations are explained in the previous section (see Section 5.2: Presentation of results of simulations). In this section, methodologies for the analysis of output results are shown for each way of data presentation. Analysis methodologies described in this section can help the user of the specific DMF in understanding how to analyze results after organizing and presenting them in one of the formats explained in Section 5.2:

- Results of case studies, obtained by the simulation by Autodesk VIZ 4, are presented in the form of charts to be used in the specific DMF (see Section 5.2.2. Description of the charts of results used in the specific DMF). Analysis of results is shown separately for the values of illuminance*days/year and luminance*days/year considering different blind orientations, sky conditions, and measurement points in the space. A comparison of the performance of the three types of blinds is made to make the selection of the preferred blinds. The criteria and tasks for the analysis of the performance of shading devices are explained to the user of the specific DMF who can use the same criteria for the analysis of blinds of his case studies. The decision on the blinds' selection is made by using the method of conversion of the values of illuminance/luminance to the scale 0-1. This is explained in the prior section (see 5.2.4.1: Conversion of values of data to the scale 0-1) so that the user of the specific DMF can get an understanding of how to apply the principles of conversion of values in the process of making the decision.
- In the previous section (see Section 5.2.3: Description of the charts of results used in the dissertation), the concept of presenting the results of a simulation at a more detailed, precise and accurate level is explained. This section takes that concept and shows its application for the analyzed case study. A combination of the six variables that affect daylighting performance of shading devices gives approximately 81 charts per set (see Figures 5-10 through 5-18). Further consideration of the facade orientation (south, west), daylighting performance parameters (illuminance, luminance), and measurement points gives 4 sets of 9 sheets and 4 sets of 7 sheets, making a total of 64 sheets or 576 charts. An analysis of the charts gives a thorough understanding of the blinds' performance and basis for making the comparison

among the blinds in order to select the preferred blinds for a particular building. The criteria used for the analysis of the charts, as well as a methodology for analysis of each sheet, is given to assist in understanding the results of the performance of shading devices presented in the format of the charts, sheets, and sets.

- The concept for the charts, which represent the results of the simulation in the format of values of daylight autonomy (DA), is explained in the previous section (see Section 5.2.4.2: Using daylight autonomy). In this section, the concept is applied for the analysis of the results of the simulation for a particular case study. The six charts that present DA/year are the result of the combination of three factors: facade orientation, blinds' tilt angle, and measurement point in the space. The criteria for the comparison of the different shading device systems are explained to guide the user of the specific DMF through the procedure of the analysis of results by using the daylight autonomy/year. Each chart analyzes DA/year in percent for each type of blinds.

All results are obtained and presented, considering the given limitations of this research¹.

5.3.1. ANALYSIS OF THE CHARTS USED IN THE SPECIFIC DMF BY THE USER OF THE DMF

By analysis of the charts for illuminance (see Figure 5-5) and luminance (see Figure 5-9)² levels in the space, as a result of the application of the different types of shading devices, the user of the DMF can make a decision about the type of the shading device that has the best performance given the limitations of this study. The following tasks are performed to analyze the charts:

- Comparison among the performances of the different types of shading devices.
- Comparison of the performance of each type of shading device with the performance required by the standards.
- Evaluation of the effect of the sky conditions on the performance of the shading device.
- Comparison between the performance for the south and west orientation for each shading device system.

¹ Refer to Section 1.6: Research limitations

² For more detailed results, refer to Appendix B.2: Charts and tables – for the user of the DMF.

- Comparison between performance for two points in the space (window and interior) for each type of shading device.

5.3.1.1. Analysis of results of illuminance*days/year

The charts shown in Figure 5-5 present values of illuminance*days/year for three types of shading devices (existing, patented, new), for three sky conditions (clear, partly cloudy, cloudy), for south and west facade orientation, and two points in the space (window desk and interior desk).

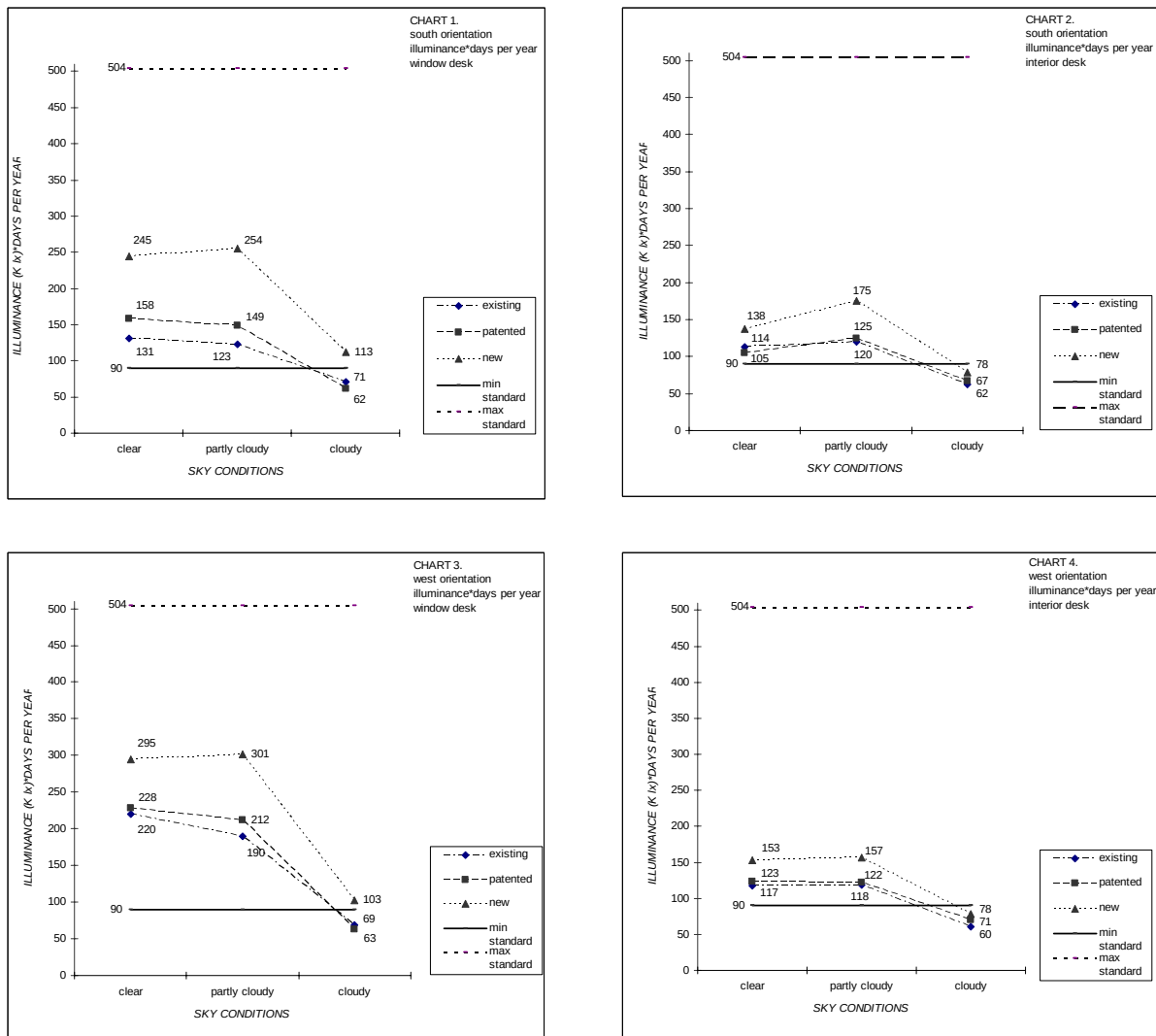


Figure 5-5 Relationship between illuminance - days levels and sky conditions for three types of blinds

Chart 1 shows that the new shading device gives the highest values of illuminance-days/year for all sky conditions, compared to the patented and existing shading device systems at the south orientation and at the desk close to the window, given the limitations of this research. The patented shading device gives higher values of illuminance*days/year for clear and partly cloudy sky conditions, compared to the existing shading device system, while the existing shading device performs better than the patented shading device for cloudy sky conditions. All three types of shading devices meet the requirements of the standards for the minimum illuminance*days/year for clear and partly cloudy sky days, but only the new shading device meets the minimum requirements of the standards for cloudy sky conditions. Chart 1 illustrates that sky conditions have a significant effect on the performance of all three types of shading devices. The values of illuminance*days/year do not differ significantly for clear and partly cloudy sky days for all three types of shading devices, but they have a significantly lower performance (approximately 50%) for cloudy sky conditions.

Chart 2 illustrates the performance of three types of shading devices at the south-oriented facade and for the measurements taken at the desk close to the interior partition wall. The new shading device shows the best performance, compared to the existing and patented shading device for all sky conditions, given the limitations of this study. The existing shading device shows a better performance than the patented shading device for clear sky conditions, and the patented shading device performs better than the existing shading device for partly cloudy and cloudy sky days. All three types of shading devices meet the requirements of the standards for clear and partly cloudy sky conditions, and none of them meet the requirements for cloudy sky conditions. All three types of shading devices show a higher value of illuminance*days/year for partly cloudy sky conditions than for clear sky conditions, while values of their performance for cloudy sky days are 50% lower, compared to partly cloudy sky conditions.

Chart 3 shows the performance of three types of shading devices oriented to the west with measurements made at the desk close to the window. The new shading device performs significantly better than the patented and existing shading device for all sky conditions, given the limits of this research. The patented shading device shows a slightly better performance than the existing shading device for clear and partly cloudy sky conditions. The existing

shading device performs better than the patented shading device for cloudy sky days. Only the new shading device meets the minimum requirements of the standard for all sky conditions, while the patented and existing shading devices meet the minimum requirements for clear and partly cloudy sky days, but not for cloudy sky days. Cloudy sky conditions significantly affect the performance of all three types of shading devices. The values of illuminance*days/year are 50% lower for cloudy sky days than for partly cloudy and clear sky conditions.

Chart 4 illustrates the performance of shading devices oriented to the west and measurements taken at the top of the desk close to the interior wall. The new shading device shows the highest values of illuminance*days/year, compared to the patented and existing systems, for all sky conditions, given the limitations of this study. The patented system performs slightly better than the existing system for all sky conditions. All three types of shading devices meet the minimum performance requirements of standards for clear and partly cloudy conditions, but they do not meet the minimum requirements for cloudy sky conditions. All three types of shading devices show almost the same performance for clear and partly cloudy sky days, but values of illuminance*days/year drop for 50% for cloudy sky days.

A comparison between the south- and west-oriented shading devices shows that:

- The new shading device performs better for west orientation at the point close to the window for clear and partly cloudy sky days, and better for south orientation for cloudy sky days. At the point close to the interior wall, the values of illuminance*days/year are the same for cloudy sky conditions, higher for partly cloudy sky conditions at the south-oriented facade, and higher for clear sky conditions at the west-oriented facade.
- The patented shading device shows almost the same performance for south and west orientation for all sky conditions at the point close to the window. At the point close to the interior wall, the patented shading device has almost the same performance at the south and west orientation for partly cloudy and cloudy sky conditions, while for clear sky conditions they perform better at the west orientation.
- The existing shading device: at the point close to the window, the existing shading device shows better performance for clear and partly cloudy sky days at the west

orientation and almost the same performance for cloudy sky conditions at the south and west orientation. At the point close to the interior wall, plastic blinds have almost the same performance at the south and west orientation.

A comparison of values of illuminance*days/year at two measured points shows that for both orientations the highest values are achieved at the point close to the window for all three types of shading devices for clear and partly cloudy sky days. For cloudy sky days, the values of illuminance*days/year slightly differ between two points for the patented and existing shading devices regardless of their orientation, while the new shading device shows 30% lower values of illuminance*days/year at the point close to the interior wall.

An analysis of the four charts in Figure 5-5 shows that the new shading device gives the highest values of illuminance*days/year, compared to the other two types of blinds, given the limitations of this study. The new blinds meet the minimum requirements of the standards for all sky conditions at the point close to the window. They do not meet the minimum requirements only for cloudy sky conditions at the point close to the interior wall. It means that daylight will be sufficient for most of the time except for cloudy sky conditions, for which electric lighting will be needed only in the depth of the space close to the interior partition wall.

5.3.1.2. Analysis of expected results of illuminance*days/year obtained by applying different control strategies

The previous section (5.3.1.1.) analyzes the results of illuminance*days/year obtained by applying the conventional control strategy. In the conventional control strategy, the blinds' tilt angle is changed, based on the sun angle and the values of actual outdoor and required indoor illuminance. The values of the tilt angle are the same for all slats relative to the height of the window (see Figure 5-6). In the advanced control strategy, split control of the blinds' tilt angle is used. The split control means that not all slats have the same tilt angle relative to the height of the window (see Figure 5-7). Slats in the lower window part have a particular tilt angle to protect the space from direct sun and glare. Slats in the upper part of the window have a different angle than slats in the lower part to let daylight in the space, redirect it to the ceiling and by reflection from the ceiling to provide daylight in the depth of the space at the point close to the interior wall.

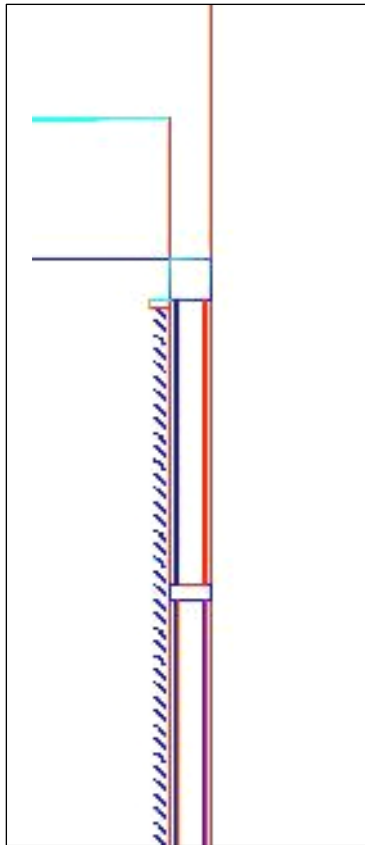


Figure 5-6 Conventional control strategy

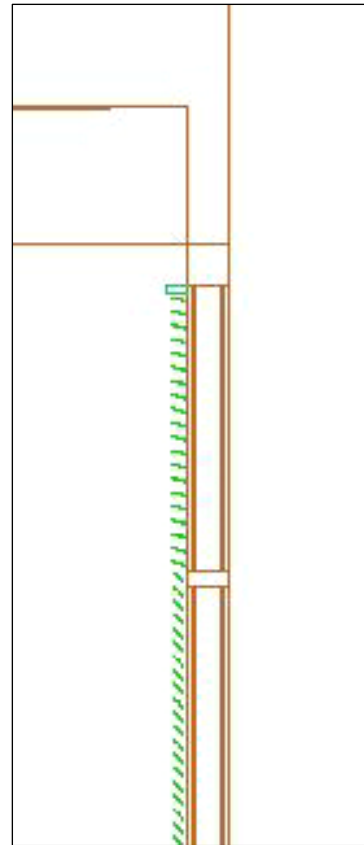


Figure 5-7 Advanced control strategy

Figure 5-8 shows six charts which compare the values of illuminance*days/year for the two control strategies: conventional and advanced. Charts 1, 3, and 5 show the performance of blinds in the case of the conventional control of the blinds' tilt angle, while charts 2, 4, and 6 present the blinds' performance in the case of the advanced control. These six charts consider south orientation of the blinds and the three different sky conditions. The values of illuminance*days/year in charts 1, 3, and 5 (conventional control) are obtained by the simulation in the case study, and the values in charts 2, 4, and 6 are expected/predicted values that can be obtained by an application of advanced control strategy.

An analysis of the six charts shows that values of illuminance*days/year for the new and the existing blinds will remain the same at the point close to the window. This is acceptable knowing that the values fall within the recommended range of values. At the point close to the interior wall, values of illuminance*days/year will increase for 30% for the advanced control strategy, compared to the conventional control. Also, the advanced strategy provides

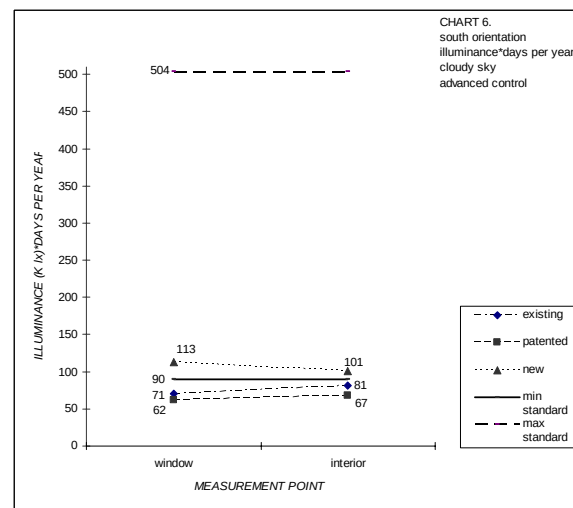
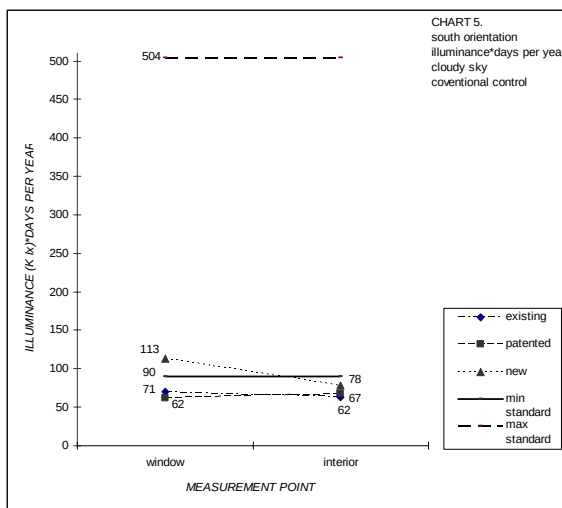
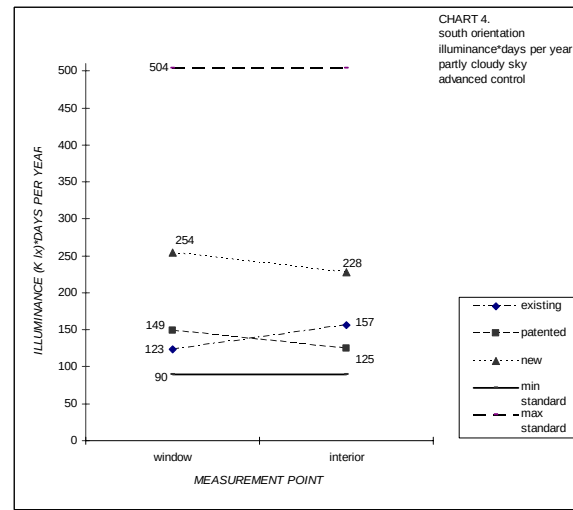
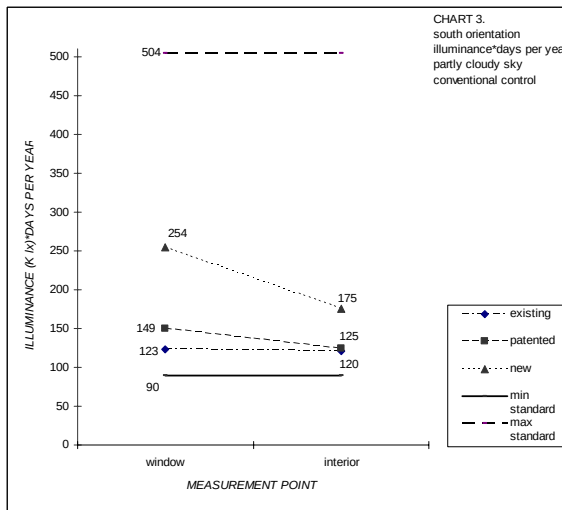
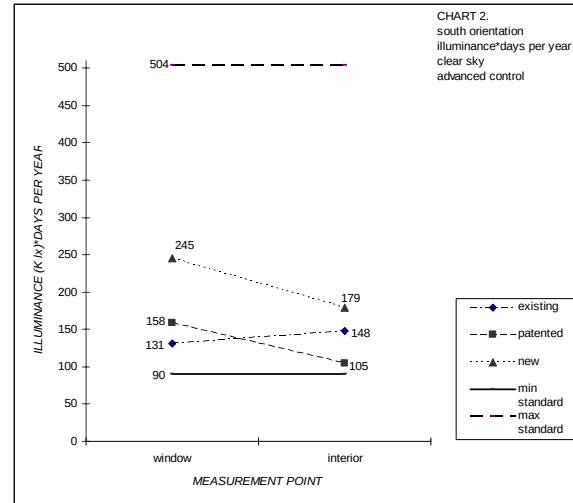
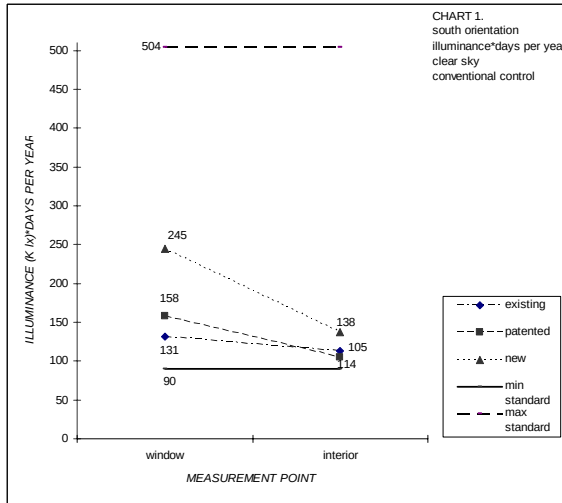


Figure 5-8 Relationship between illuminance - days levels and measurement points, for three types of blinds, and two different control strategies

a uniform daylight distribution in the space because the illuminance levels differ slightly between the two measurement points (close to the window and close to the interior wall). In the conventional strategy, the values of illuminance differ significantly between the two measurement points, especially for the new blinds. A comparison of the two control strategies is done only for the existing and new blinds because the patented blinds are always in the fixed position, which is defined by the design.

Charts 1 and 2 analyze the blinds' performance for clear sky conditions and at the two measurement points in the space. An analysis of chart 1 shows that the values of illuminance*days/year differ between the two measurement points (window and interior) for 54% for the new blinds and 20% for the existing blinds if the conventional control strategy is used. An analysis of chart 2 shows that the difference in illuminance *days/year values decreases as the result of the application of the advanced control strategy. The difference in values is 27% for the new blinds and 11% for the existing blinds. Also, the advanced control provides the higher level of illuminance*days/year in the depth of the space for the existing blinds.

Charts 3 and 4 show the values of illuminance*days/year for partly cloudy sky conditions. An analysis of chart 3 shows that the difference in the values at the two points in the space for the new blinds is 32% and only 3% for the existing blinds, as a result of a use of the conventional control strategy. In the case of the advanced control strategy (chart 4), the difference between the values at two points in the space is 10% for the new blinds. The difference of 22% between the two measurement points is obtained by using the existing blinds, and is the result of increasing the illuminance level in the depth of the space.

Charts 5 and 6 present the values of illuminance*days/year in the cloudy sky condition. An analysis of chart 5 shows that the difference of the values for the two measurement points is 30% for the new blinds and 6% for the existing blinds. The new blinds meet the minimum requirements of the standard for the illuminance*days/year only at the point close to the window. The existing blinds do not meet the requirements of the standard at all for cloudy sky conditions and the conventional control strategy. By applying the advanced control strategy (chart 6), the new blinds' performance improves by providing a higher level of illuminance*days/year in the depth of the space and above the minimum value required by the standard. The difference between the values between the two measurement points is 11%

for the new blinds and 12% for the existing blinds. The existing blinds still do not meet the requirements of the standard, but the light level in the depth of the space is increased 30%, compared to the values obtained by the conventional control strategy.

In conclusion, an application of the advanced/split blinds' control strategy improves the light levels in the depth of the space for both the new and existing blinds by 30%, compared to the conventional control strategy, given the limitations of this study. In the case of the existing blinds, the advanced control strategy provides higher levels in the depth of the space than at the point close to the window because the upper part of the window blinds redirects light into the ceiling and into the depth of the space.

5.3.1.3. Analysis of results of luminance*days/year

The charts in Figure 5-9 show the values of luminance-days/year for three types of shading devices, three sky conditions, two orientations, and two points in the space. An analysis of chart 1 shows that the new shading device application gives the highest value of luminance-days/year at the point close to the window for the south orientation, compared to the existing and patented shading devices for all sky conditions, given the limitations of this research. The patented shading device gives higher values of luminance-days/year than the existing shading devices for all sky conditions. All three types of shading devices meet the requirements of the standards for the minimum values of luminance-days/year in clear and partly cloudy sky conditions. The values of luminance-days/year obtained by new and patented systems in cloudy sky conditions are higher than the minimum values recommended by the standards. The new and patented shading devices' performance in cloudy sky conditions are higher than the minimum values recommended by the standards. The existing shading devices' performance do not meet the requirements of the standards for the minimum luminance-days/year in cloudy sky conditions. Sky conditions affect the values of luminance-days/year for all three types of shading devices. The highest values are obtained in the clear sky conditions, and the lowest values are achieved in cloudy sky conditions.

Chart 2 shows the performance of shading devices at the point close to the interior partition wall for the south-oriented facade. The new system provides the highest value of luminance-days/year for all sky conditions, compared to the patented and existing systems, given the limitations of this research. The patented shading device has a better performance than the existing system for all sky conditions. The new and patented shading devices' performance meets the requirements of the standards for the minimum luminance-days/year values for the clear and partly cloudy sky conditions, but the performance does not meet the minimum requirements for cloudy sky days. The existing shading device meets the minimum requirements of the standards for only partly cloudy sky days. Sky conditions affect the

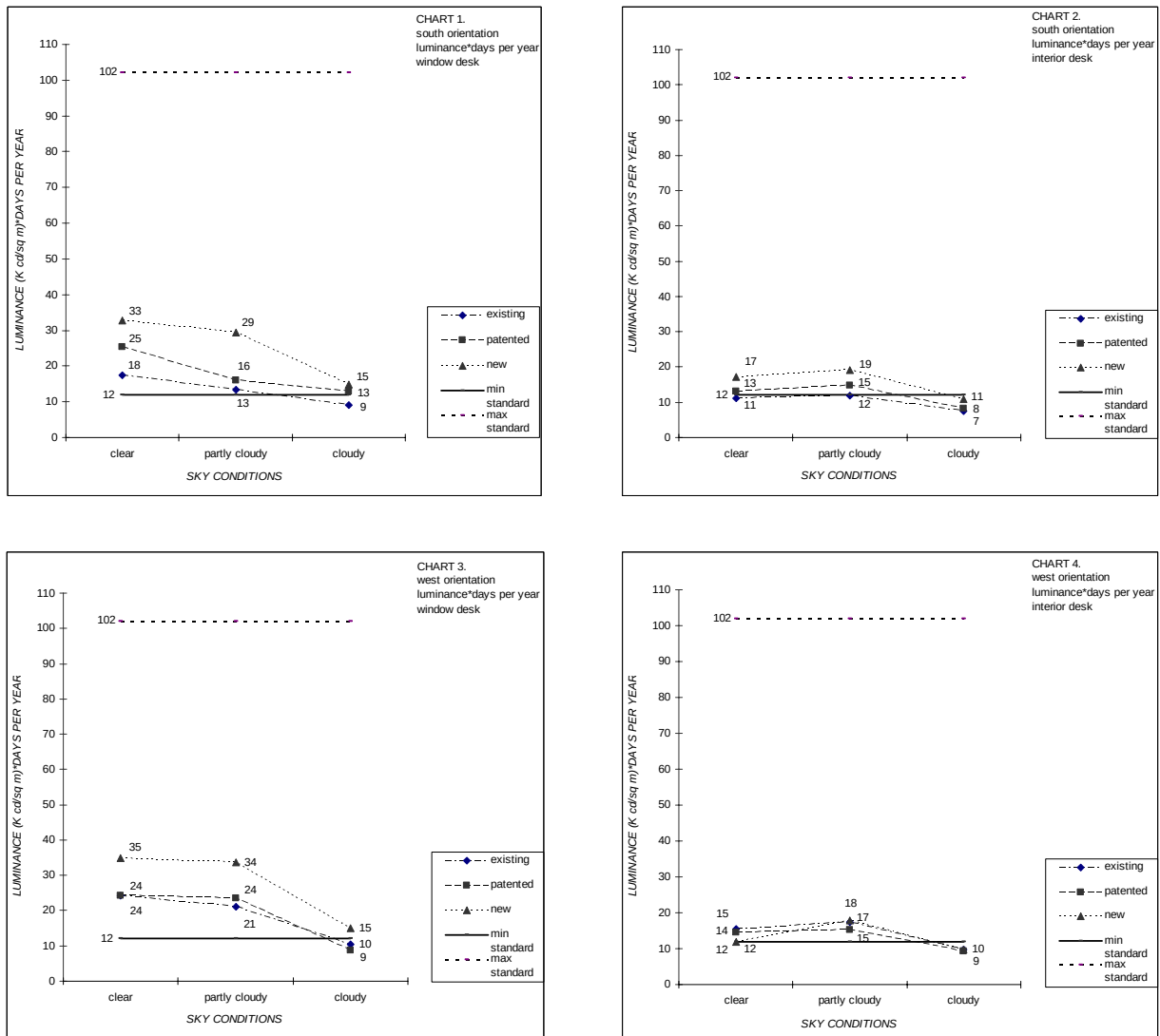


Figure 5-9 Relationship between luminance - days levels and sky conditions for three types of blinds

performance of shading devices: values of luminance-days/year are the highest in partly cloudy sky conditions for all three types of the shading devices, and the values in the clear sky conditions are higher than the values in the cloudy sky conditions.

Chart 3 illustrates the values of luminance-days/year for shading devices installed at the west-oriented facade with measurements taken at the point close to the window. The highest values are achieved by the new system in all sky conditions, given the limitations of this study. The patented system has the same performance in clear sky conditions, better performance in partly cloudy sky conditions, and worse performance in cloudy sky conditions compared to the existing system. All three types of shading devices achieve a better performance than the minimum performance required by the standards in clear and partly cloudy sky conditions. In cloudy sky conditions, only the new shading device meets the requirements of the standards for the minimum luminance-days/year. Cloudy sky conditions drop the values of luminance-days/year by 60% for all three types of shading devices, compared to their performance in clear and partly cloudy sky conditions. The new and patented shading devices' performance is almost the same in clear and partly cloudy sky conditions, while the performance of the existing system is slightly lower in partly cloudy sky conditions than in clear sky conditions.

Chart 4 represents the values of luminance-days/year achieved at the point close to the interior partition wall for the west-oriented blinds. The new system has a better performance in clear and partly cloudy sky conditions than the other two types of shading devices, given the limits of this research. The new and existing shading devices have the same performance in cloudy sky conditions and better performance than the patented shading device. The existing shading device gives higher values of luminance-days/year than the patented system in all sky conditions. All three types of shading devices meet the requirements of the standards for minimum luminance-days/year in clear and partly cloudy sky conditions, but none of them meets the requirements in cloudy sky conditions. The highest values of luminance-days/year are in partly cloudy sky conditions for all three types of shading devices, and the lowest values are gained in cloudy sky conditions.

A comparison between values of luminance-days/year for south- and west-oriented shading devices shows that:

- The new shading device performs better for the west orientation at the point close to the window in clear and partly cloudy sky conditions. The performance is the same for both orientations in cloudy sky conditions. At the point close to the interior wall, the values of luminance-days/year are higher for the south-oriented shading device for all sky conditions.
- The patented shading device performs slightly better in clear sky conditions, significantly better in partly cloudy sky conditions, and worse in cloudy sky conditions, at the point close to the window at the west orientation, compared to the south orientation. At the point close to the interior wall, the patented system performs slightly better at the west-oriented facade, compared to the south-oriented facade.
- The existing shading device gives higher values of luminance-days/year for the west orientation, compared to the south orientation at both measured points in the space in all sky conditions.

A comparison between the values of luminance-days/year for the south orientation shows higher values at the point close to the window than at the point close to the interior wall for all three types of shading devices and in all sky conditions. For the west orientation, the higher values are achieved at the points close to the window in clear and partly cloudy sky conditions for all types of shading devices. In cloudy sky conditions, the new system has a higher performance at the points close to the window, and the patented and existing shading devices show the same performance at both points.

Based on an analysis of the four charts in Figure 5-9, the new shading device application provides the highest values of luminance-days/year, compared to the other two systems for both orientations at both measured points and in all sky conditions, given the limitations of this study. The new shading device meets the requirements of the standards for the minimum luminance-days/year at the point close to the window for both orientations and all sky conditions. At the point close to the interior wall, the new system does not meet the minimum requirements of standards only in cloudy sky conditions.

In conclusion, given the limitations of this research, the new shading device overall gives the best performance among the three simulated shading device systems due to its geometry and material. The triangular cross section of the blind and the clear plastic with a silver reflective coating applied on one side of the triangle contribute to higher illuminance levels

in the space, compared to the other two types of shading devices. The optical properties of transparent prisms include a natural phenomenon of refraction of the light through the prism, as well as an internal reflection in the prism, that helps in redirecting the light into the ceiling and deep into the space.¹ An application of the silver coating on the hypotenuse of the blind additionally helps in these processes, especially due to the excellent reflective properties of the coating. The new shading device meets the minimum requirements of the standard for all sky conditions at the point close to the window, even for cloudy sky conditions, which is not the case with the other two shading device systems. The new shading device, as well as the two other systems, does not meet the minimum requirements of the standards for light level in the cloudy sky conditions at the point close to the interior wall. This is to be expected as a result of a low outdoor illuminance level in cloudy sky conditions and the large distance of the measurement point from the window wall.

The patented shading device performs better than the existing shading device for clear and partly cloudy sky days, and they have almost the same performance for cloudy sky days, given the limits of this research. The better performance of the patented shading device is a result of its geometry and transparency. The tooth-shaped cross section of the slat and transparent material properties are used for redirecting sunlight into the ceiling and deep into the space, depending on the sun angle. The principles of optical physics, such as refraction, total internal reflection, and external reflection, are applied in the design and functioning of this shading device system.² The patented shading device meets the minimum requirements at both points in the space for clear and partly cloudy sky conditions, but not for the cloudy sky conditions at all.

The existing shading device gives the lowest performance compared to the other two types of shading devices. It still meets, however, the requirements of the standards for the minimum light level in the space for clear and partly cloudy sky conditions, but not for cloudy sky conditions.

Sky conditions have a significant effect on the light level in the space, as well as on the daylight performance of the shading devices. The level of outdoor illuminance and, consequently, the level of indoor illuminance decrease by increasing the percentage of the

¹ Refer to Appendix A.1.1.2: Reflection/refraction through glass prism.

² Refer to Appendix A.1: Basic optical physics, and Section 2.4.2: Patented shading device systems.

sky cover. This is the reason that shading devices have a satisfactory performance for clear and partly cloudy sky days and very low performance for cloudy sky days.

The shading device shows a better performance at the point close to the interior walls for partly cloudy sky conditions than for clear sky conditions. This is due to the natural phenomena that sunlight is additionally reflected from the cloud edges, which contributes to increasing the illuminance from a partly cloudy sky conditions by 10% to 15%.

An analysis of the shading device performance for the south and west facade orientation shows that the new and existing shading device performs better for the west orientation. Averaging the results of the simulations has the result of higher levels of light for the west facade because of the direct sunlight at 4:00 p.m. for all the simulated dates. This is the case in clear and partly cloudy sky conditions for the point close to the window. The performance is almost the same for both orientations in cloudy sky conditions. This analysis shows that all three tested systems have an acceptable performance at both orientations.

As expected, all shading device systems have a better performance at the point close to the window than at the point close to the interior wall. Such a performance is predictable knowing that the illuminance level drops asymptotically by increasing the distance from the window wall.

Based on the conclusion that the new blinds show the best performance overall and for most of the time meet the requirements of the standards for both the illuminance and luminance levels in the space, the user of the DMF can make a decision to chose the new blinds to be applied at an office building in Roanoke, Virginia, given the economic consideration and limits of this research.

This decision is made based on the analytical approach in looking at the daylighting performance of the three systems of shading devices. A further step in making the decision is to use a conversion of the values, as explained in Section 4.2.5: Task 5 – Making the decision. This decision-making process is explained in the next section.

5.3.1.4. Analysis of results, obtained by converting the values of the data to the scale 0-1

Table 5-20 shows the values of illuminance*days, and Table 5-21 represents the values of luminance*days for three types of blinds, two facade orientations, two measurement points in

the interior space, and three sky conditions. These values are taken from the charts shown in Figures 5-5 and 5-9.¹

Table 5-20 Values of illuminance*days (in K lx*days)

	illuminance *days											
	south						west					
	window			interior			window			interior		
	clear	partly cloud	cloudy	clear	partly cloud	cloudy	clear	partly cloud	cloudy	clear	partly cloud	cloudy
existing	131	123	71	114	120	62	151	131	69	117	116	60
patented	158	149	62	105	125	67	159	154	63	123	122	71
new	245	254	113	138	175	78	227	243	103	153	157	78

Table 5-21 Values of luminance*days (in K (cd/sq m)*days)

	luminance*days											
	south						west					
	window			interior			window			interior		
	clear	partly cloud	cloudy	clear	partly cloud	cloudy	clear	partly cloud	cloudy	clear	partly cloud	cloudy
existing	18	13	9	11	12	7	24	21	10	15	17	10
patented	25	16	13	13	15	8	24	24	9	14	15	9
new	33	29	15	17	19	11	35	34	15	12	18	10

The values of illuminance*days and luminance*days are then converted to the corresponding values on the scale 0-1, which are given in Tables 5-22 and 5-23.

Table 5-22 Values of illuminance*days converted to values on the scale 0-1

	luminance*days											
	south						west					
	window			interior			window			interior		
	clear	partly cloud	cloudy	clear	partly cloud	cloudy	clear	partly cloud	cloudy	clear	partly cloud	cloudy
existing	0.125	0.125	0	0	0	0	0.125	0.125	0	0.125	0.125	0
patented	0.125	0.125	0.125	0.125	0.125	0	0.125	0.125	0	0.125	0.125	0
new	0.125	0.125	0.125	0.125	0.125	0	0.125	0.125	0.125	0	0.125	0

Table 5-23 Values of luminance*days converted to values on the scale 0-1

	illuminance *days											
	south						west					
	window			interior			window			interior		
	clear	partly cloud	cloudy	clear	partly cloud	cloudy	clear	partly cloud	cloudy	clear	partly cloud	cloudy
existing	0.125	0.125	0	0.125	0.125	0	0.25	0.125	0	0.125	0.125	0
patented	0.25	0.25	0	0.125	0.125	0	0.25	0.25	0	0.125	0.125	0
new	0.625	0.75	0.125	0.125	0.375	0	0.625	0.625	0.125	0.25	0.25	0

¹ For more detailed results, refer also to Appendix B.2: Charts and tables – for the user of the DMF.

The values from Tables 5-22 and 5-23 are added up for each shading device and for each performance parameter, which is shown in Table 5-24. The values from Table 5-24 are divided by the number of cells for each shading device type and performance parameter, which, in this case, is 12. This is done to get values on the scale 0-1 again that are represented in Table 5-25.

Table 5-24 *Sum of the converted values*

	illuminance*days	luminance*days
existing	1.125	0.75
patented	1.5	1.125
new	3.875	1.125

Table 5-25 *Sum of the converted values*

	illuminance*days divided by 12	luminance*days divided by 12
existing	0.094	0.063
patented	0.125	0.094
new	0.323	0.094

In the next step of the decision-making process, the weighting factors are considered and new values of the performance parameters are obtained by multiplying the values from Table 5-25 with corresponding weighting factors, which, in this case, is 0.65 for illuminance*days and 0.35 for luminance*days (see Table 5-26). Finally, the values in Table 5-26 are added up to get one number that represents the performance of the specific type of the shading device. The value for the new shading device system performance is the highest showing that this system should be selected, given the research limitations.

Table 5-26 *Weighting factors*

	(illuminance*days divided by 12)*0.65	(luminance*days divided by 12)*0.35	SUM
existing	0.061	0.022	0.083
patented	0.081	0.033	0.114
new	0.210	0.033	0.243

5.3.2. ANALYSIS OF THE CHARTS USED IN THIS DISSERTATION

The daylight performance of the three types of shading devices is evaluated by analyzing the set of charts provided in Appendix B.3. The following criteria are considered in this analysis:

1. Which shading device gives the highest and which one the lowest illuminance and luminance levels in the space?
2. Do performances of the shading device meet the requirements of the standards?
3. How does the major variable affect the daylighting performance of each shading device system?
4. How do minor variables affect the daylighting performance of the shading devices?

An example of this kind of analysis is given by investigating and exploring the performance of the three types of shading devices (existing, patented, and new) for the south-oriented facade and actual illuminance level at the top of the desk close to the window. Set 1 consists of nine sheets presented in Figures 5-10 through 5-18 and the sheets are described in this section.¹ In each chart, a major variable is given on the horizontal axis and the performance parameter (illuminance or luminance) values are given on the vertical axis. The charts show a comparison of the three types of shading devices, as well as the range of the values recommended by the standard (minimum and maximum). The shading devices are analyzed for the position relative to the window for which they give the best performance:

- The existing system: for the interior position
- The patented and new system: for the between-glass position

Considering the blinds' tilt angle, data in charts are selected based on the following criteria:

- For the existing and new system:
 - 45° angle for clear and partly cloudy sky conditions
 - 0° angle for cloudy sky conditions
- For the patented system: 0° angle for all sky conditions

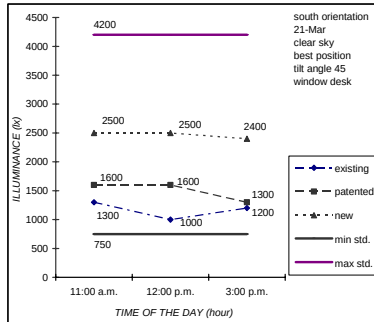
¹ The rest of the sets (2-8) are given in Appendix B.3

ILLUMINANCE- effect of the time -for different dates-for different sky conditions

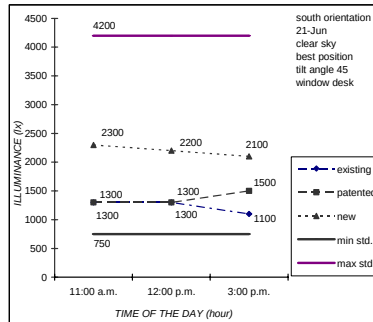
	existing	patented	new
BEST POSITION	inside	between	between

SOUTH SHEET 1
ILLUMINANCE SET 1
WINDOW

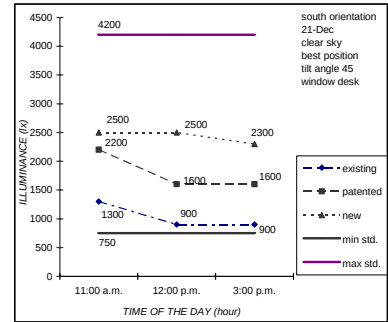
illuminance		11:00 a.m.	12:00 p.m.	3:00 p.m.
south orientation	existing	1300	1000	1200
21-Mar	patented	1600	1600	1300
clear sky	new	2500	2500	2400
best position	min std.	750	750	750
tilt angle 45	max std.	4200	4200	4200
window desk				



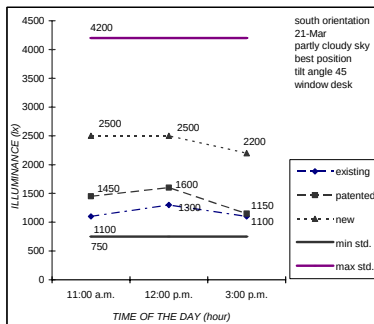
illuminance		11:00 a.m.	12:00 p.m.	3:00 p.m.
south orientation	existing	1300	1300	1100
21-Jun	patented	1300	1300	1500
clear sky	new	2300	2200	2100
best position	min std.	750	750	750
tilt angle 45	max std.	4200	4200	4200
window desk				



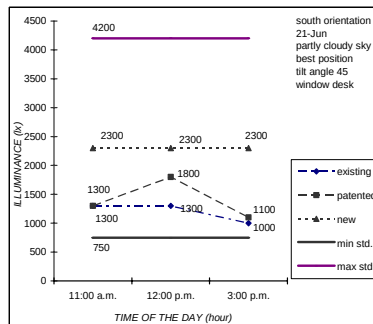
illuminance		11:00 a.m.	12:00 p.m.	3:00 p.m.
south orientation	existing	1300	900	900
21-Dec	patented	2200	1600	1600
clear sky	new	2500	2500	2300
best position	min std.	750	750	750
tilt angle 45	max std.	4200	4200	4200
window desk				



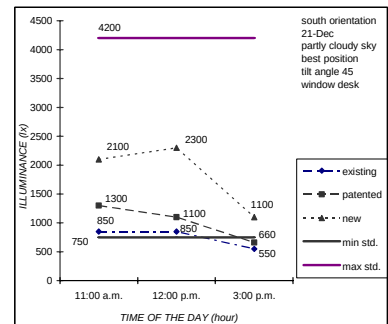
illuminance		11:00 a.m.	12:00 p.m.	3:00 p.m.
south orientation	existing	1100	1300	1100
21-Mar	patented	1450	1600	1150
partly cloudy sky	new	2500	2500	2200
best position	min std.	750	750	750
tilt angle 45	max std.	4200	4200	4200
window desk				



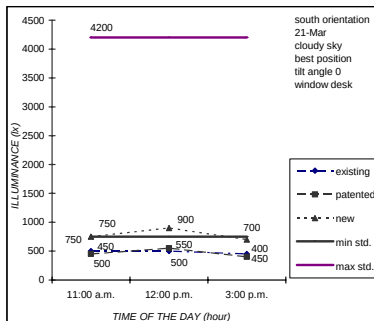
illuminance		11:00 a.m.	12:00 p.m.	3:00 p.m.
south orientation	existing	1300	1300	1000
21-Jun	patented	1300	1800	1100
partly cloudy sky	new	2300	2300	2300
best position	min std.	750	750	750
tilt angle 45	max std.	4200	4200	4200
window desk				



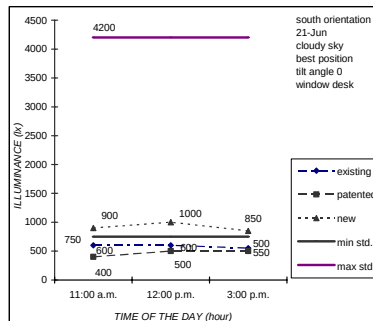
illuminance		11:00 a.m.	12:00 p.m.	3:00 p.m.
south orientation	existing	850	850	550
21-Dec	patented	1300	1100	660
partly cloudy sky	new	2100	2300	1100
best position	min std.	750	750	750
tilt angle 45	max std.	4200	4200	4200
window desk				



illuminance		11:00 a.m.	12:00 p.m.	3:00 p.m.
south orientation	existing	500	500	450
21-Mar	patented	450	550	400
cloudy sky	new	750	900	700
best position	min std.	750	750	750
tilt angle 0	max std.	4200	4200	4200
window desk				



illuminance		11:00 a.m.	12:00 p.m.	3:00 p.m.
south orientation	existing	600	600	550
21-Jun	patented	400	500	500
cloudy sky	new	900	1000	850
best position	min std.	750	750	750
tilt angle 0	max std.	4200	4200	4200
window desk				



illuminance		11:00 a.m.	12:00 p.m.	3:00 p.m.
south orientation	existing	500	450	10
21-Dec	patented	300	400	10
cloudy sky	new	550	600	500
best position	min std.	750	750	750
tilt angle 0	max std.	4200	4200	4200
window desk				

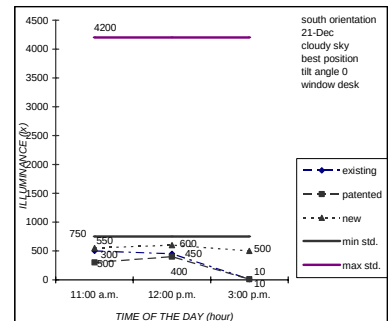


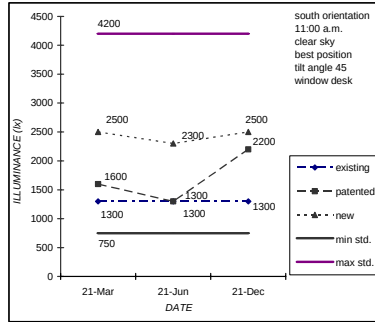
Figure 5-10 An example of sheet 1 – effect of time on illuminance at the point close to the window for the south orientation

ILLUMINANCE- effect of the date-for different times-for different sky conditions

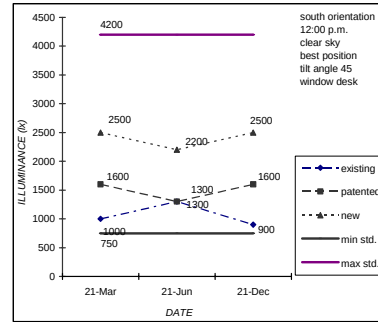
	existing	patented	new
BEST POSITION	inside	between	between

SOUTH SHEET 2
ILLUMINANCE SET 1
WINDOW

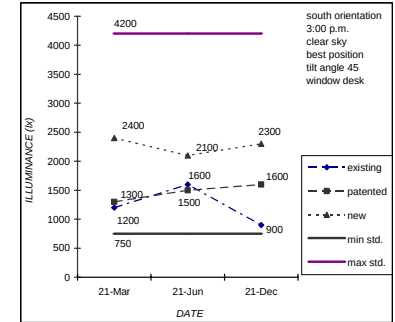
illumiance		21-Mar	21-Jun	21-Dec
illumiance	existing	1300	1300	1300
11:00 a.m.	patented	1600	1300	2200
clear sky	new	2500	2300	2500
best position	min std.	750	750	750
tilt angle 45	max std.	4200	4200	4200
window desk				



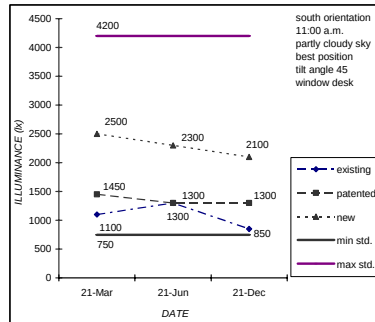
illumiance		21-Mar	21-Jun	21-Dec
illumiance	existing	1000	1300	900
12:00 p.m.	patented	1600	1300	1600
clear sky	new	2500	2200	2500
best position	min std.	750	750	750
tilt angle 45	max std.	4200	4200	4200
window desk				



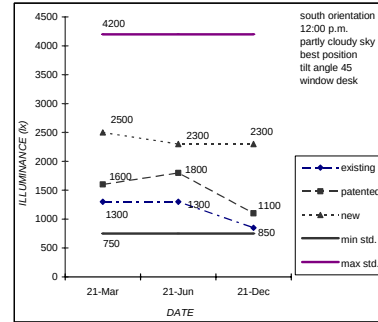
illumiance		21-Mar	21-Jun	21-Dec
illumiance	existing	1200	1600	900
3:00 p.m.	patented	1300	1500	1600
clear sky	new	2400	2100	2300
best position	min std.	750	750	750
tilt angle 45	max std.	4200	4200	4200
window desk				



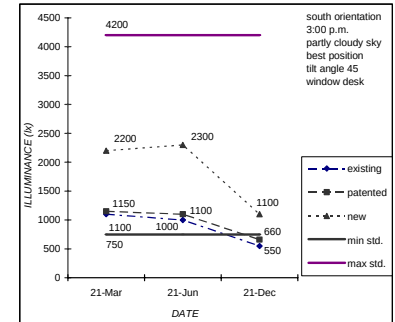
illumiance		21-Mar	21-Jun	21-Dec
illumiance	existing	1100	1300	850
11:00 a.m.	patented	1450	1300	1300
partly cloudy sky	new	2500	2300	2100
best position	min std.	750	750	750
tilt angle 45	max std.	4200	4200	4200
window desk				



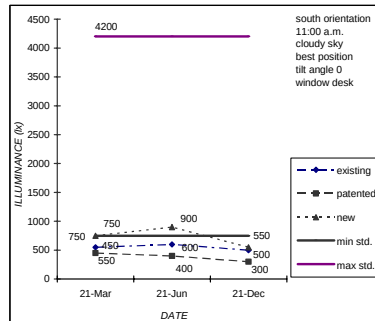
illumiance		21-Mar	21-Jun	21-Dec
illumiance	existing	1300	1300	850
12:00 p.m.	patented	1600	1800	1100
partly cloudy sky	new	2500	2300	2300
best position	min std.	750	750	750
tilt angle 45	max std.	4200	4200	4200
window desk				



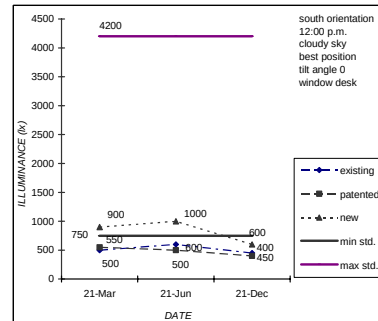
illumiance		21-Mar	21-Jun	21-Dec
illumiance	existing	1100	1000	550
3:00 p.m.	patented	1150	1100	660
partly cloudy sky	new	2200	2300	1100
best position	min std.	750	750	750
tilt angle 45	max std.	4200	4200	4200
window desk				



illumiance		21-Mar	21-Jun	21-Dec
illumiance	existing	550	600	500
11:00 a.m.	patented	450	400	300
cloudy sky	new	750	900	550
best position	min std.	750	750	750
tilt angle 0	max std.	4200	4200	4200
window desk				



illumiance		21-Mar	21-Jun	21-Dec
illumiance	existing	500	600	450
12:00 p.m.	patented	550	500	400
cloudy sky	new	900	1000	600
best position	min std.	750	750	750
tilt angle 0	max std.	4200	4200	4200
window desk				



illumiance		21-Mar	21-Jun	21-Dec
illumiance	existing	450	550	100
3:00 p.m.	patented	400	500	100
cloudy sky	new	700	850	500
best position	min std.	750	750	750
tilt angle 0	max std.	4200	4200	4200
window desk				

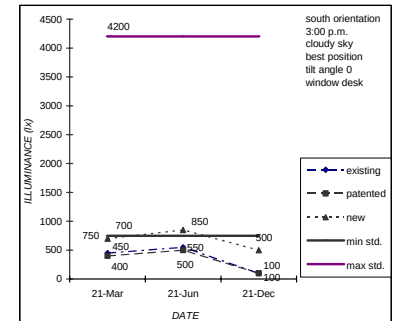


Figure 5-11 An example of sheet 2 – effect of date on illuminance at the point close to the window for the south orientation

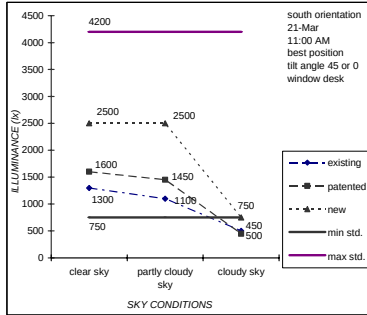
ILLUMINANCE - effect of sky conditions for different times for different dates

existing blinds - tilt angle 45 for clear sky and partly cloudy sky and 0 for cloudy sky
 patented blinds - tilt angle 0 always
 new blinds - tilt angle 45 for clear sky and partly cloudy sky and 0 for cloudy sky

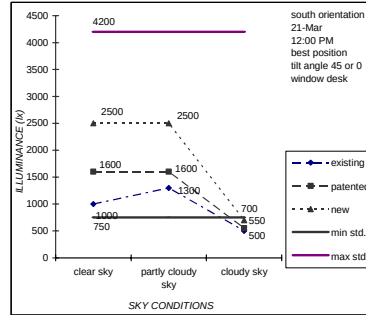
	existing	patented	new
BEST POSITION	inside	between	between

SOUTH SHEET 3
 ILLUMINANCE SET 1
 WINDOW

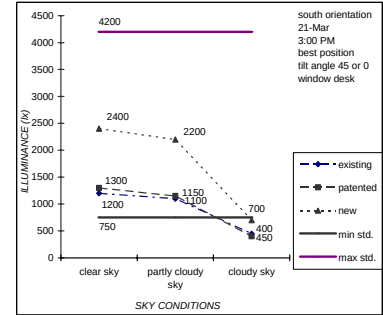
	clear sky	partly cloud	cloudy sky
illuminate south orientation			
21-Mar			
11:00 AM			
best position			
tilt angle 45 or 0			
window desk			
existing	1300	1100	500
patented	1600	1450	450
new	2500	2500	750
min std.	750	750	750
max std.	4200	4200	4200



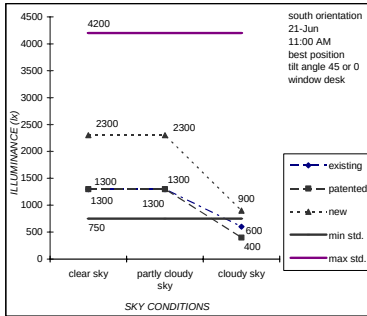
	clear sky	partly cloud	cloudy sky
illuminate south orientation			
21-Mar			
12:00 PM			
best position			
tilt angle 45 or 0			
window desk			
existing	1000	1300	500
patented	1600	1600	550
new	2500	2500	700
min std.	750	750	750
max std.	4200	4200	4200



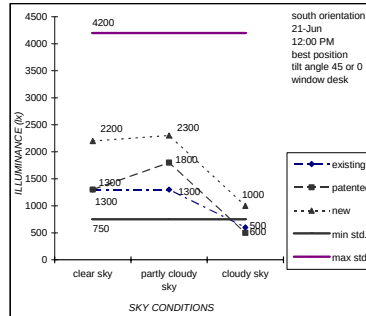
	clear sky	partly cloud	cloudy sky
illuminate south orientation			
21-Mar			
3:00 PM			
best position			
tilt angle 45 or 0			
window desk			
existing	1200	1100	450
patented	1300	1150	400
new	2400	2200	700
min std.	750	750	750
max std.	4200	4200	4200



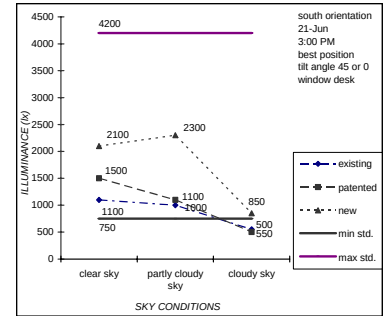
	clear sky	partly cloud	cloudy sky
illuminate south orientation			
21-Jun			
11:00 AM			
best position			
tilt angle 45 or 0			
window desk			
existing	1300	1300	600
patented	1300	1300	400
new	2300	2300	900
min std.	750	750	750
max std.	4200	4200	4200



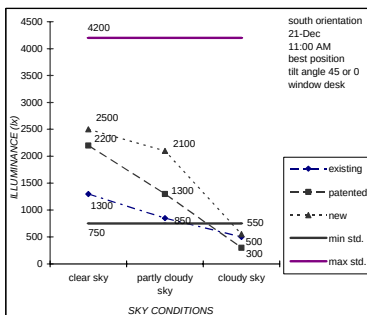
	clear sky	partly cloud	cloudy sky
illuminate south orientation			
21-Jun			
12:00 PM			
best position			
tilt angle 45 or 0			
window desk			
existing	1300	1300	600
patented	1300	1800	500
new	2200	2300	1000
min std.	750	750	750
max std.	4200	4200	4200



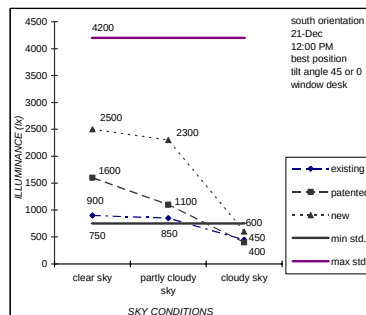
	clear sky	partly cloud	cloudy sky
illuminate south orientation			
21-Jun			
3:00 PM			
best position			
tilt angle 45 or 0			
window desk			
existing	1100	1000	550
patented	1500	1100	500
new	2100	2300	850
min std.	750	750	750
max std.	4200	4200	4200



	clear sky	partly cloud	cloudy sky
illuminate south orientation			
21-Dec			
11:00 AM			
best position			
tilt angle 45 or 0			
window desk			
existing	1300	850	500
patented	2200	1300	300
new	2500	2100	550
min std.	750	750	750
max std.	4200	4200	4200



	clear sky	partly cloud	cloudy sky
illuminate south orientation			
21-Dec			
12:00 PM			
best position			
tilt angle 45 or 0			
window desk			
existing	900	850	450
patented	1600	1100	400
new	2500	2300	600
min std.	750	750	750
max std.	4200	4200	4200



	clear sky	partly cloud	cloudy sky
illuminate south orientation			
21-Dec			
3:00 PM			
best position			
tilt angle 45 or 0			
window desk			
existing	900	550	100
patented	1600	600	100
new	2300	1100	500
min std.	750	750	750
max std.	4200	4200	4200

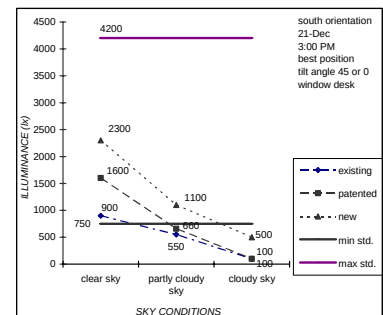


Figure 5-12 An example of sheet 3 – effect of sky conditions on illuminance at the point close to the window for the south orientation

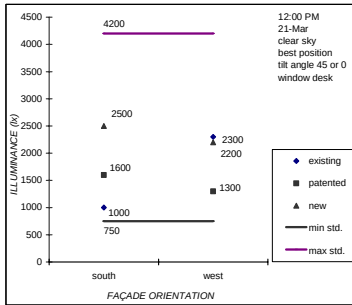
ILLUMINANCE - effect of façade orientation - for different dates - for different times

existing blinds - tilt angle 45 for clear sky and partly cloudy sky and 0 for cloudy sky
 patented blinds - tilt angle 0 always
 new blinds - tilt angle 45 for clear sky and partly cloudy sky and 0 for cloudy sky

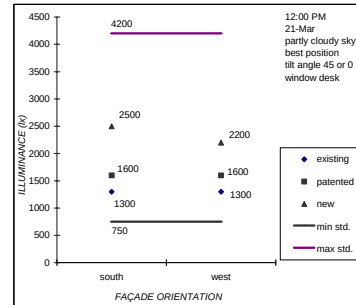
SOUTH SHEET 4
 ILLUMINANCE SET 1
 WINDOW

	existing	patented	new
BEST POSITION	inside	between	between

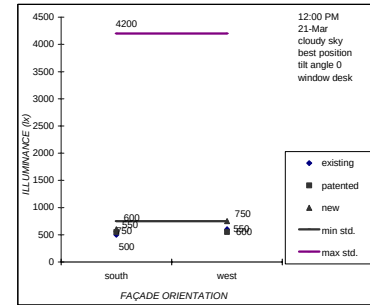
	illumination	illumination	illumination
	12:00 PM	12:00 PM	12:00 PM
	21-Mar	21-Mar	21-Mar
	clear sky	partly cloudy sky	cloudy sky
	best position	best position	best position
	tilt angle 45 or 0	tilt angle 45 or 0	tilt angle 0
	window desk	window desk	window desk
	min std.	min std.	min std.
	max std.	max std.	max std.
	4200	4200	4200
	2300	2300	2300
	2200	2200	2200
	1600	1600	1600
	1300	1300	1300
	750	750	750
	4200	4200	4200



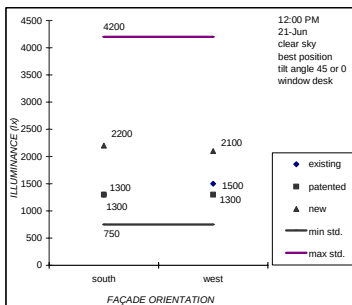
	illumination	illumination	illumination
	12:00 PM	12:00 PM	12:00 PM
	21-Mar	21-Mar	21-Mar
	partly cloudy sky	partly cloudy sky	partly cloudy sky
	best position	best position	best position
	tilt angle 45 or 0	tilt angle 45 or 0	tilt angle 45 or 0
	window desk	window desk	window desk
	min std.	min std.	min std.
	max std.	max std.	max std.
	4200	4200	4200
	2200	2200	2200
	1600	1600	1600
	1300	1300	1300
	750	750	750
	4200	4200	4200



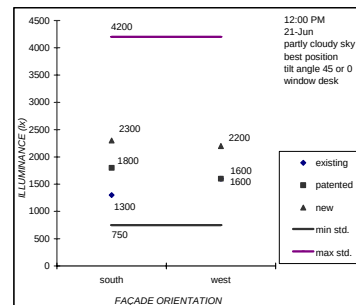
	illumination	illumination	illumination
	12:00 PM	12:00 PM	12:00 PM
	21-Mar	21-Mar	21-Mar
	cloudy sky	cloudy sky	cloudy sky
	best position	best position	best position
	tilt angle 0	tilt angle 0	tilt angle 0
	window desk	window desk	window desk
	min std.	min std.	min std.
	max std.	max std.	max std.
	4200	4200	4200
	600	600	600
	550	550	550
	600	600	600
	750	750	750
	4200	4200	4200



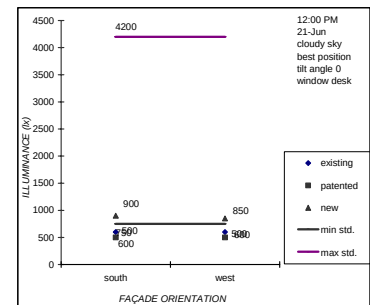
	illumination	illumination	illumination
	12:00 PM	12:00 PM	12:00 PM
	21-Jun	21-Jun	21-Jun
	clear sky	clear sky	clear sky
	best position	best position	best position
	tilt angle 45 or 0	tilt angle 45 or 0	tilt angle 45 or 0
	window desk	window desk	window desk
	min std.	min std.	min std.
	max std.	max std.	max std.
	4200	4200	4200
	2100	2100	2100
	1500	1500	1500
	1300	1300	1300
	750	750	750
	4200	4200	4200



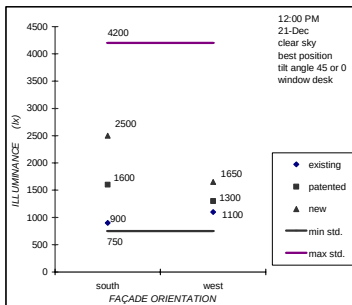
	illumination	illumination	illumination
	12:00 PM	12:00 PM	12:00 PM
	21-Jun	21-Jun	21-Jun
	partly cloudy sky	partly cloudy sky	partly cloudy sky
	best position	best position	best position
	tilt angle 45 or 0	tilt angle 45 or 0	tilt angle 45 or 0
	window desk	window desk	window desk
	min std.	min std.	min std.
	max std.	max std.	max std.
	4200	4200	4200
	1600	1600	1600
	1300	1300	1300
	750	750	750
	4200	4200	4200



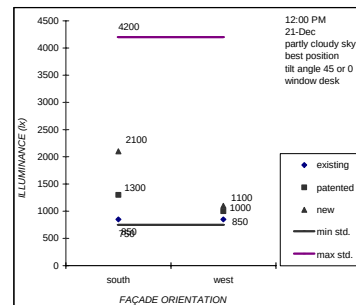
	illumination	illumination	illumination
	12:00 PM	12:00 PM	12:00 PM
	21-Jun	21-Jun	21-Jun
	cloudy sky	cloudy sky	cloudy sky
	best position	best position	best position
	tilt angle 0	tilt angle 0	tilt angle 0
	window desk	window desk	window desk
	min std.	min std.	min std.
	max std.	max std.	max std.
	4200	4200	4200
	850	850	850
	500	500	500
	600	600	600
	4200	4200	4200



	illumination	illumination	illumination
	12:00 PM	12:00 PM	12:00 PM
	21-Dec	21-Dec	21-Dec
	clear sky	clear sky	clear sky
	best position	best position	best position
	tilt angle 45 or 0	tilt angle 45 or 0	tilt angle 45 or 0
	window desk	window desk	window desk
	min std.	min std.	min std.
	max std.	max std.	max std.
	4200	4200	4200
	1650	1650	1650
	1300	1300	1300
	1100	1100	1100
	750	750	750
	4200	4200	4200



	illumination	illumination	illumination
	12:00 PM	12:00 PM	12:00 PM
	21-Dec	21-Dec	21-Dec
	partly cloudy sky	partly cloudy sky	partly cloudy sky
	best position	best position	best position
	tilt angle 45 or 0	tilt angle 45 or 0	tilt angle 45 or 0
	window desk	window desk	window desk
	min std.	min std.	min std.
	max std.	max std.	max std.
	4200	4200	4200
	1100	1100	1100
	850	850	850
	750	750	750
	4200	4200	4200



	illumination	illumination	illumination
	12:00 PM	12:00 PM	12:00 PM
	21-Dec	21-Dec	21-Dec
	cloudy sky	cloudy sky	cloudy sky
	best position	best position	best position
	tilt angle 0	tilt angle 0	tilt angle 0
	window desk	window desk	window desk
	min std.	min std.	min std.
	max std.	max std.	max std.
	4200	4200	4200
	600	600	600
	350	350	350
	500	500	500
	4200	4200	4200

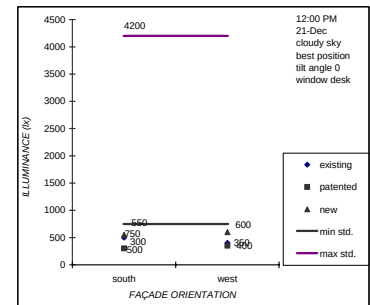


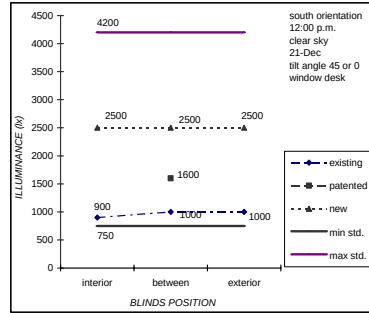
Figure 5-13 An example of sheet 4 – effect of façade orientation on illuminance at the point close to the window for the south orientation

ILLUMINANCE- effect of the blinds position-for different dates -for different sky conditions

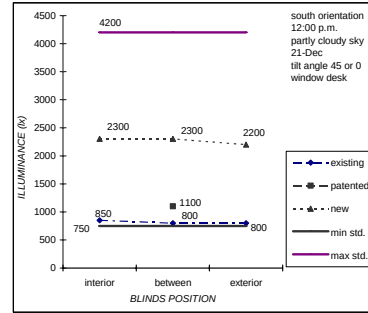
SOUTH SHEET 5
ILLUMINANCE SET 1
WINDOW

existing blinds - tilt angle 45 for clear sky and partly cloudy sky and 0 for cloudy sky
patented blinds - tilt angle 0 always
new blinds - tilt angle 45 for clear sky and partly cloudy sky and 0 for cloudy sky

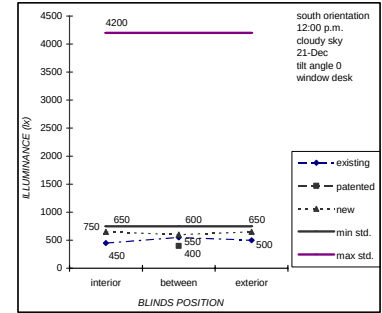
	interior	between	exterior
illuminance			
south orientation			
12:00 p.m.			
clear sky			
21-Dec			
tilt angle 45 or 0			
window desk			
existing	900	1000	1000
patented		1600	
new	2500	2500	2500
min std.	750	750	750
max std.	4200	4200	4200



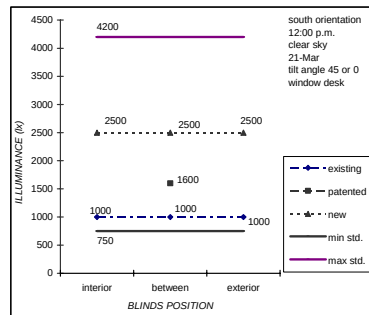
	interior	between	exterior
illuminance			
south orientation			
12:00 p.m.			
partly cloudy sky			
21-Dec			
tilt angle 45 or 0			
window desk			
existing	850	800	800
patented		1100	
new	2300	2300	2200
min std.	750	750	750
max std.	4200	4200	4200



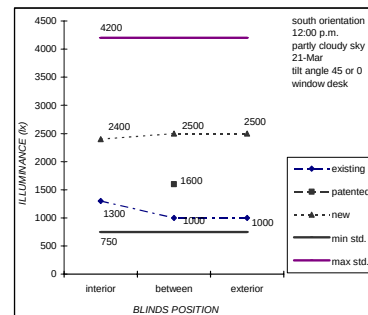
	interior	between	exterior
illuminance			
south orientation			
12:00 p.m.			
cloudy sky			
21-Dec			
tilt angle 0			
window desk			
existing	450	550	500
patented		400	
new	650	600	650
min std.	750	750	750
max std.	4200	4200	4200



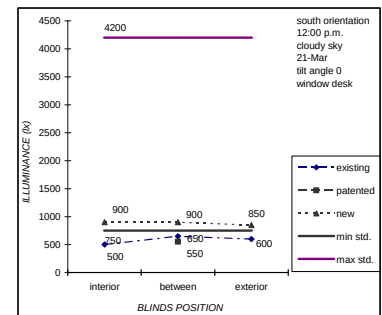
	interior	between	exterior
illuminance			
south orientation			
12:00 p.m.			
clear sky			
21-Mar			
tilt angle 45 or 0			
window desk			
existing	1000	1000	1000
patented		1600	
new	2500	2500	2500
min std.	750	750	750
max std.	4200	4200	4200



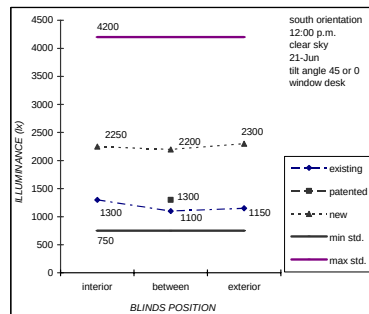
	interior	between	exterior
illuminance			
south orientation			
12:00 p.m.			
partly cloudy sky			
21-Mar			
tilt angle 45 or 0			
window desk			
existing	1300	1000	1000
patented		1600	
new	2400	2500	2500
min std.	750	750	750
max std.	4200	4200	4200



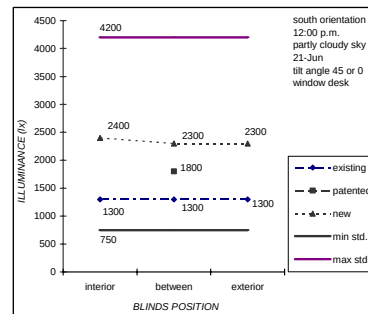
	interior	between	exterior
illuminance			
south orientation			
12:00 p.m.			
cloudy sky			
21-Mar			
tilt angle 0			
window desk			
existing	500	650	600
patented		550	
new	900	900	850
min std.	750	750	750
max std.	4200	4200	4200



	interior	between	exterior
illuminance			
south orientation			
12:00 p.m.			
clear sky			
21-Jun			
tilt angle 45 or 0			
window desk			
existing	1300	1100	1150
patented		1300	
new	2250	2200	2300
min std.	750	750	750
max std.	4200	4200	4200



	interior	between	exterior
illuminance			
south orientation			
12:00 p.m.			
partly cloudy sky			
21-Jun			
tilt angle 45 or 0			
window desk			
existing	1300	1300	1300
patented		1800	
new	2400	2300	2300
min std.	750	750	750
max std.	4200	4200	4200



	interior	between	exterior
illuminance			
south orientation			
12:00 p.m.			
cloudy sky			
21-Jun			
tilt angle 45			
window desk			
existing	600	650	700
patented		500	
new	1000	1000	900
min std.	750	750	750
max std.	4200	4200	4200

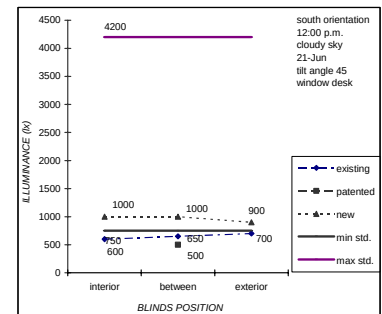


Figure 5-14 An example of sheet 5 – effect of blinds' position on illuminance at the point close to the window for the south orientation

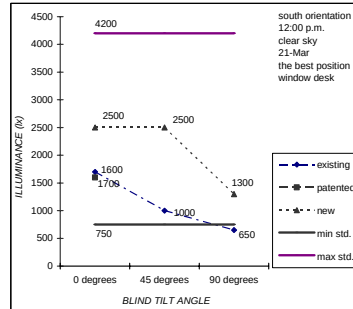
ILLUMINANCE- effect of the blind tilt angle -for different dates-for different sky conditions

SOUTH
ILLUMINANCE
WINDOW

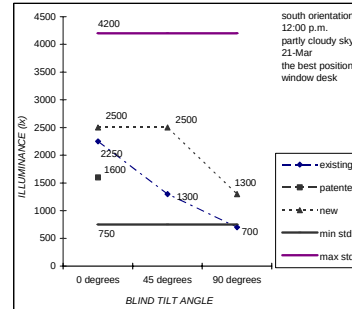
SHEET 6
SET 1

	existing	patented	new
BEST POSITION	inside	between	between

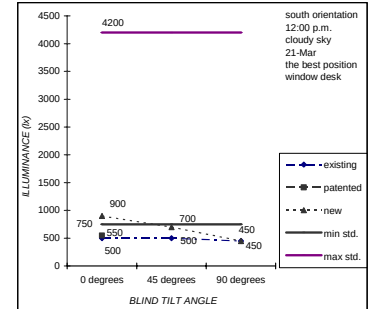
illumination	0 degrees	45 degree	90 degrees
south orientation	existing 1700	1000	650
12:00 p.m.	patented 1600		
clear sky	new 2500	2500	1300
21-Mar	min std. 750	750	750
the best position	max std. 4200	4200	4200
window desk			



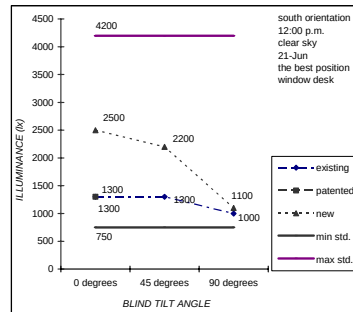
illumination	0 degrees	45 degree	90 degrees
south orientation	existing 2250	1300	700
12:00 p.m.	patented 1600		
partly cloudy sky	new 2500	2500	1300
21-Mar	min std. 750	750	750
the best position	max std. 4200	4200	4200
window desk			



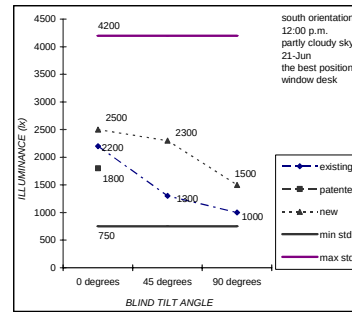
illumination	0 degrees	45 degree	90 degrees
south orientation	existing 500	500	450
12:00 p.m.	patented 550		
cloudy sky	new 900	700	450
21-Mar	min std. 750	750	750
the best position	max std. 4200	4200	4200
window desk			



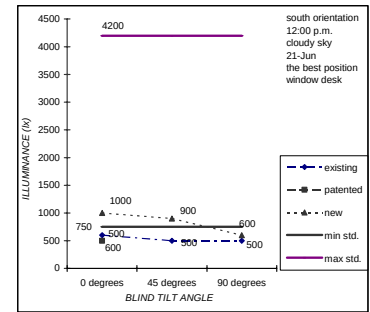
illumination	0 degrees	45 degree	90 degrees
south orientation	existing 1300	1300	1000
12:00 p.m.	patented 1300		
clear sky	new 2500	2200	1100
21-Jun	min std. 750	750	750
the best position	max std. 4200	4200	4200
window desk			



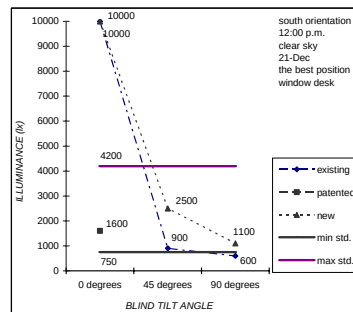
illumination	0 degrees	45 degree	90 degrees
south orientation	existing 2200	1300	1000
12:00 p.m.	patented 1800		
partly cloudy sky	new 2500	2300	1500
21-Jun	min std. 750	750	750
the best position	max std. 4200	4200	4200
window desk			



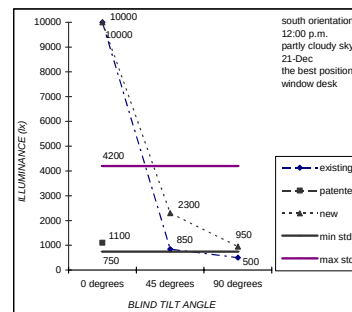
illumination	0 degrees	45 degree	90 degrees
south orientation	existing 600	500	500
12:00 p.m.	patented 500		
cloudy sky	new 1000	900	600
21-Jun	min std. 750	750	750
the best position	max std. 4200	4200	4200
window desk			



illumination	0 degrees	45 degree	90 degrees
south orientation	existing 10000	900	600
12:00 p.m.	patented 1600		
clear sky	new 10000	2500	1100
21-Dec	min std. 750	750	750
the best position	max std. 4200	4200	4200
window desk			



illumination	0 degrees	45 degree	90 degrees
south orientation	existing 10000	850	500
12:00 p.m.	patented 1100		
partly cloudy sky	new 10000	2300	950
21-Dec	min std. 750	750	750
the best position	max std. 4200	4200	4200
window desk			



illumination	0 degrees	45 degree	90 degrees
south orientation	existing 450	350	350
12:00 p.m.	patented 400		
cloudy sky	new 600	580	280
21-Dec	min std. 750	750	750
the best position	max std. 4200	4200	4200
window desk			

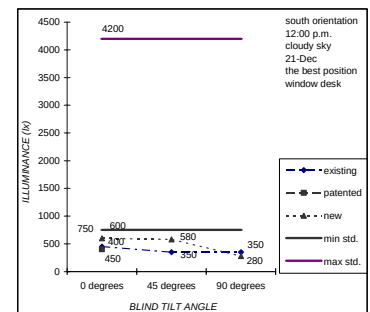
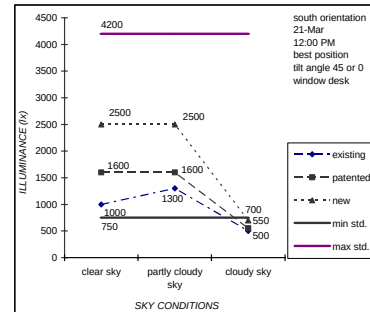


Figure 5-15 An example of sheet 6 – effect of blinds’ tilt angle on illuminance at the point close to the window for the south orientation

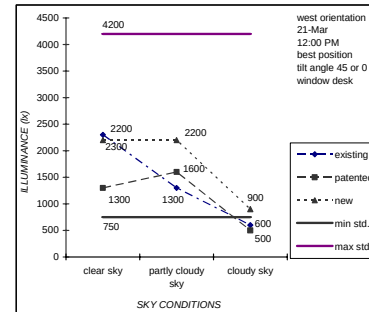
existing blinds - tilt angle 45 for clear sky and partly cloudy sky and 0 for cloudy sky
 patented blinds - tilt angle 0 always
 new blinds - tilt angle 45 for clear sky and partly cloudy sky and 0 for cloudy sky

	plastic	patented	new
BEST POSITION	inside	between	between

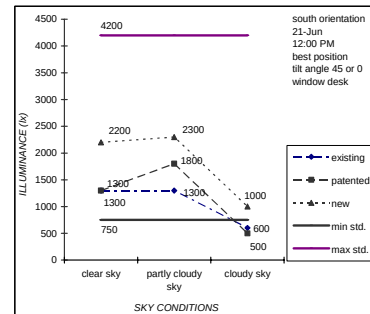
illuminate	clear sky	partly cloud	cloudy sky
south orientation			
21-Mar			
12:00 PM			
best position			
tilt angle 45 or 0			
window desk			
existing	1000	1300	500
patented	1600	1600	550
new	2500	2500	700
min std.	750	750	750
max std.	4200	4200	4200



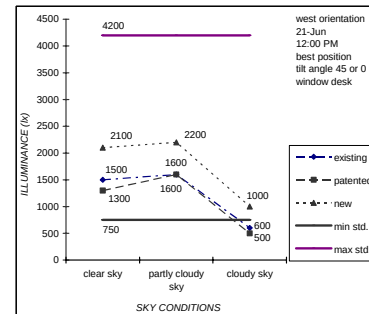
illuminate	clear sky	partly cloud	cloudy sky
west orientation			
21-Mar			
12:00 PM			
best position			
tilt angle 45 or 0			
window desk			
existing	2300	1300	600
patented	1300	1600	500
new	2200	2200	900
min std.	750	750	750
max std.	4200	4200	4200



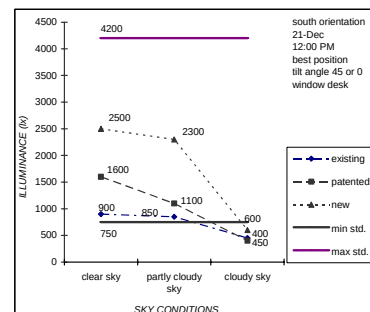
illuminate	clear sky	partly cloud	cloudy sky
south orientation			
21-Jun			
12:00 PM			
best position			
tilt angle 45 or 0			
window desk			
existing	1300	1300	600
patented	1300	1800	500
new	2200	2300	1000
min std.	750	750	750
max std.	4200	4200	4200



illuminate	clear sky	partly cloud	cloudy sky
west orientation			
21-Jun			
12:00 PM			
best position			
tilt angle 45 or 0			
window desk			
existing	1500	1600	600
patented	1300	1600	500
new	2100	2200	1000
min std.	750	750	750
max std.	4200	4200	4200



illuminate	clear sky	partly cloud	cloudy sky
south orientation			
21-Dec			
12:00 PM			
best position			
tilt angle 45 or 0			
window desk			
existing	900	850	450
patented	1600	1100	400
new	2500	2300	600
min std.	750	750	750
max std.	4200	4200	4200



illuminate	clear sky	partly cloud	cloudy sky
west orientation			
21-Dec			
12:00 PM			
best position			
tilt angle 45 or 0			
window desk			
existing	1100	850	400
patented	1300	1000	350
new	1650	1100	600
min std.	750	750	750
max std.	4200	4200	4200

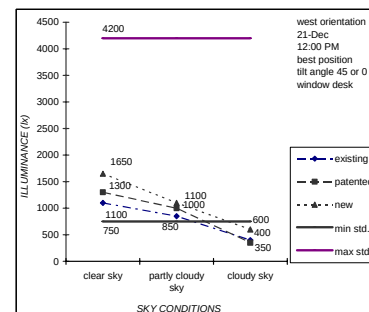
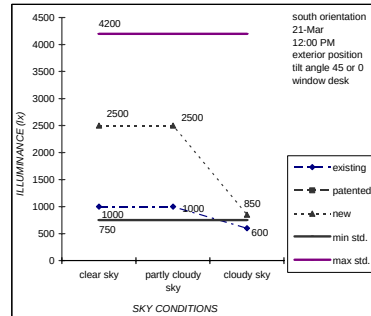


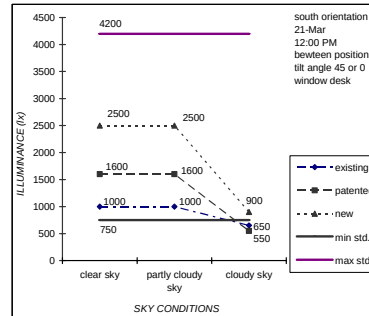
Figure 5-16 An example of sheet 7 – effect of sky conditions on illuminance at the point close to the window for the south orientation

existing blinds - tilt angle 45 for clear sky and partly cloudy sky and 0 for cloudy sky
 patented blinds - tilt angle 0 always
 new blinds - tilt angle 45 for clear sky and partly cloudy sky and 0 for cloudy sky

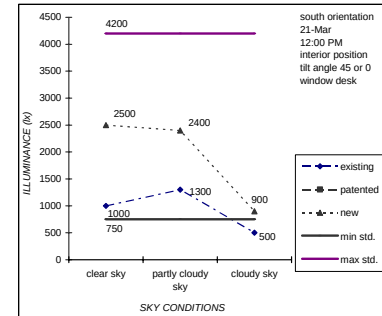
illumination	clear sky	partly cloud	cloudy sky
illumination			
south orientation			
21-Mar			
12:00 PM			
exterior position			
tilt angle 45 or 0			
window desk			
existing	1000	1000	600
patented			
new	2500	2500	850
min std.	750	750	750
max std.	4200	4200	4200



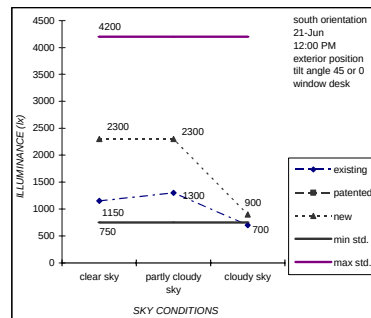
illumination	clear sky	partly cloud	cloudy sky
illumination			
south orientation			
21-Mar			
12:00 PM			
between position			
tilt angle 45 or 0			
window desk			
existing	1000	1000	650
patented	1600	1600	550
new	2500	2500	900
min std.	750	750	750
max std.	4200	4200	4200



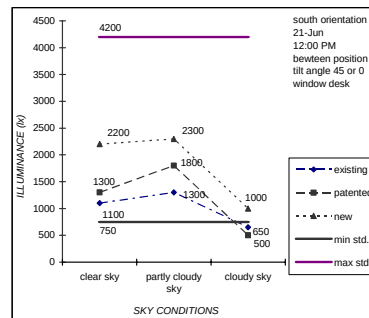
illumination	clear sky	partly cloud	cloudy sky
illumination			
south orientation			
21-Mar			
12:00 PM			
interior position			
tilt angle 45 or 0			
window desk			
existing	1000	1300	500
patented			
new	2500	2400	900
min std.	750	750	750
max std.	4200	4200	4200



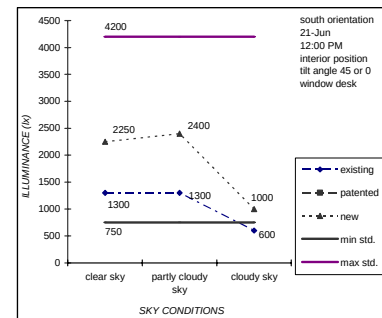
illumination	clear sky	partly cloud	cloudy sky
illumination			
south orientation			
21-Jun			
12:00 PM			
exterior position			
tilt angle 45 or 0			
window desk			
existing	1150	1300	700
patented			
new	2300	2300	900
min std.	750	750	750
max std.	4200	4200	4200



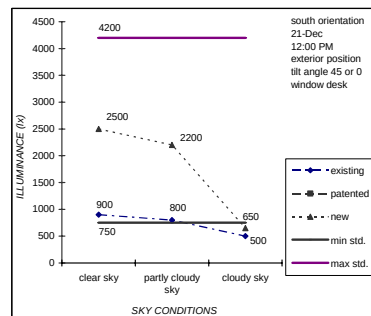
illumination	clear sky	partly cloud	cloudy sky
illumination			
south orientation			
21-Jun			
12:00 PM			
between position			
tilt angle 45 or 0			
window desk			
existing	1100	1300	500
patented	1300	1800	500
new	2200	2300	1000
min std.	750	750	750
max std.	4200	4200	4200



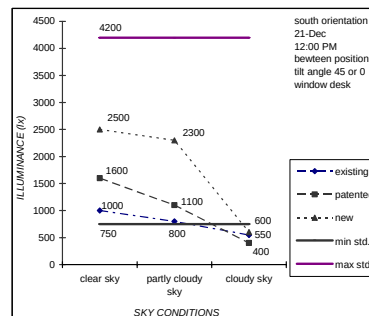
illumination	clear sky	partly cloud	cloudy sky
illumination			
south orientation			
21-Jun			
12:00 PM			
interior position			
tilt angle 45 or 0			
window desk			
existing	1300	1300	600
patented			
new	2250	2400	1000
min std.	750	750	750
max std.	4200	4200	4200



illumination	clear sky	partly cloud	cloudy sky
illumination			
south orientation			
21-Dec			
12:00 PM			
exterior position			
tilt angle 45 or 0			
window desk			
existing	900	800	500
patented			
new	2500	2200	650
min std.	750	750	750
max std.	4200	4200	4200



illumination	clear sky	partly cloud	cloudy sky
illumination			
south orientation			
21-Dec			
12:00 PM			
between position			
tilt angle 45 or 0			
window desk			
existing	1000	800	550
patented	1600	1100	400
new	2500	2300	600
min std.	750	750	750
max std.	4200	4200	4200



illumination	clear sky	partly cloud	cloudy sky
illumination			
south orientation			
21-Dec			
12:00 PM			
interior position			
tilt angle 45 or 0			
window desk			
existing	900	850	450
patented			
new	2500	2300	650
min std.	750	750	750
max std.	4200	4200	4200

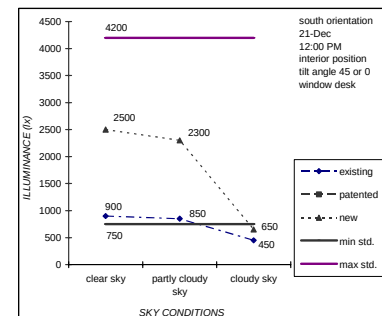
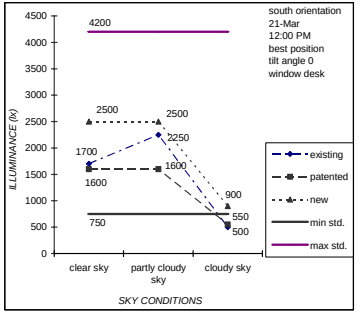


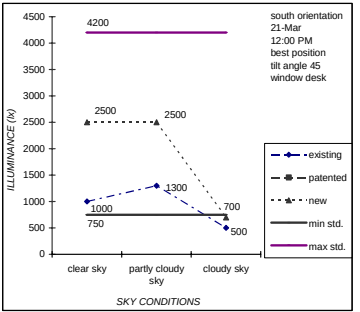
Figure 5-17 An example of sheet 8 – effect of sky conditions on illuminance at the point close to the window for the south orientation

	existing	patented	new
BEST POSITION	inside	between	between

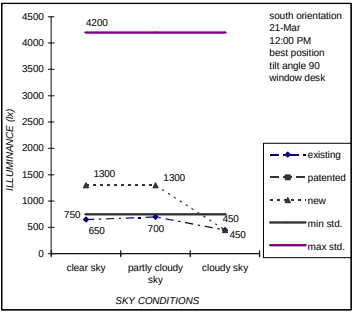
illumination		clear sky	partly cloud	cloudy sky
south orientation				
21-Mar	existing	1700	2250	500
12:00 PM	patented	1600	1600	550
best position	new	2500	2500	900
tilt angle 0	min std.	750	750	750
window desk	max std.	4200	4200	4200



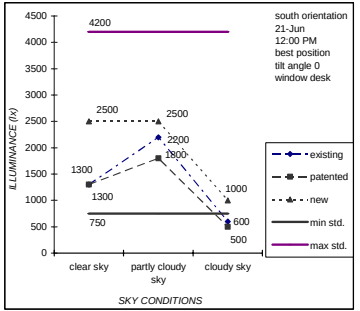
illumination		clear sky	partly cloud	cloudy sky
south orientation				
21-Mar	existing	1000	1300	500
12:00 PM	patented			
best position	new	2500	2500	700
tilt angle 45	min std.	750	750	750
window desk	max std.	4200	4200	4200



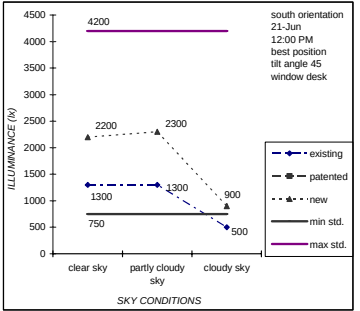
illumination		clear sky	partly cloud	cloudy sky
south orientation				
21-Mar	existing	650	700	450
12:00 PM	patented			
best position	new	1300	1300	450
tilt angle 90	min std.	750	750	750
window desk	max std.	4200	4200	4200



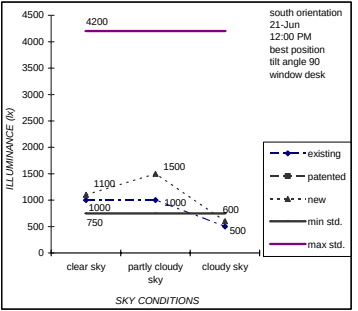
illumination		clear sky	partly cloud	cloudy sky
south orientation				
21-Jun	existing	1300	2200	600
12:00 PM	patented	1300	1800	500
best position	new	2500	2500	1000
tilt angle 0	min std.	750	750	750
window desk	max std.	4200	4200	4200



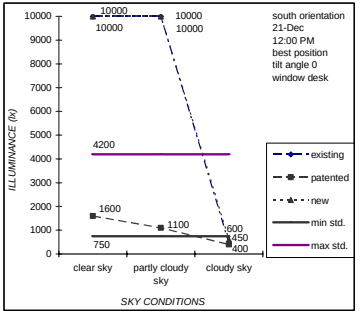
illumination		clear sky	partly cloud	cloudy sky
south orientation				
21-Jun	existing	1300	1300	500
12:00 PM	patented			
best position	new	2200	2300	900
tilt angle 45	min std.	750	750	750
window desk	max std.	4200	4200	4200



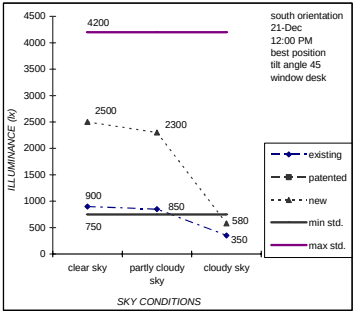
illumination		clear sky	partly cloud	cloudy sky
south orientation				
21-Jun	existing	1000	1000	500
12:00 PM	patented			
best position	new	1100	1500	600
tilt angle 90	min std.	750	750	750
window desk	max std.	4200	4200	4200



illumination		clear sky	partly cloud	cloudy sky
south orientation				
21-Dec	existing	10000	10000	450
12:00 PM	patented	1600	1100	400
best position	new	10000	10000	600
tilt angle 0	min std.	750	750	750
window desk	max std.	4200	4200	4200



illumination		clear sky	partly cloud	cloudy sky
south orientation				
21-Dec	existing	900	850	350
12:00 PM	patented			
best position	new	2500	2300	580
tilt angle 45	min std.	750	750	750
window desk	max std.	4200	4200	4200



illumination		clear sky	partly cloud	cloudy sky
south orientation				
21-Dec	existing	600	500	350
12:00 PM	patented			
best position	new	1100	950	280
tilt angle 90	min std.	750	750	750
window desk	max std.	4200	4200	4200

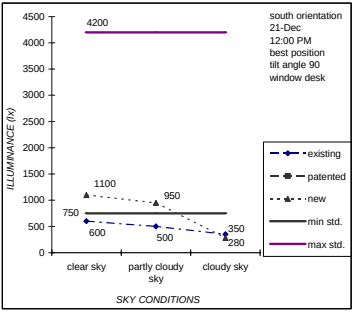


Figure 5-18 An example of sheet 9 – effect of sky conditions on illuminance at the point close to the window for the south orientation

Sheet 1 analyzes the effect of **time** (see Figure 5-10) as a major variable, as well as effects of the dates and sky conditions as minor variables, on the illuminance level in the space provided by the application of three different types of shading devices.

1. A comparison of the charts shows that the new shading device gives the highest illuminance levels for all analyzed times, dates, and sky conditions due to its geometry and applied materials for the slats, given the research limitations. The patented system has a better performance than the existing shading device for most of the time, dates, and sky conditions, with the exception of a few conditions for which the existing system has a better performance:

- on December 21, at 12:00 p.m., for clear sky conditions
- on March 21, at 11:00 a.m. and 3:00 p.m., for cloudy sky conditions
- on June 21 and December 21, at all times for cloudy sky conditions

This analysis shows that the existing blinds perform better than the patented blinds for cloudy sky conditions, but none of these two systems meets the minimum requirements of the standards in cloudy sky conditions.

2. Regarding the range of values of illuminance required by the standards, sky conditions have the strongest effect on the performance of shading devices and meeting the requirements of the standards. All three types of shading devices meet the requirements of the standards for all the times and dates for clear sky conditions, and for all times on March 21 and June 21 for partly cloudy sky conditions. This is expected due to the higher values of the outdoor illuminance for these two dates. For the rest of the times and dates, the performances are as follows:

- On December 21 for partly cloudy sky conditions, all three types of shading devices meet the requirements of the standard at 11:00 a.m. and 12:00 p.m. At 3:00 p.m., only the new blinds' performance is above the minimum required level of illuminance.
- On March 21 for cloudy sky conditions, the patented and the existing system do not meet the requirements of the standard for any of the times. The new blinds have the same or better performance than that required by the standards at 11:00 a.m. and 12:00 p.m., and a slightly lower performance at 3:00 p.m.

- On December 21 for cloudy sky condition, none of the shading device systems meets the requirements of the standards.
3. For most of the dates and sky conditions, the performance of the **new** shading device system is the same at 11:00 a.m. and 12:00 p.m., for clear sky conditions for all dates, and for partly cloudy sky conditions on March 21 and June 21. For partly cloudy sky conditions on December 21, levels are higher at 12:00 p.m. than at 11:00 a.m. because at 12:00 p.m. the sun is perpendicular to the south-oriented facade and gives higher outdoor illuminance levels. For cloudy sky conditions, illuminance levels provided by the new system are always higher at 12:00 p.m. than at 11:00 a.m. The lowest levels of illuminance are at 3:00 p.m. for all sky conditions and dates.

The **patented** shading device has the same performance at 11:00 a.m. and 12:00 p.m. on March 21 and June 21, for clear sky conditions, better performance at 12:00 p.m. than at 11:00 a.m. on March 21 and June 21 for partly cloudy and cloudy sky days, and on December 21 for cloudy sky days. On December 21, for clear and partly cloudy sky days, the values of illuminance are lower at 12:00 p.m. than at 11:00 a.m. The values of illuminance obtained at 3:00 p.m. are lower than at 11:00 a.m. and 12:00 p.m. for most of the time except:

- On December 21 when values at 12:00 p.m. and 3:00 p.m. are the same
- On June 21, when values at 3:00 p.m. are higher than values at 11:00 a.m. and 12:00 p.m.

The **existing** system provides the same illuminance level in the space at 11:00 a.m. and 12:00 p.m. on June 21 in all sky conditions, on March 21 for cloudy sky conditions, and on December 21 for partly cloudy sky conditions. The values of illuminance are higher at 12:00 p.m. than at 11:00 a.m. on December 21 in clear sky conditions, and on March 21 for partly cloudy sky conditions. The values obtained at 3:00 p.m. are the lowest for all sky conditions and dates except on March 21 and clear sky conditions when the values at 3:00 p.m. are higher than the values at 12:00 p.m. but lower than those at 11:00 a.m.

An analysis of **time's** effect for all three types of shading devices shows that illuminance levels are the same at 11:00 a.m. and 12:00 p.m. or higher at 12:00 p.m. than at 11:00 a.m.,

and most of the time the lowest at 3:00 p.m., which is expected due to the sun angle and outdoor illuminance levels at the particular times.

A quick analysis of two minor variables, date and sky conditions, shows that:

- Light levels for all three types of shading devices are slightly higher on June 21 than on March 21 and drop on December 21 for cloudy sky conditions. For clear and partly cloudy sky days, the date does not significantly affect the performance.
- For all three dates and types of shading devices, the performance is almost the same for clear and partly cloudy sky conditions and significantly lower for cloudy sky conditions.

The charts presented in **sheet 2** analyze the effect of the **date** (see Figure 5-11) as a major variable on the performance of shading devices. The minor variables considered in this sheet are the time and sky conditions.

1. An analysis shows that the new shading device gives the highest levels of illuminance for all dates and for all times and sky conditions, compared to the patented and the existing system, given the research limitations. The patented shading device shows a better performance, that is, higher illuminance levels than the existing system for most dates except on June 21 at 3:00 p.m. for clear sky conditions, all dates at 11:00 a.m. and 3:00 p.m. for cloudy sky conditions, and on December 21 and June 21 at 12:00 p.m., when the existing system shows a better performance.
2. All three types of the shading devices meet the standards:
 - for all dates and times for clear sky conditions
 - for all dates, at 11:00 a.m. and 12:00 p.m. for partly cloudy sky conditions
 - on March 21 and June 21 at 3:00 p.m. for partly cloudy sky conditions

The new shading device meets the requirements of the standards also on December 21 at 3:00 p.m. for partly cloudy sky days, on June 21 for all the times for cloudy sky days, and on March 21 at 12:00 p.m. for cloudy sky days. The new system does not meet the requirements of the standards on December 21 for cloudy sky days. The patented and the existing system do not meet the requirements for any date and time for cloudy sky conditions and on December 21 at 3:00 p.m. for partly cloudy sky conditions.

3. The values of illuminance obtained by the application of the **new** system vary slightly for different dates for clear sky conditions. Slightly higher levels are achieved on December 21 and March 21 than on June 21. For partly cloudy sky conditions, the highest levels are obtained on March 21, lower on June 21, and the lowest on December 21 at 11:00 a.m. and 12:00 p.m. The values on December 21 at 3:00 p.m. are 50% lower than the values on March 21 and June 21 for partly cloudy sky conditions. The new shading device shows the highest performance on March 21, and the lowest performance on December 21 for cloudy sky conditions.

The **patented** system performance is affected significantly by the date for clear sky conditions. The lowest levels of illuminance are obtained on June 21, higher levels on March 21, and 60% higher values on December 21 at 11:00 a.m. and 12:00 p.m. At 3:00 p.m., the date slightly affects the performance of the patented blinds, resulting in the lowest level on March 21, higher on June 21, and the highest on December 21. For partly cloudy sky conditions, the levels of illuminance slightly differ for three dates at 11:00 a.m. At 12:00 p.m., the illuminance levels on June 21 are slightly higher than those on March 21, and on December 21, the values are 30% lower than those on March 21. At 3:00 p.m., the values are almost the same on June 21 and March 21, while the values on December 21 are 50% lower. For cloudy sky conditions, the values are the lowest on December 21 for all the times, the highest on March 21 at 11:00 a.m. and 12:00 p.m., and on June 21 at 3:00 p.m.

The **existing** system has the constant performance for all dates for clear sky conditions at 11:00 a.m. At 12:00 p.m. and 3:00 p.m., the lowest levels are on December 21 and the highest on June 21. In the partly cloudy sky conditions, the lowest levels are always on December 21, the highest on June 21 at 11:00 a.m., and on March 21 at 12:00 p.m. For cloudy sky conditions, the highest levels are achieved on June 21, and the lowest on December 21, for all the times.

An analysis of the **date** effect on the light levels shows that the values on March 21 and June 21 differ slightly for all sky conditions, and for all the types of blinds. The values on December 21 drop for all three types of blinds for partly cloudy and cloudy sky conditions, compared to the values on March 21 and June 21. A quick analysis of two minor variables, time and sky conditions, shows the following results:

- Performance of the shading devices does not change significantly from 11:00 a.m. to 12:00 p.m., but it drops slightly at 3:00 p.m.
- Performances of the shading devices differ slightly for clear and partly cloudy sky conditions, but the values drop for cloudy sky conditions.

The charts in **sheet 3** analyze the effect of the **sky condition** (see Figure 5-12) as a major variable on the performance of shading devices. The minor variables analyzed in this sheet are the time and date.

1. An analysis of the charts shows that the new shading device performs the best for all sky conditions regardless of time and date, compared to two other types of shading devices, given the research limitations. The patented system performs better than the existing system for clear and partly cloudy sky conditions for most dates and times except on December 21 at 12:00 p.m. when the existing system performance is better. For cloudy sky conditions, performance of the patented and the existing systems differs slightly:
 - o At 11:00 a.m. and 3:00 p.m. for all dates and at 12:00 p.m. on June 21 and December 21, the existing blinds perform better than the patented blinds.
 - o At 12:00 p.m. on March 21, the patented blinds perform better than the existing blinds.
2. Performances of all three types of shading devices meet the requirements of the standards for clear and partly cloudy sky conditions for almost all dates and times except for the patented and the existing systems' performances on December 21 at 3:00 p.m. for partly cloudy sky days. For cloudy sky conditions, the patented and the existing system never meet the requirements of the standards, but the new system has a minimum required performance on June 21 all the time, and on March 21 at 11:00 a.m. For the rest of the dates and times, the new blinds do not meet the minimum requirements by the standard.
3. Performance of the **new** system differs slightly for clear and partly cloudy sky conditions for most of the time and dates except on December 21 at 3:00 p.m. The values are the same for clear and partly cloudy sky conditions on March 21 at 11:00 a.m. and 12:00 p.m. and on June 21 at 11:00 a.m. The values are slightly higher for clear sky conditions than for partly cloudy sky conditions on March 21 at 3:00 p.m. and on December 21 at 11:00 a.m. and 12:00 p.m. The values for partly cloudy sky conditions are higher than

those for clear sky conditions on June 21 at 12:00 p.m. and 3:00 p.m. On December 21 at 3:00 p.m., the value of illuminance for partly cloudy sky conditions is 50% of the value for clear sky conditions.

The **patented** system performance differs slightly for clear and partly cloudy sky conditions on March 21 for all the times and on June 21 at 11:00 a.m.:

- Performance is the same for clear and partly cloudy sky conditions at 12:00 p.m. on March 21 and at 11:00 a.m. on June 21.
- Performance is slightly higher for clear sky conditions than for partly cloudy sky conditions on March 21 at 11:00 a.m. and 3:00 p.m.

On June 21 at 12:00 p.m., performance is higher in the partly cloudy sky conditions by 40%, compared to the performance for clear sky conditions. On December 21, performance of the patented blinds is significantly affected by the cloud cover:

- At 11:00 a.m., it drops by 40% from clear to partly cloudy sky conditions, and 75% from partly cloudy to cloudy sky conditions.
- At 12:00 p.m. it drops by 30% from clear to partly cloudy sky conditions, and 65% from partly cloudy to cloudy sky conditions.

As expected, the values of illuminance for cloudy sky conditions are significantly lower than for partly cloudy sky conditions:

- On March 21, the values drop approximately 65% to 70% for cloudy sky conditions, compared to partly cloudy sky conditions.
- On June 21, the values drop by 55% at 3:00 p.m., 70% at 11:00 a.m. and 12:00 p.m. for cloudy sky conditions, compared to values for partly cloudy sky conditions.
- On December 21, the values drop by 75% at 11:00 a.m., 65% at 12:00 p.m., and 85% at 3:00 p.m. for cloudy sky conditions, compared to partly cloudy sky conditions.

The **existing** shading device performance does not change significantly for clear and partly cloudy sky conditions on June 21 and March 21. The performance of the existing system is either:

- The same – as on June at 11:00 a.m. and 12:00 p.m.
- Slightly higher for clear sky conditions as on March 21 at 11:00 a.m. and 3:00 p.m., and on June 21 at 3:00 p.m.
- Higher for partly cloudy sky conditions as is case on March 21 at 12:00 p.m.

On December 21 at 11:00 a.m. and 3:00 p.m., the values for clear sky conditions are higher by 35% and at 12:00 p.m. by 65%, compared to the values for partly cloudy sky conditions. As predicted, the values are significantly lower for cloudy sky conditions for all the times and dates: on March 21, the illuminance value drops for cloudy sky conditions by 55% to 60%, on June 21 by 45% to 55% and on December 21, by 40% to 47% at 11:00 a.m. and 12:00 p.m., and by 80% at 3:00 p.m., compared to the values for partly cloudy sky conditions.

An analysis of the **sky condition** effect on shading device performances shows that performance differs slightly for clear and partly cloudy sky conditions on June 21 and March 21, and differs significantly on December 21 for all three types of shading devices. Cloudy sky conditions significantly affect illuminance by dropping its values by approximately 50%, compared to the values for partly cloudy sky conditions.

A quick analysis of two minor variables, date and time, shows that the time and date just slightly affect illuminance levels. The lowest levels of illuminance are obtained on December 21 at 3:00 p.m., as predicted.

Sheet 4 analyzes the effect of the **facade orientation** (see Figure 5-13) as a major variable, as well as the effect of dates and sky conditions as the minor variables on the illuminance levels in the space.

1. A comparison of the charts shows that the new shading device systems provide the highest levels of illuminance for both south and west orientations, compared to the existing and patented systems for almost all dates and sky conditions, given the research limitations. Only at the west-oriented facade on March 21 for clear sky conditions the existing blinds perform better than the new blinds. The patented system provides a higher illuminance than the existing blinds for the south orientation on March 21 for all sky conditions, and on June 21 and December 21 for partly cloudy sky conditions, and for the west orientation on March 21 and December 21 for partly cloudy sky conditions. For the rest of the dates and sky conditions, the existing system performs better than the patented system.
2. Regarding the requirements of the standard for the minimum illuminance level, all three types of blinds meet the requirements for both orientations for clear and partly cloudy sky

conditions for all dates. For cloudy sky conditions, the patented and the existing blinds do not meet the minimum requirements of the standards for any orientation and date. The new blinds provide the minimum illuminance level required by the standards only at the west-oriented facade on March 21, and for both orientations on June 21 for cloudy sky conditions.

3. An application of the **new** shading device is more appropriate for the south orientation since the higher illuminance levels are obtained for the south for most of the time. On March 21 for clear and partly cloudy sky conditions, the illuminance level at the south is 10% higher than at the west, while on June 21 and for all sky conditions, performance at the south is slightly better (5%) than the performance at the west. On December 21, the south-oriented blinds give 35% higher values than the west-oriented blinds for clear sky conditions and 50% for partly cloudy sky conditions. For cloudy sky conditions on March 21 and December 21, performance of west-oriented blinds is 10% to 20% higher than that of the south-oriented blinds.

The **patented** blinds show almost the uniform performance for both orientations:

- Performance is the same for the south and west orientation on March 21 for all sky conditions, and on June 21 for clear and cloudy sky conditions.
- Performance is 10% to 20% higher for the south-oriented facade, compared to the west orientation on June 21 and December 21 for partly cloudy sky conditions, and on December 21 for clear sky conditions.
- The west-oriented blinds perform 15% better than the south-oriented blinds only on December 21 for cloudy sky conditions.

The **existing** system shows the same performance for the south and west orientation on March 21 and December 21 for partly cloudy sky conditions, and on June 21 for cloudy sky conditions. A 15% better performance is obtained for the west facade on March 21 for cloudy sky conditions, and on June 21 for clear and partly cloudy sky conditions. But on March 21 for clear sky conditions, the south blinds' performance value is 40% of the west one. On December 21, the south-oriented blinds give more than 100% higher illuminance for clear sky conditions and 20% for cloudy sky conditions, compared to the west-oriented blinds.

An analysis of the effect of the **facade orientation** on the performance of shading devices shows that all three types of blinds can be applied at both orientations. The new and the patented blinds perform slightly better for the south orientation because the horizontal position of the shading device gives a better performance for the south orientation and vertical position for the west. The existing blinds have a better performance for the west orientation.

Sheet 5 investigates the effect of the **blinds' position** relative to the window on the illuminance level for three types of blinds (see Figure 5-14). The minor variables considered in this sheet are the date and sky conditions.

1. A comparison of the charts shows that the new system provides the highest illuminance levels for all blinds' positions and all dates and sky conditions, compared to the other two types of blinds, given the research limitations. Since the patented blinds are always installed in the between-glass position, their performance can be compared with the performance of the other two types of blinds, based just on their between-glass position. The patented blinds show a better performance than the existing blinds in the between-glass position for all dates for clear and partly cloudy sky conditions, while the existing blinds perform better than the patented blinds in the between-glass position for all dates for cloudy sky conditions.
2. Regarding the requirements of the standards, the blinds' position does not significantly affect achieving the minimum required performance. Again, sky conditions are the dominant factor in obtaining the minimum illuminance level in the space. The new and existing systems meet the requirements of the standards in all positions. The patented system in the between-glass position meets the requirements for clear and partly cloudy sky conditions. None of the shading devices meets the minimum requirements on December 21 for cloudy sky conditions, regardless of their position relative to the window. On March 21 and June 21, for cloudy sky conditions, only the new shading device meets the requirements of the standards for all positions, given the research limitations.
3. The position of the shading device relative to the window does not significantly affect its performance, that is, the obtained illuminance levels in the space. The **new** system has

the same performance for all positions of blinds for clear sky conditions on December 21 and March 21, and for the rest of the dates and sky conditions, the values of illuminance differ 5% to 10%, depending on the blinds' position:

- On December 21 and June 21 for partly cloudy sky conditions, and on March 21 and June 21 for cloudy sky conditions, the exterior position gives a 5% lower illuminance level, compared to the other two positions.
- On March 21 for partly cloudy sky conditions and on June 21 for the clear sky conditions, the exterior position gives 3% to 4% higher illuminance, compared to the other two positions of blinds.

The **existing** blinds also have the uniform performance regarding the blinds' position relative to the window. The same performance is obtained for all three positions of blinds on March 21 for clear sky conditions, and June 21 for partly cloudy sky conditions. By installing blinds in the interior position, 30% higher levels of illuminance are achieved on March 21 for partly cloudy sky conditions, 20% on June 21 for clear sky conditions, and 5% on December 21 for partly cloudy sky conditions, compared to the other two positions of blinds. The exterior position of the existing blinds gives 8% higher values of illuminance than the other two positions on June 21 for cloudy sky conditions. The blinds in the between-glass position achieve 10% higher values of illuminance than the blinds in the exterior position, and 20% higher values than the blinds in the interior position on December 21 and March 21 for cloudy sky conditions.

An analysis shows that the **position of the blinds** does not significantly affect the illuminance levels in the space. However, the existing shading device shows a slightly better performance in the interior position, as expected, and defined by its design. The new shading device gives a uniform performance for most of the time so the between-position selected in this design is appropriate for the application on the proposed building. The minor variables considered in sheet 5 are sky conditions and date, and they are previously analyzed as major variables.¹

¹ Refer to explanation of sheets 2 and 3.

The charts in **sheet 6** analyze the effect of the **blinds' tilt angle** as a major variable on the performance of shading devices (see Figure 5-15). The minor variables considered in sheet 6 are dates and sky conditions, as in the previous sheets.

1. The new and the existing systems are simulated for three blinds' tilt angles, while the patented system is tested only for the 0° tilt angle, which is constant by the design. The new system has the best performance for all tilt angles on June 21 and March 21 for all sky conditions, given the research limitations. On December 21 for clear and partly cloudy sky conditions, the new system has the best performance for the 45° and 90° tilt angles. If the new system is set at the 0° tilt angle, it provides very high illuminance levels (more than 10000 lx), which is much beyond the comfort zone, and it causes glare. On December 21 for cloudy sky conditions, the existing blinds have a slightly better performance than the new blinds for the 0° tilt angle, but they are below the minimum values required by the standards. Considering only the 0° tilt angle, both the existing and new systems have better performance than the patented system on March 21 and June 21, and on December 21 for cloudy sky conditions. On December 21 for clear and partly cloudy sky conditions, the new and existing blinds provide higher illuminance levels, but since they are out of the range of the comfort zone, the performance of the patented blinds is considered to be the best since it fits in the recommended range of values, given the research limitations.
2. Considering the requirements of the standard for the minimum and maximum illuminance levels, the **new** blinds fit in this range of values for all tilt angles on March 21, and June 21 for clear and partly cloudy sky conditions. On March 21 for cloudy sky conditions, the new blinds' performance is in the comfort zone only for the 0° tilt angle. If the new blinds are set at 0° and 45° tilt angles, they provide a minimum illuminance on June 21 for cloudy sky conditions. On December 21 for clear and partly cloudy sky conditions, the new blinds at the 0° tilt angle provide illuminance higher than that recommended by the standards, but at 45° and 90° angles, they provide acceptable values. On December 21, the new blinds cannot provide minimum illuminance in the space for cloudy sky conditions even if they are in the completely open position.

The **patented** blinds, that are always in the completely open position, have performance that meets the requirements for minimum illuminance for all dates, for clear and partly cloudy sky but not for cloudy sky condition.

The **existing** blinds meet the requirements of the standards for all tilt angles only on June 21 for clear and partly cloudy sky conditions. If they are set at 0° and 45° tilt angles, they provide a minimum illuminance on March 21 for clear and partly cloudy sky conditions. On December 21, they meet the requirements at the 45° tilt angle for clear and partly cloudy sky conditions. At the 0° tilt angle, they provide the illuminance level much higher than the maximum recommended level, and at the 90° tilt angle, values are lower than the recommended minimum values. The existing blinds cannot provide a minimum illuminance for cloudy sky conditions even in the completely open position.

3. The blinds' tilt angle significantly affects the illuminance levels in the space. As expected, the open blinds provide higher levels of illuminance, compared to partially open/closed blinds or completely closed blinds. The difference in performance of the **new** blinds at the 0° and 45° tilt angles is 10% on March 21 and June 21 for all sky conditions, due to high outdoor illuminance level at 12:00 p.m. and due to the geometry and materials of the blinds. The values of illuminance drop 35% to 50% after closing the blinds completely (90° tilt angle). On December 21 for clear and partly cloudy sky conditions, it is necessary to keep blinds at a 45° tilt angle since completely open blinds provide uncomfortably high illuminance levels in the space. The sun angle at 12:00 p.m. in December is low, and it has a perpendicular position to the south facade so direct sunlight enters the interior space causing high daylight levels and glare. If the blinds are completely closed (90°), they still provide a sufficient amount of illuminance in the space for clear and partly cloudy sky conditions, but values are 55% lower than those provided by setting the blinds at the 45° tilt angle. On December 21 for cloudy sky conditions, the completely open new blinds cannot provide a minimum level of illuminance due to very low levels of outdoor illuminance.

The **existing** blinds' performance shows that the blinds' tilt angle has a significant impact on the illuminance levels in the space. On March 21 for clear and partly cloudy sky conditions, changing the blinds' tilt angle from 0° to 45° and from 45° to 90° causes decreasing values of illuminance by 35% to 40% in each case. On June 21 for clear sky

conditions, performance is the same for 0° and 45° angles, and it drops by 30% if blinds are completely closed. On June 21 for partly cloudy sky conditions, changing the blinds' tilt angle from 0° to 45° decreases the values of illuminance by 40%, and from 45° to 90° by 25%. On December 21, the performance of the existing blinds is very similar to that of the new blinds. If the blinds are completely open, the illuminance level is much beyond the comfort zone for clear and partly cloudy sky conditions. The values drop to acceptable levels for the 45° tilt angle, and the illuminance drops by 30% to 40%, and below the minimum required by the standards for the 90° tilt angle. Even completely open blinds cannot obtain a minimum illuminance in the space for cloudy sky conditions on all analyzed dates.

Considering sky conditions as a minor variable, a strong relationship exists with the blinds' tilt angle and control strategy for adjusting the tilt angle. For example, the analysis shows that the new and existing blinds can be kept at the 45° tilt angle for all dates for clear and partly cloudy sky conditions, providing comfortable light levels in the space. For cloudy sky conditions, the new blinds in the open position can provide a sufficient amount of daylight on March 21 and June 21, which is not the case with the existing and patented blinds, given the research limitations. The patented blinds, fixed in the completely open position by the design, perform well and provide a minimum illuminance level always for clear and partly cloudy sky conditions, but never for cloudy sky conditions.

Sheets 7, 8, and 9 analyze the effect of sky conditions on the performance of shading devices, considering also the dates and minor variables such as facade orientations, blinds' positions, and blinds' tilt angles. Since these effects are already explained in sheets 4, 5, and 6, different ways of presenting the data in the charts are shown in sheets 7, 8 and 9. The sky condition effect can be read directly from these sheets.

Sheet 7 analyzes sky condition effects on the illuminance level, relative to the orientation of the facade (see Figure 5-16). The behavior of shading devices is similar for the south and west orientations regardless of the sky condition. It means that for both orientations the values of illuminance, as a result of application of particular blinds, change in the same manner with changing the sky cloud cover. As the cloudiness of the sky increases, the values of illuminance drop for both orientations.

Sheet 8 analyzes the effect of the sky conditions on the illuminance level relative to the position of the shading device (see Figure 5-17). As explained in sheet 5, the position of the shading device does not significantly affect the light level in the space. An analysis of the charts in sheet 8 shows that the blinds change their performance with the change of sky cover regardless of their position. It means that values of illuminance in the space drop significantly with the increasing cloudiness, but not with changing the position of the blinds relative to the window.

Sheet 9 analyzes the effect of the sky conditions on the illuminance levels in the space relative to the tilt angles of the blinds (see Figure 5-18). As explained in sheet 6, a strong relationship exists between sky conditions and the blinds' tilt angle. The higher the percentage of the sky cover, the more open the blinds are, as predicted. The charts show that for clear sky conditions, the new and existing blinds for all three tilt angles obtain a sufficient amount of light, with the exception of March 21 and June 21 when the existing blinds should not be completely closed. On December 21 at 12:00 p.m., the 0° tilt angle is not acceptable since light levels in the space are uncomfortably high causing glare. For partly cloudy sky conditions, all three tilt angles work well on March 21 and June 21 for the new and existing blinds, but not on December 21 when a more sensitive control strategy for the blinds' tilt angle adjustment is needed. For cloudy sky conditions, even the completely open blinds cannot provide the minimum recommended daylight with the exception of the new blinds on March 21 and June 21.

An analysis of sheets 1-9 in set 1 focuses on the performance of the three types of shading devices that are installed at the south-oriented facade. The illuminance levels, as a result of the application of these systems, are measured at the top of the desk close to the window. To make an accurate decision which blinds should be selected, all eight sets need to be analyzed. Based on the analysis of the first set, the following conclusions can be made:

The **new** shading device gives the best performance overall, that is, the highest level of illuminance for most of the times and dates, for all sky conditions, for both orientations, and for all blind positions, given the limitations of this research. They have the constant performance in the morning hours for clear and partly cloudy sky conditions in March and June, and the performance values drops rapidly for cloudy sky conditions. The highest levels of illuminance are obtained in March, lower in June, and the lowest in December. The new

system performs slightly better for the south than for the west although it can provide a sufficient amount of illuminance at the west orientation, too. The new shading device system has almost the same performance in all positions relative to the window, so the between-glass position proposed by this research gives satisfactory performance. Regarding the blinds' tilt angle, the new blinds have the best performance for all angles in March and June and for all sky conditions, given the research limitations. The critical conditions are in December for clear sky conditions, when the blinds cannot be completely open in order to avoid an uncomfortably high illuminance in the space and glare. The new blinds meet the requirements of the standards for most of the conditions, except in December for cloudy sky conditions when the levels are below the minimum values. In December for clear and partly cloudy sky conditions, if the new blinds' tilt angle is 0°, illuminance levels are much beyond the maximum recommended by the standard.

The **patented** blinds are the second choice based on the analysis of sheets 1-9 since they have a better performance than the existing blinds for most of the times, dates, and sky conditions, given the research limitations. The patented blinds have a uniform performance in the morning hours in March and June for clear sky conditions. They provide the highest levels of illuminance in the space in December, lower in March, and the lowest in June. The patented system performs almost the same for clear and partly cloudy sky conditions, and significantly lower for cloudy sky conditions. They have the same performance for the south and the west orientations. Compared to the existing blinds, the patented system performs better for the south orientation and worse for the west orientation. The patented blinds are always installed in the between-glass position, and they have a better performance than the existing blinds for that position. The patented blinds meet the minimum requirements of the standards all the time for clear and partly cloudy sky conditions, and never for cloudy sky conditions.

The **existing** blinds provide the lowest illuminance levels overall, compared to two other types of blinds, given the limitations of this research. They have a uniform performance in morning hours in June for all sky conditions, in December for partly cloudy sky conditions, and in March for cloudy sky conditions. Their performance does not differ significantly for the clear and partly cloudy sky conditions, but drops rapidly for cloudy sky conditions. The highest levels of illuminance are provided in June, lower in March, and the lowest in

December. The existing system works well for both orientations although slightly better for the west orientation. The existing blinds system has a uniform performance for all positions relative to the window, but slightly better in the interior position that is chosen by the design. Regarding the blinds' tilt angle, the values of illuminance drop significantly with closing the blinds, as expected. As is the case with the new blinds, the existing blinds should not be set at the 0° angle in December in the afternoon for clear sky conditions. This helps in avoiding high illuminance levels in the space that are out of the comfort zone. The existing blinds meet the minimum requirements of the standards always for clear and partly cloudy sky conditions, and never for cloudy sky conditions. Performance of the existing blinds is much beyond the maximum recommended by the standard in December at 4:00 p.m. for the clear sky conditions if the blinds' tilt angle is 0°.

The other three sets of nine sheets and four sets of seven sheets can be found in Appendix B.3: Charts of results--used just in the dissertation. The methodology used to explain nine sheets (from set 1) in this chapter can be applied for the analysis of the rest of results given in Appendix B.3.

5.3.3. ANALYSIS OF THE CHARTS - DAYLIGHT AUTONOMY (DA)

In the analysis of the charts (see Figure 5-19) that compare daylight autonomy (DA) per year for the three types of shading devices, the following comparisons are performed:

1. Overall comparison of DA for the three types of shading devices.
2. Comparison of DA at two points in the space for each type of shading device for particular angles and facade orientations.
3. Comparison of DA for the three blinds' tilt angles for each type of shading device for a particular point in the space and blinds' tilt angle.
4. Comparison of DA for two orientations of the facade for each type of shading device and for a particular point in the space and blinds' tilt angle.

Six charts combine the following factors considered in the analysis of DA:

- Facade orientation: south or west
- Blinds' tilt angle: 0°, 45°, 90°
- Measurement point in the space: close to the window or close to the interior wall

An analysis of these charts shows the following results:

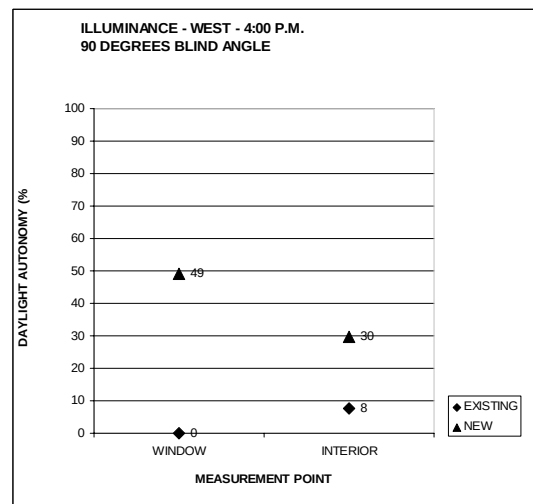
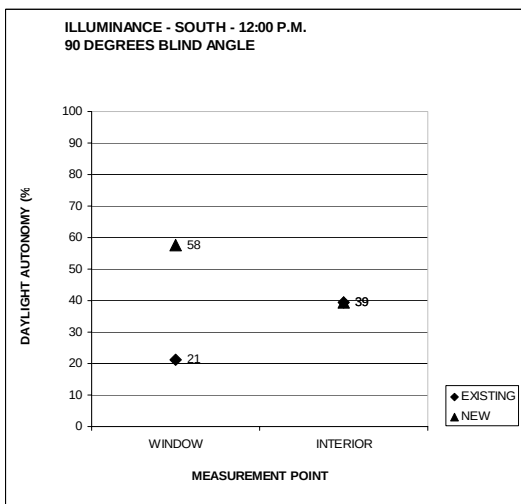
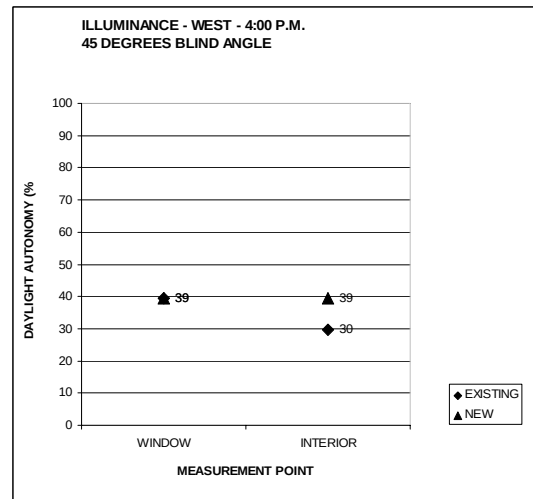
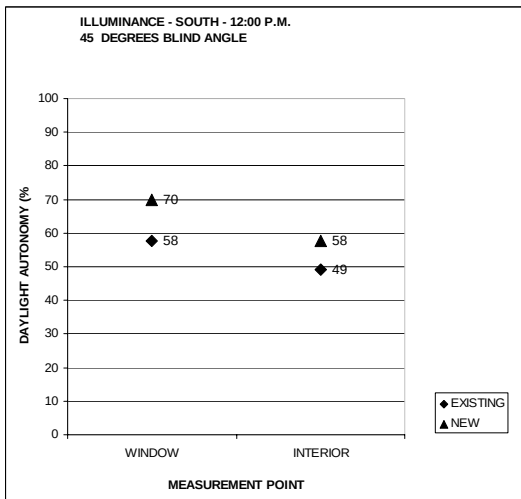
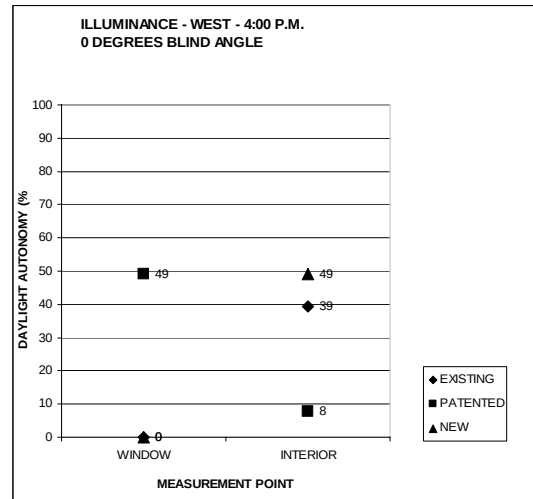
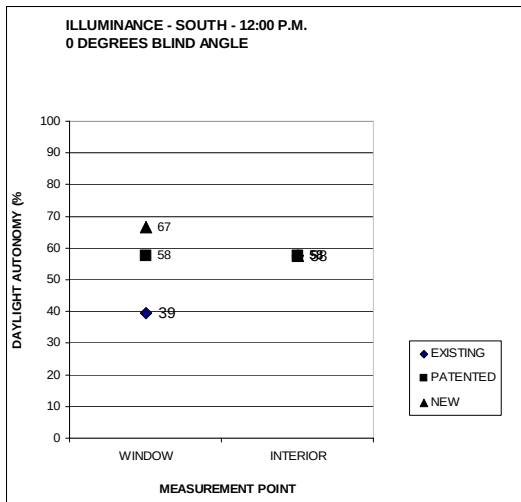


Figure 5-19 Charts for DA for illuminance, at the south and west orientation for 0°, 45°, and 90° blinds' tilt angle

1. Given the research limitations, the new shading device has the highest DA in almost all situations, except for the west orientation at the measurement point close to the window. If the blinds are set at the 0° tilt angle, the illuminance levels are significantly higher than the maximum level recommended by the standards, so the new blinds cannot be kept completely open, resulting in assigning the 0 value for the DA. Since the patented blinds can have only a completely open position, that is, 0° tilt angle, their DA can be compared with the DA of the two other systems just for 0° tilt angle.
 - At the south-oriented facade at the 0° tilt angle, the new blinds have 9% higher DA than the patented blinds, and the patented blinds have 19% higher DA than the existing blinds at the point close to the window, given the research limits. At the point close to the interior wall, all three types of shading devices have the same value of DA. At the west-oriented facade at the 0° tilt angle, the new and existing blinds have 0 value of DA at the point close to the window due to the actual illuminance levels that are out of the comfort zone. At the point close to the interior wall, the DA of the new blinds is 10% higher than the DA of the existing blinds, while the existing blinds have 31% higher DA than the patented blinds, given the research limits.
 - At the south-oriented facade and the 45° tilt angle, the new blinds have 12% higher DA than the existing blinds at the point close to the window, and 9% at the point close to the interior, given the research limits. At the west-oriented facade, the DA for both types of blinds are the same at the point close to the window. At the point close to the interior wall, the DA of the new blinds is 9% higher than the DA of the existing blinds.
 - At the south orientation and at the 90° tilt angle, the new and existing blinds have the same performance at the point close to the interior wall, while at the point close to the window, the new blinds' DA is 37% higher than the DA of the existing blinds, given the research limitations. At the west orientation, the new blinds have 49% higher DA than the DA of the existing blinds at the point close to the window, and 22% at the point close to the interior wall, given the research limitations.
2. A comparison of the DA at the two points in the space shows that:
 - The **new** blinds have the higher DA at the point close to the window than at the point close to the interior wall for the south orientation for all tilt angles and for the west

- orientation at the 90° tilt angle. At the south orientation and at the point close to the window, the DA is higher by ~10% for the 0° and 45° tilt angles, and by ~20% for the 90° tilt angle. At the west orientation, the DA is the same at two points for the 45° tilt angle, and by ~20% higher at the 90° tilt angle at the point close to the window.
- The **patented** blinds show a uniform performance at the south-oriented facade since the DA is the same at the two measurement points. At the west-oriented facade, the DA at the point close to the window is 40% higher than at the point close to the interior.
 - The **existing** blinds at the south orientation at the 0° and 90° tilt angles have ~19% lower DA at the point close to the window, compared to the point close to the interior, while at the 45° tilt angle, the DA is ~9% higher than at the point close to the window. At the west orientation, the values of the DA are 0 for the 0° and 90° tilt angles at the point close to the window because the actual illuminance is out of the comfort zone. At the 45° tilt angle, the DA at the point close to the window is 9% higher than at the point close to the interior wall.
3. A comparison of the DA for the three blind tilt angles shows that:
- The **new** blinds have almost the same DA at the 0° and 45° tilt angles for the south orientation at both points in the space (~70% at the window point and 58% at the point close to the interior wall). The values of the DA drop for the 90° tilt angle by 10% at the point close to the window and ~20% at the point close to the partition wall. For the west orientation, the values of the DA drop by 10% for changing the tilt angle from 0° to 45°, and from 45° to 90° at the point close to the interior wall. At the point close to the window, the DA values are 10% higher for the 90° tilt angle than for the 45° tilt angle.
 - At the point close to the window at the south orientation, the **existing** blinds have a 19% higher DA at the 45° tilt angle than at 0° tilt angle and a 37% higher DA at the 45° tilt angle than at the 90° tilt angle. At the point close to the interior wall, the DA is 10% higher for 0° than for 45° and for 45° compared to 90°. At the west orientation, at the point close to the interior wall, the DA for the 0° tilt angle is 9% higher than for the 45° tilt angle and 22% higher for the 45° tilt angle than for the 90° tilt angle. At

the point close to the window, the values of the DA are 0 for the 0° and 90° tilt angles because the illuminance is out of the comfort zone.

4. A comparison of the DA for the two facade orientations shows that:

- The **new** blinds have higher values of the DA at the south orientation for all three blind tilt angles at both measurement points:
 - o For the 0° tilt angle, the DA value is 9% higher at the south orientation than at the west orientation at the point close to the interior.
 - o For the 45° tilt angle, the DA value is 31% higher at the south orientation than at the west orientation at the point close to the window, and 19% at the point close to the interior.
 - o For the 90° tilt angle, the DA is 9% higher for the south orientation than for the west orientation at both measurement points.
- The **patented** blinds also have higher DA values for the south orientation than for the west orientation. At the point close to the window, the values of DA are 9% higher, and at the point close to the interior, the values are 50% higher for the south orientation than for the west orientation.
- The **existing** blinds also have higher values of the DA for the south orientation than for the west orientation for all tilt angles and both measurement points:
 - o For the 0° tilt angle, the DA is 19% higher for the south orientation than for the west orientation at the point close to the interior walls, and 39% higher at the point close to the window.
 - o For the 45° tilt angle, the DA is 19% higher at the south orientation than at the west orientation at both measurement points.
 - o For the 90° tilt angle, the DA is 21% higher at the south than at the west orientation at the point close to the window, and 31% higher at the point close to the interior wall.

In conclusion, the **new** blinds have the higher DA than the patented and existing blinds at the south orientation for all tilt angles at both measurement points, given the limitations of this study. For the west orientation, the DA of the new blinds is higher than that of the other two systems for all tilt angles at the point close to the interior wall. The new blinds have the higher DA at the point close to the window, as is predicted for the south orientation and all

tilt angles. The new blinds have the uniform performance for 0° and 45° tilt angles, and a slightly lower performance at the point close to the window, and rapidly lower at the point close to the interior for the 90° blinds' tilt angle. The new blinds have higher values of the DA for all tilt angles and both measurement points for the south-oriented facade compared to the west orientation.

The **patented** blinds have the higher DA than the existing blinds at the south orientation and the point close to the window, while the existing blinds perform better at the point close to the interior for the west orientation. The patented system has the uniform performance at the south-oriented facade for both measurement points. The patented blinds have the higher DA for the south orientation than for the west orientation.

The **existing** blinds have the lowest performance for all tilt angles, orientations, and measurement points compared to the two other systems, given the research limitations. The existing system has the higher DA for the south orientation for the 0° and 90° blind tilt angles for both orientations. The existing system has a higher DA for the south orientation than for the west orientation for all blind tilt angles and both measurement points.

Given the research limitations, the new blinds have the highest DA overall, except for the west orientation at the point close to the window and for the 0° blinds' tilt angle, and that is the reason to select the new system for the application on the proposed building.

5.3.3.1. Analysis of expected results of daylight autonomy obtained by applying different control strategies

As explained in Section 5.3.1.2: Analysis of expected results of illuminance*days/year, p. 215, different control strategies of adjustment of the blinds' tilt angles will result in different levels of illuminance in the space. The values of daylight autonomy per year analyzed in the prior section are obtained by using the conventional control strategy. In a conventional control strategy, all slats have the same tilt angle regardless of their position in the window. If the advanced strategy is used, slats will have different tilt angles, depending on their position in the window. As explained in Section 5.3.1.2., the slats in the upper part of the window should have such tilt angles so that the slats redirect daylight into the ceiling and into the depth of the space. Assuming that the illuminance level in the interior space increases by

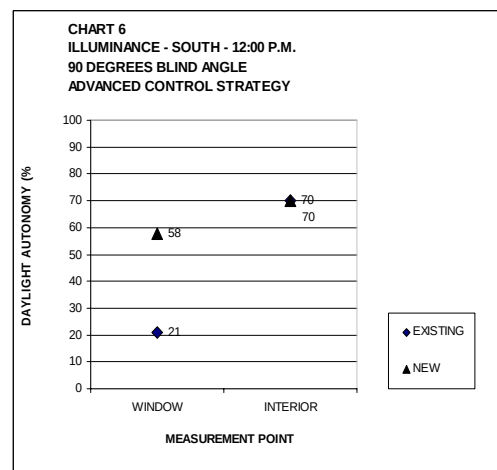
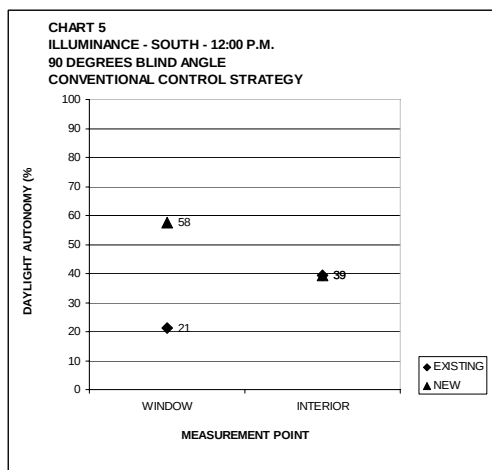
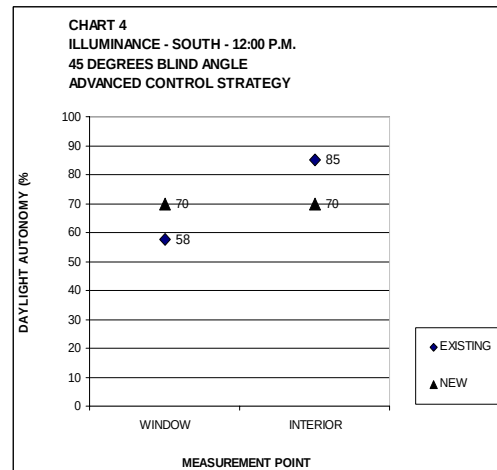
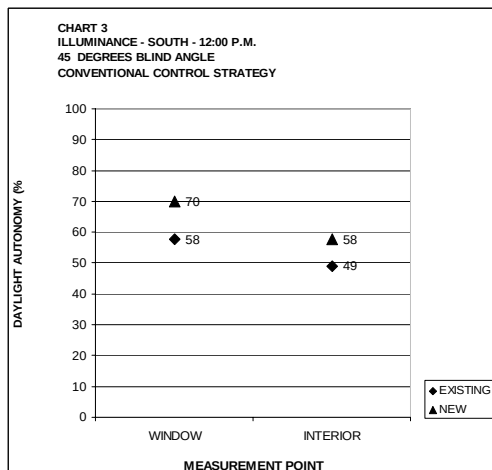
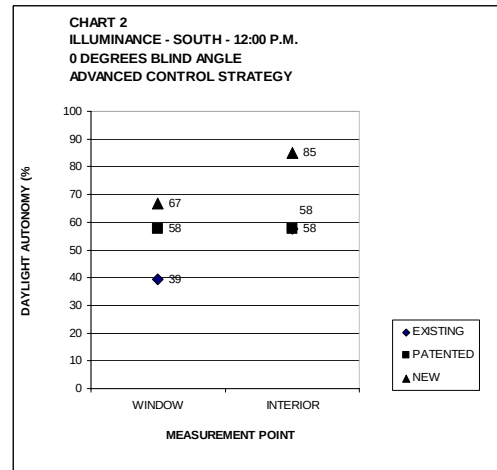
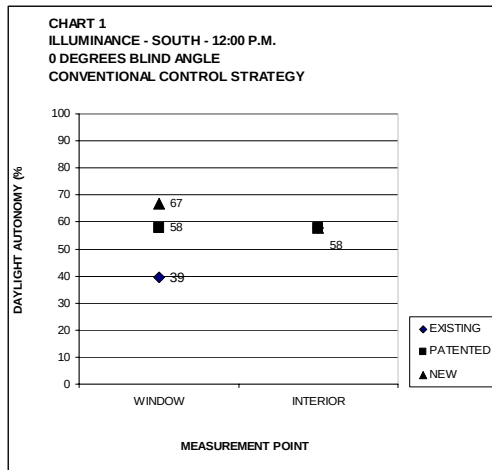


Figure 5-20 Charts for the DA for illuminance, at the south orientation for 0°, 45° and 90° blinds' tilt angles and two different control strategies

30% by using the advanced control strategy, it can be expected that the values of daylight autonomy per year will also increase for the new and existing blinds. Figure 5-20 consists of charts that represent daylight autonomy for the three types of blinds oriented to the south at 12:00 p.m. at the two measurement points in the space: one close to the window and the other close to the interior. Chart 1 presents the values of the DA for blinds that have a tilt angle of 0° in the case of a conventional strategy. Chart 2 presents the values of the DA for blinds that have a tilt angle of 0° at the lower part of window, and an angle of 15° inclined to the inside in the upper part of the window in the case of the advanced control strategy. A comparison of charts 1 and 2 shows that new blinds provide 32% higher values of the DA at the point close to the interior wall for advanced control strategy, compared to the conventional strategy. Also, the DA is higher at the interior point for 20% than the DA at the point close to the window. The existing blinds show the same performance, that is, the same DA at the point close to the interior wall for the both control strategies.

Chart 3 shows the values of the DA for the blinds that have an angle of 45° in the case of the conventional control strategy. Chart 4 shows the values of the DA for blinds that have an angle of 45° in the lower window part and an angle of 30° in the upper window part in the case of advanced control strategy. The new blinds provide 17% higher DA per year at the point close to the interior wall for the advanced control strategy, compared to the conventional strategy. In the case of the advanced strategy, the new blinds provide the same DA of 70% at the two measurement points, indicating a uniform light distribution in the space. The existing blinds provide 43% higher DA at the point close to the interior wall if the advanced control strategy is used. Also, the values of the DA increase in the depth of the space by 32%, compared to the point close to the window if the blinds are more open in the upper part of window, that is, if the advanced control strategy is used.

Chart 5 shows the values of the DA for blinds that have a tilt angle of 90° (completely closed) in the case of conventional control strategy. Chart 6 represents the values of the DA for the blinds that have a tilt angle of 90° in the lower window part and 45° in the upper window part in the case of the advanced control strategy. Both the new blinds and existing blinds provide 44% higher DA per year at the point close to the window wall for the advanced control strategy, compared to the conventional strategy. In the case of the advanced control strategy, the values of the DA are higher by 13% at the point close to the interior wall

than at the point close to the window for the new blinds due to the 45° tilt angle in the upper window part, which lets daylight in and redirects it to the ceiling and the depth of the space. The existing blinds have a 70% better performance at the point close to the window in the case of the advanced control strategy due to the blinds' tilt angle of 45° in the upper part of the window.

As concluded in Section 5.3.2.1., the advanced control strategy seems to improve the daylight levels in the depth of the space. The values of the DA per year increase at the point close to the interior wall compared to the values at the same point in the case of conventional strategy. Also, if the advanced control strategy was applied in this case study, the blinds' tilt angle will be larger (more open blinds) in the upper window part than the blinds' angle in the lower window part, resulting in the higher values of the DA per year at the point close to the interior wall than the values of the DA at the point close to the window.

5.4. SUMMARY

The **first** part of the chapter shows different ways of presenting the results of the case studies: from more complex charts to be used for a thorough analysis of the blinds' performance to simplified charts that help the user of the DMF to quickly analyze the blinds' performance and decide which blinds to apply on the particular building.

The matrixes of data (see Table 5-3, p. 191) show in a very complex way the results of the simulations. The matrixes include the shading device variables (type of blinds, blinds' tilt angle, and blinds' position), the performance parameters (illuminance and luminance) at two points in the space, and the date, time, and sky conditions variables. This way of presenting data is appropriate for a very detailed analysis of the blinds' performance.

Based on the information taken from the matrixes of data, charts (see Figure 5-1, p. 193) that present a comparison of illuminance*days/year and luminance*days/year for the three types of blinds are created. The charts present the values of illuminance*days/year (or luminance*days/year) based on the three sky conditions for each type of blinds, for two orientations (south and west), and two measurement points in the space (close to the window and close to the interior partition).

Another set of charts (see Figure 5-2, p. 198) is made based on the information taken from the matrixes of data. These charts provide a large amount of information about the performance of shading devices and are meant to be used only for discussion in this dissertation for a detailed analysis of such a performance. The charts present the effect of six variables on the blinds' performance: time, date, sky conditions, orientation of the facade, the blinds' position and blinds' tilt angle. A combination of these variables gives nine (or seven) sheets (see Appendix B.3, p. 416). Also, there are four sets of nine sheets and four sets of seven sheets. Each set combines the following parameters: performance (illuminance, luminance), facade orientation (south/west), measurement points in the space (close to the window and close to the interior wall).

The simplified tables are developed from the matrixes of data that include just selected results of the simulations for each type of blinds (based on the selected blinds' tilt angle and blinds' position) and for all analyzed dates, times, and sky conditions, as well as two performance parameters (illuminance and luminance) measured at two points in the space. The results of the simulations--actual illuminance and luminance--levels are converted to the values on the scale 0-1 to simplify an evaluation of the blinds. This approach of presenting data can be used by the user of the DMF and is shown in Tables 5-11 through 5-15, p. 204-206.

Another set of tables and charts (see Tables 5-16 through 5-19, p. 209) is made based on the matrixes of the data. The charts represent the values of the daylight autonomy (DA) per year for each type of blinds for two orientations (south/west) at two measurement points in the space (window, interior). A combination of these variables gives six charts of DA. The values of the DA are obtained based on the results presented in the matrixes of the data. Only the results of illuminance for:

- the three types of blinds
- a particular blinds' tilt angle
- the three dates in year
- the three sky conditions
- the two points in the space

are taken from the matrixes of data to calculate the average DA per year at one orientation, and for one blinds' tilt angle. These charts can be used for a simplified and quick analysis of the blinds' performance by the user of the DMF.

In the **second** part of the chapter, the analysis of the results of the case studies is explained. The analysis of the charts is performed that represent: 1) the values of illuminance*days/year and luminance*days/year for each type of blinds; 2) a comparison of their performance with the performance required by the standards; 3) an evaluation of the sky effect on the blinds' performance; and 4) a comparison between the performance for the south and west orientations, and for two points in the space for each type of shading device. This is found in Figures 5-5, p. 212 and 5-9, p. 220. The analysis shows that the new shading device system has the best performance compared to the other two systems due to its geometry and material, given the research limitations. The new blinds also meet the requirements of the standards for almost all sky conditions, except for cloudy sky conditions at the point close to the interior wall. Based on this analysis, the new shading device should be the preferred blinds for the application on the particular building, given the economic consideration and research limitations. Another step in the same analysis is to use the conversion tables, which also show that the new blinds have the best performance, given the research limitations.

The analysis of the results, which is presented in the charts (see Figures 5-10 through 5-18, p. 228-236) used in this dissertation, considers: 1) which type of shading device gives the highest/lowest values of illuminance/luminance; 2) do their performances meet the requirements of the standards; and 3) how major and minor variables represented in a particular sheet of charts affect the daylighting performance of each type of blinds. The analysis of these charts shows that the new shading device system has the best performance overall for most of the times, dates, and sky conditions, for both facade orientations, and for the three blinds' positions, given the research limitations. The new blinds meet the requirements of the standards for most of the conditions, except in December for cloudy sky conditions (when the values are lower than the minimum required by the standard) and for clear sky conditions at 4:00 p.m. (when values are higher than the maximum recommended by the standards if the blinds have the 0° tilt angle).

The analysis of the results that present daylight autonomy (DA) (see Figure 5-19, p. 253) compares the DA for the three types of blinds overall, the DA at two points of the space, for three blinds' tilt angles, and two facade orientations for each shading device type. The analysis shows that the new blinds have the highest DA compared to the two other types of blinds for all blinds' tilt angles and both measurement points at the south orientation, given the research limitations. At the west orientation, the DA of the new blinds is the highest only at the point close to the interior wall. The new blinds have a higher DA at the point close to the window than to the interior wall. They have a uniform performance for 0° and 45° tilt angles, while values drop for the 90° tilt angle. The new blinds have a better performance at the south orientation than at the west orientation.

6. CONCLUSIONS AND RECOMMENDATIONS

This research presents the development of the decision-making framework (DMF) that can be used both by the building designers and designers of the shading devices. Two decision-making frameworks are created in this study: the general DMF and specific DMF. The general DMF includes several specific DMFs, based on the different performance parameters: thermal, visual, acoustic, aesthetic, cost, and control. The specific DMF, created in this study, is a tool for an analysis of daylighting performance of the shading devices, that is, an analysis of what levels of illuminance and luminance in the space can be provided by the application of a particular shading device system. The specific DMF presents the process of the analysis of the daylighting performance in the selection of the existing shading device system, as well as the design of the new shading device system. The specific DMF is developed to better understand and validate the general DMF.

The case study that analyzes the three different shading device systems is performed to validate the specific DMF. A proposed office building located in Roanoke, Virginia, is tested for the south- and west-oriented facade for three seasons. An existing, a patented, and a new shading device system are simulated to find out what light levels in the office space are achieved by their application.

The software Autodesk VIZ 4 is used to simulate daylighting performance of shading devices. Autodesk VIZ 4 calculates the illuminance and luminance levels in the space, which is the output of the simulation. The results, which are obtained by the simulation for the three different shading device systems, are compared to find out which system has the best performance. Three different ways of analyzing the results of the case studies are used in this research, and all of them show that the new shading device has the best performance on average for all times, dates, sky conditions, facade orientations, and the blinds' positions and tilt angles, given the research limitations.

6.1. RESULTS AND CONTRIBUTIONS OF THE RESEARCH

Results - The most important results of this research are the two decision-making frameworks: the general DMF and specific DMF based on illuminance and luminance. The general DMF includes variables (independent, dependent and shading device variables) and

performance parameters (thermal, visual, acoustic, aesthetic, cost, and control) that need to be analyzed when selecting/designing the shading device system. The general DMF can be divided into several specific DMFs that analyze various performances of the shading device. The specific DMF, based on illuminance and luminance, proposes a methodology:

- For an analysis of the shading device daylighting performance, particularly to obtain illuminance and luminance levels in the space. To analyze daylighting performance of shading devices, the following elements are identified: independent, dependent, and shading device variables, performance parameters to be measured in the space, output of the simulation, and the ways of presenting the results.
- For making the decision about the selection of the shading device system with the best performance. The methodology for making the decision includes different ways of analyzing the results of the simulation and the process of making the decision, based on the analysis of the results.

The research also has the following results:

- The theoretical validation of the specific DMF proposes the process for the analysis of daylighting performances of shading devices, and it proves that the DMF has the ability to test the various shading devices and select the system with the best performance.
- A new shading device system is proposed by this research. The triangular cross section of the blinds and application of the clear plastic and silver reflective coating as the materials for the blinds utilize the principles of optical physics in the design. Given the limitations of this study, the proposed new blinds provide high illuminance and luminance levels in the space by redirecting light into the ceiling and deep into the space. Also, the new system provides a sufficient amount of daylight in all sky conditions, except in winter at 3:00 p.m. The new system provides a transparency of the facade since it is made of clear plastic.

Contributions - The main contribution of this research is the decision-making framework, that is, the methodology for analysis of the shading device performance and the process of making the decision about the application of the specific shading device system. The general DMF includes possible variables and performance parameters to be considered when analyzing the shading device performance. The general DMF is a tool for overall

analysis of the blinds in the process of the selection and design of the blinds. The specific DMF, based on illuminance and luminance, is a useful tool for:

- Users of the general DMF: the specific DMF helps users to better understand how to use the general DMF.
- Building designers because the specific DMF helps them to understand:
 - Which methodology to use when making the decision about selecting the best shading device among the several existing systems.
 - Which parameters to consider when analyzing the shading device daylighting performance.
 - How to apply principles of daylighting in the design of the building, facade, and the shading device from the conceptual phase to the detail phase of design.
- Manufacturers of shading devices: the specific DMF helps them to understand which variables affect daylighting performance so that they can consider these variables while designing the new shading device systems. By using the specific DMF, the designer of shading devices can improve daylighting performance of the new systems.

This research is also significant because it proposes a new design of blinds. In this case, the role of the manufacturer is performed. Based on the limitations of this research, the new system seems to indicate much better behavior than the existing shading device systems. It seems that the new system application solves the problem of an insufficient amount of daylight in the cloudy sky condition and in the depth of the space.

The advanced control strategy (split control) for the blinds' tilt angle adjustment, which is proposed by this research, is also the contribution. Based on the limited modeling in this research, it seems that split control strategy can have significant benefits to increase illuminance and luminance level in the space, especially in the depth of the space, and to reduce glare.

6.2. CONCLUSIONS OF THE RESEARCH

The following conclusions can be drawn from this research:

- The general DMF is created. The general DMF is a tool for overall analysis of the blinds' performance in the process of the blinds' selection/design. The general DMF

consists of the following components: variables (independent, dependent, and shading device variables) and performance parameters (thermal, visual, acoustic, aesthetic, cost, and control). The general DMF also includes the process for making the decision, explained at the conceptual level.

- The specific decision-making framework is developed, and it can be used for making the decision about the selection of a shading device with the best daylighting performance. The specific DMF proposes a methodology that is a useful tool for the architect/building designer, as well as the manufacturer of shading devices. The specific framework consists of the following major components: input information (independent, dependent, and shading device variables) and output information (actual values of illuminance and luminance in the space). The specific DMF also includes ways of presenting the output information, that is, the results of the simulations and the process of making the decision.
- The theoretical validation of the specific DMF is done by performing the case study. Daylighting performance for the three types of blinds, installed at an office space in Roanoke, Virginia, is simulated by using the software Autodesk VIZ 4, that calculates illuminance and luminance levels.
- The theoretical validation shows that the specific DMF works and provides a concept for both the analysis of the daylighting performance of shading devices and for making the decision about the selection of the best possible shading device system, based on the output information.
- The DMF is an algorithm that can be used for developing the computer simulation tool for making the decision about the selection of the shading device.
- Given the limitations of this research, the new shading device system proposed by this research seems to have the best daylighting performance, compared to the performance of the other two alternatives tested in this research.
- A transparent shading device can provide transparency of the wall, which is the goal of architects when using a curtain wall system. Optical physics was studied to understand how natural behavior of light can be used in the design of transparent blinds (see Appendix A.1: Basic Optical Physics, p. 286). Depending on the required lighting conditions in the space, there is a great potential in using the principles of

optics in the design of blinds to stop the light or redirect it into the depth of the space. For example, light is either reflected or refracted through the transparent material depending on the incident angle of light and index of refraction of material (see Appendix A.1: Basic optical physics, Section A.1.1.1: Reflection/refraction of light). If the tilt angle of the blinds is controlled so that incident angle of the sun always equals the angle of total internal reflection, all light can be reflected from the blind to the outside space. In this case, protection from glare and the direct sun can be provided. Also, if light needs to be partially reflected and partially refracted, then the angle between the sunlight and the surface of the blinds should be controlled to allow both reflection and refraction. By controlling that angle, the amount of reflected or refracted light is also controlled. The amount and direction of refracted light also depends on the index of the refraction of material. In the case of the transparent material use for the manufacture of blinds, the index of refraction can be controlled by careful design of chemical and physical structure of material.

Using the principles of light polarization in the blinds' design, light can be stopped partially or completely by the blinds providing a desired darkening of the space and privacy (see Appendix A.1: Basic optical physics, Section A.1.1.6: Polarization of light). Applying the two sheets of transparent material, one as a polarizer and the other as an analyzer, light can be stopped completely. Using multiple attached sheets of transparent materials, light can be partially polarized, that is, part of the light will be reflected outside and completely polarized, and part of the light will be refracted through the material and partially polarized (see Appendix A.1: Basic optical physics, Section A.1.2.1: Polarization of light).

Application of particular shapes of the cross section of blinds affects the reflection and refraction of the light. In this research, principles of light refraction through the glass prism were applied for the design of the new blinds that have a triangular cross section to improve the level of light in the space (see Appendix A.1: Basic optical physics, Section A.1.1.2: Reflection/refraction through glass prisms). If the shape of lenses is used for the cross section of blinds, the light refracted through the blinds will be redirected only to one point (focal point). The light concentrated in the focal point can be easily controlled, for example, reflected back to the outside space or

transmitted into the interior space (see Appendix A.1: Basic optical physics, Section A.1.1.5: Refraction through the lenses). The principle that light is totally reflected from the mirror at the same angle of incidence can be used in the blinds' design (see Appendix A.1: Basic optical physics, Section A.1.1.3: Reflection at the plane and spherical mirrors). The particular coatings applied on the surface of the blinds will function as a mirror and totally reflect the light. If the blinds' tilt angle is 90° , all light will be reflected to the outside, completely protecting the space from the direct sun. If the blinds' tilt angle is 0° , light will be reflected to the interior space. Depending on the light incident angle, reflected light can be redirected to the ceiling by the reflection from the coating. In this research, triangular, transparent blinds, with a silver reflective coating applied on one surface of the blind, were designed and tested (see Section 4.3.10.3: New system). These blinds provided higher illuminance levels in the space compared to the blinds without reflective coating. Application of the principles of optical physics in the blind design can significantly improve the blinds' performance, and the study in this area is the objective of future research.

- Transparent materials and their properties were investigated in this research, and it can be concluded that there is a potential of manufacturing blinds made of transparent materials, by properly designing their chemical and physical structure and manufacturing process. Glass and plastics were studied to investigate the possibility of their use for the manufacture of blinds (see Appendix A.2: Transparent materials used for the manufacture of shading device slats). There is also a potential to invent transparent materials with improved properties that will simplify the process of the manufacture of blinds and improve the blinds' daylighting performance. Smart materials' properties and application were studied, and it can be concluded that smart materials, even though still expensive, can have an application in the blinds' production. The idea of changing the blinds' shape by using smart materials will be investigated in the future (see Section 6.3: Future research).
- Control of the blinds' position and tilt angle significantly affects the blinds' performance and the illuminance and luminance level in the space. The advanced, split control strategy was investigated in this research just by predicting the blinds' performance. It is assumed that light level in the depth of the space will increase if the

split control strategy of blinds is used (see Sections 5.3.1.2: Analysis of expected results of illuminance*days/year obtained by applying different control strategies, and 5.3.4.1: Analysis of expected results of daylight autonomy obtained by applying different control strategies). The blinds in the lower window part can be partially closed to protect space from direct sunlight in the space and glare. Blinds in the upper window part can be completely open to redirect light into the ceiling and the depth of the space. The advanced control strategy is not validated in this dissertation, but it can be the objective of future research (see Section 6.3: Future research).

6.3. FUTURE RESEARCH

After development of the general decision-making framework, this research focuses on the analysis of daylighting performance of the shading devices and developing the specific decision-making model for the selection of shading devices, based on their daylighting performance only. However, several possibilities for future research can occur from this project:

- Experimental validation of the decision-making framework. In this research only theoretical validation of the specific DMF, based on illuminance and luminance, is conducted. The Autodesk VIZ 4 software is used to calculate illuminance and luminance in the space as a result of the application of the three different shading device systems. The objective of future research is to conduct experimental validation of the DMF to see how the experimental testing of the blinds collaborates with theoretical validation, that is, with computer simulation of the blinds.
- Development of the specific DMFs for the rest of the performance parameters for shading devices introduced in the general DMF (see Figure 3-2), such as thermal, acoustic, aesthetic, cost, and control systems, and the remaining visual performance parameters. The first idea of this research was to design the complete decision-making model for the selection and the design of the shading device system. The decision-making model would include possible parameters that can influence the performance of the shading device, as well as interactions among the variables. The model shown in Figure 3-2 is the first attempt to develop the complete decision-making model. This model shows the complexity of the problem and the need to focus the research on only one performance

parameter, which is daylighting performance in this research, while other performance parameters can be the scope of future research. The problem's complexity also points out the necessity to divide the design of the decision-making model into smaller parts. For example, several separated, detailed decision-making models for the selection/design of the shading device should be done, based on the shading device's particular performance, such as thermal, visual, acoustic, aesthetic, cost, control, and so forth. Added together, these individual decision-making models should form the complete, overall decision-making model for the shading device selection and design. Since daylighting performance is not the only criteria to be considered in the process of the selection/design of the shading device, all other possible performance requirements (thermal, control, cost, and so forth) ideally need to be met.

The specific decision-making model developed by this research is designed as a part of a more complex decision-making model for the selection/design of the shading device. Although the model focuses only on the shading device's daylighting performance, variables used in this decision-making model can also be used in the general, complex decision-making model, and they can affect other performance parameters that are not investigated in this model. Since the variables and performance parameters that are part of the general, complex decision-making model also can influence daylighting performance, this decision-making model takes into consideration such variables and performance parameters and allows for the addition of these factors as "plug ins."

A good approach in achieving these goals might be to start with mapping the general decision-making model which will:

- Include possible variables (independent, dependent, and shading device variables) and performance parameters, and
- Define relationships and interactions between them but on a general level, not a detailed level.

The DMF shown in Figure 3-2 is an example of the general decision-making model that shows possible variables, performance parameters, and interactions between them, which are relevant in the selection and the design of the shading device.

In the next step, one performance parameter (which, in this research, is daylighting performance and in future research is thermal, cost, and so forth) should be investigated

in detail to find possible factors that affect this particular performance parameter. These factors should be well defined, and the way of measuring the factors should be determined. Variables that affect performance parameters, as well as interactions between them, should be identified and described.

The same approach, which is used in this research, can be used in designing specific, partial decision-making models for other performance parameters and variables that influence shading device performance. The designs of these decision-making models is the objective of future research whose results can be added later as “plug ins” to the general decision-making model.

- Software for the DMF for shading devices: the specific DMF created in this research is a methodology that can be used as a basis for development of software. The software will be used for making the decision about the selection of the shading device, based on its daylighting performance. As the research expands in the future and investigates other performance parameters (thermal, cost, control, and so forth) in detail, resulting algorithms can be used for developing additional software components that are related to these performance parameters. These components can just be added together to form complete software for making the decision about selection of the shading devices. Also, such software should be compatible with other software that are used in the decision-making software for the entire building design (such as Building Design Advisor software).
- Lighting control strategy: appropriate lighting control strategy is necessary for meeting the daylighting performance requirements for the shading device. The daylighting control systems (DCS) can be linked to the entire building energy management system. The DCS controls the illuminance level in the space:
 - If the actual illuminance level in the space is lower than the designed illuminance level, then the control system will adjust/open blinds to provide a sufficient amount of daylight in the space. If the light levels in the space are above the maximum recommended by the standard, the control system should close blinds to avoid the occurrence of glare.

- If it is not possible to provide a minimum designed illuminance level in the space by adjusting the blinds' tilt angle, then the DCS will activate electric lighting as a supplement to the daylighting in the space.

The DCS is affected by the following factors:

- Designed illuminance level in the space
- Presence of the occupants in the space
- Climatic conditions

The designed illuminance level is determined by the standards, codes, and recommendations, based on the type of task performed in the space and age of the occupants. For example, if the space has multiple functions, such as an assembly room, there can be different control strategies, depending on the activity in the space. If there is a meeting that involves writing, the designed illuminance level will be 500 lx. If there is a video projection in the room, the designed illuminance level will be 100 lx, and the DCS should be able to switch from one designed condition to another. It means that blinds should be closed or open, depending on the designed illuminance level for the particular task.

If the occupants are present in the space, the DCS needs to be applied, but if the occupants are absent from the space (especially during the non-working hours), then blinds do not need to be adjusted for daylighting purposes and the electric lights should be turned off.

Climatic conditions that affect the DCS are as follows:

- Outdoor illuminance level (horizontal and vertical)
- Sun angle (azimuth and altitude angles)
- Sky conditions (clear, partly cloudy, cloudy)

The values for these variables are measured by the sensors and sent as an input to the control system. Based on the values of the outdoor climatic conditions and the values of the indoor illuminance levels, the control system will send a signal to the motor that adjusts the blinds' tilt angle. The input for the control algorithm provided by the user of the DMF includes:

- Maximum and minimum illuminance levels in the space, that is, the designed illuminance

- Frequency of the blinds' adjustment

Input for the control algorithm provided by the sensors includes:

- Actual illuminance level in the space – by ceiling photosensors
- Sun angle
- Outdoor illuminance
- Sky conditions
- Blinds' tilt angle

Based on the input information, a computer sends information for adjusting the blinds position in order to:

- Provide the designed illuminance level
- Protect the space from the glare

If the minimum designed illuminance can be provided by daylighting, the control strategy that will adjust the blinds' position is sufficient. If the designed illuminance level cannot be provided only by daylighting, then the control strategy needs to:

- Adjust the blinds' position to provide maximum possible illuminance from daylighting.
- Activate the electric lights to supplement daylighting to accomplish the designed illuminance level.

Since the daylighting illumination level varies continuously, the automatic control system for dimming electric lights is the most appropriate strategy. The dimming system provides smooth and continuous variation in the illumination level in the space. Based on the input from the daylighting sensor, the control system activates the dimming system for the electric lighting.

To apply various lighting control strategies, the space must be divided into lighting control zones. For example, one zone can include the areas close to the window wall, which has the highest illuminance level. Daylighting can provide a sufficient illuminance level in this zone. Since the illuminance level decreases with increasing the distance from the window wall, the electric lighting may be needed to supplement daylight in the depth of the space. This area can be defined as another lighting zone since the control strategy differs from the one applied in the zone close to the window wall.

- The advanced, split lighting control strategy, which provides different tilt angles of the blinds at different heights of the window. All the slats of the shading device usually have the same tilt angle. There is a possibility for the improvement of the shading device daylighting performance by adjusting the shading device slats for the different tilt angles, based on the slats' position relative to the height of the window. For example, considering various daylighting performance requirements for a particular space, daylighting needs to be:
 - Reflected to the outside space in the lower part of the window to protect the space from glare.
 - Reflected to the interior space ceiling in the middle part of the window to provide a sufficient amount of daylight and protection from glare.
 - Reflected into the depth of the room in the higher part of the window to provide a sufficient amount of daylight.

The control strategy should be designed to include various adjustments of the slat tilt angle, based on the slat position relative to the window height.

- Optimization process framework: the DMF developed in this research has the potential to become an optimization process framework. In order to optimize the selection of the most appropriate shading device system, there must be a database of the existing shading device systems and the possibility to add the new shading device systems to the library. Based on input, such as the building location, date and time of the day, and the three-dimensional model of the building, the daylighting simulation software (Autodesk VIZ 4) would perform the daylighting calculations for all shading device systems stored in the database (library). Based on these calculation results, the DMF will choose among all shading device systems stored in the database, the one which gives the best performance (for example, the one that has the actual daylighting performance values closest to the values defined by the standards and codes) for the particular location (climate, sun, sky conditions) and the building/space type.

Since there are several parameters that define the shading device system, it will be advisable if the user can have input on some parameters. It means that the user can decide about the blinds' material, for example, and then this parameter is a fixed constant. The daylighting simulation software will then analyze only the shading device systems made

of aluminum, for example. Another example will be if the user can decide to choose blinds that will be made of aluminum and are 1/2" wide and installed between two panes of glass. This decision, made in the beginning, limits the number of possible choices for the shading device system so the daylighting simulation software will analyze only the shading device systems with the properties defined by the user. Various blinds' tilt angles should also be considered in the optimization process. This DMF can eventually move toward an optimization process framework if there is an option for the user to:

- Do input for either the new or the existing shading device system or
- Use the database of the existing shading device systems or
- Add the new shading device system to the library.

Currently, this DMF allows the user to do only the graphical input of either the existing or new systems. But the DMF can be designed to have the database of the shading device systems. This means that every time the user makes an input of the particular shading device system, it can be added/saved to the library, or the database of the shading device systems can be made by someone else and just added later to the DMF.

- Transparent shading device: one of the results of this research is a new system of shading devices. The design of the blinds with a triangular cross section and made of clear plastic with a silver reflective coating is a first attempt to create a transparent shading device. Since these blinds were tested only for daylighting performance, future research can be conducted to investigate the thermal and visual performance of this system, as well as life-cycle cost and possible control strategies. In addition to the transparent blinds proposed by this research, the design of various transparent systems that use the principles of optical physics for controlling daylight transmission, reflection, refraction, and so forth, can be done in the future. The goal is to get the new system that will provide a performance competitive with the performance of shading devices currently available on the market.
- “Universal shading device”: future research on the shading devices that work for 12 orientations, with south, north, east, and west as the main orientations and a 30° angle difference among the other facade orientations. For south- or near south-(±10°) oriented walls, the horizontal shading devices are considered the most efficient solution. For east and west orientation, the vertical position of shading devices currently gives the best

protection. Sun protection is the most important in summer. On June 21 and July 21, the west and east orientations receive two times more sun radiation than the south orientations. In summer, then, the concern about shading should be for east and west orientations rather than for the south-oriented wall. Since the goal is to design “universal” or “near universal” shading devices that will serve all 12 orientations, research on the most efficient position of a shading device needs to be done. Shading devices should also work for different climates (for example, four climates in the United States) and be applicable for different types of buildings (commercial, residential, educational, and so forth).

- Shading device as a solar collector in the double-skin facade: the new system of shading devices, as a part of the double-skin facade, will not be used for rejecting sun energy, which is the main function of the currently available shading device systems. The new shading devices will be used for collecting solar energy and supplying energy to a building’s mechanical systems. The new shading devices will absorb short-wave energy and convert it into other forms of energy, such as long-wave energy (heat), which is by convection transferred to the air in the cavity. This air can be used in the heat exchanger to preheat ventilation air in winter. In summer, the air from the cavity is exhausted to the outside. The shading device in the double-skin facade needs to absorb sun radiation. Energy efficiency of the double-skin facade, with a shading device that functions as a solar collector, can decrease the cost of the energy needed for building heating, cooling, and lighting.
- Investigating various materials to be used for the production of the blinds:
 - Materials that will be basically transparent, but will provide the desired darkening of the material, and, as a result, darkening of the space as well as privacy. Materials should have a particular chemical structure that will change, based on the effect of the outside condition, such as the outdoor illuminance level or sun radiation intensity. For example, if they are too high, the material structure will change so the blinds become darker or translucent/opaque to protect space from overheating and high light levels.
 - Smart materials, such as nitinol that have the capability to change their structural properties and shape, and control their motion as a response to an electrical or magnetic field or temperature. The idea is to apply smart materials for the production

- of the slats of the shading device so that the slats can change their shape based on, for example, the sun angle or sun radiation intensity. In this way, a new approach in control of the blinds' tilt angle will be used. At this moment, smart materials are still very expensive for the mass production, but in the future, if their price drops, there is a possibility for their application for the manufacture of blinds.
- In relation to the control strategy proposed for future research, the “different blinds’ tilt angles at the different heights of the window” objective can be to investigate whether or not different materials for blinds can be used at different heights of the windows to improve the desired performance.
 - Self-cleaning system for the shading device in the double-skin facade: there is a problem of cleaning the cavity of the double-skin facade, as well as the components installed in the cavity, such as the blinds, the mechanism for the blinds’ movement, and glass surfaces oriented to the cavity. By investigating the possibility of an application of the self-cleaning systems in the double-skin facade, the cost and time of cleaning can be reduced. Also, the width of the cavity in the double-skin facade can be decreased since there will not be a need for people to walk through it in order to clean it. The self-cleaning approach will change the structure of the double-skin facade, decreasing the amount of the material used for its construction, resulting in the lower cost of the double-skin facade.

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APPENDIX A - LITERATURE REVIEW

A.1. BASIC OPTICAL PHYSICS

A.1.1. OPTICAL PROPERTIES OF LIGHT

When light strikes a material, four situations can occur. Light can be:

- absorbed so its energy is converted into different forms of energy
- transmitted through the material
- scattered, emerging from the material in all directions
- reflected from the material surface

A.1.1.1. Reflection/refraction of light

Refraction and reflection of the light generally accompany each other. Different wavelengths are reflected to different degrees, that is why white light, which is composed of different wavelengths, can be separated into the different colors of the rainbow.

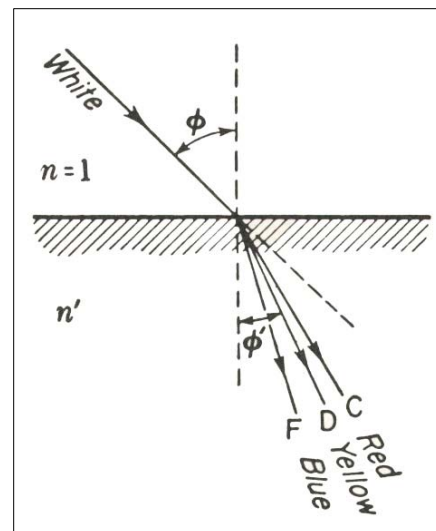
Refraction of light depends on the wavelength, as well as on the frequency. Also a wavelength influences the wave speed so that it causes a separation of white light into the colors of the rainbow. Generally, the shorter the wavelength of light, the more slowly light travels. The index of refraction increases as the frequency of the light increases. Dispersion of light is the dependence of refraction on the wavelength of light.

For light perpendicularly incident from the air, which has an index of refraction, $n=1.5$; only 4% of the incident light is reflected. The intensity of the reflected light varies with the angle of incidence (Fishbane, Gasiorowicz, & Thornton, 1993).

On the other hand, when light reaches a glass surface at an angle that exceeds the critical angle, the reflection is total. If the angle of incidence is just right, the reflected light is fully polarized.

White light separates into its component colors by refraction. Refracted rays of different colors have a different angle of refraction ϕ' . The refractive index of media n' also varies with color (see Figure A-1).

Figure A-1 Refraction of the light ray



When a light ray strikes the boundary that separates two different media (for example, air and glass), part of the light ray will be reflected into the first medium and part will be refracted as it enters the second medium (see Figure A-2). The angles of the incident ray and

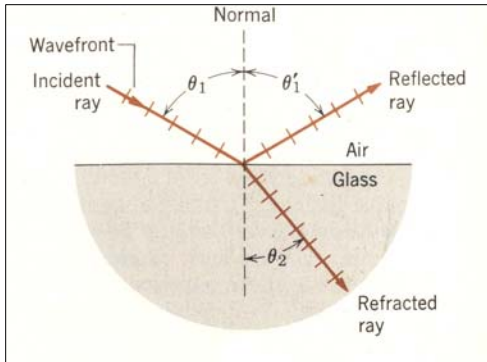


Figure A-2 Reflection and refraction of light

reflected ray are equal ($\theta_1 = \theta'_1$). The refracted ray lies in the plane of incidence, which is defined as a plain that contains an incident ray and normal to the surface. The incident plane is perpendicular to the interface that separates two media.

Refraction between the angle of incidence and angle of refraction is defined by Snell's law, which states that the ratio between sine of the angle of incidence and sine of the angle of refraction is constant and equal to the ratio of the refractive indexes of two media n_1 and n_2 :

$$\sin \theta_1 / \sin \theta_2 = n_2 / n_1$$

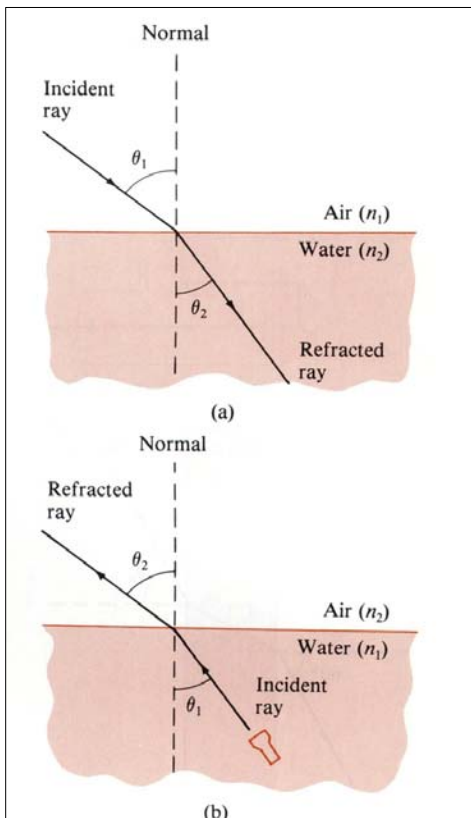


Figure A-3 shows a light ray passing from air to water (a) and from water to air (b). The ray bends toward normal when entering a more dense medium in which it travels slower (from air to water). The ray bends away from normal when entering the medium where it travels faster (from water to air).

Figure A-3 Refraction of light (a) from air into water and (b) from water into air

As the light passes from a less dense medium (air) to a more dense medium (water, glass), the angle of refraction will always be smaller than the angle of reflection. Since the incident ray angle increases, there will be a situation at which refracted ray points along the surface and the angle of

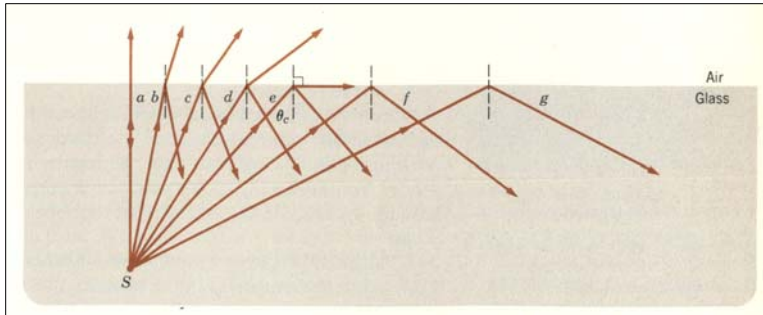


Figure A-4 Total reflection

surface and the angle of refraction is 90° . The angle of incidence for which the angle of refraction is 90° and reflection is total is called the critical angle. For all angles of incidence greater than the critical angle, refraction will

not occur (see Figure A-4).

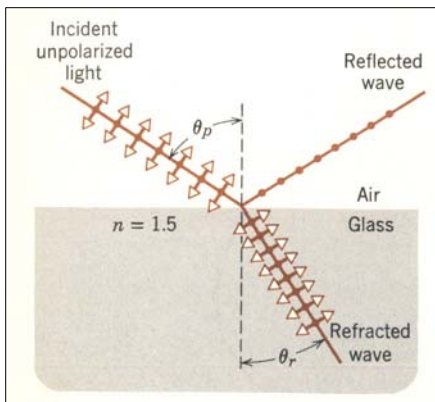


Figure A-5 Polarization of light

Light can be partially or completely polarized by reflection. For a particular angle of incidence, the reflected light will be completely polarized and transmitted light will be partially polarized. The light vector has two components (see Figure A-5):

- Perpendicular component (shown by dots), which is perpendicular to the plane of incidence.
- Parallel component (shown by arrows), which lies in the plane of incidence.

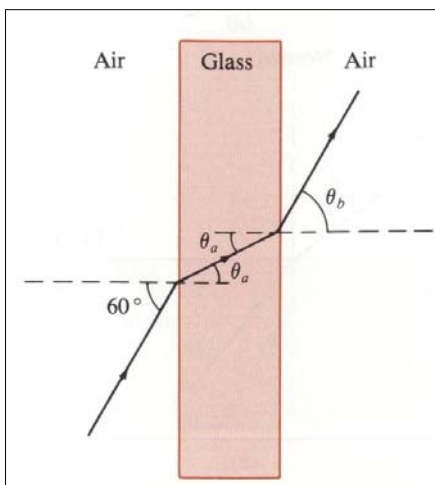


Figure A-6 Refraction of light through plane glass pane

For glass, there is a particular angle of incidence at which the reflection coefficient for the parallel component is 0. This angle is called the polarization angle. The beam reflected from the glass is polarized with its plane of vibration at the right angle to the plane of incidence. It is experimentally found that at the polarizing angle reflected and refracted beams are at right angles. When a light ray passes through a glass pane with plane surfaces that are parallel to each other, it emerges parallel to its

original path but with lateral displacement, which increases as the angle of incidence increases (see Figure A-6).

A.1.1.2. Reflection/refraction through glass prisms

Newton was the first scientist who made careful measurements of light transmission through a prism (see Figure A-7).



Figure A-7 Light transmission through a prism

He discovered that when a thin beam of light strikes a prism, the light is separated into red, orange, yellow, green, blue, and violet colors, which creates a rainbow (Fishbane, Gasiorowicz, & Thornton, 1993). If each of these colored beams is then projected on a second prism, all of them will be refracted, but further change in their color will not occur (see Figure A-8).

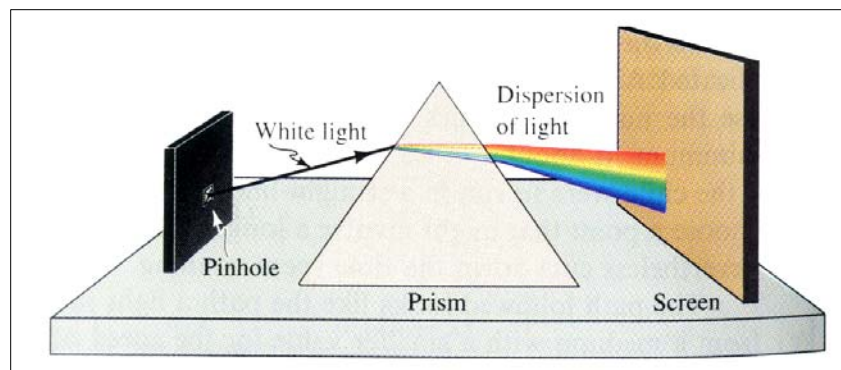


Figure A-8 Light refraction through a prism

In this case, light is refracted twice in the same direction so that the emerging light beam will appear as a full spectrum in which the violet light is refracted the most and the red the least (see Figure A-9).

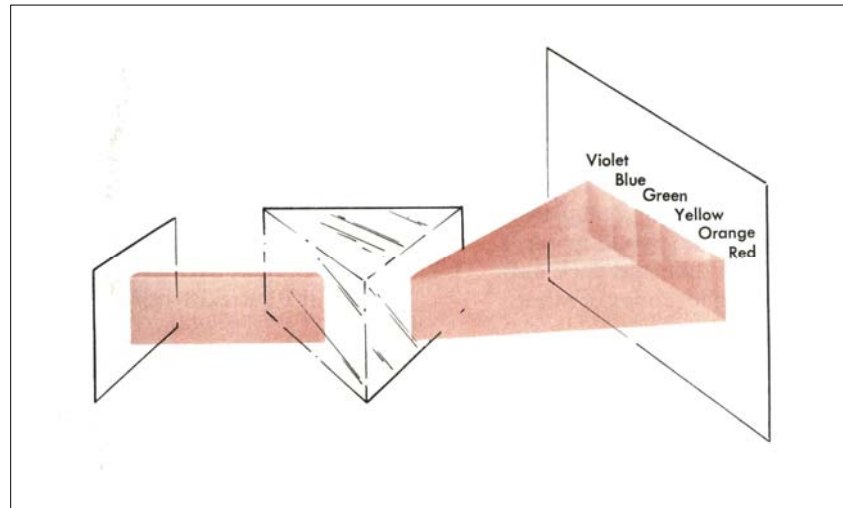
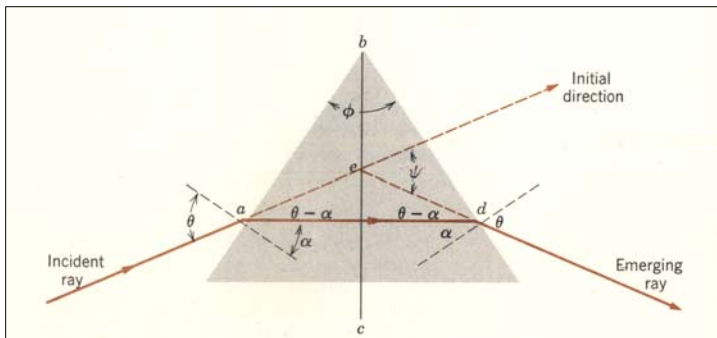


Figure A-9 Refraction of light through a prism



In a prism that has two surfaces that are inclined, there is a particular angle between the incident and emergent rays, which is called the angle of deviation Ψ (see Figure A-10).

Figure A-10 Refraction of light through a prism

Optical properties of glass prisms should also be considered as basic principles that can be used in the shading device design.

Jenkins and White (1976) show three forms of glass prisms, each of which has two angles of 45° and one of 90° (see Figures A-11, A-12, A-13). Light usually enters perpendicularly to one of the shorter faces, then it is totally reflected from the hypotenuse, and finally it leaves at right angles to the other short face (see Figure A-11).

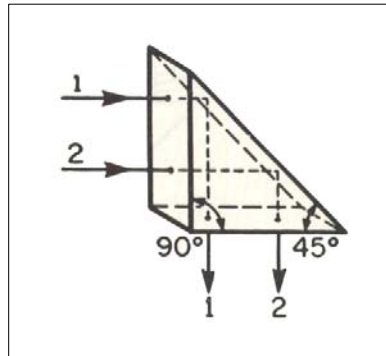


Figure A-11 Total reflection prism

Some prisms may also be used in the way shown in Figure A-12. Light enters perpendicularly to the hypotenuse. Then it has been reflected from one of the shorter faces, and then it is reflected from the other shorter face. After that it leaves at the right angle to the hypotenuse.

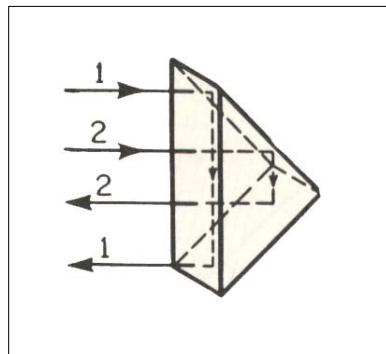


Figure A-12 Total reflection prism

The Dove prism (see Figure A-13) interchanges the two rays. Light is refracted by one of the shorter faces. Then it is reflected from the hypotenuse, and then it is refracted again but by the other shorter face. After that, it finally leaves the prism.

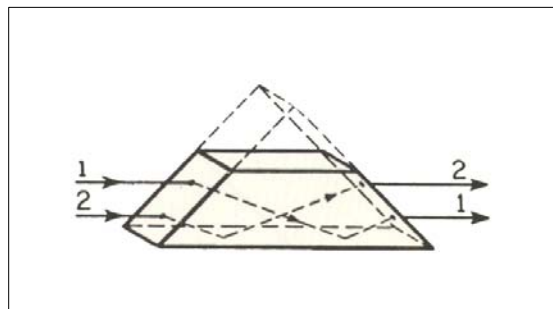


Figure A-13 Dove prism

These principles of light reflection and refraction through a glass prism can be used for different climate conditions and required strategies for the double-skin facades' shading systems.

Prismatic louvers can be moveable so that they can change the position by following the movement of the sun throughout the year, for example, for different seasons. In summer, protection of the space from overheating is required so that the shading device should totally reflect sun radiation, but it also should allow the maximum daylight to penetrate the window. The prism's shape and position, as shown in Figure A-12, would be used for summer conditions. In winter, sun radiation should enter the building as much as possible so that prism louver, as shown in Figure A-13, would be applied for this condition. In transition periods, such as spring and fall, the case shown in Figure A-12 can be used.

A.1.1.3. Reflection at the plane and spherical mirrors

Figures A-14 and A-15 show a spherical wave that strikes the plane mirror. A source of light (O) and light as a spherical wave is reflected from the mirror. If the reflected rays are extended behind the mirror, they will intersect at the point which represents an image (I) of the light source. Distances of the object (light source) and image from the mirror are equal.

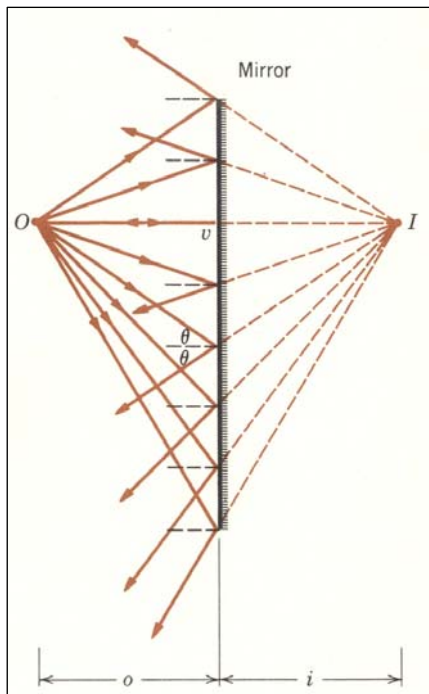


Figure A-14 Reflection of light – plane mirror

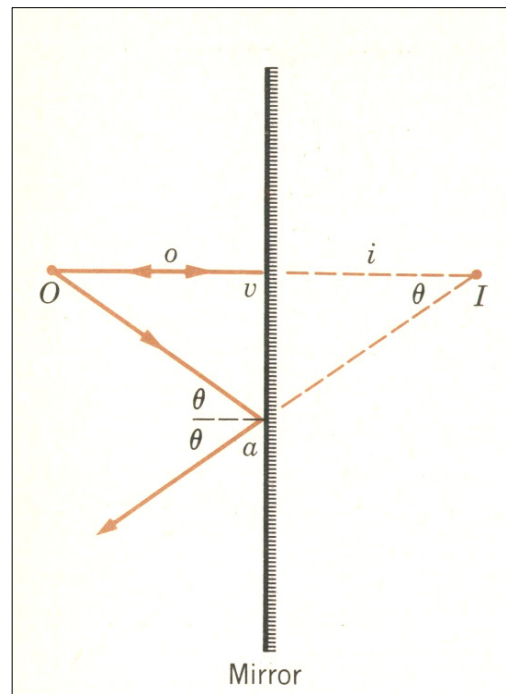


Figure A-15 Reflection of light – plane mirror

Figures A-16 through A-19 show spherical waves that strike either a concave or convex spherical mirror. In the following pictures, O is the object – light source and I is the image of the object. The convenient reference axis is a line that passes through the object, its image, and the center of curvature (C). A light ray from the object strikes the mirror at the particular angle of incidence and is reflected back and passes through the image. Angle α is the angle between a light ray and the convenient reference axis. The principle of reflection of light at a spherical mirror holds in the following cases:

- Concave mirrors (see Figure A-16)
- Convex mirrors (see Figure A-17)
- If the incident light is caused to converge toward a virtual object (see Figure A-18)
- If the incident light is caused to diverge from a real object (see Figure A-19)

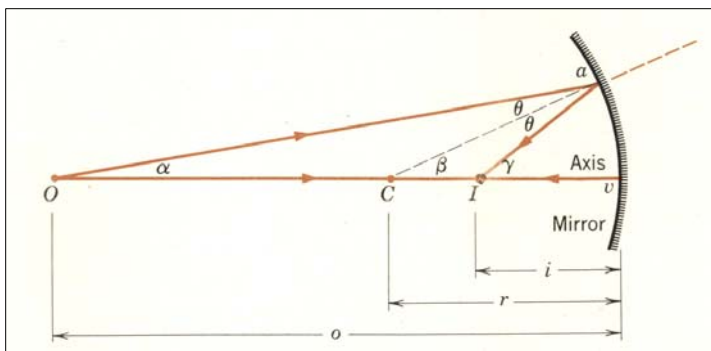


Figure A-16 Reflection of spherical wave light – spherical concave mirror

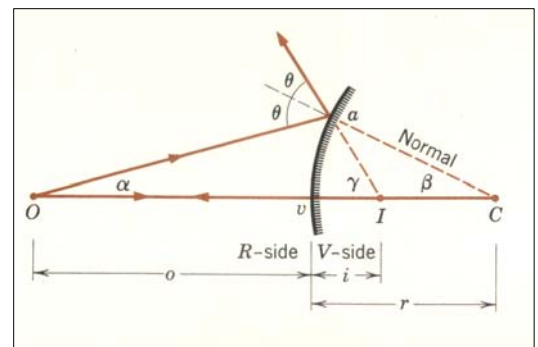


Figure A-17 Reflection of spherical wave light – spherical convex mirror

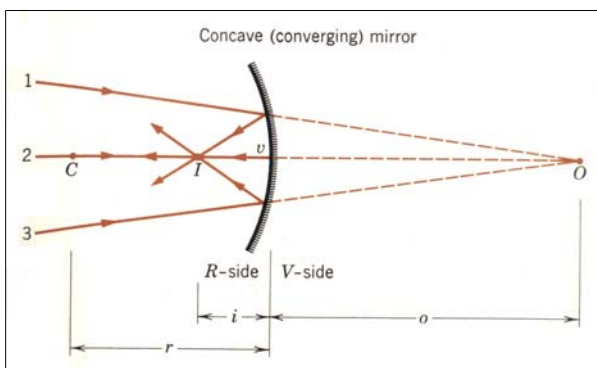


Figure A-18 Reflection of spherical wave light – spherical concave (converging) mirror

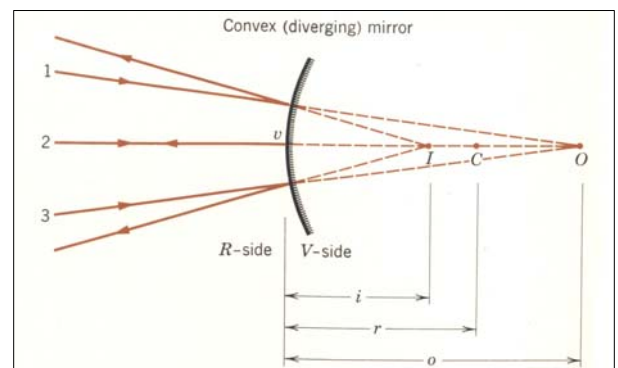


Figure A-19 Reflection of spherical wave light – spherical convex (diverging) mirror

When parallel rays of light strike a mirror, rays will be reflected and pass through the image point – the focal point F of the mirror. Figure A-20 shows reflection of the parallel rays of light for the concave spherical mirror, and Figure A-21 shows reflection of light for the convex spherical mirror.

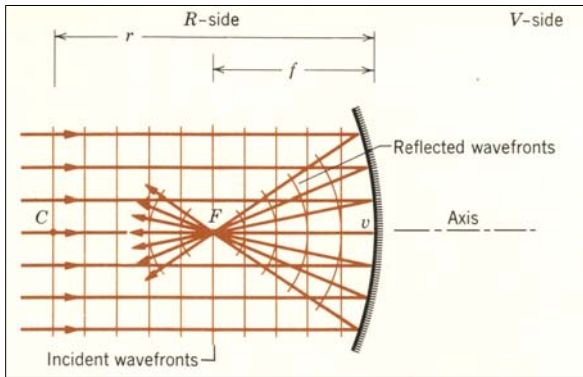


Figure A-20 Reflection of parallel spherical wave light – spherical concave mirror

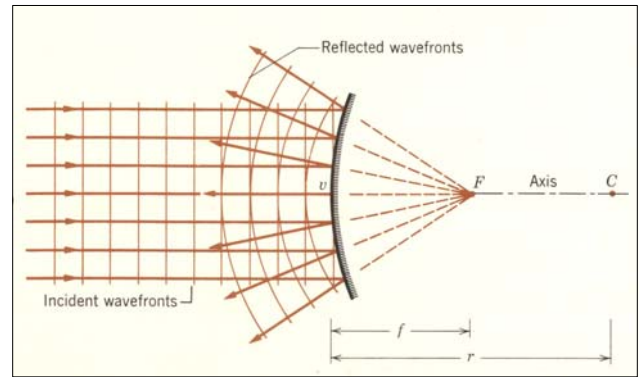


Figure A-21 Reflection of parallel spherical wave light – spherical convex mirror

A.1.1.4. Refraction through spherical refracting surfaces

Figures A-22, A-23, and A-24 show both concave and convex spherical refracting surfaces. Object O is the light source, and C is the center of curvature which has radius r . The light ray forms angle α with the convenient axis, and it strikes a spherical refracting surface, being refracted according to Snell's law. After being refracted, the ray will intersect the convenient axis at the image point I . Assuming the small angle α (between the light ray and the convenient axis), this principle holds for the following cases:

- Refracting surface is either convex, plane, or concave (see Figures A-22, A-23, A-24).
- If the densities of mediums are different, that is, $n_1 > n_2$ or $n_2 > n_1$.

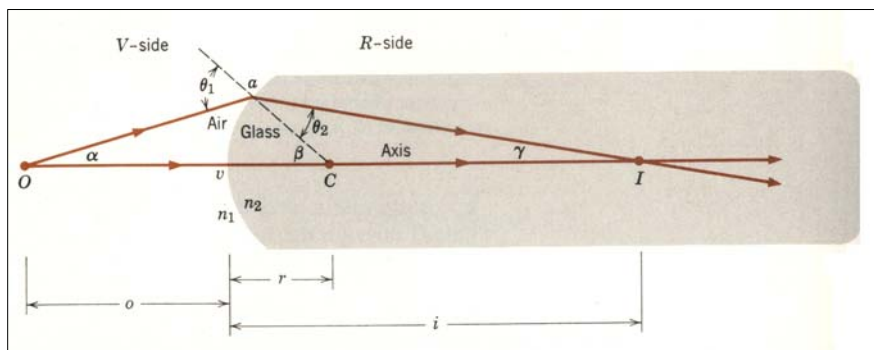


Figure A-22 Refraction of light rays through spherical refracting surfaces

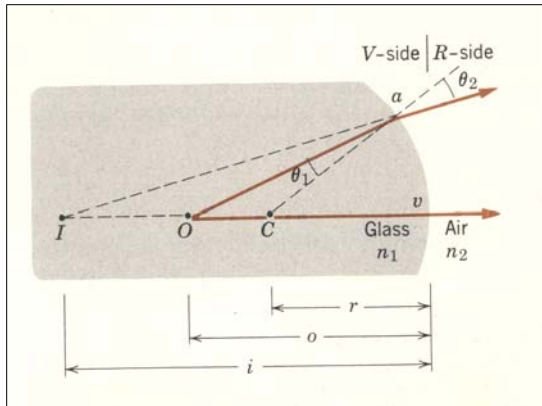


Figure A-23 Refraction of light ray – spherical concave refracted surface

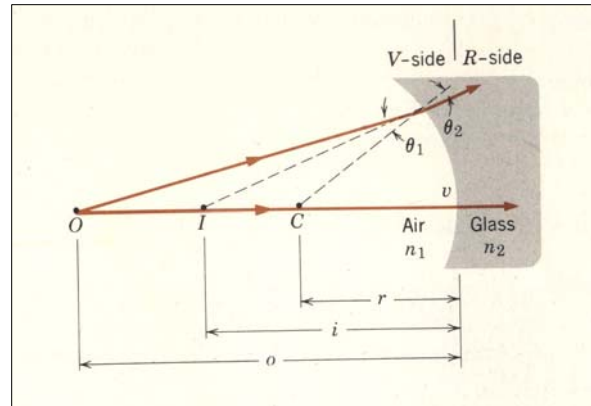


Figure A-24 Refraction of light ray – spherical convex refracted surface

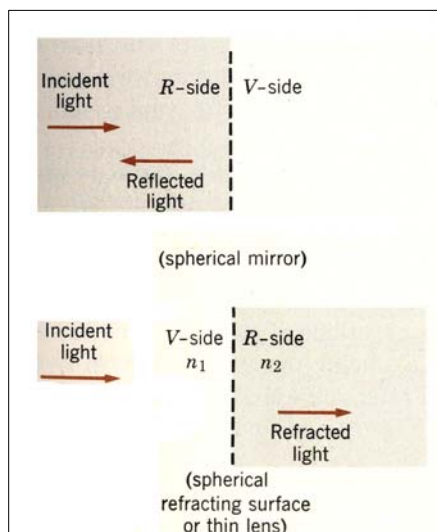


Figure A-25 shows the basic difference between forming an image for the spherical mirror and spherical refracting surface or thin lenses. For the spherical mirror, real images are formed on the same side as the incident light, and for refracting surfaces and lenses on the opposite side of the incident light.

Figure A-25 Image forming

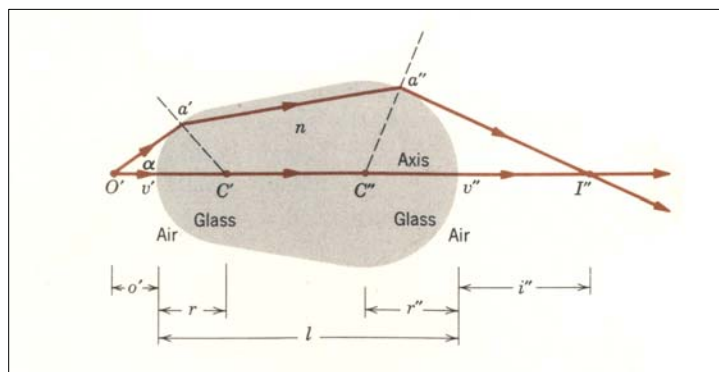


Figure A-26 Refraction of light ray – through a thick lens

Figure A-26 shows a thick glass lens of particular length and different radii of the two surfaces. The light ray from the point object O' strikes the left surface of the lens and is refracted, and then it strikes a second surface. The light is again refracted and intersects the axis at the point I'' .

A.1.1.5. Refraction through the lenses

Figures A-27, A-28, A-29, and A-30 show refraction of the light ray through different types of thin lenses and for a different relationship between the object and the image:

- A real object and a real image (see Figure A-27)
- A real object and a virtual image (see Figure A-28)
- A virtual object and a real image (see Figure A-29)
- A virtual object and a virtual image (see Figure A-30)

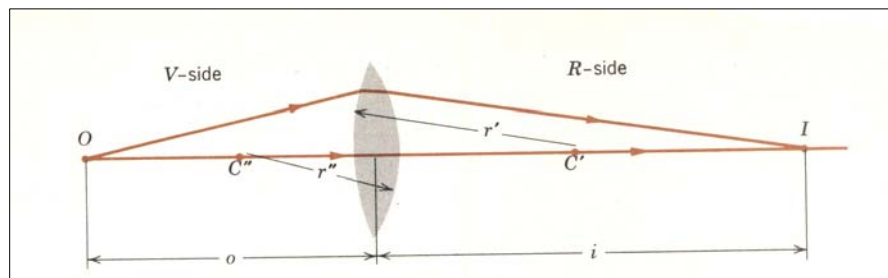


Figure A-27 Refraction of light ray – a real object and a real image

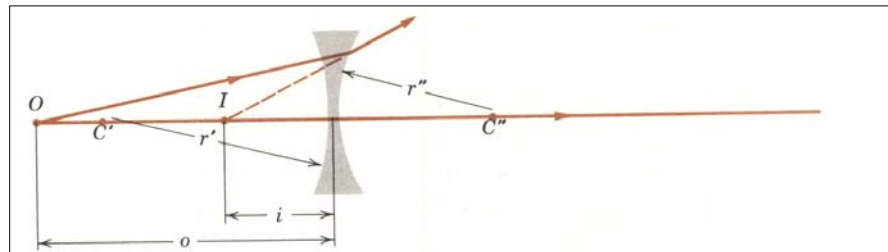


Figure A-28 Refraction of light ray – a real object and a virtual image

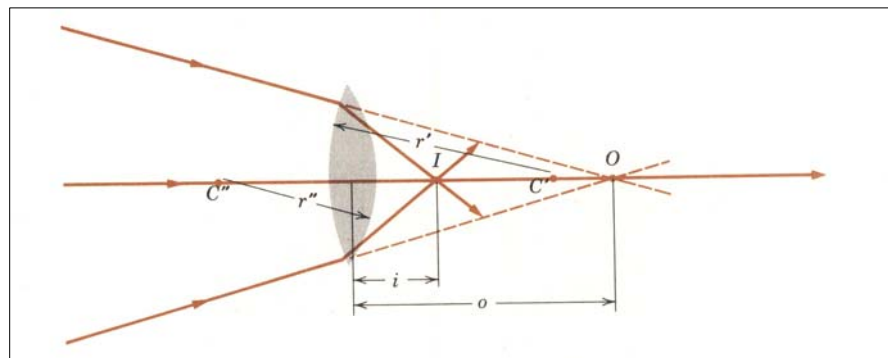


Figure A-29 Refraction of light ray – a virtual object and a real image

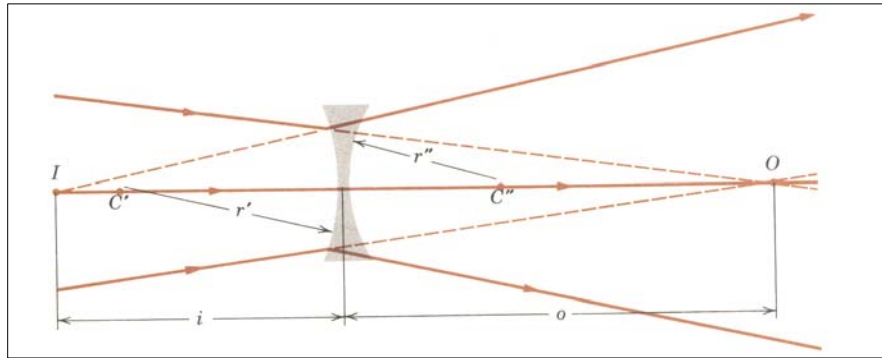


Figure A-30 Refraction of light ray – a virtual object and a virtual image

Figures A-31 and A-32 show refraction of parallel light rays through thin lenses (concave and convex). The image location is called the second focal point F_2 of the lens. For thin lenses, the first and the second focal points are on opposite sides of the lens and are equidistant from it.

In the case of converging lenses, parallel light passes through the second focal point F_2 . For diverging lenses, parallel light passes through a lens, originating at the second focal point F_2 .

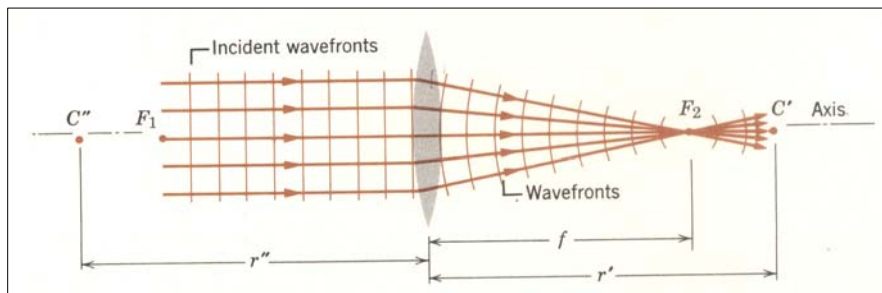


Figure A-31 Refraction of parallel light rays – a converging lens

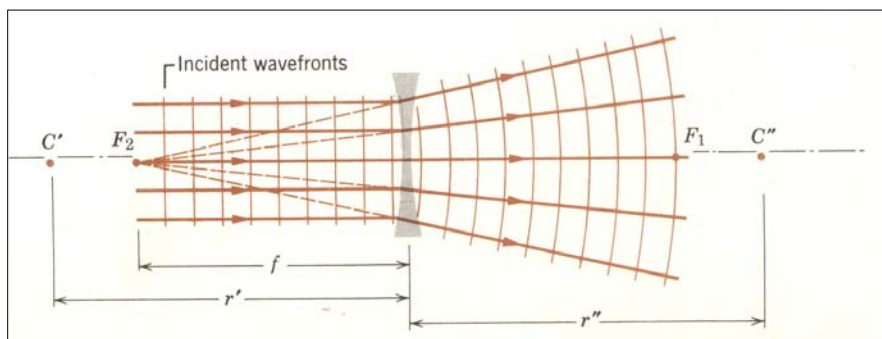


Figure A-32 Refraction of parallel light rays – a diverging lens

A.1.1.6. Polarization of light

Electromagnetic waves are transverse waves that consist of alternating electric and magnetic field vectors being at right angles to the direction of propagation. In the case of longitudinal waves, vectors are parallel to the direction of propagation. Assuming that a light wave is transverse, light can be polarized, or more precisely, plane-polarized which means that oscillations of the wave are either in the horizontal or vertical plane. This plane is called the plane of vibration (see Figure A-33), and is defined by the direction of propagation (x-axis) and the direction of polarization (y-axis).

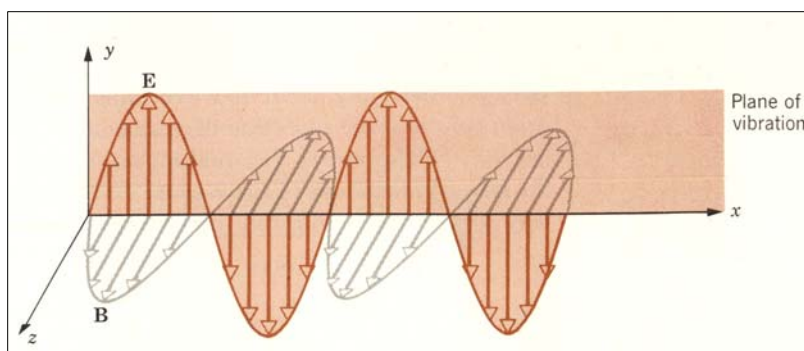


Figure A-33 Polarization of electromagnetic wave

Sunlight or light of an incandescent or fluorescent bulb is not polarized. Unpolarized light from such sources has many independent vibrations whose direction is randomly oriented about the direction of propagation. Unpolarized light can be plane-polarized by using certain crystals or a polarized sheet. The Polaroid sheet (see Figure A-34) is made by embedding long-chain molecules in a plastic sheet and then stretching the sheet so that axis of molecules becomes parallel. The Polaroid sheet has a property to transmit only those wavetrain components whose direction of vibration is parallel to the axes of the Polaroid sheet and absorbs those that are perpendicular to these axes.

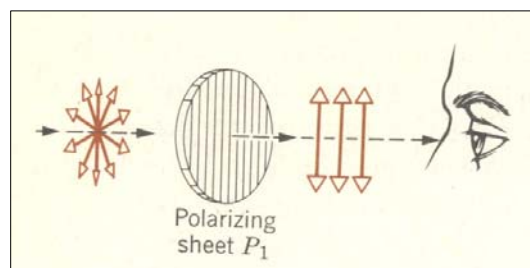


Figure A-34 Polarization of light by using the Polaroid sheet

Figure A-35 shows the plane of vibration of a randomly selected wavetrain that falls on the sheet. Vector E consists of two components: horizontal E_x (of magnitude $E \sin \theta$) and vertical E_y (of magnitude $E \cos \theta$). Only E_y will be transmitted through the polarizer since it is parallel to the polarizing direction, while E_x , which is perpendicular to the polarizing direction, will be absorbed by the Polaroid sheet.

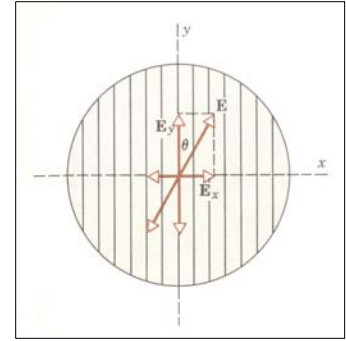


Figure A-35 Polarization of wavetrain E

A Polaroid sheet can be used as a polarizer to make plane-polarized light since only the light component parallel to the polarizing axis will be transmitted. A Polaroid sheet can also be used as an analyzer to verify whether or not light is polarized and verify its plane of polarization. If we place an analyzer behind the polarizer (see Figure A-36) and we rotate it about the direction of propagation so that angle between the axis of the polarizer and the analyzer is 90° , intensity of transmitted light is 0. This means that unpolarized light can be completely stopped by crossing two Polaroid sheets. The first sheet will make plane-polarized light, and the second sheet will eliminate this component since its direction is perpendicular to the axis of the second sheet.

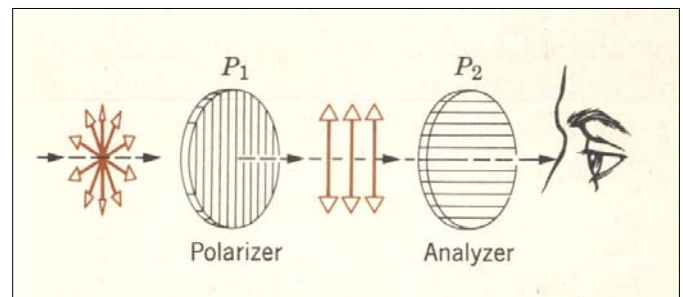
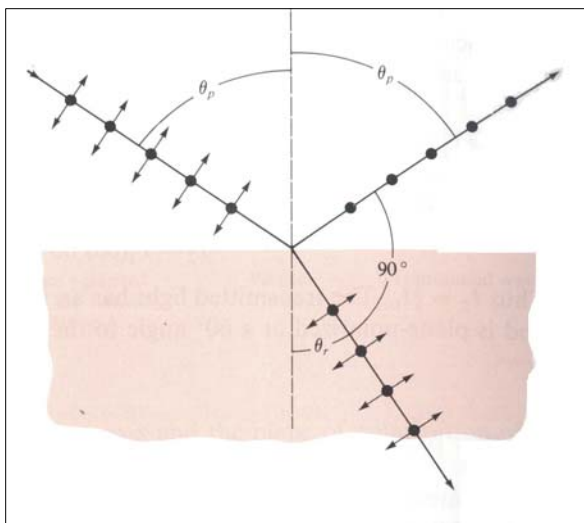


Figure A-36 Polarization by polarizer and analyzer



Unpolarized light can be polarized by reflection. When light strikes a surface at any incident angle except 90° , the reflected beam will be polarized in the plane that is parallel to the surface (see Figure A-37). The light wave component that lies in the plane perpendicular to the surface is transmitted or absorbed. Polarization of the reflected beam

Figure A-37 Polarization by reflection

depends on the angle. For the normal angle of incidence, polarization of light will not occur while 100% polarization will happen at an angle called polarization angle θ_p . Polarization angle θ_p is defined by an index of refraction of the two mediums (materials) through which light beams travel. The reflected and transmitted components of the light are perpendicular to each other.

If we put a solution between the polarizer and analyzer, and let a beam of monochromatic plane-polarized light pass through the solution (or crystal), the plane of polarization will be rotated for a particular angle (see Figure A-38). Even if the analyzer is placed at the angle of 90° to the polarizer, it will not cut all light because of the presence of the solution. If the analyzer is rotated for an angle ϕ and there is no transmitted light, it means that the plane of polarization also has been rotated through an angle ϕ by intervening substances, which are called “optically active”. Glass and plastics are optically active under stress and the plane of polarization is rotated most where the stress is greatest.

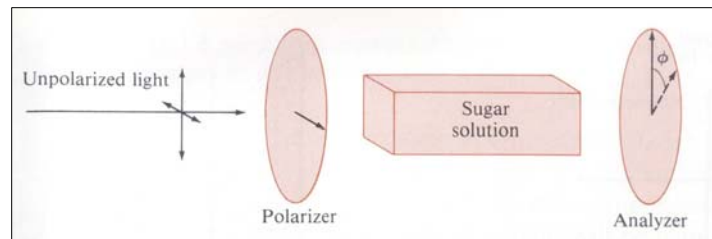


Figure A-38 Rotation of the plane of polarization by solution

A.1.1.7. Double refraction of light

Isotropic materials are transparent materials in which the speed of light is the same in all directions. In anisotropic or double refracting or birefringent materials, such as some crystals and solutions, the speed of light is different in various directions. Such crystals (for example, calcite) have an optic axis that consists of

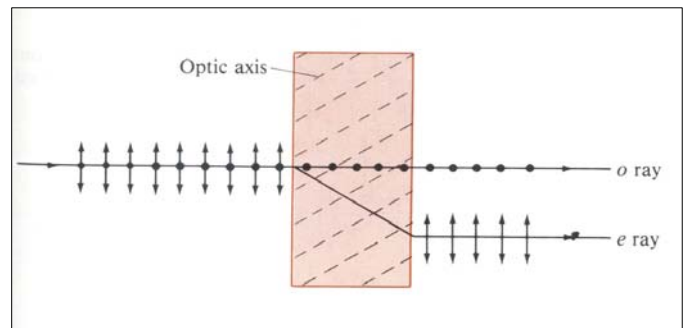


Figure A-39 Double refraction

parallel lines that represent direction in crystals. If unpolarized light falls at an angle to the optic axis, double refraction will occur, that is, there will be two refracted rays (see Figure A-39). An ordinary refracted ray (o) passes straight in a normal way, while the other extraordinary ray (e) is refracted at a particular angle. These two rays are plane-polarized in mutually perpendicular directions. An ordinary ray has a polarization perpendicular to the optic axis and its speed and index of refraction are the same in all directions. An extraordinary ray has two components of polarization: one is parallel and the other is perpendicular to the optic axis of the crystal. Applying Huygens's principle (see Figure A-40) to double refraction, we notice that:

- An ordinary wave has the same spheres as before and a wave travels straight because an ordinary wave has the same speed in all directions.
- An extraordinary wave will have elliptically shaped wavelets since it has a different speed in different directions.

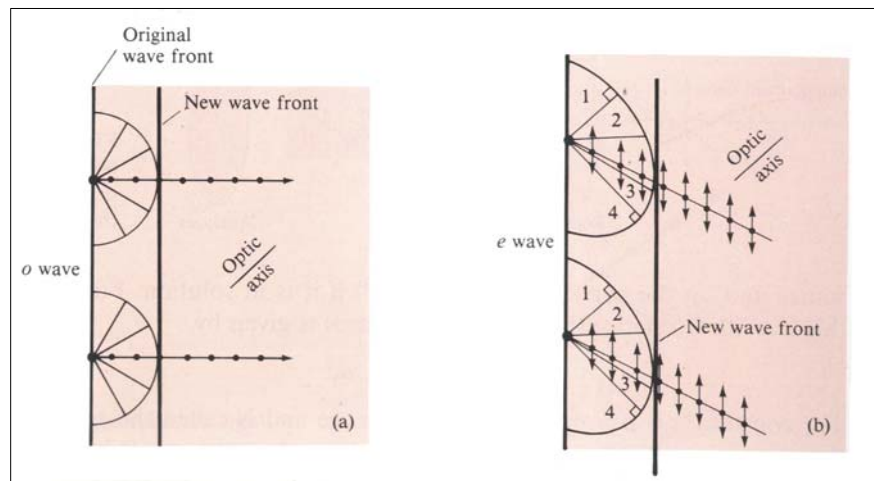


Figure A-40 Double refraction explained by Huygens's principle

A.1.1.8. Interference of light

Geometrical optics is a special case which shows that light travels in straight lines, while wave optics is a general case whose principles can be applied for all circumstances.

Figure A-41 shows a plane wave that falls on an opaque screen with a slit. The wavelength is λ and the slit width is expressed as a function of λ , so that $d = 1.5 \lambda, 3.0 \lambda, 6.0 \lambda$. In this case, principles of geometrical optics cannot be used since the wave flares out into a geometrical shadow of slit edges. Light is diffracted as it passes through a slit of the screen. The smaller the ratio d/λ , the larger the diffraction.

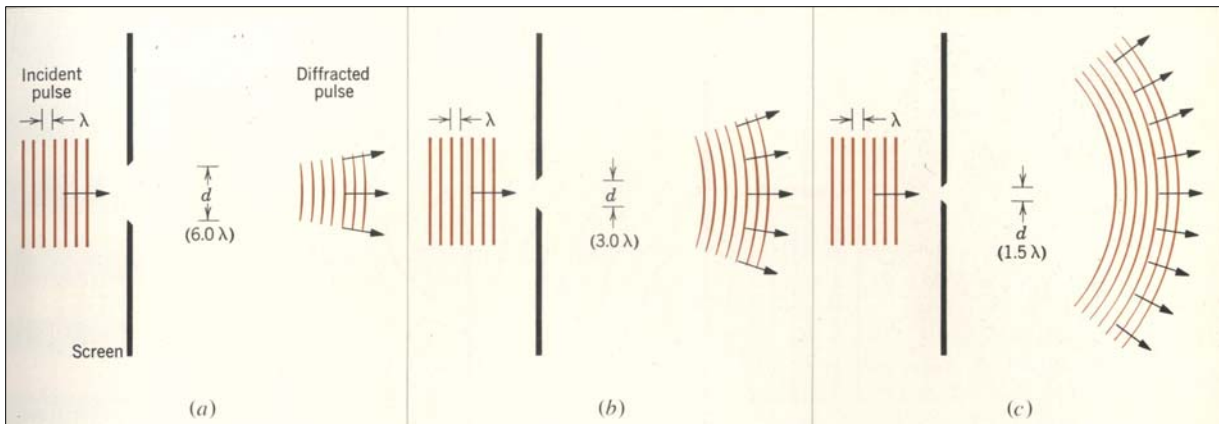


Figure A-41 Diffraction of the incident plane light

Interference of the waves will occur when two or more waves, which have the same type and frequency and constant phase relationship, travel through the same space at the same time. In 1801, Young did an interference experiment and established the wave theory of light. Figure A-42 shows interference of light waves where a sunlight ray falls on a pinhole S_0 in screen A. Light is diffracted and it falls on pinholes S_1 and S_2 in screen B. Diffraction of light occurs again, and now two waves on the right side of screen B will interfere with each other.



Figure A-42 Young's interference experiment

The light waves can be coherent or incoherent. Light waves, which travel from pinholes S_1 and S_2 to any point on this screen, have a phase difference that remains the same with

time. These two beams are called “coherent”. If there are two independent light sources in a glass envelope instead of slits S_1 and S_2 , only uniform illumination will appear on the screen C , but no interference fringes. The phase difference between two light beams arriving at any point on screen C will vary with time. In this case, light beams are incoherent since the emitting atoms in such sources act independently.

Thin film technology, as well as multiple layered films, is used for control of reflection and transmission of light and radiant heat at optical surfaces such as glass. Figure A-43 shows a thin transparent film that is illuminated by the monochromatic light from light source S . The incident ray i strikes the surface of the thin film and is reflected as a ray r_1 that enters the eye. The incident ray also enters the thin film and is refracted and then reflected from the back surface of the film at point b as a ray r_2 that enters the eye. Rays r_1 and r_2 originate at the same point source and are parallel. They are also coherent and will interfere. There will be a phase difference between rays r_1 and r_2 because their paths have different lengths, they have traversed different media, and they have different reflection in paths a and b .

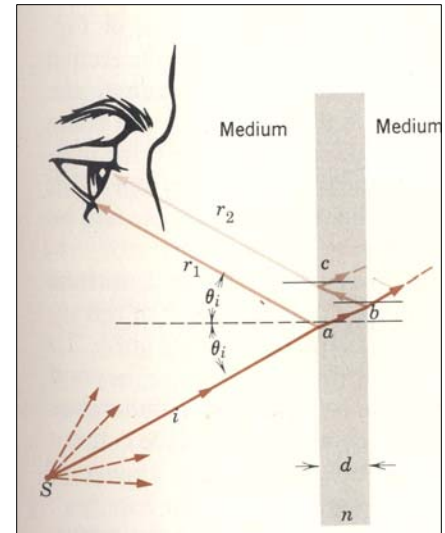


Figure A-43 Interference from thin film

If the angle of incidence is normal ($\theta = 0$), the geometrical path difference for two light rays from source S will be close to $2d$. The wavelength of the light in film λ_n is

$$\lambda_n = \lambda/n$$

where λ is the wavelength of the light in the air and n is the index of refraction of the thin film material.

In the case of the very thin film for which $2d$ is much less than the light wavelength, the phase difference between the two waves will be almost equal to 0. We can assume that one of these two rays has a phase change of 180° that is related either to reflection at the film surface or transmission through the film. The ray that is reflected from the surface will have this phase change. The other ray r_2 does not have this phase change either on transmission or on reflection at the back surface.

Figures A-44 and A-45 show phase changes on reflection at a junction between two stretched composite strings. Figure A-44 shows an incident pulse in a heavy string where reflected and incident pulses are in the same phase. These figures can be applied to a light wave in glass that approaches a surface beyond which is a less optically dense medium (that is, with a smaller index of refraction) such as air.

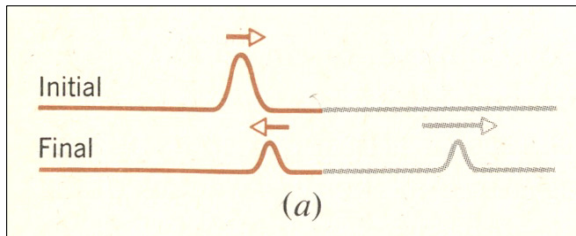


Figure A-44 Phase change – incident pulse in a heavy string (glass)

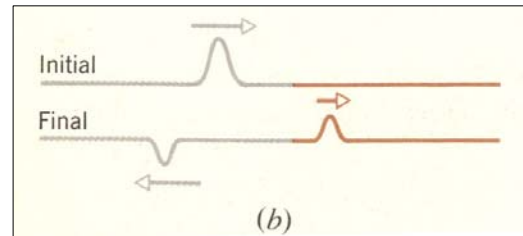


Figure A-45 Phase change – incident pulse in a light string (air)

Figure A-45 shows an incident pulse in the light string where reflected pulse and incident pulses have a difference of 180° , and the transmitted pulse is in the phase with the incident pulse. This figure can be applied for a light wave in air approaching glass, and the medium beyond the surface is more dense (that is, it has a higher index of refraction) such as glass so there is a phase change of 180° of reflected wave. The transmitted wave does not have a phase change in either use.

A.1.1.9. Diffraction of light

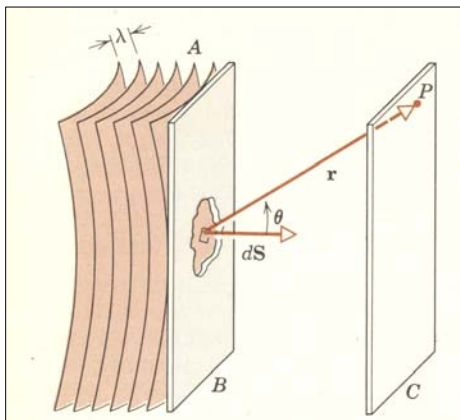


Figure A-46 Light diffraction

Diffraction of light is shown in Figure A-46. Wavefront (A) falls on the opaque screen (B) that contains an aperture of arbitrary shape. Light that passes through this aperture is received by screen C. The wavefront can be divided into elementary areas d_s , that become sources of expanding Huygens's wavelets. In this way, the pattern of light intensity on screen C can be calculated. The light intensity at point P is found by superimposing the wave disturbances that are caused

by wavelets reaching point P from all these elementary sources.

Figures A- 47, A-48, and A-49 show Fresnel diffraction. Light rays from source S falling on the diffraction aperture on screen B are not parallel and wavefronts are not planes (see Figure A-47). The light source has finite distance from screen B.

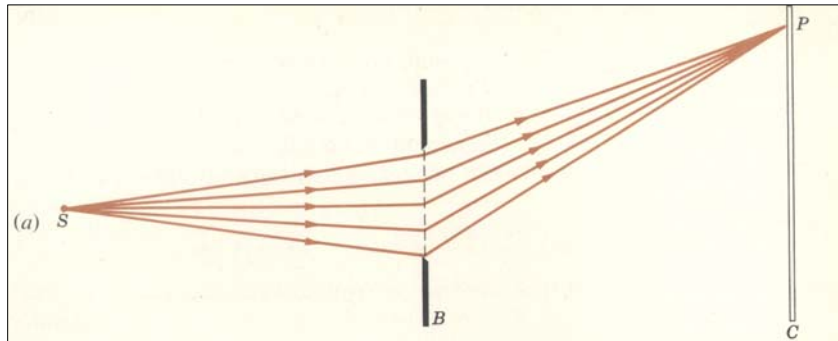


Figure A-47 *Fresnel diffraction*

In Figure A-48, the distance between light source S and screen C are large. Wavefronts that fall on the diffracting aperture are planes, and rays are parallel to each other.

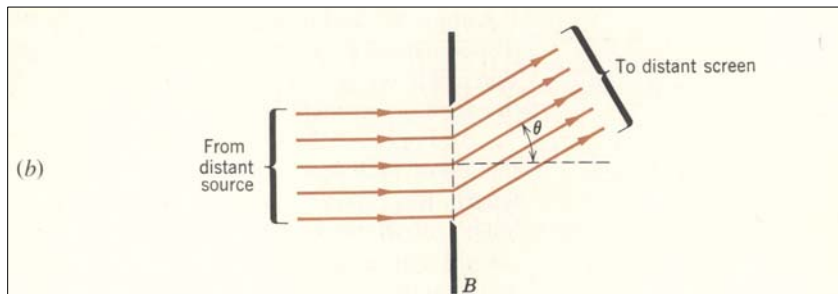


Figure A-48 *Fresnel diffraction*

Figure A-49 shows the same situation, that is, the same distance of the light source and screen C as in the first case, but two converging lenses are added on each side of the diffracting aperture. The first lens converts the diverging wave that comes from light source C into a plane wave. The second lens will cause plane waves after leaving the diffraction aperture (B) to converge to point P on screen C. All rays that leave the diffracting aperture will be parallel to each other before they reach the second lens that goes through the center of the lens and point P.

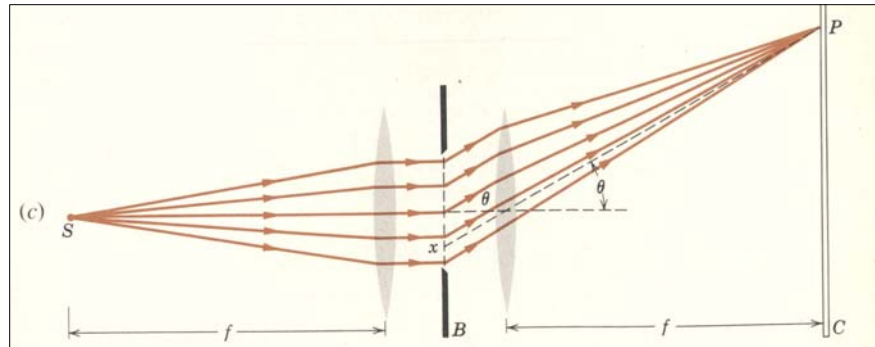


Figure A- 49 Fresnel diffraction

Figure A-50 shows diffraction from a single slit. Horizontal parallel rays that emerge from a slit are focusing at point P_0 . They have the same optical path length, and they are in phase at both the plane of the slit and at point P_0 . Light rays r_1 , r_2 , and xP_1 leave the diffraction aperture at an angle θ . If the distance $bb' = 1/2$ of the wavelength λ , rays r_1 and r_2 will be out of phase and will produce no effect on P_1 . Every ray from the upper part (half) of the slit will be cancelled by a ray from the lower part (half) of the slit that originates at the distance of $a/2$ (where a is the width of the slit). As the slit width a decreases, the angle of the rays θ will increase.

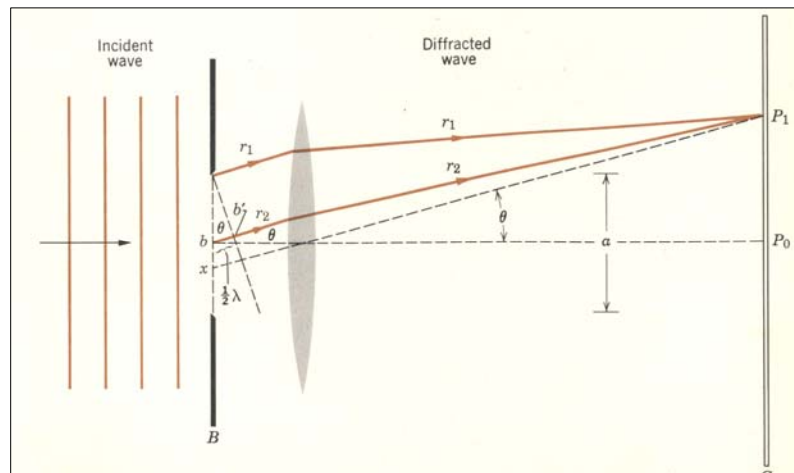


Figure A-50 Diffraction from a single slit

Figure A-51 shows diffraction from a single slit which has a width a and is divided into N parallel strips, each of which has a width Δx . Each strip is a source of Huygens's wavelet, and will make a wave disturbance at point P , the position of which is given by angle θ . If the

strips are very narrow, that is, much smaller than wavelength λ , then all points on a certain strip will have the same optical path length, and the light will have the same phase when it arrives at point P. For a very small angle θ , amplitudes of wave disturbances E_0 from various strips will be equal. Also, the wave disturbances from adjacent strips have a constant phase difference $\Delta\phi$ between them at point P. N-vectors, which have the same amplitude ΔE_0 , the same frequency, and the same phase difference $\Delta\phi$ between adjacent members, are combined to make resultant disturbance.

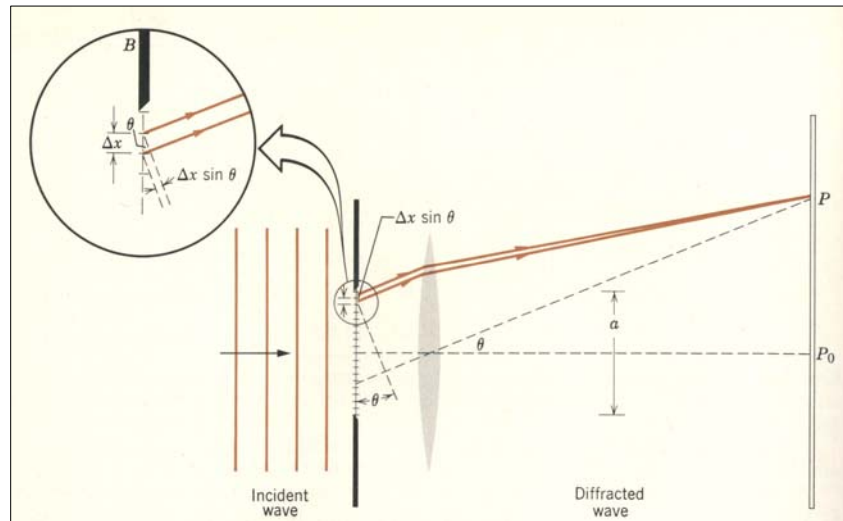


Figure A-51 Diffraction from a single slit

Figure A-52 shows diffraction through multiple slits. This arrangement is called diffraction grating and consists of many more slits. Monochromatic light, which has wavelength λ , falls on diffracting grating, and, as a result, an intensity pattern of a series of interference fringes will occur. The angle between fringes is defined by the ratio λ/d , where d is the distance between the centers of the adjacent slits. The intensity of these fringes

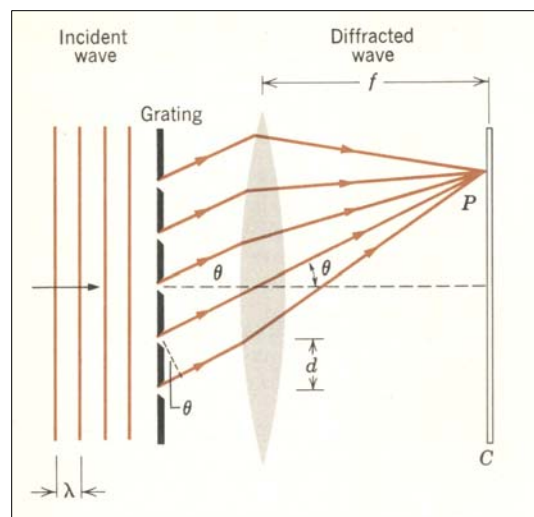


Figure A-52 Diffraction from multiple slits

is defined by a diffraction pattern of a single grating slit that depends on the ratio λ/a , where a is the width of a slit, and, in this case, is much smaller than λ .

A.1.2. PROPERTIES OF LIGHT AS WAVE

A.1.2.1. Polarization of light

Figure A-53 shows polarization by reflection from glass surfaces. A beam of unpolarized light (AB) strikes the first surface at the incident angle of 57° . This beam is reflected at an angle of 57° , strikes the second plate at point C, and is reflected again at the angle of 57° . These two glass plates are parallel. If the upper plate is rotated for a particular angle around BC as an axis, the intensity of the reflected beam will decrease; for the rotation of 90° , the intensity is 0. Zero intensity is also produced at an angle of 270° , and maximum

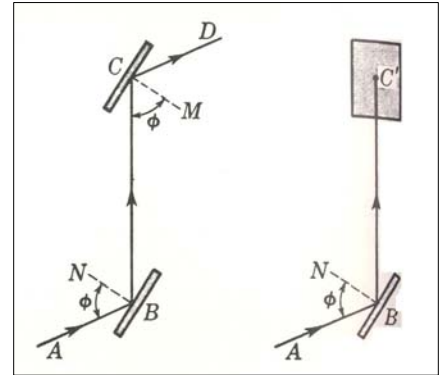


Figure A-53 Polarization by reflection

intensities are at angles 180° and 360° . The incident angle is constant for the rotation about the BC axis. This experiment will be best performed if back surfaces of the glass plates would be painted black. If the angle of incidence is ϕ , then the critical value ϕ_p that produces a 0 minimum for the second reflection is called the **polarizing** angle, and it depends on the type of glass used.

Figure A-54 shows polarization by reflection and refraction for ordinary glass. The reflected ray OR is partially plane-polarized for all angles except for the angle of 57° (polarizing angle) for which the reflected ray is plane-polarized. The angle between the reflected and refracted ray in this case is 90° , so the polarization angle is correlated to the index of refraction ($n = \tan \phi_p$, where ϕ_p is the reflection angle). Light internally reflected at an angle ϕ_p' will also be plane-polarized. Polarization depends also on the wavelength, but for ordinary glass the polarizing angle does not change much over the entire visible spectrum.

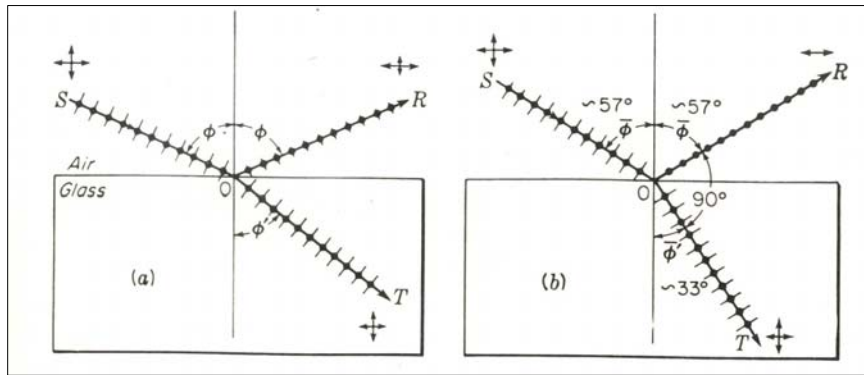


Figure A-54 Polarization by reflection and refraction for ordinary glass

The incident light sets the electrons in the atoms of the material into oscillation, and it is the re-radiation from these that generates a reflected beam. If we assume that ordinary incident light consists of two plane-polarized beams of light that are perpendicular to each other:

- Waves vibrating in the plane of incidence are partially reflected and partially refracted for all angles except for the polarizing angle for which all light is refracted, that is, 100% transmitted.
- Waves vibrating in the plane perpendicular to the plane of incidence are partially reflected and partially refracted for any angle of incidence. For a single pane of glass with an index of refraction $n = 1.50$, 85 % of the light is transmitted and 15% is reflected.

Figure A-55 shows polarization of light by a pile of glass plates. At the polarizing angle, vibrations of light waves that are:

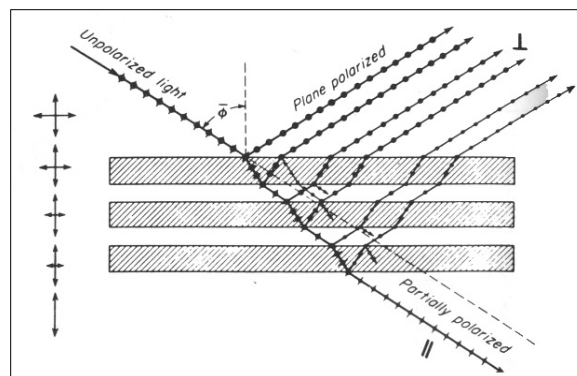


Figure A-55 Polarization of light by a pile of glass plates

- Perpendicular to the plane of incidence are reflected at each surface and also refracted. Reflected beams are all plane-polarized in the same plane.
- Parallel to the plane of incidence are refracted. The refracted beam loses more and more of its perpendicular vibrations and becomes partially plane-polarized.

Figure A-56 shows two arrangements of glass plates mounted at the polarizing angle. The first of them acts as a polarizer and the second acts as an analyzer, having their planes of incidence parallel. An incident light beam strikes glass plates in the polarizer at the polarizing angle, and the light emerging at point N is nearly plane-polarized and transmitted by the analyzer. If the analyzer is rotated about the NM axis, the transmitted light will be extinguished because vibrations are now perpendicular to the plane of incidence of the analyzer and will be reflected to the side. If the analyzer is rotated again for 90° , light will be restored.

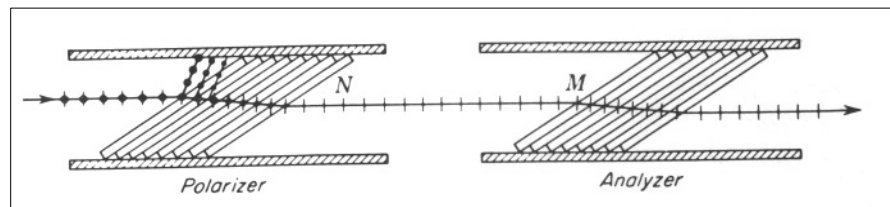


Figure A-56 Polarization of light by glass plates

Some birefringent crystals (for example, tourmalin) absorb one of the polarized components more than the other. This principle is called “Dichroism” and is used for Polaroid sheets. If the crystal is thick enough, one component of unpolarized light will be completely eliminated so the emerging light will be plane-polarized.

Figure A-57 shows polarization of light by using dichroic crystals (tourmaline). If the crystals T_1 and T_2 are parallel to each other, light that is polarized and transmitted by the first crystal will also be transmitted by the second. If the second crystal is rotated for the 90° angle, no light will be transmitted. Only vibrations

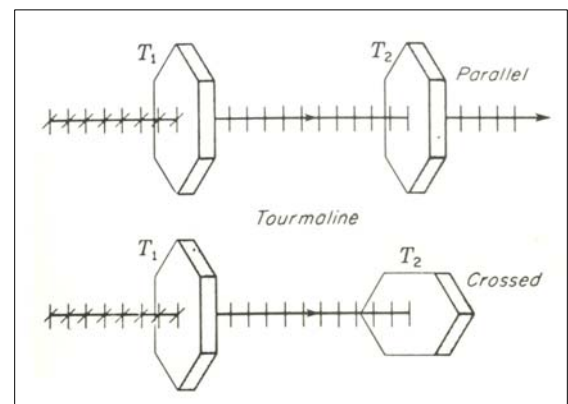


Figure A-57 Polarization by dichroic crystals

parallel to the long edges of the crystal (E vibrations) will be transmitted, while vibrations in the perpendicular plane (O vibrations) will be absorbed.

A.1.2.2. Plane, circular, and elliptical polarization of light

A transverse wave can be linearly (plane) polarized, that is, the E vector lies along a particular line. The E vector can change its size and sign, but not its direction. The E vector polarization direction is not always in the direction of the axes of the coordinate system, that is, it can lie along the line which makes a specific angle with the coordinate system axes. In this case, vector E consists of the components E_x and E_y that are also plane-polarized waves (see Figure A-58).

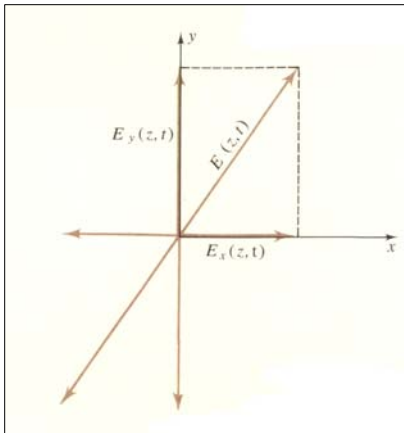


Figure A-58 Plane-polarized light wave

If the components E_x and E_y reach their maximum values at the same time, they are in phase. This means by adding two plane-polarized waves that are in phase, we get a single plane-polarized wave. By adding up two plane-polarized waves that are not in phase, we get, as a resultant, an elliptically polarized light wave whose special case is a circularly polarized wave. If the components E_x and E_y have:

- The same amplitude and phase difference of 0° , 180° , 360° : the emerging beam will be plane-polarized, and this happens in all cases of external reflection and in the case of internal reflection for all angles up to the critical angle.
- The same amplitude and phase difference of 90° : light is circularly polarized.

Circularly polarized light is equivalent to two linear vibrations that are perpendicular to each other, with the phase difference of 90° . Upon emerging from the plate, these

- two vibrations will be in phase and will give plane-polarized light that makes a particular angle with the optic axis (see Figure A-60).
- Different amplitude and/or phase difference other than multiples of 90° : light is elliptically polarized. Elliptically polarized light is a result of a single internal reflection at $\phi > \phi_c$ (an incident angle larger than a critical angle) at which reflection is total (see Figure A-59). Elliptically polarized light can be converted into plane-polarized light only if the fast axis of the quarter-wave plate coincides with a major or minor ellipse axis.

In all cases, a light wave can be resolved into its linearly polarized components.

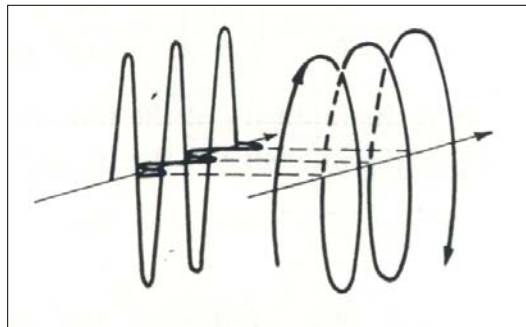


Figure A-59 Elliptical polarization

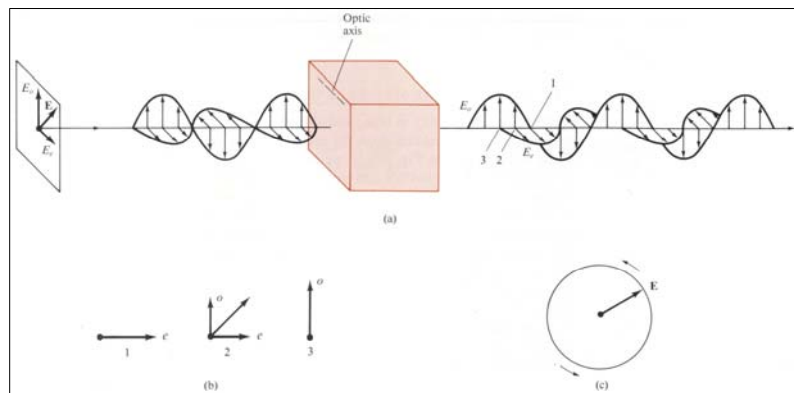
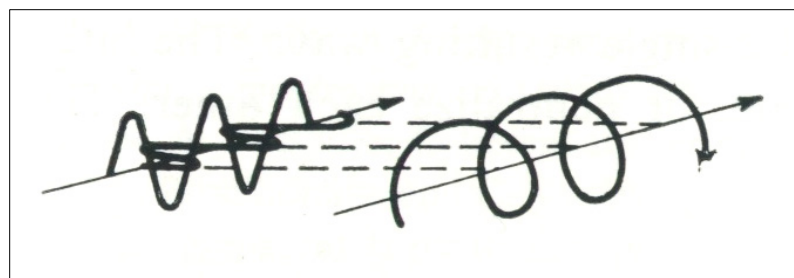


Figure A-60 Circular polarization

Figure A-60 shows a plane-polarized light beam that strikes birefringent crystals. This light beam has an optic axis parallel to the face of the crystal and an angle of 45° with the plane of polarization. The incident electric field vector E has two components: parallel to axis E_e and perpendicular to optic axis E_o . They have equal amplitudes, and they have the same path through the crystal. They do not have the same speed since they travel perpendicularly to the optic axis and emerge from the crystal out of phase. An extraordinary wave is not refracted because its vibration is parallel to the optic axis. The electric field vector E rotates in a circle of constant amplitude, and this light is circularly polarized. A quarter wave plate changes the relative phases of the components of the E vector by 90° (which is $1/4$ of the wavelength). The result of a phase change other than 90° is elliptically polarized light, and plane polarization is just a special case of elliptical polarization and occurs when the E vector lies along an axis. If plane-polarized light passes through a quarter-wave plate whose axes are at 45° to the E vector, the resultant is a circularly polarized light. Circular polarization can be either right or left, depending on whether vector E is rotated 45° clockwise or counterclockwise from the fast axis. It is easy to identify the axis, but it is not easy to determine which axis is fast and which is slow.

Unpolarized light consists of either:

- Plane-polarized light along two perpendicular axes or
- Random combinations of right and left circularly polarized light waves

Two plane-polarized waves may be added to form a circularly polarized wave, but also two circularly polarized waves can be added to form plane-polarized light.

Figure A-61 shows a light trap. Unpolarized light, after passing a linear polarizer, becomes plane-polarized. Plane-polarized light passes through a quarter-wave plate and

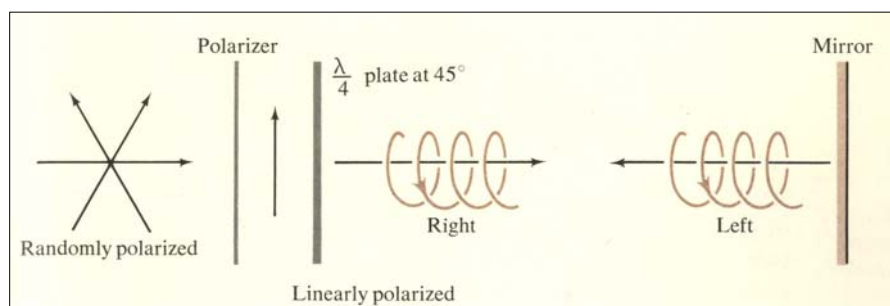


Figure A-61 Circular polarizer – light trap

becomes right circularly polarized. After being reflected from the mirror, light is left circularly polarized (since circular polarization of the light is reversed on reflection), and it is stopped by a right-circular polarizer.

A circular polarizer converts unpolarized light to circularly polarized light. It consists of a linear polarizer and a quarter-wave retarder. The angle between the linear polarizer axis and $1/4$ retarder axis is 45° . Unpolarized light, after passing through a linear polarizer and quarter-wave retarder, becomes circularly polarized, and after reflection from the reflective surface (such as a mirror), light returns and passes through the retarder again. Emerging light is now plane-polarized, but its plane of polarization is rotated 90° to the original plane of polarization. It is completely absorbed by the linear polarizer and no light emerges (see Figure A-62.).

By using circular polarizers, the reflection from a front surface mirror is reduced from 92% (mirror reflectivity) to 0.5%. The circular polarizers can be mounted on or between glass or plastic sheets and can also accept antireflective coatings. Circular polarizers are offered in sheets in the shape of a parallelogram whose size is 17" x 39.4" x 0.04".

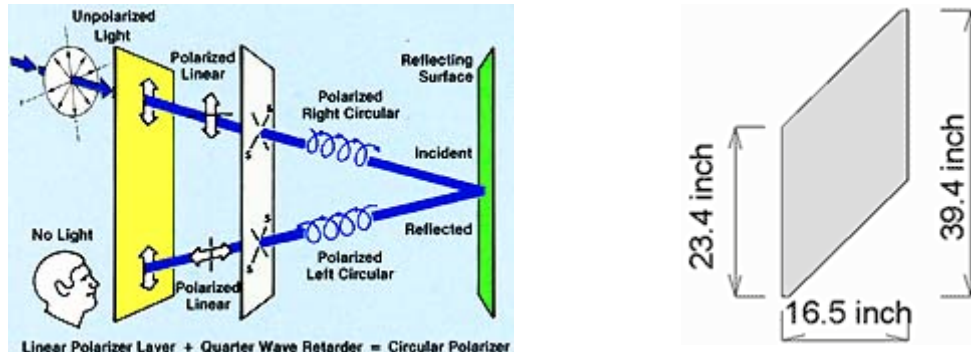


Figure A-62 Circular polarizer

When a birefringent material is placed between a polarizer and analyzer, colors will appear even though each of them is color-neutral because a birefringent slab will be an n^{th} plate at only one frequency. For example, a $1/2$ wave plate for red light will be a full wave plate for violet light. If we put the birefringent slab between the crossed polarizer and analyzer with 45° between their axes, violet light will not pass through this system. The E vector for red light is rotated 90° and it passes the analyzer. If we rotate the analyzer for 90° , the violet light will pass, but not red, so we get complementary colors.

For frequencies in between, light will be elliptically polarized and must be treated by its components. We can see that less and less light passes through the system if we go from red to violet. If we look through the system at white light, we see light that has a red-orange color. Many plastics are birefringent since they are stretched in manufacture so that their long molecules line up to some direction. If transparent materials are strained, the resultant colors can be used in locating and analyzing such strains. Rotation of any part of the system will result in complementary colors.

A.1.2.3. Double refraction in crystals

In crystals such as calcite (CaCO_3 – calcium carbonate) and quartz (SiO_2 – pure silica), which are transparent to visible and UV light (see Figure A-63), double refraction will occur when an ordinary unpolarized beam of light strikes their surface.

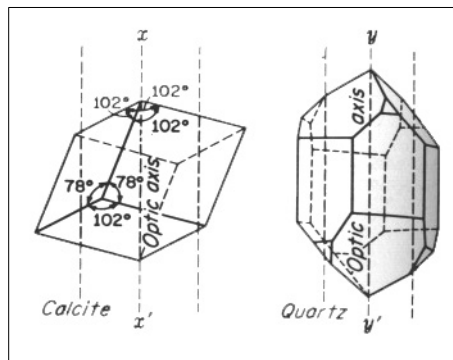


Figure A-63 Crystals

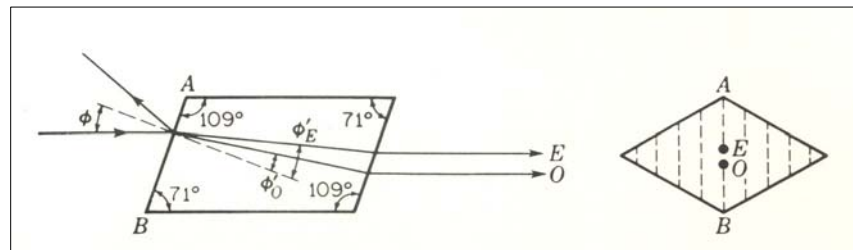


Figure A-64 Refraction of light by calcite crystal

Figure A-64 shows double refraction of light by calcite crystals which have parallel faces so that two refracted rays will be parallel to each other. An ordinary ray (O) in the crystal is in the plane of incidence, and it will pass straight through the crystal without any deviation if the incident light is normal to the surface. The double refraction in anisotropic (or uniaxial)

crystals, such as calcite and quartz, will not occur if light travels in the direction parallel to its optic axis, that is, there will be no separation of O and E rays.

Figure A-65 shows the Nicol prism that is made of calcite crystal, and it removes one of the two refracted rays by total reflection. The crystal is cut down at an angle of 68° , and cut apart along the diagonal plane. These two pieces are cemented together by Canada balsam, which is a transparent substance that has an index of refraction ($n = 1.55$) higher than the calcite for the E ray ($n = 1.48$) and lower than the calcite for the O ray ($n = 1.65$). Because of this, the E ray will be refracted into the balsam, and through the calcite crystal, and the O ray will be totally reflected for the critical angle of incidence (69°). At angles greater than 69° , some of the O rays will be transmitted.

For a particular angle of incidence, the E ray in the Nicol prism will be totally reflected by the balsam because the index of refraction of the calcite has different values for a different direction in crystals. The E ray travels along the optic axis with the same speed as the O ray and has the same index of refraction ($n = 1.65$). There will be a particular maximum angle of incidence beyond which the balsam will be optically less dense than the calcite, and there will be total reflection of the E vibrations.

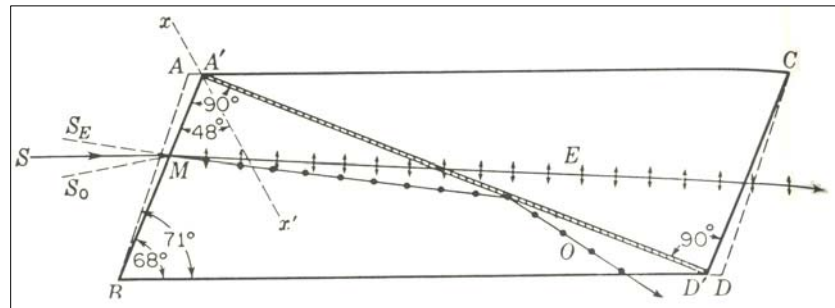


Figure A-65 Nicol prism

Plane-polarized light after emerging from the Nicol prism N_1 strikes the thin plate of calcite at the normal angle (see Figure A-66), but with its vibrations in the plane that makes a particular angle with the optic axis. Light will break up into two components:

- E wave: parallel to the optic axis, travels faster.

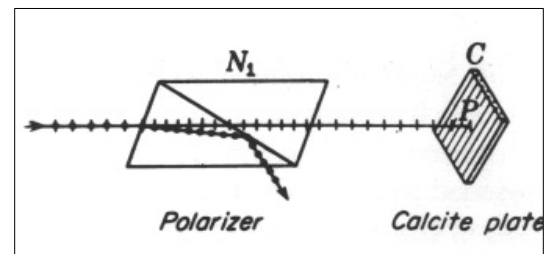


Figure A-66 Plane-polarized light incident on the calcite plate after external reflection

- O wave: perpendicular to the optic axis, travels slower.

Since the E wave travels, faster it gets ahead of the O wave by the time they have traversed the thickness of the crystal. The phase difference depends on the optical paths of E and O waves and wavelength.

- Optical path for $O = n_o * d$ and $E = n_e * d$
- Path difference $\Delta = d * (n_o - n_e)$
- Phase difference $\delta = d * (n_o - n_e) * 2\pi/\lambda$

After leaving the crystal, the E and O wave will continue in the same straight line, and their vibrations are perpendicular to each other. Within the crystal, they are also perpendicular to each other, and they have the same frequency that is equal to that of the light outside the crystal, and they have the phase difference δ . For circularly polarized light, the phase difference is $\pi/2$ or $3\pi/2$, and amplitudes of O and E rays are equal.

Figure A-67 shows two crossed Nicol prisms and the crystal plate between them. Plane-polarized light emerging from the Nicol prism N_1 enters the crystal and emerges from it as an elliptically polarized light. The plane of vibrations that arrives at the crystal plate has an amplitude A that makes angle θ with an optic axis, and it is broken into two components:

- Parallel to the optic axis $E = A * \cos \theta$
- Perpendicular to the optic axis $O = A * \sin \theta$

These two components arrive at the Nicol prism N_2 that acts as an analyzer, but only component E that is parallel to the N_2 principal section will pass. Components E' and E'' are vibrating in the same plane and

have the same magnitude ($E' = E'' = A * \sin \theta * \cos \theta$) when the polarizers are crossed, but they have phase difference. Two rays, which have the same beam of plane-polarized light as a source and are polarized at right angles, will interfere in the same manner

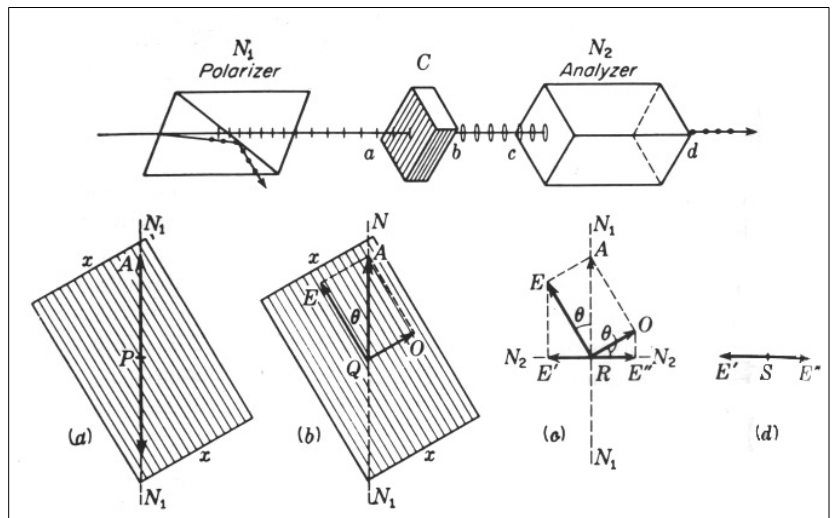


Figure A-67 Interference of light by crossed polarizer and analyzer

as ordinary light, but only if their vibrations are in the same plane.

Figure A-68 shows the Babinet compensator that consists of two wedge-shaped prisms of quartz but at a very small angle whose optic axes are perpendicular to each other.

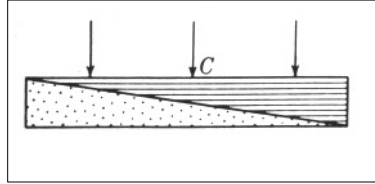


Figure A-68 Babinet compensator

If plane-polarized light normally strikes the compensator with its plane of vibration at some arbitrary angle θ to the optic axis, it will be broken up into two components:

- E component: parallel to the optic axis in the first crystal
- O component: perpendicular to the optic axis in the first crystal

When they reach the second crystal, E vibrations become O vibrations since they are now perpendicular to the axis. At the same point, O vibrations from the first crystal become E vibrations in the second crystal. The result is that one prism tends to cancel the effect of the other.

Figure A-69 shows a beam of plane-polarized light that travels along the optic axis of quartz. The plane of polarization rotates about the direction of the light beam and emerges vibrating in some other plane than that at which it entered. This rotation depends on the light wavelength and the distance traveled in the medium. This rotation of the plane of vibration is called **optical activity**. If white light passes through the crystal, different colors will be

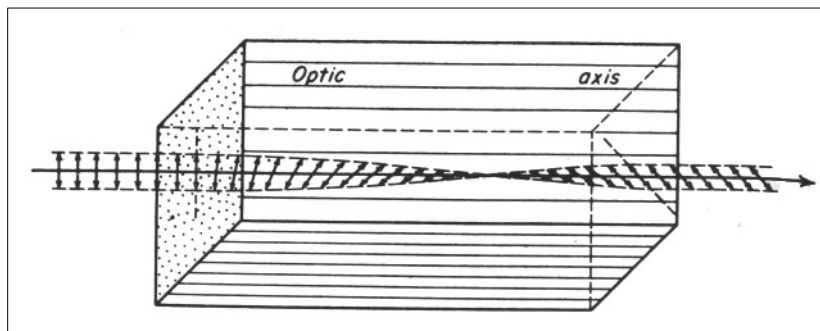
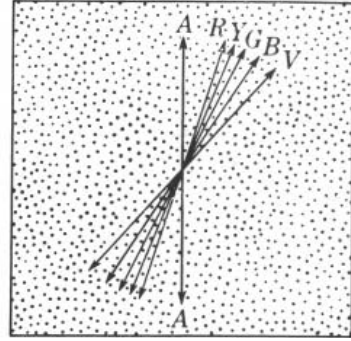


Figure A-69 Rotation of the plane of vibration

rotated for a different amount.

Figure A-70 shows rotation for different colors by a 1mm thick plate of quartz. Violet light will be rotated by 50° and red about 15° , and other colors' rotation angles are between these two.

Figure A-70 Rotation of the plane of vibration for different colors



A.1.2.4. Double refraction in glass

Homogeneous and stabilized glass is an isotropic amorphous material. If glass is internally stressed, it becomes optically anisotropic and double refraction can occur. Internal stress in glass is a result of mechanical stress, thermal shock, inhomogenities in glass, phase separation, and crystallization.

If glass is stained in **tension**, the index of refraction:

- Decreases in a direction parallel to tension.
- Increases in a direction perpendicular to tension.

If glass is under **compressive** stress, the index of refraction:

- Increases in a direction parallel to compression.
- Decreases in a direction perpendicular to compression.

Under tensile stress, glass behaves in an optical sense as a positive uniaxial crystal which means that the optical axis has the same direction as the direction of the stress. Under compressive stress, glass behaves as a negative uniaxial crystal.

Glass is frequently exposed to sudden heating or cooling, and this will produce temperature gradients in the material. Temperature gradients can produce tensile stresses in the glass surface. A surface temperature shock of 100°C produces surface tensile stress of 70 MNm^{-2} , which can cause fracture of glass. If a sudden increase of surface temperature is uniform over the entire surface of the pane of glass, that is, surface stresses are compressive, then there is no risk of glass fracture. Such temperature changes of the surface do not occur in practice.

Stresses in glass occur because different parts of the glass pane expand or contract by different amounts. Glass surface is under compressive stresses while the center of glass is

under tensile stress. There is a stress that remains in the glass, which has been cooled from the temperature that is above the annealing temperature and viscosity that is less than 10^{12} Pa s. A particular cooling rate can result in permanent stress in glass.

The stresses in glass depend on the properties of glass and on its thickness. For most of the commercial silicate glasses, the values of Young's modulus, E , and Poisson's ratio do not significantly vary for different types of glass. On the other hand, the expansion coefficient, which affects a permissible rate of cooling, varies for different glass types. The higher the thermal expansion coefficient and the greater the thickness of glass, the slower the rate of cooling.

When glass is below the strain point, the rate of cooling can be increased. It will not affect the level of permanent stress in glass after cooling is completed. After glass becomes an elastic solid, any stress that is the result of temperature gradients will disappear once those gradients are removed. The permanent stress is determined by the rate of cooling through the annealing range.

The internal stress in glass can be measured, and the method used depends on the effect of the stress on the velocity of propagation of polarized light through glass, which is known as the "photoelastic effect". The velocity of propagation of a plane-polarized light in glass, that is under stress, depends on the direction of light polarization relative to the direction of the stress.

Double refraction of light will occur in glass if glass has an internal stress in a direction that is different from the optical axis. The maximum value is reached in a direction that is perpendicular to the optical axis. In double refraction, a light beam separates into two parts, ordinary and extraordinary. They travel through glass at different velocities so that when they emerge out of the glass, there will be a phase difference between them. These velocities are inversely proportional to the indices of refraction for ordinary beam n_o and extraordinary beam n_e . Double refraction of light depends upon the degree of isotropy of the glass.

Interference effects between two waves can occur and will result in variations in light intensity or variations in colors if white light has been used. By using these optical effects, a phase difference between two waves can be measured. Since the phase difference is proportional to the stress which produces it, the measure of the magnitude of the stress in the

glass can be determined. Stress in glasses is measured by polarization equipment, such as polariscopes and polarimeters.

Figure A-71 shows the photoelastic effect. A block of glass is under uniaxial tension or compression. A monochromatic plane-polarized light beam enters the glass block perpendicularly to the stress direction, and its plane of polarization makes an angle θ with the direction of the stress. Upon entering the glass block, the light wave is divided into two components:

1. one that has direction parallel to the stress direction, and
2. one that has direction perpendicular to the stress direction

For the angle $\theta = 45^\circ$, two components have equal amplitude but which of those two components that has the higher velocity will depend on the type of the stress:

- if the stress is tensile, the wave polarized in the stress direction is slower.
- if the stress is compressive, the wave polarized in the stress direction is faster.

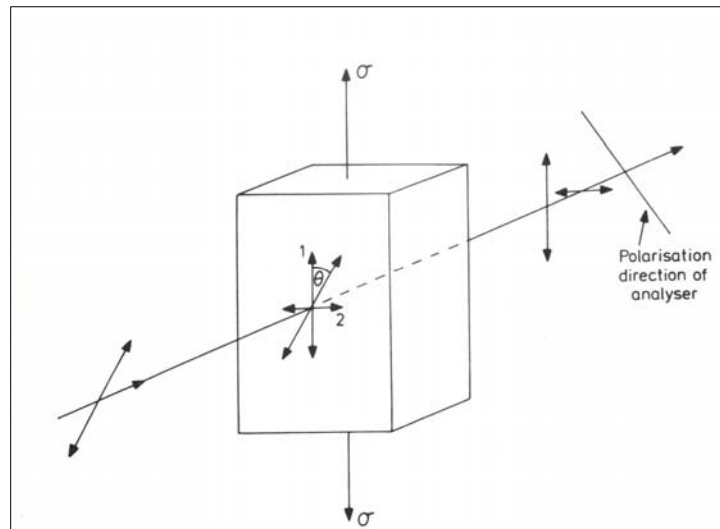


Figure A-71 Photoelastic effect

The optical path difference $\mathbf{R}$ between two waves depends on the stress σ , the thickness of glass $\mathbf{d}$, and the stress optical coefficient $\mathbf{C}$, which is the property of glass ($\mathbf{R} = \sigma \cdot \mathbf{d} \cdot \mathbf{C}$). Interference between plane-polarized waves will not occur if their planes of polarizations do not coincide. To achieve this situation, an analyzer, such as a Polaroid sheet, needs to be set at an angle of 90° to the direction of polarization of the original plane of the polarized wave,

that is, 45° to each of its components. Since the equal component of each wave is transmitted and they vibrate in the same plane wave, interference will occur.

The intensity of light that is transmitted by the analyzer depends on the phase difference δ between the two wave components, and δ depends on the optical path difference R and light wavelength λ .

$$\delta = 2\pi R/\lambda$$

$$I = k \sin^2(\delta/2)$$

$$\text{For } \theta = 45^\circ \quad I = k \sin^2(\delta/2)$$

where k is constant proportional to the intensity of the original plane-polarized wave.

An additional component, such as a compensator, can be introduced into the light path between the polarizer and analyzer. The compensator introduces retardation that is equal and opposite to the retardation produced by the stress in the glass. By adjusting these components, retardation of a particular point in the field of views is reduced to 0.

An approximation of the stress level in glass can be determined by a strain viewer, which consists of a polarizer and analyzer. A tint-plate is an additional component introduced between the polarizer and analyzer. A tint plate is a very thin plate of a uniaxial crystal cut with its optic axis in the plane of the plate. Its optical effect is similar to that produced by a piece of glass that is under uniaxial stress, and its thickness is chosen to give uniform retardation of ~ 550 nm over the entire field of view.

If a piece of stressed glass is introduced into the light path, the tint-plate retardation will either increase or decrease. It will produce other colors, the nature of which determines the magnitude and nature of stress that exists in glass. Different colors are produced due to two reasons:

- White light has a wavelength range from 400 nm to 750 nm.
- Retardation R , produced by the stress, does not depend on the light wavelength.

The phase differences δ are different for various components of white light. Different colors will be attenuated by the optical system by different amounts. For regular thickness of glass, annealing should produce retardation of less than 50 nm, but the system that consists of a polarizer and analyzer is not sensitive enough to detect it. By introducing a tint-plate,

retardation, which is a result of low stress, can be detected. The total retardation, which is the result of a combined effect of stressed glass and tinted plate, is from 500 nm to 600 nm.

Tensile and compressive stresses produce the opposite effects on the total retardation. Color will change corresponding to each type of stress. Retardation is 0 in the following cases:

- If tensile and compressive stresses are equal and of the same sign.
- In the balanced stress system, that is, the system in which stress changes from tensile to compressive along the light path.

A.1.2.5. Reflection of light

Characteristics of the reflected and transmitted (refracted) light depend on the wavelength, polarization, and angle of incidence.

For a single glass surface at normal incidence, ~4% of the light is reflected and the other 96% of light is transmitted, but for all other angles of incidence, the reflection will increase with the angle, and for 90° all light will be reflected. For the polarizing incident angle, all reflected light is plane-polarized with its electric vector perpendicular to the plane of incidence. For all other angles, reflected light will be only partially polarized.

For normal incidence (incident angle $\phi = 0$), parallel and perpendicular components of the light are equally reflected. With an increasing angle of incidence ϕ , parallel vibration reflectance will drop and perpendicular vibration reflectance rises until they reach values of 0% and 15% for the polarizing angle. For the incident angle $\phi = 90^\circ$, both parallel and perpendicular components are totally reflected.

Phase change of reflection. For external reflection where the angle of incidence is larger than the angle of refraction ($\phi > \phi'$):

- The sign of the vibrations perpendicular to the plane of incidence (s) is always negative, which means that there is a change in phase of 180° in the process of reflection ($\delta_s = \pi$).
- The sign of the vibrations parallel to the plane of incidence (p) is positive for small angles of incidence ϕ , which means there is no phase change in the process of reflection ($\delta_p = 0 - \pi$, where π is for the polarizing angle).

Figure A-72 shows the positions of the electric vector before and after external reflection from a dielectric such as glass.

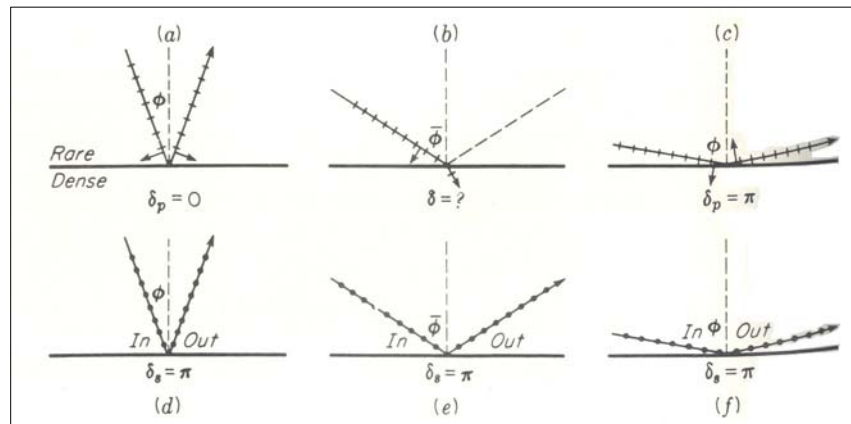


Figure A-72 Positions of the electric vector before and after external reflection

Figure A-73 shows plane-polarized light that strikes a plate of glass with a plane of vibration, making an angle $\Psi = 45^\circ$ with the perpendicular to the plane of incidence. Angle Ψ is an azimuth angle, and it is an angle between the R (reflected beam) and R_s (perpendicular) component of the reflected beam. The incident light has an amplitude E , which consists of two equal components E_p and E_s .

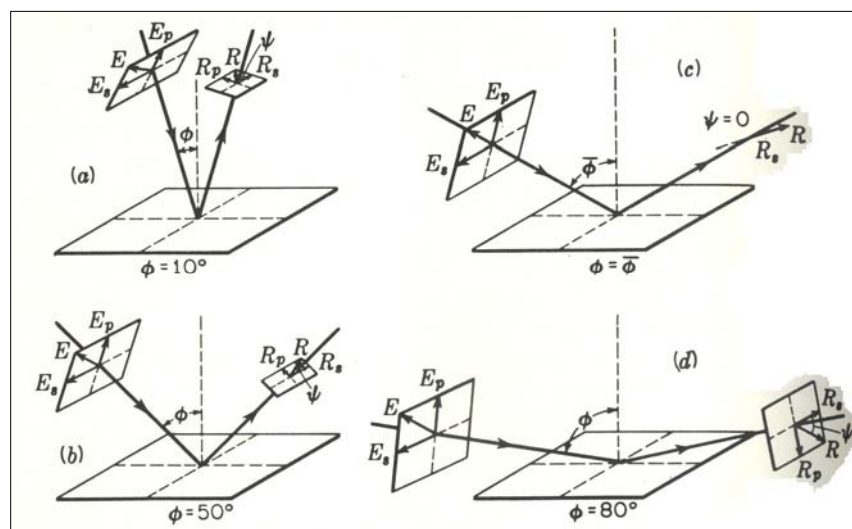


Figure A-73 Azimuths and amplitudes of plane-polarized light

- In case **a**, the angle of incidence is small ($\phi = 10^\circ$); amplitudes of the two reflected components are small and almost equal in magnitude, and they are out of phase by 180° .
- In case **b**, the incident angle is $\phi = 50^\circ$, and the azimuth of incident light is $\Psi = 45^\circ$. The parallel component R_p is small and in phase with E_p , and component R_s is larger than before and still 180° out of phase with E_s . The reflected ray is plane-polarized and the plane of vibration is farther away from the plane of incidence.
- In case **c**, the incident angle $\phi = \phi_p$ and component $R_p=0$, while component R_s is larger and in the same phase. The resultant amplitude is larger and perpendicular to the plane of incidence.
- In case **d**, the incident angle $\phi = 80^\circ$, and reflected components are the largest because for the angle of 90° , all light will be reflected. Magnitudes of reflected components are approaching the component of incident light. Both components have phase change of 180° , and the plane of vibrations approaches the planes of the incident light.

Light that is internally reflected from a glass surface has a phase that depends on the angle of incidence. For example, for an angle of incidence of 50° , there is a phase difference of 45° between the two components.

Figure A-74 shows the glass rhomb, known as the Fresnel rhomb, in which plane-polarized light normally strikes the shorter surface of the rhomb with its plane of vibration oriented at 45° to the plane of paper. Light then strikes the first diagonal surface at an internal angle of incidence of 54° . Total internal reflection occurs with a phase difference of 45° ($\pi/4$) between the two components.

An additional phase change of 45° is produced in the Fresnel rhomb by a second internal reflection so that on emergence the parallel component is 90° ahead in phase.

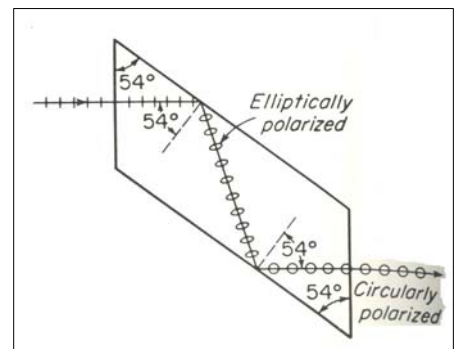


Figure A-74 Fresnel rhomb

Figure A-75 shows polarization of the reflected light when plane-polarized light undergoes a single internal reflection at various angles of incidence.

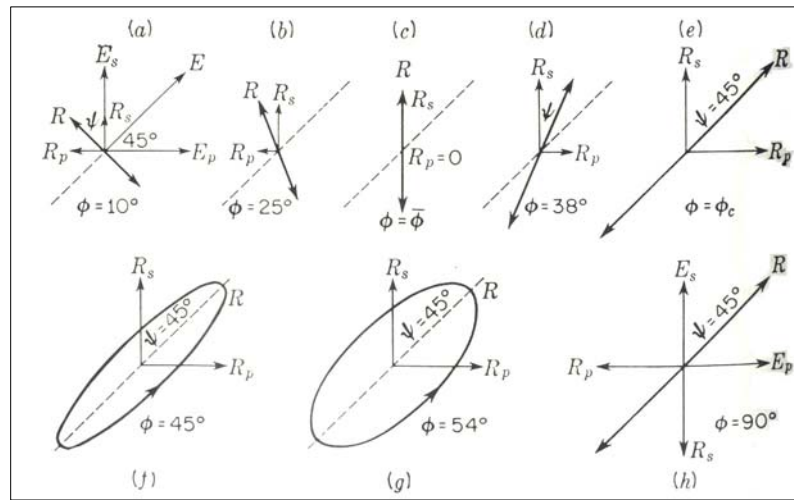


Figure A-75 Light vibrations internally reflected in glass

A.1.3. RADIATION OF LIGHT

Thermal radiation is radiation which a body emits because of its temperature. Bodies emit such radiation, as well as absorb it, from their surroundings. If a certain body has a higher temperature than its surroundings, it will emit more radiation than it absorbs so that it will cool off (Halliday & Resnick, 1986). On the other hand, if the temperature of the body is lower than that of its surroundings, the body will absorb more radiation than it emits so it will warm up. The rate of absorption and emission are equal if the thermal equilibrium of the body with its surroundings is achieved.

Thermal radiation from a hot solid body depends on the temperature:

- the higher the temperature, the more radiation is emitted.
- the higher the temperature, the shorter the wavelength of the part of the spectrum radiating more intensely. It means that all warm objects emit infrared waves, and the frequency of the waves increases as the temperature climbs. The predominant color of the hot body changes from dull red to bright yellow-orange to “white hot.”

The eye can see the colors which correspond to the most intense emission in the visible range (Halliday & Resnick, 1986). Not only a body temperature, but also material of which the body is made, such as its shape and the nature of its surface, influence the radiation that is emitted by a hot body.

Some objects convert all radiant energy that they absorb to heat energy, regardless of the color of the light. The experimental measuring of radiant energy is straightforward, although the choice of materials and methods could be tricky. When light strikes an object, it will be absorbed by the object on which it falls. Temperature rise of the object during a short time interval should be measured. The absorbed energy is equal to the energy of radiation.

$$\Delta E_{\text{absorbed}} = c \times m \times \Delta T$$

where: $\Delta E_{\text{absorbed}}$ - absorbed energy

c – specific heat of the absorber

m – mass of the absorber

ΔT – temperature rise/difference

The problem could be to get the black absorber, which means that this kind of body absorbs all light so that no light is reflected (Lehrman & Swartz, 1965). Most light sources are accompanied by heat, and as the temperature of the source rises, light gets more intense and whiter. Also, as the object is heated, the color of the radiation changes gradually from red to white. As the temperature increases, the radiation wavelength is shorter and the frequency is higher. The red color of radiation at low temperatures is caused by the maximum radiation being at a long wavelength with very low intensity in the blue. At high temperatures, the maximum point of radiation can be in blue or in the ultraviolet range (short wavelength).

A.2. TRANSPARENT MATERIALS USED FOR MANUFACTURE OF SHADING DEVICE SLATS

A.2.1. GLASS

A.2.1.1. Physical properties of glass

The essential properties of glass are transparency and durability. The other significant properties of glass are:

- Light/radiation
- Transmittance/reflectance/absorptance
- Refractive index
- Thermal properties
- Strength
- Hardness and abrasion resistance
- Chemical durability
- Weathering durability
- Specific gravity
- Fire resistance
- Sound attenuation

- **Light/radiation**

- Transmittance/reflectance/absorptance**

One of the most important performances of glass is its ability to transmit light, which is related to both radiation and visible light transmission. Radiation energy and wavelength are inversely proportional, which means if the wavelength is longer, the energy will be lower. Solar radiation consists of 3% of ultraviolet radiation, 53% of visible radiation, and 44% of near infrared radiation.

First, this energy is absorbed by glass and then is converted to heat. Glass perfectly transmits short wavelength solar energy. Transmission and absorption of sun radiation is the result of the action of photons in the electrons in the materials they impinge on. Photons

absorbed by materials lose their excess energy, causing a rise of temperature of material. After that, this material emits heat, which is long-wave radiation.

Glass transmits light at different wavelengths in different proportions, which is the result of its different forms and possibilities to apply various coatings. The transmission coefficient of glass is usually from 60% to 80% and between 400 nm and 2500 nm. Considering the relation between light and heat transmission, 53% of all solar radiation energy is in the visible part. If the total radiation transmission is below 50%, light transmission will be affected.

Most architectural high performance body-tinted glasses have various quantities of iron oxide that absorbs infrared radiation and cobalt oxide, selenium, and other chemicals that affect the glass color. The light transmission of the glass is reduced due to added colorizers. To increase reflectance of glass and reduce overheating, coatings are applied on the glass surface. Coated glass is usually part of double or triple glass.

The special types of coatings are low-emissivity coatings that have a low emission coefficient for thermal radiation. If the temperature of the body or surface is raised, they start to emit energy. Good absorbers are good emitters so that bad emitters will have good reflectance performance. Low-emissivity coatings are similar to reflective coatings, but they have low emission and reflection of long-wave rather than short-wave heat. These coatings are transparent over the visible wavelength (300 nm to 700 nm) and reflective in the long-wave infrared spectrum.

A typical system is glass with low-emissivity coating applied on the third surface. In this case, short-wave solar radiation is transmitted to the building interior. The interior surfaces heat up and begin to emit long-wave radiation back toward the glass. The glass absorbs about 90% of this long-wave energy but with its low-emissivity coating, the amount of heat radiated into the cavity is 8 to 10 times less than that which would be emitted by glass surfaces. The most significant advantage of these low-emissivity systems is that less heat is lost to the outside.

There are also interference coatings that separate solar radiation into component rays. These coatings are superimposed to produce a constructive interference pattern reducing or increasing the intensity of reflection. The advantage of interference coatings, compared to metallic coatings, is that they can be completely neutral in color.

- **Refractive index**

The refractive index for glass depends on the wavelength of the considered radiation, and the index of all types of glass decreases with the increasing wavelength. The refractive index is the most important optical performance of glass.

- **Thermal properties** include:

- maximum working temperature
- specific heat (measure of how much heat can effectively be stored in the material):
0.85 – 1.00 kJ/kg°C
- thermal conductivity (expresses how quickly heat passes through a material) – glass is a fairly good insulator): 1.02-1.38 W/m °C
- thermal expansion – values for glasses range from $0.54 - 10 \times 10^{-6}/^{\circ}\text{C}$ – glass with a low thermal expansion coefficient has good thermal shock resistance, and glass with a high coefficient can be effectively treated by thermal toughening.

- **Strength**

Glass has different strength qualities. Young's Modulus of glass is about 70,000 MN/m². Glass's ability to resist change of shape under stress is very good, and it is similar to aluminum, which is a common structural material. Glass is very strong in compression (1000 N/mm²) and weak in tension (100 N/mm²).

At normal temperatures, glass is not plastic, and it breaks when its elastic limit is exceeded. Many scientists prefer not to consider glass as having “strength,” but survival probabilities.

- **Hardness and abrasion resistance**

Hardness of glass is one of its most important properties. On the Moh scale (1-10), quartz has a hardness of 7, and soda-lime glass has a hardness from 5.4 to 5.8.

- **Chemical durability**

Chemical durability of glass is related to its good ability to resist chemical attack (water, acid, weathering from water, and sulphur dioxide). Hard borosilicates are acid-resistant, and soda-lime glasses are resistant to alkaline attack. Most glasses are not resistant to

lime and concentrated solutions of caustic soda (sodium hydroxide), but it is attacked by hydrofluoric and phosphoric acids.

- **Weathering durability**

Weathering durability is related to glass's natural resistance to a chemical attack and its ability to withstand the necessary cleaning.

- **Specific gravity**

Glass is a light material with a low specific gravity (2.2 - 2.47), which is an advantage in terms of handling, fixing, and support.

- **Fire resistance**

Conventional window glass has a very bad performance in fire. Glass with embedded wire has a fire resistance ability. Use of strong, low expansion materials (such as borosilicate glasses) and sandwich systems incorporating fire-resisting intralayers can improve the fire resistance performance of glass.

- **Sound attenuation**

Single-sheet glass has poor sound attenuation, but multiple layers and laminated glasses usually have good sound attenuation.

An appropriate selection of glass, as well as glass assembly, is very important for the thermal performance of the window and of the curtain wall. The clear glass is opaque for infrared radiation and hence absorbs long wavelengths of light. Heat through the glass has been flowing in as solar energy and either in or out as thermal energy. Solar gain through heat absorbing glass is less than solar gain through clear glass (shading coefficient for heat absorbing glass has a smaller value than that of clear glass).

Increasing the number of the layers of glass (for example, by using double glass) decreases its transmissivity. A compromise between insulation and light transmission needs to be found for making a decision about the number of layers. For double glazing, the U-value will decrease if the width of the gap between the glass layers increases. Also, the gap width affects the acoustical properties of the glass so that the optimal acoustical separation will be 6", which can complicate the assembly of the wall and its aesthetic qualities. The disadvantage of applying triple or quadruple glass is that this glass can hardly be used in

operable windows because of its weight. It is better to add low-emissivity coatings to the glass instead of adding another layer of glass.

The application of the double all-glass wall can contribute to thermal comfort. The body of the person sitting next to a cold window will radiate energy to that cold surface. If the surface temperature of the glass is close to ambient air temperature, the rate of heat exchange between body and glass will be very low, which contributes to thermal comfort. The inside pane of the glass stays closer to the temperature of the room, the outside pane stays closer to the outside temperature, and the drop in temperature happens in the air space between the two layers of glass so the window “feels” warmer.

A.2.1.2. Glass manufacture

Glass is an inorganic product made of oxides of silicon, boron, germanium, phosphorus, arsenic, and other compounds, which are heated to the point of the fusion and then carefully cooled to a rigid state without crystallizing. Molecularly, glass is amorphous like a liquid but it is a solid.

By adding certain materials to the pure silica, glass properties are improved:

- By adding iron-oxide, glass absorptivity to infrared radiation increases. It also helps in the melting process of manufacture because glass that contains iron absorbs heat better.
- By adding sodium oxide, potassium oxide and boric oxide, the melting point of pure silica is reduced from 1700°C to 1600°C.
- By adding aluminum oxide, crystallization is prevented and the viscosity of the glass is increased.

The process of making glass consists of three steps:

1. Melting: in this step, a molten mass is created. The various components are completely mixed. All components are heated to a temperature of 1600 to 1800°C, at which temperature they start to flow and can be formed.
2. Forming: is the step of the process in which glass gradually cools, and it changes from liquid to a solid. The temperature of the glass drops from 1600°C to 800°C, and its viscosity gradually decreases to the point where it can be shaped.

3. **Annealing:** is the step in the process in which glass is cooled evenly and gradually under controlled conditions from 600°C to 100°C. It is a process of heating and cooling to achieve a desired physical state.

Two processes of glass manufacture that are currently used today are:

- Float process
- Rolling process

Float process: It operates on the principle that glass at the temperature of 1100°C keeps molten the tin on which it floats. A melting point of the tin is 232°C, and the boiling point is 2720°C. Molten glass that is poured over tin will float on it because it has a lower specific gravity. Important properties of the floating process rely on the following properties:

- Melting points
- Specific gravity
- Surface tension that controls the depth of ponding

The floating process has four steps:

- Melting
- Floating
- Annealing
- Automatic cutting

Float glass is made from 2 mm up to 25 mm thickness.

Rolling process: The rolling process cannot produce the two parallel surfaces of glass like the float process. It can make glass from a different composition with one raw and one patterned surface. The rolling process has four steps:

- **Melting:** sand is melted and heated to 1600-1800°C, and then it flows toward the rollers under controlled temperature conditions.
- **Forming:** molten glass is poured as a ribbon about 1400 mm wide toward the main roller. The rollers' diameter is 240 mm, and they are removable and can produce a repeated pattern on the glass surface the length of which is equal to the roller length.
- **Annealing**

- Cutting

The “**Specialist**” glass industry needs to be investigated because flat glass might not be the only glass product that can be used for manufacture of shading devices. Manufacturing processes used for producing glass containers, tubes, or lamp gases may also be used for manufacturing glass shading devices.

- Containers are made by hand-blowing.
- Tubes: small diameter parallel sides tubes manufacture requires a different approach than that of blowing. For mass production of glass tubes, the following processes have been used:
 - Danner process: a ribbon molten glass is wrapped around an angled rod of fireclay, the end of which is stretched and drawn into a tube.
 - Vello process: glass is poured down through a ring.
 - Downdraw process: glass is drawn in a vacuum chamber.
 - Updraw process: uses an air jet to form the hollow in the tube; it makes thick wall tubing.

Diameter of the glass tubes is from 1 mm to 1 m.
- Lamp gases: must be characterized by thermal shock resistance. Soda-lime glass formed by automatic blowing is used.

A.2.1.3. Manufacture of glass rods and tubes

The pyrex brand of glass is material that is usually used for laboratory glassware. Technology of manufacturing glass rods and tubes could be applied for fabrication of glass shading devices. Three categories of this glass used in the industry are: soft, hard, and hard-silica glass.

- Soft glass: has a softening temperature around 700°C and a thermal expansion greater than 60×10^{-7} in/in/°C. It is used where heat resistance and chemical stability are not required.
- Hard glass: borosilicate glass that has a thermal expansion range $28-59 \times 10^{-7}$ in/in/°C. It has resistance to thermal shock and good chemical stability. The pyrex glass brand can withstand a thermal gradient three times more than ordinary soda-lime glass. Borosilicate glass is expensive compared to soda-lime glass.

- Hard silica glass: has more than 90% of SiO_2 . It has high softening temperatures and low thermal expansion, and it can be used at temperatures of 800°C .

Laboratory tubes are usually made of hard (borosilicate) glass. Hard glass has a compressive strength of $200,000 \text{ lb/in}^2$ and a tensile strength of $10,000 \text{ lb/in}^2$ (but 1000 lb/in^2 is used). Borosilicate tubing can be placed directly into a gas oxygen fire without preheating. It is important not to hold glass at high working temperatures for a long time since devitrification can occur. Tubes can be made by scientific blowing but annealing is also needed.

The following processes are used for fabrication of glass tubes and rods: Danner, updraw, downdraw, and Vello.

- *The Danner process* (see Figure A-76): glass from the forehearth flows in ribbon form over a mandrel that is placed inside a temperature-controlled muffle. The hollow, refractory mandrel is downward – inclined (15° to 20° from horizontal) and it rotates. Because of rotation, glass will wrap around the mandrel and then flow off the mandrel downstream. It is picked up there, cooled gradually, and placed between horizontal tractors. The tractors are located 2 m to 3 m below and 20 m to 40 m away from the mandrel so that the glass is suspended between the mandrel and the tractors. For making tubes, air is blown through the mandrel, but for making rods, a vacuum needs to be applied.

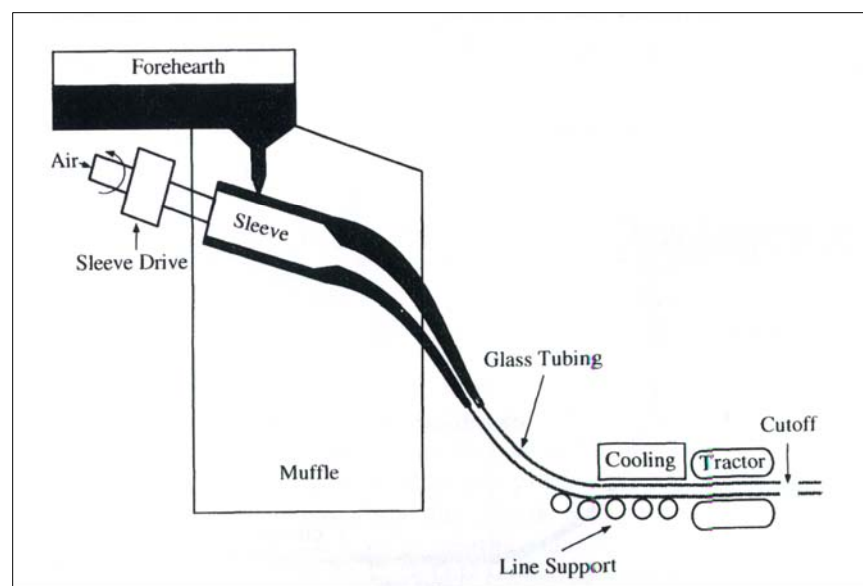


Figure A-76 *The Danner process*

- *The Updraw process:* glass is drawn vertically upwards off a hollow refractory cone. The cone is located within a rotating refractory sleeve, which is partly immersed in glass. For forming a tube, air must be blown through the hollow cone. An advantage of the updraw process is that tubes of different sizes and wall thicknesses can be made, including large, thick-walled tubes.
- *The Downdraw process:* glass flows through an orifice ring and is pulled vertically downwards by a tractor. If a tubing needs to be drawn, then glass flows over a “bell” that is located concentrically within an orifice ring. Air pressure is applied to make tubes of different diameters and wall thickness.
- *The Vello process* (see Figure A-77): the tube or rod is turned horizontally along rollers. The tube or rod is not rotated. The bell and orifice shapes can vary to give various cross-sectional shapes to the inside and outside surfaces. For example, the thermometer tube that has a cylindrical lens shape on the outside and an elliptical bore on the inside is made by using the Vello process. Also, colored strips can be introduced via channels that are carried into the Vello bowl before glass passes through the orifice.

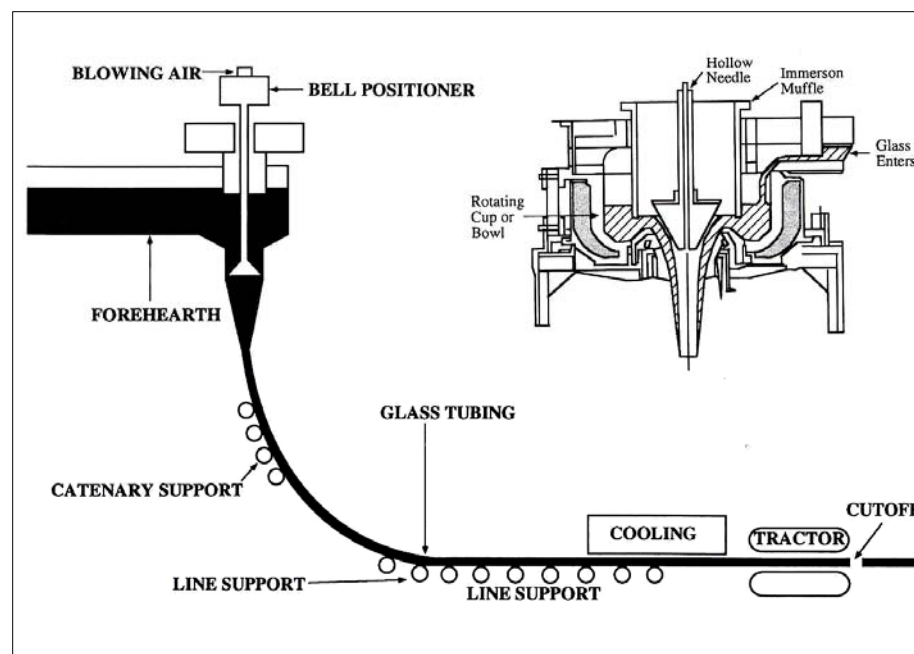


Figure A-77 The Vello process

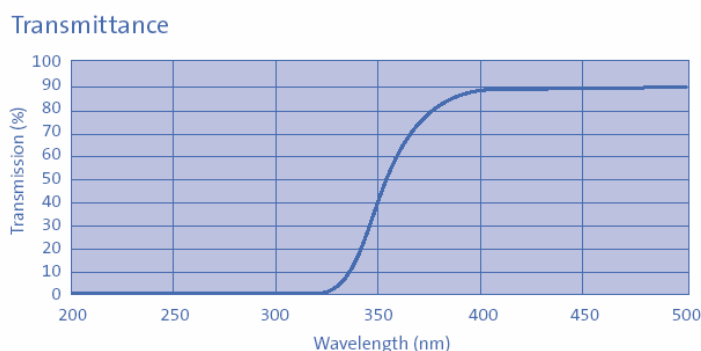
Thermometer tubing is almost completely drawn by machine. Thermometers are fabricated from two glass parts:

- A capillary tube
- A thin-walled bulb or tube

These two parts are drawn separately and sealed together in the manufacturing process. After that, glass is annealed. The standard types of capillary tubing are round tubing and triangular “lens” tubing. The shape of the bore section can be round or elliptical. Standard sizes of capillary tubing are 6/64” for the lens tubing measured across the back and 5/16” diameter for round tubing. Table A-1 shows properties of the UV-absorbing Vycor tubes.

Table A-1 Properties of the UV-absorbing Vycor tubes

Physical Properties		Optical Properties	
	Metric		
Density	2.20 g/cm ³	Index of Refraction (589.2 nm)	1.458
Strain Point	870 °C		
Anneal Point	995 °C		
Softening Point	1530 °C		
Expansion	8.0 x 10 ⁻⁷ / °C		
Transmittance		Forms Available	
			Metric
230 nm	< 4%	Tubing	4.0 mm - 20 mm
320 nm	< 4%	Rod	2.5 mm - 18 mm
340 nm	< 25%	Flat Sheet	3.0 mm - 25 mm
450 nm	> 90%	Precision Pressings	Capability available upon request
This composition is designed to absorb UV-B and UV-C.			



A.2.2. PLASTICS

Alternative materials that can be used in building technology are plastics. Four main plastics that are usable include:

- Acrylic (PMMA)
- Polyvinyl chloride (PVC)
- Polystyrene
- Polycarbonate

Acrylic and polycarbonate can be used for glazing instead of glass. Advantages of plastics compared to glass are:

- Lightness (specific gravity 0.9-1.6, compared to 2.5 for glass)
- Easy formability
- Low thermal conductivity
- High specific heat

The disadvantages of plastics (particularly clear plastics) compared to glass are:

- Lack of hardness
- Lack of durability
- Maintenance of properties (brittleness and color)
- They must be maintained in a much more careful way compared to glass because of its softness
- Maximum working temperatures are between 80°C and 135°C
- They begin to decompose at 200°C
- They lose their strength at approximately 70°C

Plastics are inorganic materials that can flow, and on application of heat and pressure, their shape can be changed. Their molecular (polymeric chain) structure provides their thermal, weight, and strength properties. The invention of acrylics (1930s) and polycarbonates (1950s) produces materials with heat distortion temperatures of more than 100°C and different transparent plastics with high potential for extrusion and formability.

Manufacture of the plastics

Thermoplastics (acrylic and polycarbonates) can be made by using two processes:

- Extruder
- Blow moulding

The **extruder** process is used for producing continuous lengths of sections, tubes, and films. It consists of a heated barrel with a screw turning inside it. Granular material is fed into the screw and heated. Material is forced along the screw and it becomes more fluid. Finally it is forced through a die which gives a final shape of the extrusion. As it comes out of the die, the extruded material is cooled (Quarmby, 1974).

The **blow moulding** process is used for producing plastic bottles. The extruder extrudes a length of the tube downwards. This tube is gripped by the closing of a two-part mould, which nips the top and bottom of the tube. Air is blown forcing the still plastic tube outwards against the walls of the mould, which then parts and drops out a bottle (Quarmby, 1974).

A.2.2.1. Properties and manufacture of acrylic (Polymethyl Methacrylate – PMMA)

Properties of acrylic - Acrylic has exceptional transparency, high resistance to ultraviolet (UV) light, and minimal yellowing. Because of resistance to UV light, it can be used as a UV filter coating to polycarbonates to avoid yellowing. Table A-2 shows the physical, thermal, and chemical properties of cast-clear acrylic.

Table A-2 Physical, thermal, and chemical properties of cast-clear acrylic

PROPERTY	VALUE
Light transmission	92% for thickness 0.04-1.00 in.
Ultraviolet light transmission	Similar to that of glass
Refractive index	1.49
Maximum working temperature	176°F - 194°F
Specific heat	0.35 – 0.38 Btu/lb°F
Thermal conductivity	0.098 – 0.127 Btu/h/ft°F
U – value	0.47 Btu/h ft ² °F
Expansion coefficient	0.00004 in./in./ °F
Tensile strength	8000-11600 lb/in. ²

Table A-2 Physical, thermal, and chemical properties of cast-clear acrylic

Charpy unnotched impact strength		3.5 ft lb
Notched Izod impact strength		0.4 ft lb/in. of notch
Elongation		4%
Hardness, Rockwell		M80
Specific gravity		1.18
Dielectric constant		3.0
Resistance to chemicals	Nonoxidizing acids (20% H ₂ SO ₄)	satisfactory
	Oxidizing acids (10% HNO ₃)	unsatisfactory
	Aqueous salt solutions (NaCl)	satisfactory
	Aqueous alkalies (NaOH)	satisfactory
	Polar solvents (C ₂ H ₅ OH)	satisfactory
	Nonpolar solvents (C ₆ H ₆)	questionable
	Water	satisfactory

The general resistance to weathering is good. Water absorption is only 2% at 100% relative humidity. In fire, it burns in the similar way to hardwood, but more easily than polycarbonates and with a low level of smoke, producing only CO₂ and CO.

It is very easy to work with acrylic. Cutting tools should be sharp to produce a good surface finish. Power saws, twist drills, turning, routing, spindle moulding, and layer cutting are possible. Acrylic can be polished by using a fine grade abrasive paper, by hand polishing, or conventional metal polishes.

Manufacture of acrylic: The monomer is heated until it becomes a heavy syrup, which is then poured into a “cell” made of two glass sheets separated by edge gaskets to get the required thickness of the sheet. The cell is then baked in the oven, cooled, and the glass sheets are removed. Moulding powder can also be made that makes a polymer that can flow easily. It is used to make extrusions.

Forming of acrylic – Acrylic becomes rubbery at temperatures between 150°C and 170°C, and it can be formed in different shapes. The curvature transforming is possible:

- Single sheets are allowed to bend or fold under their own weight.
- Double skin: requires force (air-pressure, vacuum, or male/female moulding, or a combination of these).

Since acrylic has some amount of internal stress after manufacture, annealing should be applied.

A.2.2.2. Properties and manufacture of polycarbonates

Polycarbonates are polyesters of carbolic acid H_2CO_3 (esters are formed by condensing an alcohol with an acid to eliminate water). Properties of polycarbonates are:

- High transparency
- Strong network structure
- Toughest transparent material
- Good impact resistance and mechanical properties
- Good thermal properties with a service temperature above 100°C
- Good fire performance because of its phenol base. Products of combustion are mainly CO_2 and CO .
- Coating with polymeric silicone can be applied to the surface of a polycarbonate sheet to provide:
 - Higher abrasion resistance
 - Potential for cold-curved or drape-formed sheets by formable hardened casting

Table A-3 shows the physical, thermal, and chemical properties of unfilled polycarbonates.

Table A-3 Physical, thermal, and chemical properties of unfilled polycarbonates

PROPERTY		VALUE
Light transmission		82% for thickness of 0.48 in. 90% for thickness of 0.04 in. 85% for typical thickness of 0.2 – 0.24 in.
Ultraviolet light transmission		Does not transmit
Refractive index		1.586
Maximum working temperature		275°F
Specific heat		0.286 – 0.301 Btu/lb $^\circ\text{F}$
Thermal conductivity		0.11 - 0.12 Btu/h ft $^\circ\text{F}$
U – value	For single sheet	0.767 – 0.968 Btu/h ft $^2^\circ\text{F}$

Table A-3 Physical, thermal, and chemical properties of unfilled polycarbonates

U-value	Double-skin material 6 mm thick	0.617 Btu/h ft ² °F
	Triple-skin material 32 mm thick	0.335 Btu/h ft ² °F
	Five-wall product 20 mm thick	0.326 Btu/h ft ² °F
Expansion coefficient		0.000038 in./in./ °F
Tensile strength		10400 lb/in. ²
Compressive strength		12330 lb/in. ²
Notched izod impact strength		12 – 16 ft lb / in. of notch
Elongation		110 %
Hardness, Rockwell		M70
Specific gravity		1.2
Dielectric constant		3.0
Water absorption		0.15%
Resistance to chemicals	Nonoxidizing acids (20% H ₂ SO ₄)	questionable
	Oxidizing acids (10% HNO ₃)	unsatisfactory
	Aqueous salt solutions (NaCl)	satisfactory
	Aqueous alkalies (NaOH)	unsatisfactory
	Polar solvents (C ₂ H ₅ OH)	satisfactory
	Nonpolar solvents (C ₆ H ₆)	unsatisfactory
	Water	satisfactory

Polycarbonates are made in a variety of extruded forms. Single sheets as well as double- and multiple-skin polycarbonates are available:

- Single sheets – 1-12 mm thick
- Double skin – up to 16 mm thick
- Triple skin – up to 40 mm thick

Double skin polycarbonate materials are formed as a linear cell material and can act as good insulators.

It is easy to work with polycarbonates. They can be sawned, cut, drilled, punched (up to 3 mm thick), turned, and milled. They can be polished either with a very fine polishing abrasive or by methylene chloride vapor polishing. Polycarbonate materials can be:

- Beaded (by using normal glazing techniques)
- Bounded

- Mechanically fastened

If it is cold-curved during installation, the maximum radius depends on the thickness of the sheet:

- Single sheet – radius = 100 x thickness
- Multiwall materials – radius = 175 x thickness

Polycarbonates are resistant to diluted acids, inorganic salts, alcohol, cement, and plaster.

Since they yellow under UV light, they need to be coated with:

- Acrylic, which acts as a filter, or
- Co-extruded with a high concentration of a UV-absorbing product on both sides, which will improve its weathering durability

Forming of polycarbonates

Three processes of polycarbonates' forming are:

- Thermoforming: the sheet is heated to a temperature from 175°C to 200°C and moulded using vacuum forming, free-blowing, or pressure forming.
- Drape forming: the mechanical matched mould forming the sheet is heated from 155°C to 160°C in an oven before it is transferred to the mould. It uses male and female moulds and pressure if it is needed. Annealing of the material is used to relieve surface stress.
- Cold-curving: at ambient temperature

A.2.3. THE STRUCTURE OF CRYSTALLINE AND NONCRYSTALLINE MATERIALS

The difference between crystalline and noncrystalline materials is that in **crystals** regular repetition of a structural pattern in any randomly chosen direction exists, that is, small groups of atoms form a repetitive pattern. Atoms are located in a periodic array over large atomic distances, that is, long-range order exists. The result is a **single crystal** in which all unit cells are linked in the same way and have the same orientation. Most crystalline solids consist of a collection of many small crystals, and they are known as **polycrystalline solids**.

Properties of the crystalline solids depend on the crystal structure of the material or on the way in which atoms, ions, and molecules are spatially arranged. Atoms or ions in crystalline structures are solid spheres with defined diameters, and the spheres are

representing the nearest neighboring atoms that touch one another. Crystal structures can be subdivided in unit cells that are small repeat entities. The unit cells have a form of parallelepipeds or prisms that have three sets of parallel faces and one that is drawn within the aggregate of spheres (see Figures A-78 and A-79).

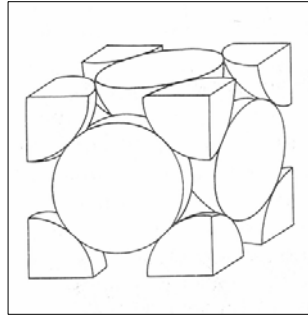


Figure A-78 A hard sphere unit cell

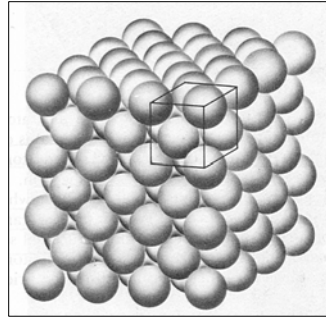


Figure A-79 An aggregate of many atoms

The unit cell shows symmetry, which is an important property of the crystals.

Noncrystalline solids such as glass do not have a regular arrangement of atoms over large atomic distances. Such materials are also known as amorphous (without form) or supercooled liquids, since their atomic structure resembles that of liquid. Their atomic structure is relatively complex and can become ordered with difficulty.

Silicates are materials that are composed of silicon and oxygen. They form silicon-oxygen tetrahedron (SiO_4^{4-}) in which each atom of silicon is bonded to four oxygen atoms. The oxygen atoms are situated at the corners of the tetrahedron, and the silicon atom is situated at the center. The most simple silicate material is silica (silicon-dioxide SiO_2). It has a three-dimensional structure in which every corner oxygen atom in each tetrahedron is shared by an adjacent tetrahedron (see Figure A-80). Silicate crystal structures are composed of one Si^{+4} ion and four O^{2-} ions that form SiO_4^{4-} tetrahedron (see Figure A-81).

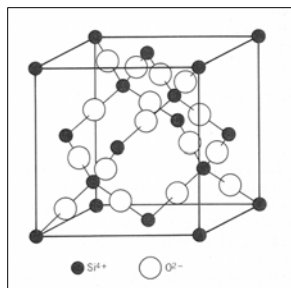


Figure A-80 A polymorph of SiO_2

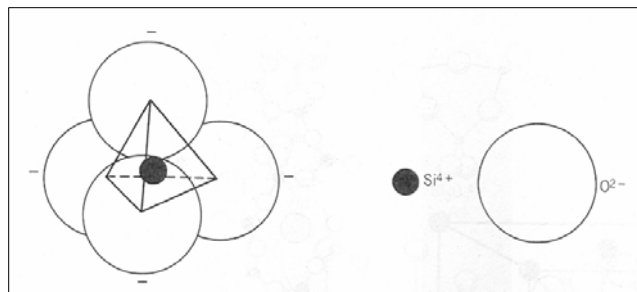


Figure A-81 A silicon-oxygen tetrahedron

Silica can exist in both crystalline and noncrystalline structures. Whether a crystalline or noncrystalline solid would form depends on the ease with which a random atomic structure in the liquid can transform to an ordered structure during the process of solidification.

Silicate glasses, similarly to silicate crystals, are three-dimensional structures that consist of SiO_4 tetrahedra and oxygen bridging between the tetrahedra. Distances between Si and O atoms are close to these distances in the crystalline silicates. Angles between structurally equivalent bonds from tetrahedron to tetrahedron are not constant, but random values within certain limits can be assumed in glass structure. Because of the irregularity of bond angles, the symmetry of the structure in glass does not occur. As a result, a three-dimensional lattice is not in order as it is in the crystals.

If we consider very small increments of volume in glass, such as 10-30 ions, we will see that many of such increments are in the order, but if we move away from this volume, orderliness will decrease. If we move on any straight line in any direction through the glass, regularity of the structure will alternately and gradually increase and decrease. This type of structure has a short-range order but does not have a long-range order. The crystals have both a short- and long-range order, but glass has only a short-range order (see Figure A-82).

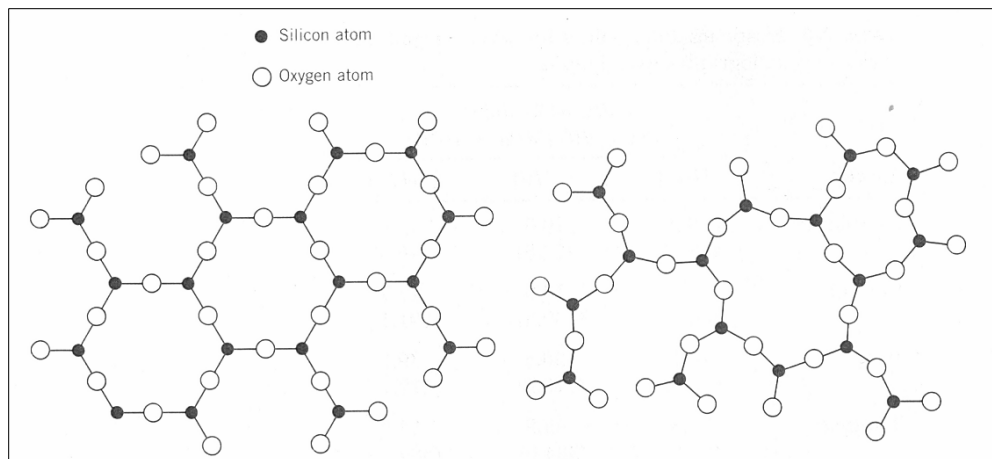


Figure A-82 Schemes of the structure of crystalline and noncrystalline silicon-dioxide

According to A.A. Lebedev, the silicate glass structure consists of a microcrystalline formation, one form of which consists of quartz microcrystals. The glass structure is an accumulation of submicrocrystalline formations of various silica and silicates. Lebedev's theory of the microcrystalline structure of glass explains the peculiar variation of the

refractive index, coefficient of thermal expansion, and heat effects that are observed in glass in the softening region.

The physical properties of a single crystal depend on the crystallographic direction in which the measurement is taken. For instance, the elastic modulus, the electrical conductivity, and the index of refraction can have different values in different directions. Materials whose properties are independent of measurement direction are *isotropic*. *Anisotropic* materials have different properties in different directions, and they are associated with the variance of atomic or ionic spacing with crystallographic directions. The extent of anisotropy in crystalline materials is a function of the symmetry of the crystal structure. The degree of anisotropy increases with the decreasing of the structural symmetry. For many polycrystalline materials, the crystallographic orientations of the individual grains are completely random. But even though each grain might be anisotropic, a specimen that is composed of these grains can behave isotropically.

Glass is an isotropic material on a macroscopic scale unless the manufacturing introduces stress. The most common anisotropic glass is inhomogeneous glass in which birefringence is a result of internal stress. Permanent internal stress and birefringence are created by thermal inhomogeneity during cooling. The thermal stresses that are the result of the rapid cooling can be measured by polarization optical instruments. It has been found that compressive stress at the surface and tensile stress in the center of glass occur.

Strain in glass has been found by its effect on polarized light, which is similar to the effect of birefracting crystal. Brewster (1813) discovered that glass plate under a load behaves as a uniaxial negative crystal. The direction of the load was an optic axis, and birefringence was proportional to the strain. The birefringence was measured by the difference between the two plane-polarized light waves formed on traversing the stained block. Thus, the birefringence is a measure of the strain, but the “stress-optical” coefficient, which is a relation between stress and strain, depends on the glass composition.

The process of glass annealing has two steps:

1. removal of the internal stress
2. prevention of the stress return after subsequent cooling

The toughened state of silicate glass is not only characterized by the existence of internal stress, but it is also distinguished by its internal structure. For instance, the difference

between indices of refraction of toughened and annealed glass is not only the result of the existence of internal stress in toughened glass. The refractive index of glass rises first almost linearly with the increase of temperature, and then begins to fall rapidly at about 520°C to 590°C.

Besides birefringence, there is another form of anisotropy in glass known as “dichroism.” The metallic inclusion, such as silver, gold, or copper particles in glass, can produce colors such as ruby or yellow, as well as phototropy and photosensitivity. If such glass is stretched beyond T_g , it will become optically anisotropic. Photochromic polarizing glass is made by stretching photochromic glass melts. Such glass can change reversibly from a clear unpolarized state to the darkened polarized state if it is exposed to light.

A.3. DOUBLE–SKIN FACADES OVERVIEW

A.3.1. CURRENT STATE OF ART

In transition periods, heated outside air can increase the temperature in the cavity and can also increase the room temperature. Control of air temperature in the cavity, especially if natural ventilation of space is wanted, is a very important issue (Daniels, 1998).

The significant advantage of the double facade is reduced wind pressure so that windows, even on the upper floors of high-rise buildings, can be opened to provide natural ventilation of offices. In this way, ventilation is controlled by occupants reducing investments in air-handling systems and reducing energy consumption for ventilation (Campagno, 1995).

Heat losses through a double wall are reduced due to reduced speed of the air flow and increased air temperature in the cavity, which lowers the rate of heat transfer on the glass surface. The result is a higher surface temperature, which provides better thermal conditions for occupants so that the space close to the window is better utilized (Campagno, 1995).

Two basic strategies used for double envelope are: passive and active.

Passive systems use natural strategies for heating and ventilation of air in the cavity. In winter, openings on the outside layer are closed so that the inside air is introduced into the cavity. Then the air is heated by the sun and after that returned to the room, reducing active heating loads. In summer, openings on the inside layer are closed, and outside vents are open. Outside air is introduced into the cavity and it captures sun energy. Warm air is rejected out by using a natural strategy, such as a stack effect, protecting the interior from overheating and reducing cooling loads.

Active systems use HVAC systems to provide air to the facade cavity. During winter, this air is heated by the sun and can be used for preheating ventilation air through a heat exchanger. In summer, warm air from the cavity is returned to the HVAC system and then rejected to the outside.

Computer simulations and tests have shown that natural air circulation can remove up to 25% of the heat resulting from solar radiation in the cavity. Generally, given appropriate panes of glass and solar control devices, g-values (total solar energy transmittance) of approximately 0.10 can be achieved (Campagno, 1995).

The height of continuous openings should be two or three floors since the air temperature increases with the increase in height (Campagno, 1995). The temperature in the cavity rises because of reflection and light absorption and can vary greatly and reach a maximum temperature of 70°C (160°F) (Daniels, 1998).

Jones, Messadi, and Shang-Shiou (2000) did a study of the cooling season performance of a ventilated double-glass wall. They found in their research that heat removal from a wall cavity increases with increasing solar radiation, while increased wind speed causes a decrease of heat removal. The average temperature difference between the inside surface of the glass and the room air is about 0.7°C, achieving the thermal comfort for occupants. About 45% of the solar radiation that flows in the cavity can be collected and either used or exhausted. In winter, the air cavity is an effective solar collector, and in summer, the shading coefficient is reduced while maintaining high quality daylighting. Jones et al. (2000) used an experimental method by monitoring a full-scale model for actual climatic conditions.

Paassen and Voorden (2000) developed simplified tools for evaluating energy performance of a double facade. They discovered that a double facade with air-tight junctions and proper air flow control in the cavity is a preheater for ventilation air. In a building with 10 floors, an overall heat recovery efficiency of 49% can be obtained. Night cooling by natural ventilation requires large open junctions in the outer facade (2% of the floor area). In order to use the double facade, as well as for night cooling as for heat recovery, controlled dampers in the open junctions are necessary. They applied an experimental approach – a computational simulation of the double facade model.

Ziller and Sedlacek (2000) carried out research related to natural ventilation of rooms with double walls. They concluded that the ventilation coefficient increased with an increasing opening section in the primary facade. The ventilation rate was reduced due to the raised temperature in the facade cavity. Dependent on the size of the door gap, the ventilation rate increased with an increasing wind speed or wind pressure difference between the facade and floor. First, an experimental approach by using a physical model with a certain geometric scale was used. After that, a full scale test in the test room with double facade ventilation system on an existing building was carried out to compare the model test and full-scale test. A wind tunnel test was also conducted.

The goal of Saelens and Hens's research (2000) was to find how dynamic U-factors and solar heat gain coefficient (SHGC) for double envelopes depend on the system properties (airflow rate, position of the shading device, typology). They found out that the U-factor is between 0.84 and 1.88 W/m²K for a raised shading device, and 0.49 and 1.44 W/m²K for a lowered shading device. The dynamic U-factor changes linearly with the intake temperature. The energy demand of the HVAC system increases with an increasing airflow rate despite the decrease in the U-factor. Surface condensation on the cavity side of the outer pane occurred due to a high set point of the relative humidity of the indoor air. The dynamic U-factor and SHGC for active envelopes becomes difficult to use, are typology dependent, and are a multi-dimensional function of the system and material properties. A suitable energy performance indicator for double envelopes should be based on the overall building energy demand rather than on energy demand indicators on the envelope level. A numerical simulation program for the calculation for the airflow windows on an existing building was used in this research.

Afifi (2000) estimated peak cooling and heating loads for the five simulation model variations. He compared the thermal performance of the double-envelope base model with that of the single-envelope base model and the other model variations. A computer simulation, which used the Building Loads Analysis and System Thermodynamics program (BLAST) for testing the proposed building model, was used in this research. Five simulation models--three variations of the double-envelope building model and two variations of the single-envelope building model--were analyzed. Identical conditions for all five models were assumed. The BLAST simulation results indicated that the double-envelope building model performed significantly better than both the externally shaded and the externally unshaded single-envelope building models in hot and dry climatic conditions, such as those in Phoenix, Arizona. More specifically, the double-envelope base model (DE-BM) reduced the total peak cooling load by 26% compared to the single-envelope base model. Heating loads are entirely eliminated, given the assumption of the 2.5% winter design-day conditions for Phoenix, Arizona. Orientation of a square-plan double-envelope building model has no significant effect on its total peak loads.

Aghemo, Filippi, and Masoero conducted a case study of a double-envelope office building. Detailed hour-by-hour simulations were performed to assess the energy

performance of the various HVAC system alternatives. The conclusion of their research was that the most promising solution appears to be one characterized by a ventilated air space, external double (or triple or double with low-emissivity coating) glazing with heat-absorbing glass, and a sun-shading device located inside the air space. The ventilated double envelope presents values of surface temperature that are very close to the ambient air. Winter envelope heat losses also are significantly reduced. Better control of summer solar gains can be achieved, thanks to the combined effect of the horizontal overhang and vertical blinds located within the air gap. The ventilated double envelope poses several technical problems with respect to maintenance, among which filtering of extract air and access to the air space for window and sun-shading cleaning are probably more critical.

A.3.2. EXAMPLES OF INSTALLED SYSTEMS

There are several environmentally friendly buildings designed and constructed mostly in Europe. Some of them have double glass walls as an envelope. The following examples are showing different systems of double glass walls, as well as shading devices.

A.3.2.1. European Parliament

This building has a completely glazed double glass wall. The outside facade layer is single laminated glass (4+4+4/4) and the inside facade layer is double clear glass (6/12/6). The air cavity between the glass layers is 1.7 m. The lower part of the outside facade layer consists of automated vents that are controlled by thermal sensors installed on the outside layer of the facade. These vents are open during the summer, avoiding natural ventilation of the facade by using the stack effect. The vents are closed during the winter, improving the thermal insulation of the facade.

FACADE PERFORMANCE

- Thermal resistance 2.2 W/m²K
- Solar heat gain coefficient
 without shading device 53%
- Light transmission 70%
- Shading value of facade 61%

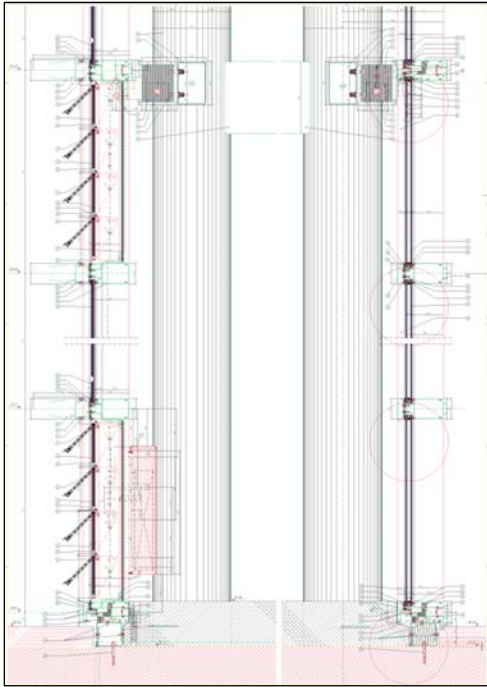


Figure A-83 Vertical section through the double glass wall

A.3.2.2. Postdamer Platz

This building facade has two layers: the inside layer of the double-glazed operable windows and the outside layer of operable laminated glass blades. The blades are controlled from the inside to protect the interior from overheating and glare.

Figure A-84 Cross section of double-skin facade
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A.3.2.3. Permasteelisa Laboratory

This building has a double glass wall composed of:

- Outside layer of 8 mm thick glass

- Inside layer of low-emissivity double glass
- Ventilated air cavity 150 mm wide with a computer-controlled shading device. The automatic control of blinds depends on solar radiation, air temperature in the cavity, and glare.

FACADE PERFORMANCE

- Thermal resistance 1.1 W/m²K
- Solar heat gain coefficient without shading device 7%
- Light transmission 68%
- Shading value of facade 8%

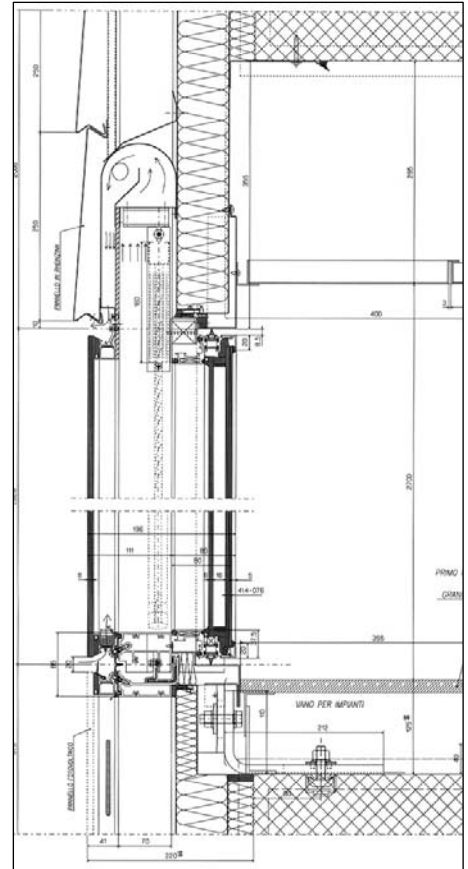


Figure A-85 Cross section of the double glass wall

A.3.2.4. Swiss Main Post Office

This administrative building was originally built in 1964, and a double glass facade was installed in front of the old one in 1999. The inside facade layer consists of double-glazed windows and the outside layer is made of moveable glass louvers.

FACADE PERFORMANCE

- Thermal resistance 1.2 W/m²K
- Solar heat gain coefficient without shading device 0.7%



Figure A-86 Moveable glass louvers interior

A.3.2.5. The Helicon, Finsbury Pavement

This office building has a double glass wall with 12 mm clear glass as an outside layer and low-emissivity double glass as an inside layer. Shading devices made of aluminum are located in the cavity and automatically controlled so that their position can be changed, depending on solar heat gain and glare. Each facade elevation is a separate thermal zone, and control of the shading devices is done independently for each facade elevation. The double glass wall works together with a chilled ceiling to provide internal thermal comfort.

FACADE PERFORMANCE

- Thermal resistance 1.6
W/m²K
- Solar heat gain coefficient
without shading device 9%
- Light transmission 58%
- Shading value of facade 14%



Figure A-87 Moveable louvers

A.3.2.6. Union Chimique Belge Center

The double glass wall applied to this building facade has an outside low-emissivity double-glazed layer, 150 mm air cavity, and an inside 8 mm clear glass layer. The shading device is installed in the cavity.

FACADE PERFORMANCE

- Thermal resistance 1.0 W/m²K
- Solar heat gain coefficient
without shading device 16%

- Light Transmission 50%

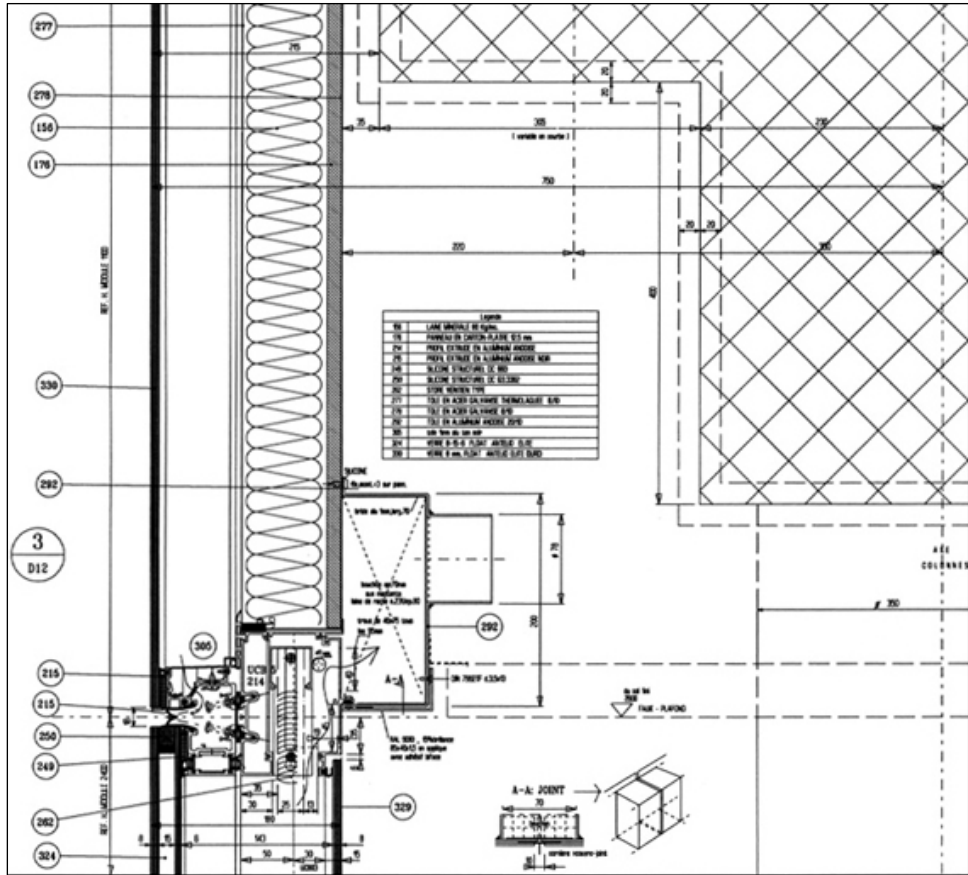


Figure A-88 Cross section through facade

A.3.2.7. Avax S.A. Headquarters

This building's east-oriented facade is protected by vertical shading devices that consist of double laminated glass panels with a silk screen printed surface, providing a shading coefficient of 70%. Vertical blinds are automatically controlled based on solar radiation. The inside facade is a conventional double-glazed conventional curtain wall. Thermal resistance of the facade assembly is $2.8 \text{ W/m}^2\text{K}$.

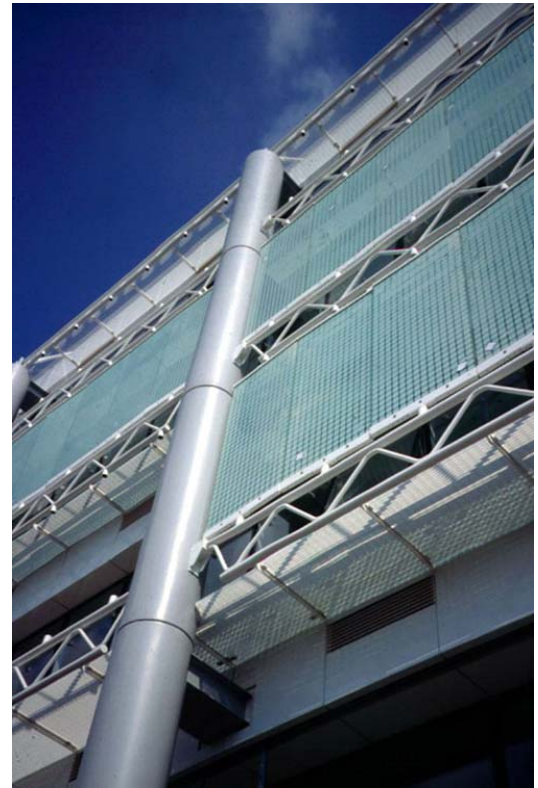


Figure A-89 *Moveable glass blinds*

A.3.2.8. Commerzbank, Frankfurt

The offices' facade is a double glass wall and is an integral part of the environmental building systems. The inside facade layer consists of an operable double-glazed window, and the outside layer is single-glazed. There is a ventilated air cavity between two facade layers, and a moveable shading device is installed in the cavity. Air is introduced in the cavity at the sill level and exhausted through a slot at the head. Small aerofoil section strips are installed at the sill level of the panel to prevent exhausted air to re-enter the window cavity above.

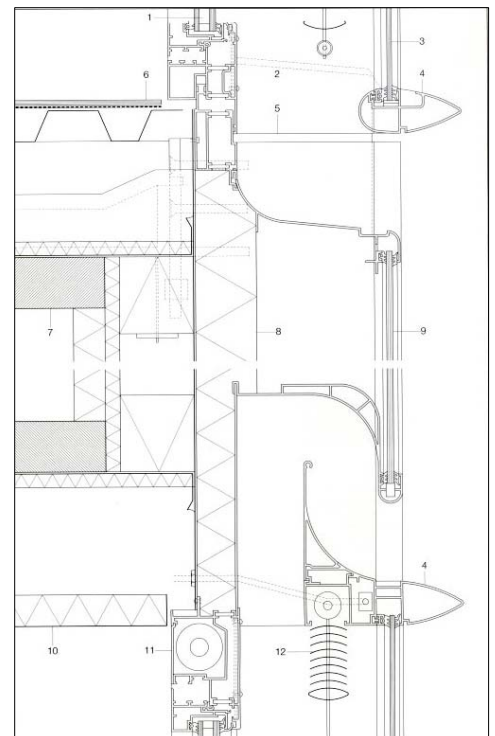


Figure A-90 *Vertical section through the facade*

A.3.2.9. RWE AG Headquarters, Essen, Germany

The double glass wall of the cylinder-shaped building consists of:

- Outside single-glazed layer; glass is 10 mm (3/8") thick, and fixed with bolts
- Inside double-glazed layer with operable windows
- Air cavity 19 1/2" wide that contains a shading device
- "Fish-mount" airflow valve is a part of the outside layer, and it controls the airflow into and out of the cavity.

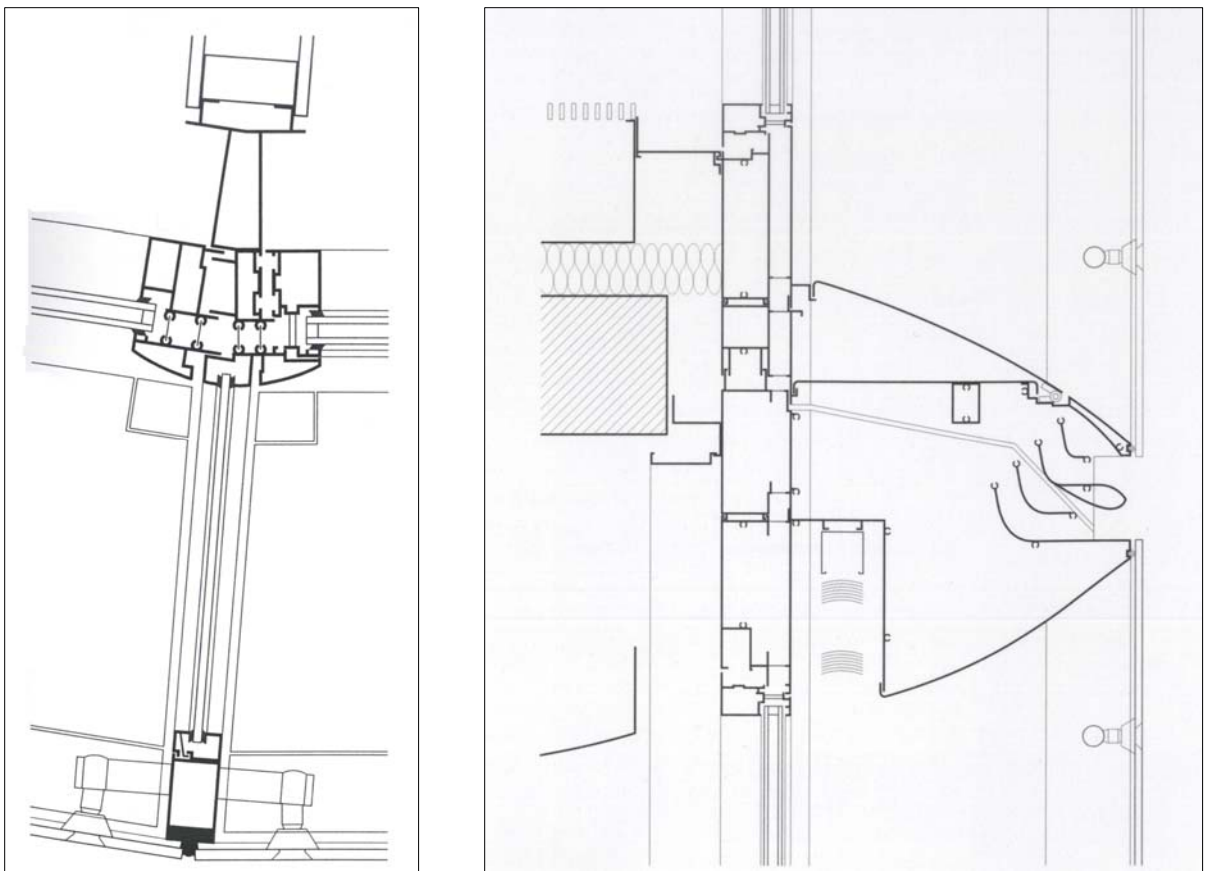


Figure A-91 Horizontal and vertical section through the facade--figure from "Glass in Architecture" by Michael Wigginton

A.3.2.10. Occidental Chemical Center, Niagara Falls, New York

The double glass wall consists of:

- Outside double-glazed layer (blue/green glass)

- Inside single-glazed layer (clear glass)
- Air cavity 1.5 m wide in which aerofoil louvers are installed

Louver blinds are connected in banks and they rotate automatically to shade the building and collect the sun radiation. Each bank has one blade that has a solar cell at the back, which registers when the sun falls on it and moves all the blades in that bank. The floor level grilles installed in the cavity provide access for cleaning and allow warm air to rise to the top of the building. Each of the four facades is independently controlled.



Figure A-92 Elevation – corner--figure from “Glass in Architecture” by Michael Wigginton

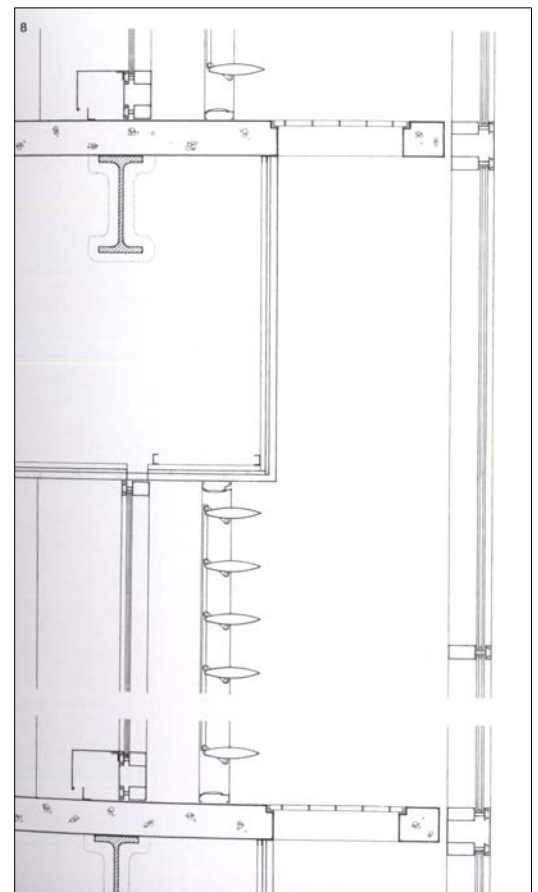
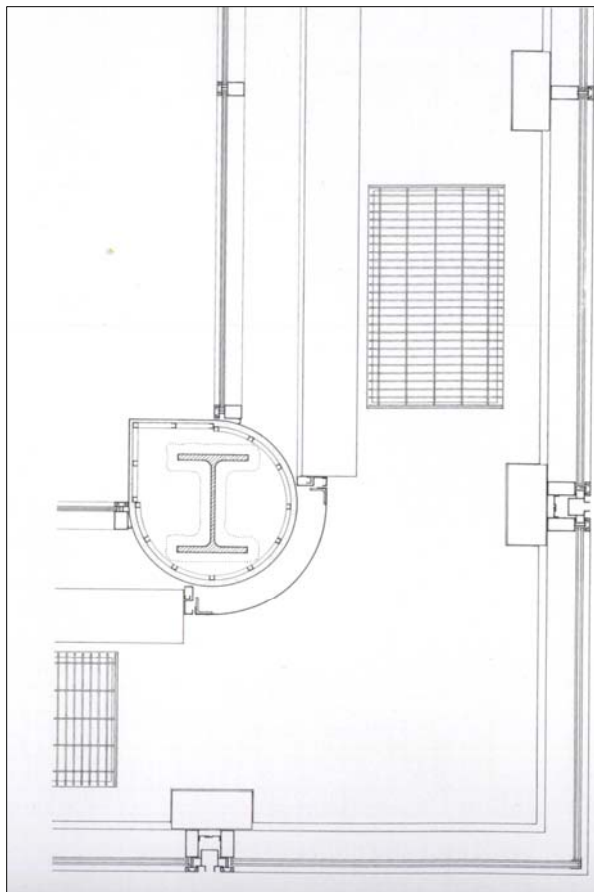


Figure A-93 Horizontal and vertical section through the facade--figure from “Glass in Architecture” by Michael Wigginton

A.3.2.11. Business Promotion Center, Duisburg, Germany

The double-glass wall is made of:

- Single-glazed outside layer
- Double-glazed inside layer (double low-emissivity glass filled with argon)
- Ventilated air cavity 200 mm (8") wide in which Venetian blinds are located.

Venetian blinds are 10% perforated and provide solar control and collect sun radiation. Air is let into the cavity or pumped if it is necessary at a controlled temperature and taken out of the building via the plant room.

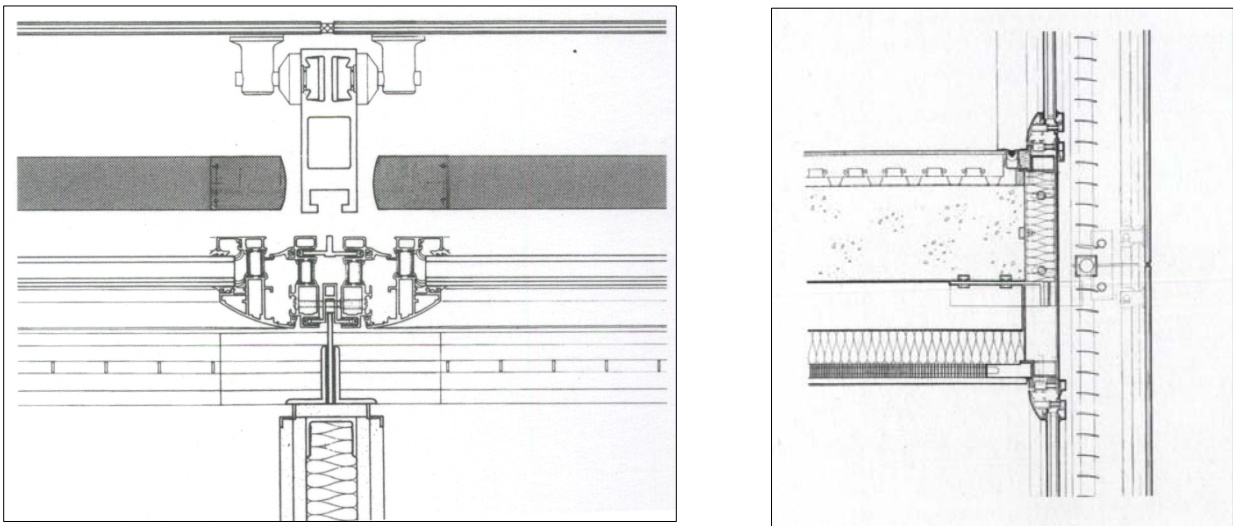


Figure A-94 Horizontal and vertical section through the facade--figure from "Glass in Architecture" by Michael Wigginton

A.4. INCIDENT ANGLE OF SUN

The direct radiation transmitted through the glass varies markedly with the angle of incidence (see Figure A-95), remaining fairly steady until about 50° but dropping sharply after 60° (see Table A-4).

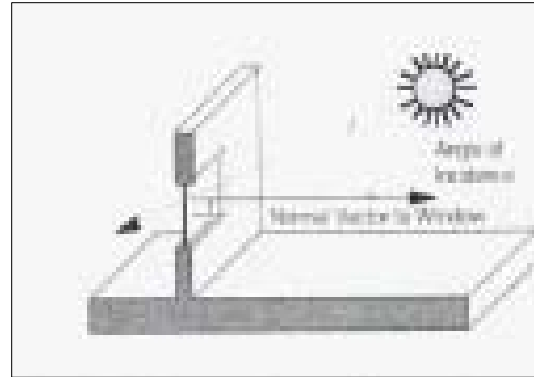


Figure A-95 Incident angle

Table A-4 Transmission of light depending on the angle of incidence and type of the window/glass

ANGLE OF INCIDENCE	SINGLE-GLAZED WINDOW	DOUBLE-GLAZED WINDOW
0°	0.90	0.81
20°	0.90	0.81
40°	0.89	0.80
50°	0.87	0.77
60°	0.82	0.71
70°	0.77	0.59
80°	0.44	0.29
90°	0.00	0.00

The intensity of the reflected light varies with the angle of incidence. For different orientations of the facades, reflection and transmission of the light will be different. Also, considering one facade, reflection and transmission might change because the angle of incidence of sun rays changes during the day and also during the year. The sun angle also changes because the position of the sun changes during the day and year. The altitude of the sun varies during the day, achieving its maximum at noon, but also the altitude angle at noon varies from day to day, achieving its maximum on June 21 and its minimum on December 21.

For the radiation angle of incidence of 40°, glass admits a certain percent of solar thermal energy that strikes the glass surface:

- Ordinary glass 85%
- Reflective glass 63%

- Heat-absorbing glass 60%
- Certain specialized glasses 60%

Radiation striking the surface perpendicularly has an angle of incidence of 0° . Radiation moving parallel to the surface has an angle of incidence of 90° .

For the angle of incidence of:

- More than 45° , sun radiation will be reflected
- Less than 45° , sun radiation will be transmitted

When light is coming perpendicularly to uncoated glass, very little of it is reflected. This reflection grows in proportion as the angle of incidence increases, at first slowly and then dramatically. For approximately an 87° angle of incidence, all incident light is reflected. Glass remains approximately 85% transparent to incoming radiation until between 40° to 50° , and then it drops off rapidly (see Figure A-96).

The relationship between transmissivity and the angle of incidence and the type of the glass is shown in Figure A-97.

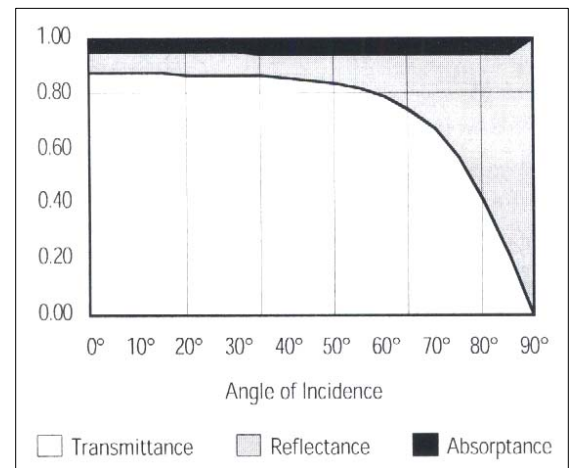


Figure A-96 Relationship between transmissivity and angle of incidence

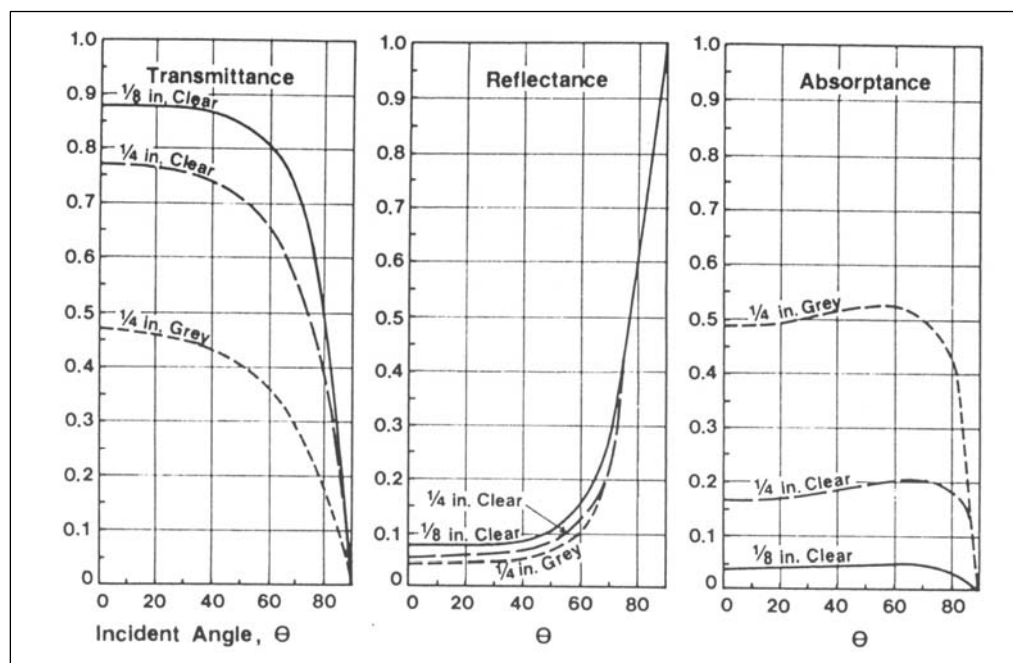


Figure A-97 Relationship between the incident angle and solar optical properties for clear and heat absorbing glass

The shading coefficient is calculated only for a normal angle of incidence, while the coated glazing also changes in response to an increasing angle of incidence.

Vertical glass is used as a reference point for determining the relationship between the incident angle and solar optical properties of the glass. If a different glass angle is used, the ratio between reflected and transmitted light will change, compared to those of vertical glass. For glass angles less than 90°, the percentage of the reflected light will increase while the percentage of the transmitted light decreases.

A.4.1. SUN POSITION CALCULATION

By using Microsoft Excel software, the exact position of the sun for each hour of every day of the year can be found. The users' input includes:

- Geographical location, that is, longitude and latitude of the city (in degrees)
- Time zone (in hours)

By using the following equations, the sun position is calculated:

$$(FY) \quad \text{FRACTIONAL YEAR} = 2 \pi * (\text{day of year} - 1 + (\text{hour} - 12)/24)/365$$

By using fractional year values, **equation of time** (in minutes) and the **solar declination angle** (in radians) can be calculated:

$$(ET) \quad \text{EQUATION OF TIME} = 229.18 * (0.000075 + 0.001868 * \cos(FY) - 0.032077 \sin(FY) - 0.014645 \cos(2*FY) - 0.040849 * \sin(2*FY))$$

$$(SDA) \quad \text{SOLAR DECLINATION ANGLE} = 0.006918 - 0.39991 * \cos(FY) + 0.070257 * \sin(FY) - 0.006758 * \cos(2*FY) + 0.000907 * \sin(2*FY) - 0.002697 * \cos(3*FY) + 0.00148 * \sin(3*FY)$$

Next, the solar hour angle (in degrees) is calculated by using the following equations: **Apparent solar time** (AST) (in minutes) depends on the equation of time (ET), local standard time (LST) (in minutes), and longitude correction. The longitude correction is four minutes of time per degree difference between the local (site) longitude (LON) (in degrees of arc) and the longitude of the local standard meridian (LSM) (in degrees of arc) for the time

zone. Standard meridians are found every 15° from 0° at Greenwich, England. In the United States, these values are:

- 60° for Atlantic Standard time
- 75° for Eastern Standard time
- 90° for Central Standard time
- 105° for Mountain Standard time
- 120° for Pacific Standard time
- 135° for Alaska Standard time
- 150° for Hawaii-Aleutian Standard time

(AST) APPARENT SOLAR TIME = LST + ET + 4*(LSM – LON)

Where 4 is the number of minutes required for one degree rotation of the earth

Solar Hour Angle (SHA) (in degrees) depends on the number of minutes from the local solar noon (LSN).

(SHA) SOLAR HOUR ANGLE = 0.25* (LSN – AST)

After finding the solar hour angle, the solar altitude (ALT) and solar azimuth (AZM) angles (in degrees) can be calculated by using the following formulas:

Altitude $\sin (ALT) = \cos (LAT) * \cos (SDA) * \cos (SHA) + \sin (LAT) * \sin (SDA)$

Azimuth $\cos (AZM) = [\sin (ALT) * \sin (LAT) - \sin (SDA)] / \cos (ALT) * \cos (LAT)$

Where (LAT) is the local latitude (in degrees).

A.5. SHADING DEVICE COST

A.5.1. STRUCTURE OF THE SHADING DEVICE COST

The cost of the shading device is one of the performance requirements that needs to be considered in the process of selection and design of the shading devices. Although the shading device system can achieve a high quality thermal, visual, and aesthetic performance, if its cost is above an acceptable range, the system cannot be chosen.

The cost of the shading device varies and depends on:

- Location of the building
- Climate
- Orientations of the facades/windows
- Building function

Relationships between the cost of the shading device and variables that influence the cost are given in Figure 3-2.

Because of the variables that influence the selection of the shading device, a separate cost analysis of the shading devices must be made for each specific building (Olgay & Olgay, 1957).

In calculating the cost of the shading device systems, as well as the entire building cost, it is important to consider all costs consisting of initial, operational, and maintenance cost, that is, the life-cycle cost.

The **initial cost** of the shading device consists of the costs of manufacture and installation of the shading device elements. The cost of the labor involved and the equipment used need to be estimated for both the manufacture and the installation of the shading device. The cost of the manufacture of the shading device depends on whether or not elements are custom-made or mass-produced. Considering the installation of the shading device, it can be installed in the factory, usually in between two glass layers in the window. The shading device can also be installed on the site, inside or outside of the window, which increases the price of the installation and decreases the quality of work. The shading device installed in front of the window requires fixing brackets, which will also increase the price.

The total cost of the material used for the shading device production will depend on the type of material, whether or not coatings are applied, and whether the shading device system

is fixed or moveable. If the shading device system is moveable, the type of moving mechanism and type of control system will affect the cost.

Part of the initial cost is an indirect cost, which includes overhead and profit of the manufacturer as well as sales tax. For example, estimate of the initial cost of the shading devices can be found by using RS Means data, specifically RS Means Interior Cost Data in which Division 12 – Furnishing and Accessories includes pricing of the blinds and shades. The items in this division are priced either per square foot of the window area or per unit and they are categorized based on the material of the blinds and size of the window. The cost is given as a total base cost, which includes the cost of material, labor, and equipment, and as a total cost, including overhead and profit.

The same importance that is given to the initial cost of the shading device needs to be given to the future cost, that is, operational and maintenance cost. The operational cost of the shading device consists of the cost of energy needed for:

- Operating the shading device itself
- Heating, cooling, and lighting of the building, which are affected by the use of the shading devices

If the shading device is fixed, no energy is needed for its operation. If it is moveable, there is usually a motor that provides the movement of the slats so electricity is needed to run the motor.

Regarding the cost of maintenance of the shading devices, two aspects have to be considered:

- Cleaning of the shading devices
- Repair of the shading devices

The cost of the cleaning largely depends on the position of the shading device relative to the window:

- If the shading device is installed in front of the window, that is, outside, it must be cleaned more often (for example, every three years). Lifting equipment would be required to provide access to the shading device and safety for labor, which increase the price of the cleaning.
- If the shading device is installed in between two glass layers, it is less exposed to outside dirt and dust, so it will require cleaning less frequently (for example, every

four years). Access for the shading device cleaning is from the interior space, which excludes the cost of the lifting equipment. In the case of the airflow window or double-ventilated-skin facade cleaning of the system would be needed. In the case of a closed system (the blinds between two panes of glass in the double insulated glass unit), there is less chance that air--and therefore dust and dirt--will enter the cavity between two glass layers. As a result, no cleaning or less frequent cleaning will be required.

- If the shading device is installed inside, it is not exposed to the outside air so that less frequent cleaning will be required.

The cost of repair of the shading device system includes cost of material, labor, and equipment needed for repair/replacement of the slats, as well as the parts of the moving mechanisms if the blinds are adjustable and control systems needed for the slats' movement. The cost of repair of the shading device system is influenced by the type of moving mechanism (if there is any) and the type of control systems. The shading device life-cycle cost structure and parameters are given in Figure A-98.

A.5.2. STRUCTURE OF THE BUILDING COST

The building life-cycle cost consists of:

- Initial cost of the building
- Future building one-time cost
- Future building annual cost
- Functional use (or associated) cost

The **initial cost** of the building depends on the size of the building, location of the building, time of construction, required quality of work, and general market conditions. The most important component of the initial cost is the construction cost, which consists of direct and indirect cost. The direct cost is related to the cost of construction of the building and includes cost of material, labor, and equipment for both in-house construction and subcontracted work. The initial cost of the building can be estimated by using, for example, RS Means Building Construction Data in which all cost data have been divided in 16 divisions. For each division, all items are described in detail, the needed crew is listed, and productivity is given. Prices are given per unit of item. The cost is given as a total cost,

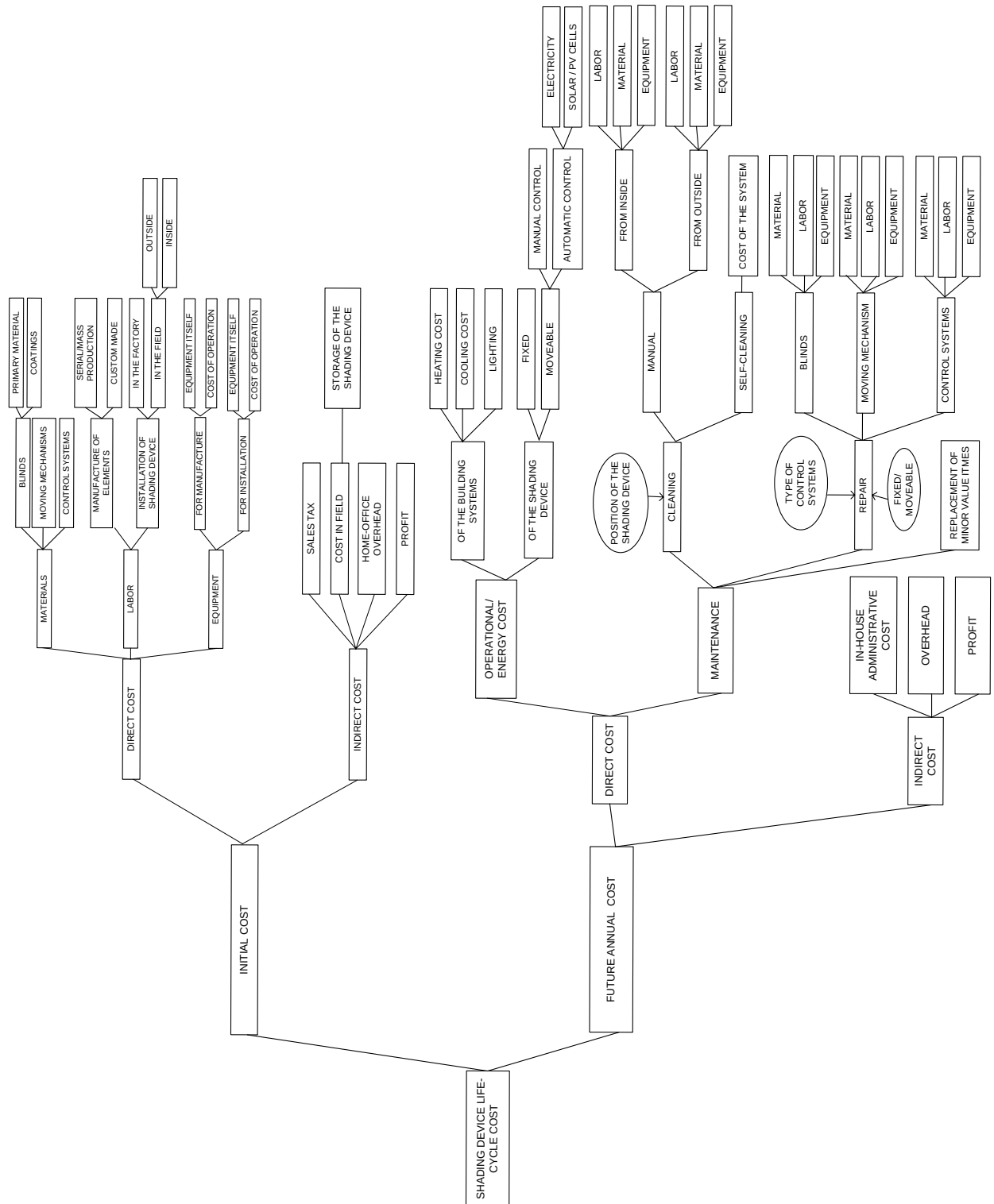


Figure A-98 Structure and parameters of the shading device life-cycle cost

which includes the bare cost of material, labor, and equipment, and as a total cost with overhead and profit.

The **future building one-time cost** is related to the cost of replacement, alternations, salvage, and other one-time costs.

The **future building annual cost** consists of the cost of running the facility, excluding the cost of what the facility produces. It includes the cost of operations, maintenance, taxes, insurance, and security. The operational cost includes the cost of the energy needed for operation of the building's mechanical and electrical systems. The maintenance cost consists of the cost of cleaning and repair of building elements, as well as annual maintenance cost and staff salaries.

The energy consumption can be estimated if the building energy consumption rate and hours of operation are known. There are different methods for calculating hours of operation, such as degree days, or hour-by-hour methods, used to determine heating and cooling loads of the building. Energy consumption for the building falls into the following major groups:

- Heating, cooling, and ventilation
- Lighting
- Power
- Domestic hot water

The building maintenance cost can be calculated by using, for example, RS Means data: Cost planning and estimating for facilities maintenance, which can be used for an estimate of the cost of removal and replacement of defective parts and equipment. Work estimated by using these data is based on the frequency of the maintenance work to be performed during the year. The cost of maintenance and repair can be categorized as:

- Direct cost: which includes cost of material, labor, and equipment
- Indirect cost: which includes the contractors' overhead or in-house administrative costs, such as administrative salaries, supervision, office supplies, office space, and transportation

The **functional use** (or associated) **cost** includes the cost of the production of the building, such as the cost of staffing, denial-of-use, and building management. The structure and parameters of the building life-cycle cost are shown in Figure A-99.

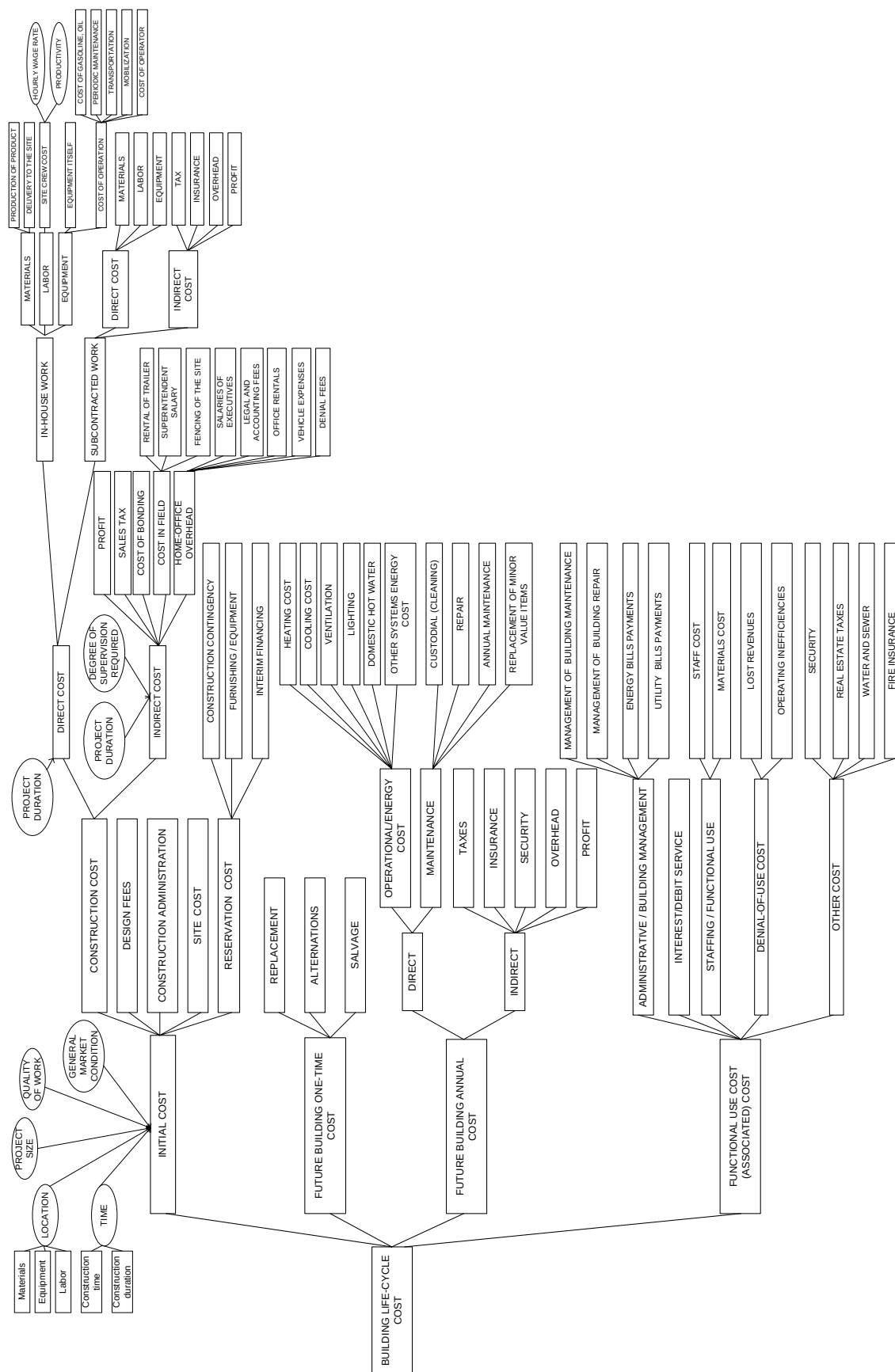


Figure A-99 Structure and parameters of the building life-cycle cost

A.5.3. COST CRITERIA

By comparing the shading device life-cycle cost (see Figure A-98) and the building life-cycle cost (see Figure A-99) one can find out that these two costs are compatible, and the same parameters are used for determining both the shading device and the building life-cycle cost. The purpose of this comparison is to try to express the shading device system's cost as the percentage of the building's total cost:

- The initial building cost includes the cost of subcontracted work. Shading device production, delivery to the site, and installation on the site are considered subcontracted work. Therefore, the initial cost of the shading device system can be expressed as the percentage of the initial, specifically construction, direct cost of the building.
- Regarding future building costs, the operational and maintenance cost of the building also includes the operational and maintenance cost of the shading device systems. The cost of the energy needed to operate the shading device can be expressed as the percentage of the total cost of energy needed to operate the building systems. The cost of the cleaning and repair of the shading device is also included in the total cost of the building maintenance cost, so their relationship can be expressed in percentages.

One approach can be to determine the percentage range instead of a particular percentage or ratio between the cost of the shading device and the total building cost (including initial, operational, and maintenance cost) since both costs vary.

The cost of the shading device depends on the following variables:

- Material used for slats
- Moving mechanisms
- Control systems
- Manufacturers
- Amount of the windows at which the shading devices are applied, which also depends on the building type, facade orientation, and climate

The cost of the building depends on the following variables:

- Project size
- Building type

- Location of the building
- Time of construction
- Quality of work

The variables that influence the cost of the shading device should be analyzed, and for each of them specific, different values need to be assigned to get prices for the different shading device systems. Also, variables that determine the cost of the building should be defined and assigned possible values so that different total building costs can be calculated.

After the prices are calculated, the ratios between various shading device costs and various building costs should be ascertained. The ratios can be the guidance for comparisons of new buildings costs, as well as shading devices costs. Since the calculation is not accurate and precise enough, this approach can be acceptable for a rough, conceptual estimate of the price.

Instead of performing a detailed estimate of both the total building and the shading device cost (including initial, operational, and maintenance cost), rough calculations can be done to determine the ratio between the two costs and compare that ratio with ratios given in the guidance.

By using construction estimate data, such as RS Means Square Foot Cost, and applying the square foot estimate, the cost of the specific building can be determined if its floor area is given. As explained before, the cost of the specific building depends on several parameters, but for a rough estimate, the pricing per square foot of the floor is acceptable. Most shading device manufacturers give the price of the shading device per square foot of the window area.

If the floor area is given for the particular type of building (residential, commercial, industrial), and the ratio between window and floor area can be taken from the design guidance, then the window area for the particular building can be determined. It means that if we know:

- The building floor area
- The window area
- The cost of the building per square foot of the floor area
- The cost of the shading device per sq. ft. of the window area

as an input, then the cost of the shading device can be expressed as the percentage of the building cost by using the following formula:

$$\text{ratio} = [(\text{cost of shading device per sq. ft. of window area}) \times (\text{window area/floor area})] / [(\text{cost of building per sq. ft. of floor area}) \times (\text{floor area})]$$

When this ratio is found, it can be compared to the ratio from the guidance to check if the price of the shading device is in the acceptable range.

The opposite approach would be to set up criteria for the shading device cost by performing the following tasks:

- Use the acceptable values for the ratio between the cost of the shading device and the total cost of the building from the guidance.
- Assume the window area for the particular type of building by using the design guidance although the window area strongly depends on the design.
- Determine what is an acceptable cost of the shading device by using the following formula:

$$\text{cost of **shading device** per sq. ft. of window area} = (\text{cost ratio}) \times [(\text{cost of building per sq. ft. of floor area}) \times (\text{floor area})] / (\text{window area/floor area})]$$

- If there are several manufacturers to be considered, we need to check the prices per square foot for each type of shading device to see which one fits the best in the price range for the shading device determined by the formula.

As explained, the life-cycle cost of the shading devices can be expressed as a percentage of the life-cost of the building, but this calculation can be used only for the rough estimate. For a precise and accurate calculation of the shading device cost, a detailed estimate for the specific type of shading device and for the particular project should be performed.

Also, intangible costs, as a result of the shading device use, should be taken into consideration in addition to the shading device life-cycle cost. For example, if the occupants of the building feel more comfortable in the space because of the appropriate use of the shading device, such as protection from overheating and providing a sufficient amount daylight, the occupants might be more productive, and the profit of the company might increase. This cost benefit should be added to the total cost of the shading device.

A.5.4. “IDEAL” VERSUS “REALISTIC” SHADING DEVICE SYSTEM

The structure of the life-cycle cost of the shading device given in Figure A-98 shows that the decision-making framework can be used for the selection and design for both an “ideal” and a “realistic” system. For example, possible alternatives for the blinds’ materials and coatings, as well as for moving mechanisms and controls, can be given. By combining these alternatives, different shading device systems can be selected and their cost estimated. The same approach can be used for the estimate of the operational and maintenance cost of the shading device. However, there is potential for the “ideal” shading device system to become the “realistic” system.

The value of the shading device system can be measured not only by its cost, but also by its performance. It means that the cheapest shading device system might have low performance and from that perspective it is not cost effective. To achieve cost effectiveness of the shading device system, a balance between the quality of the system performance and its cost should be found, that is, to achieve the best possible performance for the lowest cost. Table A-5 shows two examples of the shading device systems:

- “ideal” - with better performance and higher cost
- “realistic” – with lower cost and lower quality of performance

Table A-5 Comparison between an ideal and a realistic system based on the cost criteria

			“IDEAL” SYSTEM	“REALISTIC” SYSTEM	
INITIAL COST	MATERIAL	primary	glass	aluminum	
		coatings	yes	no	
	MOVING MECHANISM		yes	no	
	CONTROL SYSTEMS		yes, automatic	no	
	PRODUCTION		serial	serial	
	INSTALLATION		in the factory	in the field	
				from inside	from outside
OPERATIONAL/ENERGY COST			yes, electrical or PV cells	no	
MAINTENANCE COST	CLEANING		self-cleaning system	manual	
				from inside	from outside
	REPAIR OF BLINDS		higher chance for repair	little chance for repair	
	REPAIR OF MOVING SYSTEM		yes	no	
	CONTROL SYSTEM		yes	no	

The question is how to make the “ideal” system more “realistic” or to recognize the areas that have potential for the cost reduction. By comparing an “ideal” and a “realistic” system, we can conclude that the “ideal” system has a higher initial maintenance and operational cost, compared to the “realistic” system. Therefore, we need to look at the possibilities to decrease the initial maintenance and operational cost to make the “ideal” system more realistic. The initial cost of the shading device can be reduced in the process of both design and manufacture. In the design phase, issues, such as performance, manufacturability, reliability, maintainability, and economic feasibility, need to be addressed.

If reliability and maintainability of the shading device systems are considered during the design phase, then the total cost of the system can be reduced. For example, if the system is designed to fail less frequently, then the need for maintenance will be reduced. High reliability means that the shading device system is available for the operation when it is needed, but it increases the cost of the system. Objectives of the maintainability design are: 1) to reduce the cost of the maintenance of the shading device system while it is on the operation, and 2) to decrease the cost of the remaining needed maintenance.

Considering the manufacturability in the design phase, if two or more materials can have the same performance, then their cost, availability, and processing costs need to be compared to find out which one is the best. Considering productivity, the shading device might be designed to have excellent performance, but it may not be designed properly from a productivity perspective.

Also, the shading device must be designed to be manufacturable with minimum cost and time and maximum quality. These goals can be achieved by:

- Using existing equipment and labor skills instead of introducing new ones
- Automatization of the manufacture process
- Standardization of the elements of the shading device system
- Mass production
- Modular design can also be used for improving the production pace with easier and faster maintenance

Besides the possibility to decrease the cost of the shading device in the manufacturing process, the price can also be reduced through marketing. Although the product might be “ideal,” it can also be “realistic” by applying appropriate marketing. For example, if the

unique shading device system is produced for only one project, such as the Commerzbank in Frankfurt, it will be expensive. But if we use the same design of the shading device for mass production, and if it is completely manufactured and installed in the window in the factory, it can decrease the initial cost of the shading device. If production of the shading device is becoming less expensive, it will be easier to market it, that is, to sell it. The “ideal” system is becoming “realistic”, therefore by applying an appropriate manufacturing and marketing strategy.

A.6. EXPERIMENTAL PROCEDURES TO MEASURE DAYLIGHTING PERFORMANCE PARAMETERS

Two basic ways to perform experimental testing of the shading device systems are:

- 1) In the actual building in the full-scale test rooms under real climatic conditions
- 2) In the scale models under artificial sky conditions

Results of the shading device performance determined in these ways are difficult to compare since experimental test rooms and sky conditions vary with climate and location of the building.

Measurement equipment

Depending on the performance variable that needs to be measured, various types of measuring equipment can be used. Photometry is a “measurement of the radiation in terms of human visual response while radiometry is the measurement of optical radiation.”¹

Radiometric measurement equipment consists of²:

- A detector
- A means of conditioning or amplifying the output of the detector
- A method of displaying/storing of the measurement
- An optical element/system of elements used to collect the radiant power that needs to be measured

The radiometers are used for measuring radiant power for infrared, ultraviolet, and visible wavelengths of light, and the photometer is a kind of radiometer that is filtered (either optically or electronically) to approximate a special sensitivity function of the eye.³

Photometers are used for measurement of luminance, illuminance, and luminous intensity.

Illuminance measurement

Illuminance photometers are used for field measurements of the illumination level. They measure the total luminous flux density that is incident on the surface (such as the top of the desk or wall), and they are calibrated in luxes or footcandles or both. They consist of a

¹ IESNA - *Lighting Handbook: Reference and Application*. 8th edition. IESNA. New York (1993)

² IESNA - *Lighting Handbook: Reference and Application*. 8th edition. IESNA. New York (1993)

³ IESNA - *Lighting Handbook: Reference and Application*. 8th edition. IESNA. New York (1993)

photovoltaic detector with a photopic correction filter, which is connected to an operational amplifier with display.¹

The IESNA gives recommendations for determination of average illuminance on a horizontal plane (from general lighting only)²:

- The measurement instrument should be positioned so that the detector is in a horizontal plane 76 cm (30") above the floor level.
- A small portable stand is needed to support the detector.
- The measured area should be divided in squares 60 cm x 60 cm (2' x 2'). Readings should be taken in each square and the average illumination calculated.

Luminance measurement

The measurement of luminance is very important for consideration of glare because luminance and subjective brightness and brightness contrast, which are caused by the photometric luminance, are what we see.³

The luminance meter is used for luminance measurement and it gives values in cd/m^2 . Since design recommendations for lighting levels are given in terms of illuminance levels (in lux), lux meters can also be used because they are simpler to use and less expensive. The new systems of the photometers for luminance measurement are video-based photometers, that is, video cameras that incorporate charge-couple devices (CCDs). This system consists of the camera, an acquisition board, and a microcomputer. The CCDs are very useful if a large number of luminance measurements need to be taken since they are fast and convenient to use.

Reflectance measurement

If reflectance of the surface is measured, then this value can be used for calculation of the luminance. Reflectances of the surfaces are measured by photometers called reflectometers. Reflectance is not the material property. Reflectance is the ratio between the incident and reflected light so it depends on the measurement geometry, that is, the spatial characteristics

¹ IESNA - *Lighting Handbook: Reference and Application*. 8th edition. IESNA. New York (1993)

² IESNA - *Lighting Handbook: Reference and Application*. 8th edition. IESNA. New York (1993)

³ Stein B., Reynolds J. *Mechanical and Electrical Equipment of Buildings*. John Wiley & Sons, (2000)

of the light source and the detector.¹ There is a special type of reflectometer (such as the Baumgartner reflectometer) that measures both the total reflectance and diffuse transmittance. In the case of the large specimen, several measurements need to be taken at different points and the average computed.

Illumination distribution measurement

Distribution photometers are used for the measurement of luminous intensity to find out spatial distribution of illumination. The various types of photometers include²:

- Goniometer and single detector: the light source is mounted on the goniometer, and it rotates around horizontal and vertical axes. A single, fixed detector is used for the measurement of luminous intensity.
- Fixed-multiple-detector photometers: several individual detectors are located at different angles around the light source. Each detector is used for the measurement of the lighting intensity to determine its distribution.
- Moving-detector photometer: consists of a detector which rides on the rotating boom or arc-shaped track. The light source is centered in the arc and traced by the detector. The detector is positioned at the desired angle and readings are taken.
- Moving-mirror photometer: the mirror rotates around the light source and reflects the intensity to a single detector. Measurements are taken at each desired angle when the mirror moves to that position.

Contrast reduction measurement

A contrast/luminance meter is used for the measurement of the contrast reduction, which is important in determining the protection from glare. A contrast device should be positioned on the work plane and exposed to the illumination. The task contrast is measured at the angle at which it would be normally observed, and the contrast reduction is automatically computed and shown. A map of the contrast reduction of the work surface can be made based on these measurements. Based on the map, changes of work and the observer position, as well as illumination sources, can be made to decrease contrast reduction.

¹ IESNA - *Lighting Handbook: Reference and Application*. 8th edition. IESNA. New York (1993)

² IESNA - *Lighting Handbook: Reference and Application*. 8th edition. IESNA. New York (1993)

Luminous flux measurement

The total luminous flux from a light source, such as a lamp or a luminaire, can be measured with an integrating-sphere photometer. An integrating sphere is an empty sphere that has a diffusing inner surface and uniform nonselective reflectance. Every point on the inner surface of the integrating sphere reflects light to every other point, and the illuminance at any point consists of two components of the flux:

- One coming from the light source
- One reflected from the other parts of the sphere wall

“The illuminance and the luminance of any part of the wall due to reflected light are proportional to the total flux from the source regardless of its distribution.”¹ The measurement by the integrating sphere can be obtained quickly with high accuracy and in one measurement only.

Experimental methods

Research on the daylighting performance of the shading device systems has been conducted in the United States in the Lawrence Berkeley National Laboratory (LBNL), as well as in research centers in Europe. Various experimental methods for measurement of the daylighting performance parameters have been used in these studies.

DiBartolomeo et al. (1996)² explain research conducted at the LBNL.³ The objective of their research was to construct a working prototype of an integrated dynamic envelope and lighting system. The prototype was tested to find out whether or not it can meet the performance requirements that will minimize energy use and achieve a needed comfort level for the occupants. Adjustable blinds and an electric lighting system were controlled by measuring room **luminance levels** and **brightness distribution** that were detected by a charge-couple device (CDD) camera.

Performance criteria were set up for the prototype system:

- The designed illuminance level for the work plane should be 538 lx (50 cd) within the range of (-10)% and (+25)%.

¹ IESNA - *Lighting Handbook: Reference and Application*. 8th edition. IESNA. New York (1993)

² DiBartolomeo, D.L. et al. *Developing a Dynamic Envelope/Lighting Control System with Field Measurement*. The 1996 IESNA Annual Conference (1996)

³ Lawrence Berkeley National Laboratory

- Motorized Venetian blinds should be installed at the window interior.
- The electric lighting system should be fluorescent lamps.
- The control system should acquire data to assess the performance and should have user-adjustable controls.

The experimental model consisted of the (1:3) scale model of the single-person office, 3.3 m wide and 4.6 m deep with automated Venetian blinds and a lighting control system. A single pane of clear glass 6.3 mm thick was installed in the window. Venetian blinds were horizontal, slightly curved, metal blinds 25 mm wide with a matte/semi-specular, light pink surface. The blinds were motorized, and the electronic circuit used to control the blinds' motor was completely rebuilt to accept digital control signals and translate these signals into the pulls that drive the blinds' motor.

Illuminance measurements: were performed by photometric sensors (Li-cor 210 s) that were located in the center of each wall, in the ceiling, and on the floor (four sensors).

Global and diffuse horizontal exterior illuminance measurements: were taken by a Li-cor photosensor with and without a shadow band apparatus.

Blinds' tilt angle: was measured as the voltage divide in the potentiometer coupled to the blind control shaft.

Lighting power measurement was taken by a watt transducer (Ohio Semitronic GWS).

Sun altitude angle was measured by a sun angle sensor.

Control algorithms were graphically written and tested with a virtual instrument front panel and adjustment of the control systems' design. Control algorithms were tested by National Instrument Hardware and Lab View software.

User adjustments for the Venetian blinds included the following parameters:

- Minimum and maximum work plane illuminance levels
- Frequency of blinds' movement/adjustment
- Changing blinds' position to greater openness or closure

To provide the blinds' control, the following input data for the computer system were needed:

- Signal from the ceiling photosensor
- Power consumption of the electric lighting
- Sun altitude angle

- Blinds' tilt angle

The control system was adjusting the blinds to meet the following requirements:

- To block the direct sunlight
- To provide designed work plane illuminance levels with daylight
- To provide total illuminance from daylight and electric lighting within the designed illuminance level range

Based on the direct sun presence, the computer control system will set the blinds' position to:

- Horizontal: if the direct sun is not present to maximize the view to the outside
- To correct the blinds' angle: if direct sun is present, to block the direct sun

To find out whether or not the blinds' adjustment meets the illuminance control objective, a ceiling photosensor and lighting power consumption were used. If the illuminance levels were outside the design illuminance range, the blinds were adjusted until the design illuminance was achieved. The blinds were adjusted every minute to meet the proposed control objectives.

To find out contributions of daylight and electric lighting to the work plane illuminance levels in the room, three correlations were used:

- 1) Correlation between lighting power consumption (W) and average illuminance ($I_{avg.}$), with electric lighting contribution only.
- 2) Correlation between a ceiling sensor signal (V) and average illuminance ($I_{avg.}$) with electric lighting contribution only.
- 3) Correlation between a ceiling sensor signal (V) and average illuminance ($I_{avg.}$) with daylighting contribution only.

Where $I_{avg.}$ is the average of four work plane illuminance sensors.

Advantages of the experimental method used in research of DiBartolomeo et al. are as follows:

- A scale model is less expensive to use for testing than a full-scale model in the actual building, and it gives data with sufficient accuracy. The daylighting performance of the scale model can be tested both outdoors under real climatic conditions, and also indoors in the laboratory under various artificial sky conditions. In this way, the results of the outdoor and indoor tests could be compared to validate laboratory testing.

- The experimental method used in this study considers complex interactions between daylighting and electric lighting and either their independent or integrated contributions to the designed illumination levels in the space. This method also takes into consideration the illumination level dependence on the sun altitude angle and the blinds' tilt angle.

The **disadvantages** of the experimental method were related to the problems with measurement and control equipment used in the testing:

- The first problem concerned the control systems of the fluorescent lighting. When the work plane illuminance level increased, the control systems were not optimally reducing fluorescent light levels due to the lack of proper feedback.
- The second problem was related to the ceiling sensors that could not be adjusted to the designed illuminance level of 538 lx.
- The third problem concerned the sun angle sensors that measured less accurately if direct sun was present and for solar altitudes greater than 45°.

From the research methodology perspective, the experimental method used in DiBartolomeo et al. research can be **appropriate** for my research since the measurements of the distribution of illuminance for various sun angles and for the different blinds' tilt angles are needed. The blinds' tilt angle can be different depending on:

- Sun angle
- Desired illumination level
- Height of the window

This means that the same experimental procedure and the same measurement equipment can be used in my research. A different control algorithm should be used since the blinds' tilt angle would be different at various positions within the window height.

Beltran et al. (1996)¹ show results of the research conducted in LBNL.²

Beltran et al. tested two advanced daylighting systems: light shelves and light pipes that are used to provide higher illuminance levels in the depth of the room. The daylighting performance of the systems and energy consumption evaluation were investigated. Prototype

¹ Beltran, L.O. et al. *Advanced Optical Daylighting Systems: Light Shelves and Light Pipes*. The 1996 IESNA Annual Conference (1996)

² Lawrence Berkeley National Laboratory

designs of the daylighting systems were evaluated by using the ray-tracing software to find out the appropriate geometry of the elements of the daylighting systems. Ray-tracing was done for various sun incident altitude angles by tracing rays from the target, which was located at the ceiling at the depth of 4.6-9.1 m from the window and then back to the reflector.

Four different types of light shelves were tested:

- Base case light shelf
- Single level light shelf
- Bi-level light shelf
- Multi-level light shelf

The width of the light shelves was between 0.4-1.1 m (1.5-3.75'). The sill height was 0.91m (3') and the window height is either 4' or 5'. The ceiling height was 10'. The light shelves were installed above the south-oriented windows.

Four different types of light pipes were tested. The cross section of the pipes, as well as the reflectors' design varies, so it gives the following light pipe types:

- Base case light pipe
- Rectangular section light pipe with central reflectors
- Rectangular section light pipe with side reflectors
- Trapezoidal section light pipe with side reflectors (two pipes were installed in the room)

Different methods were used to evaluate the daylighting performance of the light shelves and light pipes:

1) *Reduced-scale models* of all prototypes were used to evaluate:

- Critical daylighting
- Penetration of sun
- Glare

2) An *outdoor test* was performed to evaluate:

- Qualitative daylight performance of each prototype
- Daylight distribution in the space
- Visual characteristics of the space

- 3) An *experiment under laboratory conditions* was conducted to evaluate more accurately daylight performance of the system.
- 4) The *IDC (Integration of Directional Coefficients) Method* was used to simulate annual daylight performance of the light shelves and light pipes. This method combines:

- Scale model photometric measurements
- Computer-based simulations such as Sun Sky and Ground (SSG) software

The IDC method is used to find the daylight factor and daylight illuminance levels for various sun, sky, and ground conditions.

The experiment was conducted at LBNL by using a Scanning Radiometer to measure the illuminance level in the 1:20 scale model of an office space that was 6.1m wide, 9.1 m deep, and 3.1 m high. The window wall and ceiling were removable to provide quick and easy installation of various types of light shelves and light pipes. Work plane illuminance levels were measured at 30 reference points. Li-Cor photometers (cosine- and color-corrected) were positioned in five parallel lines (six photometers in each line) in the model, and they were used for measurement of the illuminance levels.

Directional work plane illuminance coefficients were determined for each of 30 reference points, and then used as an input in SSG software. The SSG integrates directional work plane illuminance coefficients over the luminance distribution of the sky and the ground to simulate daylight performance of the modeled space. Simulation was performed for 168 sun positions under the CIE clear and overcast sky luminance distribution and for uniform ground reflectance of 0.20. The SSG software generates a set of daylight factors for hourly sun positions of a typical clear day for each month for a particular latitude. These daylight factors were multiplied by the exterior horizontal (sky or sun) component to get work plane illuminance.

- 5) *Outdoor physical model test*: the same prototype physical scale model used in the IDC method was photographed in outdoor clear sky conditions for various times of the year. The Beltran et al. tests:
- Evaluate efficiency of the system.
 - Visualize the amount of the redirection of daylight.

- Show how the sun penetrates into the interior.
- Show the presence of the specular reflections and bright areas as a result of optical film applications.

Energy performance was evaluated by using DOE-2 software.¹ Simulation was done for the prototypical floor in a commercial office building in Los Angeles, California. The simulation model consists of four perimeter zones/four offices, each office is 9.1 m deep, 6.1 m wide, 3.1 m high with a plenum 0.8 m high. Daylight performance was simulated for each perimeter zone. Designed illuminance of 538lx (50cd) and continuous dimming control with a light output of 0.001% of a minimum power input of 10% were used. Daylight levels were calculated for two reference points in each perimeter zone by using the IDC method (within DOE-2). System coil loads were computed for each perimeter zone. The DOE-2 software was used for comparing lighting energy of the light pipes and light shelves with their base case counterparts. The lower window area was not included in the calculations, and lighting controls were dimming in the 4.6-9.2 m depth of the space.

The experimental procedure used in the Beltran et al. study had the following ***advantages***:

- Use of the scale model is less expensive than the use of the full-scale model.
- Use of the scale model in this study gives the opportunity for fast and inexpensive testing of various types of advanced daylighting systems (four types of both light shelves and light pipes).
- Results of the outdoor tests can be used for validation of the results of the laboratory experiments.
- A laboratory experiment evaluates more accurately the daylight performance of the system.
- A laboratory experiment provides opportunity for testing the system under various sky and climatic conditions.
- Use of the simulation software, as a part of the IDC method, quickly provides large number of illumination distribution data, compared to the amount of data that can be obtained only by the experiment.

¹ DOE-2 Building Energy Simulation Program

The **disadvantage** of the experimental method used in the Beltran et al. study is that the results obtained by the computer simulation need to be validated to test their accuracy.

The research and experimental methodology used in the Beltram et al. study can be **incorporated into** this work. Instead of using light shelves and light pipes, Venetian blinds installed in the scale model of the particular space can be used. The illuminance level and light distribution in the space, as a result of the use of Venetian blinds, can be tested by using the same experimental procedure.

Breitenbach et al. (2001) show¹ results of research done at Cardiff University in the United Kingdom. They tested two systems of Venetian blinds installed between two panes of glass in a double insulating glass unit to evaluate their optical and thermal performance.

Breitenbach et al. tested two samples that have an area of 1 m²:

- The first sample has adjustable blinds that consist of 16 mm wide, metallic, slightly curved slats, spaced 12.5 mm apart. The slats were horizontal, and their position was adjusted by using an electric motor. Double insulating glass consisted of two 4 mm single-glass panes separated by a 22 mm air space. A low-emissivity coating was applied on the inside of the outer pane of glass.
- The second sample has fixed blinds that consist of 3 mm wide slats, spaced 2 mm apart, with a 40° tilt angle. The slats were embedded in a 4 mm thick clear plastic. The double insulating glass consisted of a 4 mm inner pane of float glass and an outer pane of two layers of 4 mm glass, with a 12 mm space between the two panes.

The following properties of the two systems were measured:

- The spectral and spatial distributions of transmittance
- Optical properties of double insulating glazing units (normal transmittance and near normal reflectance)

The **spectral and spatial distributions of transmittance** were measured by a goniospectrometer, which can determine the angle and wavelength-dependent optical properties of the fenestration system by one measurement. The measurement equipment was fully computer controlled and it consisted of:

¹ Breitenbach, J. et al. *Optical and Thermal Performance of Glazing with Integral Venetian Blinds*. Energy and Buildings. 33 (2001), 433-442.

- A light source
- An adjustable sample holder
- A goniometer
- A light collection system
- An optical spectrum analyzer

The *light collection system* consists of an axis parabolic mirror. Light that strikes the mirror is formed paraxially onto the end of an optical fiber bundle. The size of the view area of the sample ranges from 20 mm to 90 mm in diameter, and it can be adjusted by an iris diaphragm installed in front of the light collection system. The light collection system is mounted on the goniometer and can be located anywhere in the hemisphere.

The *scanning spectrometers* were used for measurement of the spectral distribution. Spectrometers were connected to the light collection system via optical fiber. The light source consisted of:

- An aluminum reflector
- A tungsten halogen lamp operating at 24V and 250W

The light source produces a beam that has a high output over the desired spectral range. If the light source is positioned 2 m from the sample, then the illuminated sample area can increase in size compared to one seen by the light collection system. The light source provides uniform illumination of the sample. If the illumination of the sample is not uniform, then the average intensity of the illumination of the sample will depend on the position of the light collection system. For instance, if the optical axis of the light collection system coincides with the normal to the sample, then the sampled area has a shape of the circle. But for all other positions of the light collection system, the sampled area has an elliptical shape. The light source was fixed so that light was parallel to and centered on the z-axis of the goniospectrometer. In order to adjust the angle of incidence, the sample is rotated around the y-axis of the goniospectrometer.

The spatial distribution of light transmittance by the samples was measured for various desired angles of the light collection system. For each position of the light collection system, spectral data were collected and average values computed.

The visible light transmittance is determined by multiplying:

- The illuminant D65 spectral distribution, and

- The standard photopic luminous efficiency

The **optical properties** of double insulating glass unit such as:

- Normal transmittance
- Near normal reflectance

were measured by a dual beam spectrophotometer with an integrating sphere. Measurements were taken at 2 nm intervals for the range of 300 nm to 2300 nm, and then the average values were calculated. The diffuse component of the reflected light was measured by placing the sample perpendicularly to the beam. The total reflectance was determined with the sample placed at the angle of 8° to the normal, and the specular component is calculated as the difference.

The **advantages** of the experimental procedure used in Breitenbach et al.'s study: Since full-scale windows with Venetian blinds were tested under laboratory sky conditions, the spectral and spatial distributions of the samples could be tested for various sun angles and climatic conditions. The experimental set-up is simple, and it provides accurate needed data. Both diffuse components of the reflectance and total reflectance were obtained by the experimental testing.

The experimental method used in Breitenbach et al.'s (2001) study can be **appropriate** for this research since the samples used in Breitenbach et al.'s research are similar to the samples that might be used in this research. Also, the same performance parameters measured in this study need to be measured in the potential experiments in this research. Therefore, Breitenbach et al.'s experimental method can be incorporated into this work.

A.7. DECISION-MAKING PROCESS MODELING

Decision analysis is a theory that helps the decision-maker analyze a decision situation by providing analytical tools for understanding and solving the decision problem.

Characteristics of the decision-making process are as follows:

- Decision problems are usually complex, so the decision-making theory introduces methods that help in structuring the problem to make it easier to be analyzed. The decision structure consists of possible ways of action and possible outcomes, as well as probability of these outcomes and possible consequences of the various outcomes. Decision trees and influence diagrams are the structuring methods in the decision-making theory modeling.
- Uncertainty exists in some decision situations so the decision-making theory provides methods for determining sources of uncertainty and presenting them in an analytical way.
- Very often multiple objectives exist in the decision problem, so the decision-making theory provides methods for an analysis of multiple objectives.
- If there is more than one decision-maker, then the problem can be how to solve differences in their opinions about the decision situation. The decision-making theory provides methods that help in bringing different perspectives in agreement.

Better decisions can be made by the appropriate application of the decision analysis methods.

These methods help people to better understand the decision situation and to identify objectives, uncertainties, outcomes, and consequences of their decision. Besides being an analytical tool, the decision-making theory involves a personal, subjective judgment of the decision-maker as an important component of the decision-making process.

The decision-making process consists of four basic steps:

1. The decision-maker *identifies* the *decision situation* and *objectives* in that situation.
2. Based on objectives, the decision-maker *identifies alternatives*, as well as *uncertainties* and *ways of measuring outcomes*.
3. The decision-maker *decomposes* the problem to understand its structure and measure uncertainty. After that, the *model* of the decision problem can be *created* by using

influence diagrams and *decision trees*. Uncertainty in the problem is measured by using probability. In the case of multiple objectives in the decision problem, hierarchical and network models are used.

4. After creating a model of the decision problem, the decision-maker performs a sensitivity analysis that shows how a decision can change, based on making slight changes in the model. If the decision is sensitive to these changes, then the decision-maker needs to reconsider aspects of the problems that are sensitive to the changes.

Figure 100¹ represents the flowchart of the decision-making process.

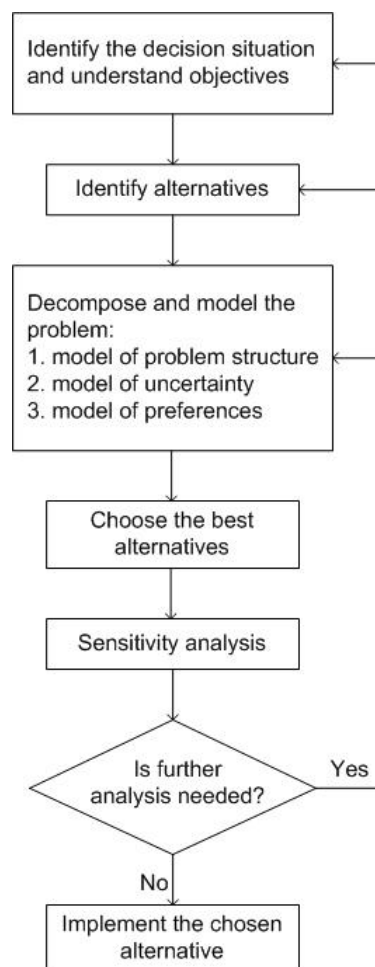


Figure A-100 A decision-making process flowchart

¹ Clemen, R.T. *Making Hard Decisions. An Introduction to Decision Analysis*. Pacific Grove: Duxbury Press at Brooks/Cole Publishing Company, 1996.

Modeling decision

Basic elements of the decision model include: values and objectives, a decision that needs to be made, uncertainties, and consequences. An objective in the decision situation is a particular task that needs to be accomplished, and it determines what is important for the decision-maker. The decision context is a specific situation defined by those objectives. The decision situation cannot be identified without knowing what the decision problem is so the crucial step is defining the main decision, as well as possible alternatives. Some decisions can have particular alternatives, while other decisions would require a selection of specific values out of range of values. In every decision situation, the decision-maker has a choice of doing nothing, of waiting for more information, or preventing from possible loss.

Very often there is not just one decision to be made in the decision situation. There are sequential decision situations in which one decision leads to another in a sequence. In other words, a future decision depends on the previous one so the decision-maker needs to know in which sequence a particular decision occurs.

Existence of uncertain events in the decision situation makes a decision more difficult because the decision-maker cannot know what will happen in the future, that is, what the future outcome of the decision will be at a particular point. There might be several uncertainties in the decision situation, but only those that are relevant for the outcome should be considered. The more relevant, uncertain events in the decision situation, the more complicated the decision-making will be. If an uncertain event is solved before the decision is made, then it makes the decision situation less complicated. There can be a natural order of uncertain events, and if it is specified during the modeling of the problem, it will help the decision-maker. Dovetailing uncertain events is very important because it specifies which events are uncertain and what information can be provided for each decision at each point.

Once all uncertain events are solved, the last decision can be made. If there are multiple objectives in the decision context, then there are two or more consequences for each objective. The end of the time line--after all decisions are made and all uncertain events are solved--is called the "planning horizon". Consequences at the planning horizon are observed from the current time and current decision (see Figure A-101).¹ The question is always

¹ Clemen, R.T. *Making Hard Decisions. An Introduction to Decision Analysis*. Pacific Grove: Duxbury Press at Brooks/Cole Publishing Company, 1996.

where the planning horizon is, that is, how far into the future to observe. When the planning horizon and dimensions of consequences are defined, consequences can be measured.

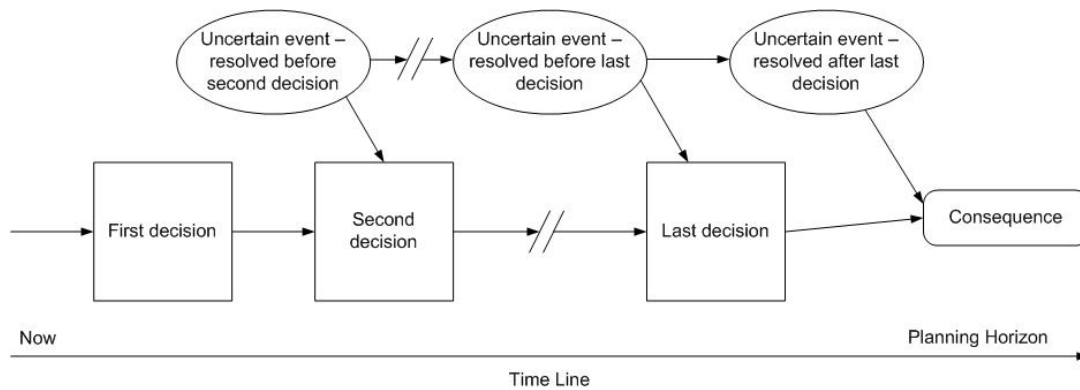


Figure A-101 Dovetailing uncertain events, sequential decisions, and consequences

Structuring decision

Decision modeling consists of three basic steps:

- Defining and structuring objectives and values
- Creating a logical framework of the elements of the decision situation by using influence diagrams and decision trees
- Refining and defining precisely the elements of the decision model

The first step in decision modeling is to structure values and objectives. If there is only one objective in the decision situation, it can be easily identified. In the decision situation with multiple objectives, balancing those objectives is of crucial importance. It is necessary to understand and identify objectives in such a situation.

The first step is to distinguish fundamental objectives and means. Fundamental objectives are those that show what the decision-maker wants to achieve, that is, why he considers a particular decision situation and what are the criteria he uses in evaluating the alternatives. The fundamental objectives are organized into hierarchies that can have upper and lower levels. The upper level consists of more general objectives, and the lower level consists of important elements of more general objectives. The means objectives are objectives that help

in achieving other objectives, such as fundamental objectives. They are useful in creating new alternatives in the decision situation. The means objectives are organized into networks, which show that means objectives can be connected to several fundamental objectives, and they help in accomplishing these fundamental objectives.

In the multiple objective decision situation, the appropriate creation of fundamental objective hierarchies, as well as distinguishing fundamental and means objectives, are very important for the decision-maker so that he is sure that the right objectives are considered.

In creating the decision context, the decision-maker must consider the following criteria:

- Does decision context include the exact problem?
- Who has the authority to make the decision in the particular decision context? Does the decision-maker really makes the decision or does he report the analysis of the decision situation to someone else who has the authority to make the decision? If the decision-maker does not have authority to make the decision, then the decision context should be narrower to match the level of authority that the decision-maker has.
- Are time and resources, which are assigned for a particular analysis of the decision situation, sufficient in the specific context? If the decision context is broader, time and resources might not be sufficient for performing a needed analysis resulting in a poor decision-making process. In this situation, it will be much better to narrow the decision context in order to accomplish the decision-making in a limited time and with available resources.

Influence diagrams

The influence diagram is a graphical representation of the decision situation. It consists of the following decision elements: fundamental and means objectives, decisions, alternatives, uncertain events, outcomes, and consequences. In the influence diagram, different decision elements have different shapes. These shapes are connected with arrows, which *represent* the relationships between the decision elements. For example, in the influence diagrams:

- Rectangles can represent decisions.
- Ellipsoids can represent chance events.
- Rectangles with rounded corners can represent consequences.

These three shapes are called “nodes”, such as decision nodes, chance nodes, and consequence nodes. Nodes are connected by arcs (or arrows), and together they form a graph (see Figure A-102).¹ The node at the beginning of an arc is a predecessor, and the node at the end of an arc is a successor. The decision and the chance nodes affect the consequence node. A consequence node depends on the predecessor’s node, that is, on what occurs and what is decided before it.

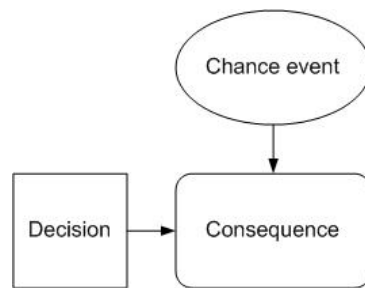


Figure A-102 *Influence diagram*

An arrow (arc) shows either relevance or sequence in the relationship between the nodes:

- An arc that points into a chance node represents relevance, that is, the predecessor is relevant for determining chances that are related to uncertain events. An arc that points from a decision node to a chance node also represents relevance, that is, the particular decision is relevant for determining chances that are related to succeeding uncertain events. Relevance arcs can also point into a consequence node, showing that the outcome of the predecessor node affects the consequence.
- An arc that points into a decision node represents sequence, that is, information available at the time of making a decision. A decision is made based on outcome of the predecessor node. An arc that points from a chance node to a decision shows that uncertain events related to a chance event are solved and the outcome is known at the time of making the decision. An arc that points from one decision to another decision

¹ Clemen, R.T. *Making Hard Decisions. An Introduction to Decision Analysis*. Pacific Grove: Duxbury Press at Brooks/Cole Publishing Company, 1996.

represents the sequential order of decision, that is, the first decision is made before the second.

The most appropriate strategy for constructing an influence diagram will be to create a simple diagram first, and then add details to get the diagram of the complete decision situation.

Decision trees

The decision tree is a graphical representation of the decision situation that shows more details, compared to the influence diagram, which shows basic elements/structure of the decision problem. Different graphical shapes represent different elements of the decision situation (see Figure A-103) ¹:

- Squares represent *decisions*.
- Circles represent *chance events*.
- Branches originating from a square (decision) represent possible *alternatives*. The branches originating from a circle represent possible *outcomes* of a chance event.
- *Consequence* is located at the end of branches.

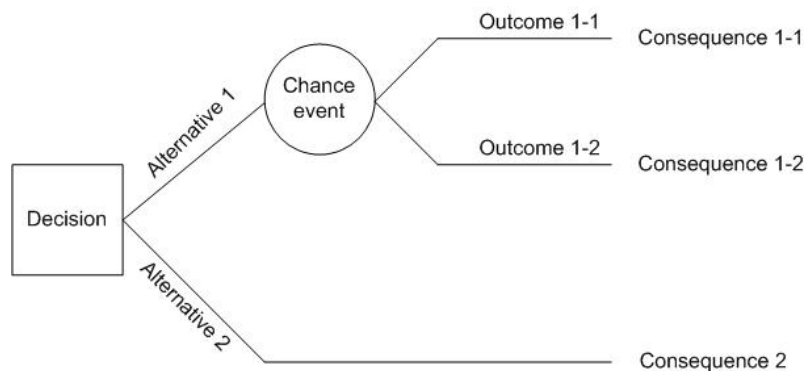


Figure A-103 Decision tree elements

The decision tree needs to meet the following requirements:

¹ Clemen, R.T. *Making Hard Decisions. An Introduction to Decision Analysis*. Pacific Grove: Duxbury Press at Brooks/Cole Publishing Company, 1996.

- Alternatives at the end of branches, which originate from a decision node, should be presented in such a way that the decision-maker can select only one alternative.
- Each chance node must have branches that match with:
 - Mutually exclusive outcomes: only one of the outcomes can occur.
 - Collectively exhaustive outcomes: there are no other possibilities; one of the specified outcomes must happen.

It means that one and only one of the outcomes can happen after uncertain events are solved.

- The decision tree should include all possible directions that the decision-maker can take, as well as all possible decision alternatives and outcomes.
- Nodes should be represented in chronological order. The decision is located on the left side of the decision tree. Then moving to the right direction, there are other decisions or chance events.

It is very important to dovetail a decision and chance events in the decision tree. If the chance event is located to the left of a decision node, then the decision depends on the outcome of the chance event. On the other hand, if the chance event is located to the right of a decision node, then the chance event must be considered while making the decision.

All relevant consequences should be shown at the end of each branch to present multiple objectives in the decision tree. A consequence matrix can be used to show multiple objectives. Rows of the matrix present alternatives while columns show objectives (see Figure A-104). Each alternative must be measured for each objective, and evaluation of the alternatives consists of filling the cells of the matrix.



Figure A-104 Decision tree represented as a matrix

A comparison of the influence diagrams and decision trees shows that:

- The decision tree contains much more information than the influence diagram.
- The decision tree becomes more complicated faster than the influence diagram in the case of increasing the complexity of the decision problem.
- Influence diagrams are useful for presentation of large and complex problems at the general level, while decision trees show details of the problem. Influence diagrams can be used in the beginning of the decision process to show the most important elements of the decision situation. After that, the decision tree can be used to show details of the problem.
- Influence diagrams and decision trees are just two different ways of presenting a decision situation, and a decision should not depend on the presentation of the problem. If the influence diagrams and decision trees are correctly created, they can be easily converted one to another. Depending on the particular decision problem, the decision-maker can choose to use either an influence diagram or decision trees, depending on their appropriateness for the specific decision situation.

Measuring of objectives

Accomplishment of the objectives needs to be measured; some of the objectives are measured by a natural numerical scale (for example, hours, dollars, and so forth). An attribute scale is a suitable scale for measurement of the objectives. If an attribute scale is not natural, then there are two optional ways for measuring objectives:

- To use a different scale as a proxy.
- To create an attribute scale that can be used for measuring accomplishment of the objective.

The measurement scale should include meaningful levels (such as best, intermediate, and worst). These levels should be clearly described to show their connection with objectives, as well as with measurement of the consequences.

Making choices

After the structure of the problem is created by using influence diagrams and/or decision trees, details can be used to select the best possible alternative. This process includes analysis

techniques, such as performing calculations, constructing graphs, and investigating results to get an understanding of the decision. Selecting an alternative that has the highest expected value is one approach for choosing one among several other risky alternatives.

Decision trees can be used to find expected values. This approach is known as “folding back the tree.” The process starts from the right side of the decision tree, that is, from the endpoints of the branches. The process goes toward the left side, calculating expected values when encountering a chance node and selecting the branch with the highest value when encountering a decision node. The expected value strategy can also be used in the decision situation with multiple objectives. In this case, the expected value must be calculated for each individual objective.

APPENDIX B. CASE STUDIES SIMULATION RESULTS

B.1. – MATRIXES OF DATA

SOUTH			21-Dec																	
Blinds' type	Blinds' position	Blinds' angle	clear sky						partly cloudy sky						11:00 a.m.					
			illumination (lx)			luminance (cd/sq m)			illumination (lx)			luminance (cd/sq m)			illumination (lx)		luminance (cd/sq m)			
			window	inside wall	outside wall	window	inside wall	outside wall	window	inside wall	outside wall	window	inside wall	outside wall	window	inside wall	outside wall	window	inside wall	outside wall
existing	exterior	0																		
		45																		
		90																		
	between	0																		
		45																		
patented	interior	90																		
		0																		
		45	1300	650	150	110	10000	700	1000	70	500	400	10	10						
	between	90	650	500	110	90	850	500	100	90										
		0	2200	650	200	100	1300	600	160	120	300	400	10	10						
new	exterior	0																		
		45																		
		90																		
	between	0																		
		45	2500	1300	400	150	10000	900	1000	130	550	400	10	10						
interior	90	1300	700	170	110	1100	650	150	110											
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interior	90																			

SOUTH														21-Dec											
Blinds' type	Blinds' position	Blinds' angle	clear sky						partly cloudy sky						12:00 p.m.										
			illumination (lx)		luminance (cd/sq m)		illumination (lx)		luminance (cd/sq m)		illumination (lx)		luminance (cd/sq m)		illumination (lx)		luminance (cd/sq m)								
			inside wall	window	inside wall	window	inside wall	window	inside wall	window	inside wall	window	inside wall	window	inside wall	window	inside wall	window	inside wall	window					
existing	exterior	0																							
		45	1000	650	150	110	10000	800	600	1000	900	1000	110	500	400	10	10								
		90																							
	between	0																							
		45	1000	700	170	130	10000	800	700	1000	850	1000	110	550	450	110	90								
patented	interior	0	10000	1300	1000	150	10000	1000	940	80	450	400	30	10											
		45	2500	1300	650	120	850	700	90	70	350	450	10	10											
		90	600	650	80	85	500	650	110	90	350	450	10	10											
	between	0	1600	850	180	140	1100	850	120	90	400	450	10	10											
		0					10000	1000	1000	130	650	550	10	10											
new	exterior	45	2500	1000	515	150	2200	900	260	110															
		90																							
		0	10000	1800	1000	220	10000	1000	1000	130	600	500	110	100											
	between	45	2500	1300	430	170	2300	900	260	130	580	430	10	10											
		90	1100	700	200	120	950	700	150	110	280	330	10	10											
	interior	0					10000	1000	1000	130	650	550	110	90											
		45	2500	1700	500	190	2300	900	260	130	550	450	90	90											

SOUTH			21-Dec 3:00 p.m.											
Blinds' type	Blinds' position	Blinds' angle	clear sky				partly cloudy sky				cloudy sky			
			illuminance (lx)		luminance (cd/sq m)		illuminance (lx)		luminance (cd/sq m)		illuminance (lx)		luminance (cd/sq m)	
			window	inside wall	window	inside wall	window	inside wall	window	inside wall	window	inside wall	window	inside wall
existing	exterior	0												
		45												
		90												
	between	0												
		45												
patented	interior	0												
		45	900	750	70	50	10000	550	1000	80	100	100	10	10
		90	550	650	100	80		500	70	50				
	between	0	1600	1000	160	120	660	550	70	50	100	100	10	10
		45												
new	exterior	0												
		45												
		90												
	between	0	2300	1000	320	130	10000	700	1000	110	500	200	10	10
		45	1000	800	150	110	1100	650	170	130	100	100	10	10
	interior	0												
		45												
		90												
		0												
		45												

SOUTH			21-Mar 11:00 a.m.											
Blinds' type	Blinds' position	Blinds' angle	clear sky				partly cloudy sky				cloudy sky			
			illuminance (lx)		luminance (cd/sq m)		illuminance (lx)		luminance (cd/sq m)		illuminance (lx)		luminance (cd/sq m)	
			window	inside wall	window	inside wall	window	inside wall	window	inside wall	window	inside wall	window	inside wall
existing	exterior	0												
		45	1300	900	150	130								
		90												
	between	0												
		45	1300	1000	150	110								
patented	interior	0	2100	1100	210	130	2200	1300	240	140	500	450	70	60
		45	1300	1300	125	80	1100	1000	150	110				
		90	800	850	130	140								
	between	0	1600	1000	160	120	1450	1150	160	140	450	500	80	85
		45												
new	exterior	0												
		45												
		90												
	between	0	2500	1300	320	190	2500	1700	380	190	750	550	130	70
		45	1650	950	190	130	1300	900	170	130	650	550	80	40
	interior	0												
		45												
		90												
		0												
		45												

SOUTH			21-Mar											
Blinds' type	Blinds' position	Blinds' angle	12:00 p.m.											
			clear sky				partly cloudy sky				cloudy sky			
			illuminance (lx) window	illuminance (lx) inside wall	luminance (cd/sq m) window	luminance (cd/sq m) inside wall	illuminance (lx) window	illuminance (lx) inside wall	luminance (cd/sq m) window	luminance (cd/sq m) inside wall	illuminance (lx) window	illuminance (lx) inside wall	luminance (cd/sq m) window	luminance (cd/sq m) inside wall
existing	exterior	0												
		45	1000	850	150	110	1000	900	130	110	600	550	110	90
		90												
	between	0												
		45	1000	850	150	130	1000	900	130	110	650	550	110	90
new	interior	90												
		0	1700	1000	210	150	2250	1300	220	120	500	450	50	30
		45	1000	900	120	100	1300	1000	120	80	500	600	50	30
	between	90	650	800	80	100	700	900	150	130	450	550	50	30
		0	1600	900	150	130	1600	1000	158	138	550	500	70	60
		45					2500	1700	380	190	850	600	110	90
	exterior	90	2500	1300	300	150	2500	1600	300	190	700	600	110	90
		0	2500	1900	410	220	2500	1600	380	200	900	600	130	110
		45	2500	1300	340	150	2500	1600	340	170	700	550	110	90
	interior	90	1300	900	170	130	1300	1100	170	130	450	500	70	50
		0					2500	1700	380	210	900	600	150	110
		45	2500	1600	300	190	2400	1600	280	190				

SOUTH			21-Mar											
Blinds' type	Blinds' position	Blinds' angle	3:00 p.m.											
			clear sky				partly cloudy sky				cloudy sky			
			illuminance (lx) window	illuminance (lx) inside wall	luminance (cd/sq m) window	luminance (cd/sq m) inside wall	illuminance (lx) window	illuminance (lx) inside wall	luminance (cd/sq m) window	luminance (cd/sq m) inside wall	illuminance (lx) window	illuminance (lx) inside wall	luminance (cd/sq m) window	luminance (cd/sq m) inside wall
existing	exterior	0												
		45												
		90												
	between	0												
		45												
new	interior	90												
		0	1200	1000	125	100	1500	1000	180	100	450	400	80	75
		45	700	1000	80	120	1100	1000	70	60	300	400	60	30
	between	90	1300	1000	150	130	700	900	110	150	400	450	30	10
		0					2300	1300	280	150				
		45									600	500	110	70
	exterior	90												
		0					2300	1300	300	170	700	500	60	70
		45	2400	1300	320	170	2200	1100	220	150	600	500	30	10
	interior	90	1300	1000	150	130	1300	1000	90	130				
		0												
		45									600	550	110	130

SOUTH		21-Jun											
		11:00 a.m.											
		clear sky			partly cloudy sky			cloudy sky					
Blinds' type	Blinds' position	Blinds' angle	illuminance (lx)	luminance (cd/sq m)	illuminance (lx)	luminance (cd/sq m)	illuminance (lx)	luminance (cd/sq m)	illuminance (lx)	luminance (cd/sq m)	illuminance (lx)	luminance (cd/sq m)	illuminance (lx)
existing	exterior	0					2200	1700	230	170			
		45											
		90											
	between	0					2100	1700	220	190			
		45											
		90											
patented	interior	0					2200	1600	180	140	600	500	100
		45	1300	1600	158	178	1300	1500	160	180			80
		90	1100	1700	110	180							
	between	0	1300	1300	158	138	1300	1600	120	140	400	500	100
		45											110
		90											
new	exterior	0											
		45											
		90											
	between	0					2500	2100	340	220	900	650	150
		45	2300	1700	240	200	2300	1600	240	200			90
		90	1600	1700	150	170							
new	interior	0											
		45											
		90											

SOUTH		21-Jun											
		12:00 p.m.											
		clear sky			partly cloudy sky			cloudy sky					
Blinds' type	Blinds' position	Blinds' angle	illuminance (lx)	luminance (cd/sq m)	illuminance (lx)	luminance (cd/sq m)	illuminance (lx)	luminance (cd/sq m)	illuminance (lx)	luminance (cd/sq m)	illuminance (lx)	luminance (cd/sq m)	illuminance (lx)
existing	exterior	0											
		45	1150	1200	130	150	1300	1600	150	170			90
		90											
	between	0									650	550	110
		45	1100	1100	130	190	1300	1600	150	170			
		90											
patented	interior	0											
		45	1300	1300	170	150	2200	1500	200	160	600	550	80
		90	1000	1100	100	140	1000	1600	150	170	500	600	70
	between	0	1300	1300	150	130	1800	1700	140	160	500	550	60
		45					2500	2000	320	210	900	650	130
		90	2300	1700	260	190	2300	1800	300	220	900	650	130
new	exterior	0											
		45	2500	1700	280	220	2500	2200	320	220	1000	650	150
		90	2200	1600	220	180	2300	1900	260	180	900	650	150
	between	0											
		45	1100	1000	170	150	1500	1700	170	190	600	650	110
		90									1000	650	150
new	interior	0											
		45	2250	1650	220	190	2400	1800	260	210			
		90											

SOUTH			21-Jun 3:00 p.m.													
Blinds' type	Blinds' position	Blinds' angle	clear sky				partly cloudy sky				cloudy sky					
			illumination (lx)	illumination (cd/sq m)	inside wall	window	illumination (lx)	illumination (cd/sq m)	inside wall	window	illumination (lx)	illumination (cd/sq m)	inside wall	window		
existing	exterior	0														
		45														
		90														
	between	0														
		45														
		90														
patented	interior	0	1600	1700	150	190	1600	1500	180	160	550	110	100			
		45	1100	1600	140	180	1000	1600	138	158						
		90														
	between	0	1500	1700	120	160	1100	1300	130	150	500	80	70			
		45														
		90									650	110	130			
new	exterior	0														
		45														
		90														
	between	0	2100	1700	230	190	2300	1600	280	190	850	600	130	90		
		45	2100	1700	220	180	2300	1600	240	200	700	550	110	100		
		90	1300	1600	150	190										
interior	0															
	45															
	90															

WEST			21-Dec 12:00 p.m.													
Blinds' type	Blinds' position	Blinds' angle	clear sky				partly cloudy sky				cloudy sky					
			illumination (lx)		luminance (cd/sq m)		illumination (lx)		luminance (cd/sq m)		illumination (lx)		luminance (cd/sq m)			
existing	exterior	0														
		45														
		90														
	between	0														
		45														
		90														
patented	interior	0														
		45	1100	1600	130	170	1000	1100	450	400	300	60	50			
		90	1150	1300	130	170	850	1000	90	130						
	between	0	1300	1500	140	180	1000	900	100	120	350	450	10	10		
		45														
		90														
new	exterior	0														
		45														
		90														
	between	0	1700	1600	220	200	800	1000	90	130						
		45	1650	1600	220	240	1100	1000	170	150	600	500	70	50		
		90	1100	1600	160	200	850	1000	130	150	400	450	10	10		
interior	0															
	45															
		90														

WEST											
Blinds' type		Blinds' position	Blinds' angle	21-Dec							
				clear sky					partly cloudy sky		
				illumination (lx)		luminance (cd/sq m)		illumination (lx)		luminance (cd/sq m)	
existing	exterior	0	90	inside wall	window	inside wall	window	inside wall	window	inside wall	window
								1100	700	150	110
				950	850	150	130				
existing	between	0	90	950	850	150	130	1100	600	170	110
patented	interior	0	90					1300	600	120	80
				1050	850	130	110	700	600	170	190
				850	800	130	150				
				1300	800	160	120	800	600	120	100
				2500	1300	280	170	2100	850	230	110
new	exterior	0	90								
new	between	0	90	2300	1150	260	150	1900	1100	220	130
				1100	800	150	110	1300	800	190	110
new	interior	0	90								
								600	450	70	70

WEST											
Blinds' type		Blinds' position	Blinds' angle	21-Dec							
				clear sky					partly cloudy sky		
				illumination (lx)		luminance (cd/sq m)		illumination (lx)		luminance (cd/sq m)	
existing	exterior	0	90	inside wall	window	inside wall	window	inside wall	window	inside wall	window
				10000	550	1000	110	10000	300	1000	50
existing	between	0	90	10000	500	1000	100	10000	300	1000	50
existing	interior	0	90	10000	650	1000	110	10000	300	1000	100
				10000	500	1000	100	10000	300	1000	50
				450	400	90	70	250	300	10	10
patented	between	0	90	10000	550	1000	120	10000	300	1000	50
new	exterior	0	90	10000	700	1000	130	10000	400	1000	90
new	between	0	90	10000	800	1000	150	10000	500	1000	90
				10000	700	1000	130	10000	450	1000	90
				900	500	130	90	500	350	10	10
new	interior	0	90	10000	700	1000	130	10000	500	1000	110

WEST			21-Mar 12:00 p.m.											
Blinds' type	Blinds' position	Blinds' angle	clear sky				partly cloudy sky				cloudy sky			
			illumination (x) window	inside wall	lumiance (cd/sq m) window	inside wall	illumination (x) window	inside wall	lumiance (cd/sq m) window	inside wall	illumination (x) window	inside wall	lumiance (cd/sq m) window	inside wall
existing	exterior	0												
		45												
		90												
	between	0												
		45												
		90												
new	interior	0					2100	2150	200	180	600	550	100	100
		45	2300	1600	190	230	1300	2050	150	230				
		90	1600	2200	160	220								
	between	0	1300	2200	160	200	1600	1700	190	230	500	550	60	80
		45												
		90												
	exterior	0												
		45												
		90												
	between	0	2300	2400	260	280	2300	2200	240	220	900	750	150	90
		45	2200	2300	220	240	2200	2100	220	200	700	550	110	90
		90	1700	2300	180	220	1600	1900	190	200	550	650	70	50
	interior	0												
		45												
		90												

WEST			21-Mar 2:00 p.m.											
Blinds' type	Blinds' position	Blinds' angle	clear sky				partly cloudy sky				cloudy sky			
			illumination (x) window	inside wall	lumiance (cd/sq m) window	inside wall	illumination (x) window	inside wall	lumiance (cd/sq m) window	inside wall	illumination (x) window	inside wall	lumiance (cd/sq m) window	inside wall
existing	exterior	0												
		45	1300	1100	150	110								
		90												
	between	0					2100	1300	210	130				
		45	900	850	130	110								
		90												
new	interior	0					2150	1300	240	120	600	500	110	100
		45	1300	1000	170	150	1000	900	130	150				
		90	900	1200	130	150								
	between	0	1600	900	170	130	1300	1100	150	130	500	550	90	100
		45									800	600	110	90
		90												
	exterior	0												
		45												
		90												
	between	0					2500	1600	340	180	750	550	130	70
		45	2400	1300	300	170	2300	1500	260	170				
		90	1300	900	300	170								
	interior	0												
		45												
		90					1050	1300	210	150				

WEST			21-Mar 4:00 p.m.												
Blinds' type	Blinds' position	Blinds' angle	clear sky			partly cloudy sky			cloudy sky						
			illumination (lx)	luminance (cd/sq m)	inside wall	illumination (lx)	luminance (cd/sq m)	inside wall	illumination (lx)	luminance (cd/sq m)	inside wall				
existing	exterior	0													
		45	1100	800	170	130	800	650	110	90	550	450	50		
		90													
	between	0													
		45	1100	700	150	130	800	650	110	90	500	450	50		
		90													
patented	interior	0	10000	1200	1000	150	10000	900	1000	110	500	450	50		
		45	1100	850	170	110	850	500	110	90	300	400	10		
		90	650	600	130	110	550	650	90	110	300	400	10		
	between	0	1900	700	180	100	1000	650	140	100	450	500	50		
		0	10000	1700	1000	170					600	500	90	70	
		45	2500	1300	380	150	2150	850	230	110	550	450	90	70	
new	exterior	90					950	650	150	110					
		0	10000	1700	1000	190	10000	1000	1000	130	600	500	90	70	
		45	2500	1300	360	150	2200	850	220	110	550	450	90	70	
	between	90	1500	950	190	130	950	650	150	110	450	500	90	70	
		0									600	500	90	70	
		45	2500	1300	500	190	2300	950	240	130	600	500	90	70	

WEST			21-Jun																
Blinds' type	Blinds' position	Blinds' angle	clear sky						partly cloudy sky						cloudy sky				
			illumination (lx)		luminance (cd/sq m)		illumination (lx)		luminance (cd/sq m)		illumination (lx)		luminance (cd/sq m)		illumination (lx)		luminance (cd/sq m)		
			window	inside wall	window	inside wall	window	inside wall	window	inside wall	window	inside wall	window	inside wall	window	inside wall	window	inside wall	
existing	exterior	0																	
		45																	
		90																	
	between	0																	
		45																	
90																			
interior	0																		
	45	1500	2200	170	210	2200	2300	1600	200	2200	2300	180	200	600	550	100	80		
	90	1300	2200	150	210														
	between	0	1300	2200	140	180	1600	2300	1600	180	140	500	550	110	115				
		45																	
new	exterior	0																	
		45																	
		90																	
	between	0	2200	2400	240	260	2300	2200	300	260	1000	650	130	90					
		45	2100	2300	220	260	2200	2300	260	240	850	650	130	90					
90		2300	1700	200	240	1900	2200	220	260	600	650	110	90						
interior	0																		
	45																		
		90																	

WEST			21-Jun 2:00 p.m.													
Blinds' type	Blinds' position	Blinds' angle	clear sky				partly cloudy sky				cloudy sky					
			illumination (lx)		luminance (cd/sq m)		illumination (lx)		luminance (cd/sq m)		illumination (lx)		luminance (cd/sq m)			
			window	inside wall	window	inside wall	window	inside wall	window	inside wall	window	inside wall	window	inside wall		
existing	exterior	0														
		45	1000	900	150	130										
		90														
	between	0														
		45	1000	900	130	90										
		90														
patented	interior	0														
		45	1100	1000	150	130		2200	1300	200	120		550	500	100	100
		90	800	900	90	130		1150	1250	150	200					
	between	0	1300	1100	158	118		1300	1100	160	140		500	550	120	100
		45											900	650	150	110
		90											800	600	110	90
new	exterior	0														
		45														
		90														
	between	0	2500	1700	320	170		2500	1700	370	210		900	600	150	90
		45	2500	1300	240	150		2500	1700	320	170		750	650	130	90
		90	1000	850	150	110		1600	1300	170	150		600	650	110	90
interior	0															
	45															
		90														

WEST			21-Jun 4:00 p.m.													
Blinds' type	Blinds' position	Blinds' angle	clear sky				partly cloudy sky				cloudy sky					
			illumination (lx)		luminance (cd/sq m)		illumination (lx)		luminance (cd/sq m)		illumination (lx)		luminance (cd/sq m)			
			window	inside wall	window	inside wall	window	inside wall	window	inside wall	window	inside wall	window	inside wall	window	inside wall
existing	exterior	0														
		45	950	850	150	110	900	800	130	110	600	500	70			
	90															
	between	0														
		45	950	850	150	110	900	800	130	110	550	500	50			
patented	interior	90														
		0	10000	1100	1000	130	10000	1000	1000	120	450	350	50			
	45	1000	900	150	110	900	800	130	90	400	450	50				
	90	600	800	70	90	600	700	110	130	400	500	50				
	0	1300	900	158	118	1300	700	160	80	450	500	50				
new	exterior	0	10000	1700	1000	190					700	550	110	90		
		45	2500	1300	340	170	2400	1100	280	130	650	550	110	90		
	90															
	0	10000	1700	1000	190	10000	1600	1000	170	700	550	110	90			
	45	2500	1300	340	170	2400	1000	300	140	600	500	110	90			
interior	90	1300	1000	190	130	1000	850	150	130	500	550	90	70			
	0									700	550	110	90			
	45	2500	1700	340	190	2300	1300	280	190	600	550	110	90			

B.2. CHARTS AND TABLES--FOR
THE USER OF THE DMF

ILLUMINANCE SOUTH

TABLE 1.

SKY CONDITIONS NUMBER OF DAYS			
month	clear	partly cloud	cloudy
january	8	8	15
february	8	7	13
march	8	9	14
april	8	9	13
may	7	11	13
june	7	12	11
july	7	13	11
august	8	12	11
september	10	9	11
october	13	7	11
november	9	8	13
december	9	8	14
annual	102	113	151

TABLE 2.

ILLUMINANCE AT THE POINT CLOSE TO THE WINDOW (lx)

EXISTING BLINDS			PATENTED BLINDS			NEW BLINDS		
month	clear	partly cloud	cloudy	clear	partly cloud	cloudy	clear	partly cloud
january	1433	889	394	1700	1147	333	2444	2022
february	1300	1028	439	1600	1273	400	2456	2211
march	1167	1167	483	1500	1400	467	2467	2400
april	1189	1178	517	1456	1400	467	2378	2367
may	1211	1189	550	1411	1400	467	2289	2333
june	1233	1200	583	1367	1400	467	2200	2300
july	1211	1189	550	1411	1400	467	2289	2333
august	1189	1178	516	1456	1400	467	2378	2367
september	1167	1167	483	1500	1400	467	2467	2400
october	1300	1028	439	1600	1273	400	2456	2211
november	1433	889	394	1700	1147	333	2444	2022
december	1567	750	350	1800	1020	267	2433	1833
annual	15401	12851	5699	18500	15660	5001	28701	26800

TABLE 3.

ILLUMINANCE x DAYS AT THE POINT CLOSE TO THE WINDOW (lx*days)

EXISTING BLINDS			PATENTED BLINDS			NEW BLINDS		
month	clear	partly cloud	cloudy	clear	partly cloud	cloudy	clear	partly cloud
january	11467	7111	5917	13600	9173	5000	19556	16178
february	10400	7194	5706	12800	8913	5200	19644	15478
march	9333	10500	6767	12000	12600	6533	19733	21600
april	9511	10600	6717	11644	12600	6067	19022	21300
may	8478	13078	7150	9878	15400	6067	16022	25667
june	8633	14400	6417	9567	16800	5133	15400	27600
july	8479	15457	6049	9878	18200	5135	16023	30333
august	9513	14136	5691	11644	16800	5136	19024	28400
september	11670	10503	5313	15000	12600	5137	24670	21600
october	16903	7196	4825	20800	8913	4402	31925	15478
november	12801	7112	5126	15300	9173	4335	22001	16178
december	14100	6000	4900	16200	8160	3733	21900	14667
annual	131388	123287	70567	158311	149333	61878	244921	254478

TABLE 4.

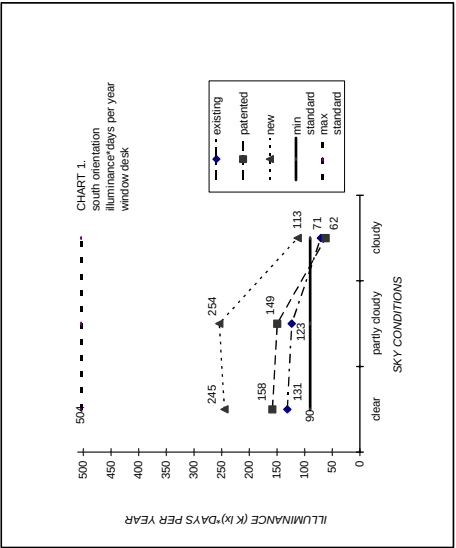
ANNUAL ILLUMINANCE x DAYS (lx*days)

	clear	partly cloud	cloudy
existing	131388	123287	70567
patented	158311	149333	61878
new	244921	254478	112667
min stand	90000	90000	90000
max stand	504000	504000	504000

TABLE 5.

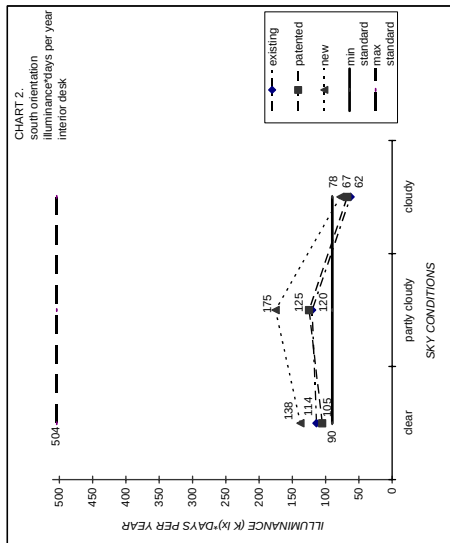
ANNUAL ILLUMINANCE x DAYS (lx*days)

	clear	partly cloud	cloudy
existing	131	123	71
patented	158	149	62
new	245	254	113
min stand	90	90	90
max stand	504	504	504



SKY CONDITIONS		NUMBER OF DAYS	
month	clear	partly cloudy	cloudy
January	8	8	15
February	8	7	13
March	8	9	14
April	8	9	13
May	7	11	13
June	7	12	11
July	7	13	11
August	8	12	11
September	10	9	11
October	13	7	11
November	9	8	13
December	9	8	14
annual	102	113	151

month	EXISTING BLINDS			PATENTED BLINDS			NEW BLINDS		
	clear	partly cloud	cloudy	clear	partly cloud	cloudy	clear	partly cloud	cloudy
january	956	711	344	878	783	372	1233	1189	428
february	1011	856	389	922	900	428	1267	1444	489
march	1067	1000	433	967	1017	483	1300	1700	550
april	1211	1167	461	1122	1189	500	1422	1711	578
may	1356	1333	489	1278	1361	517	1544	1722	606
june	1500	1500	517	1433	1533	533	1667	1733	633
july	1356	1333	489	1278	1361	517	1544	1722	606
august	1211	1167	461	1122	1189	500	1422	1711	578
september	1067	1000	433	967	1017	483	1300	1700	550
october	1011	856	389	922	900	428	1267	1444	489
november	956	711	344	878	783	372	1233	1189	428
december	900	567	300	833	667	317	1200	933	367
annual	13601	12200	5049	12601	12701	5449	16400	18200	6300



month	EXISTING BLINDS			PATENTED BLINDS			NEW BLINDS		
	clear	partly clou	cloudy	clear	partly clou	cloudy	clear	partly clou	cloudy
january	7644	5689	5167	7022	6267	5583	9867	9511	6417
february	8089	5989	5056	7378	6300	5561	10133	10111	6356
march	8533	9000	6067	7733	9150	6767	10400	15300	7700
april	9689	10500	5994	8978	10700	6500	11378	15400	7511
may	9489	14667	6356	8944	14972	6717	10811	18944	7872
june	10500	18000	5683	10033	18400	5867	11667	20800	6967
july	9490	17333	5377	8945	17696	5682	10811	22389	6661
august	9691	14000	5070	8980	14269	5498	11378	20533	6356
september	10670	9000	4763	9670	9153	5313	13000	15900	6050
october	13147	5989	4275	11992	6302	4703	16467	10111	5378
november	8601	5689	4476	7901	6268	4837	11100	9511	5561
december	8100	4533	4200	7500	5333	4433	10800	7467	5133
annual	113643	120399	62483	105076	124810	67461	137811	175378	77961

	clear	partly cloudy	cloudy
existing	113643	120389	62483
patented	105076	124810	67461
new	137811	175378	77961
min stand	90000	90000	90000
max stand	504000	504000	504000

ANNUAL ILLUMINANCE DATA (Klx)	clear	partly cloudy	cloudy
existing	114	120	62
patented	105	125	67
new	138	175	78
min stand	90	90	90
max stand	504	504	504

ILLUMINANCE WEST

ILLUMINANCE AT THE POINT CLOSE TO THE WINDOW (lx)

SKY CONDITIONS NUMBER OF DAYS			EXISTING BLINDS			PATENTED BLINDS			NEW BLINDS		
month	clear	partly clou cloudy	clear	partly clou cloudy	clear	partly clou cloudy	clear	partly clou cloudy	clear	partly clou cloudy	clear
january	8	8	15	3222	2917	322	3333	3056	328	3889	3500
february	8	7	13	2394	1983	444	2467	2178	406	3128	2867
march	8	9	14	1567	1050	567	1600	1300	483	2367	2233
april	8	9	13	1444	1106	556	1500	1333	483	2234	2278
may	7	11	13	1322	1161	544	1400	1367	483	2100	2322
june	7	12	11	1200	1217	533	1300	1400	483	1967	2367
july	7	13	11	1322	1161	545	1400	1367	483	2100	2322
august	8	12	11	1445	1106	556	1500	1333	483	2234	2278
september	10	9	11	1567	1050	567	1600	1300	483	2367	2233
october	13	7	11	2395	1983	445	2467	2178	405	3128	2866
november	9	8	13	3222	2917	322	3333	3056	328	3889	3500
december	9	8	14	4050	3850	200	4200	3933	250	4650	4133
annual	102	113	151	25151	21500	5601	26100	23800	5099	34051	32899

ILLUMINANCE x DAYS AT THE POINT CLOSE TO THE WINDOW (lx*days)

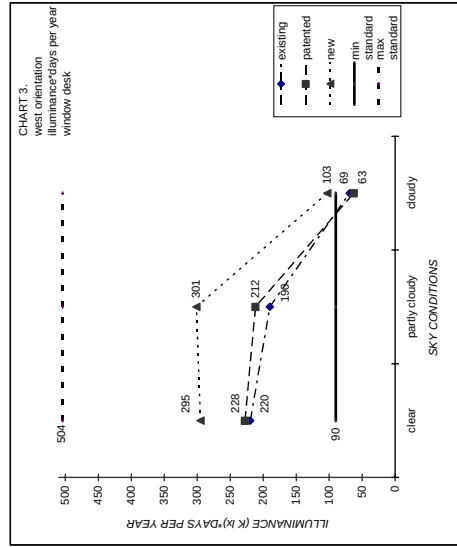
EXISTING BLINDS			PATENTED BLINDS			NEW BLINDS		
month	clear	partly clou cloudy	clear	partly clou cloudy	clear	partly clou cloudy	clear	partly clou cloudy
january	25778	23333	4833	26667	24444	4917	31111	28000
february	19156	13883	5778	19733	15244	5272	25022	20067
march	12533	9450	7933	12800	11700	6767	18933	20100
april	11556	9950	7222	12000	12000	6283	17867	20500
may	9256	12772	7078	9800	15033	6283	14700	25544
june	8400	14600	5867	9100	16800	5317	13767	28400
july	9256	15094	5990	9800	17767	5315	14701	30187
august	11557	13267	6114	12000	16000	5314	17868	27331
september	15670	9450	6237	16000	11700	5313	23670	20097
october	31131	13883	4881	32067	15244	4459	40664	20065
november	29001	23333	4190	30000	24444	4260	35001	27999
december	36450	30800	2800	37800	31467	3500	41850	33067
annual	219743	189817	68933	227767	211844	63000	295154	301357

ANNUAL ILLUMINANCE x DAYS (lx*days)

	clear	partly clou cloudy
existing	219743	189817
patented	227767	211844
new	295154	301357
min stand	90000	90000
max stand	504000	504000

ANNUAL ILLUMINANCE x DAYS (k lx*days)

	clear	partly clou cloudy
existing	220	190
patented	228	212
new	295	301
min stand	90	90
max stand	504	504



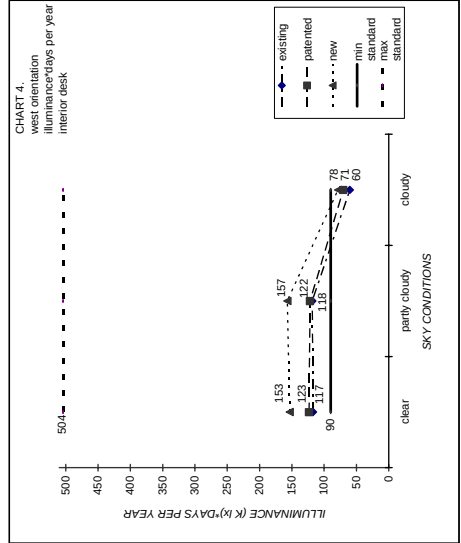
ILLUMINANCE WEST

ILLUMINANCE AT THE POINT CLOSE TO THE INTERIOR PARTITION (lx)												
SKY CONDITIONS NUMBER OF DAYS				EXISTING BLINDS			PATENTED BLINDS			NEW BLINDS		
month	clear	partly clou	cloudy	clear	partly clou	cloudy	clear	partly clou	cloudy	clear	partly clou	cloudy
january	8	8	15	1039	606	278	1056	767	378	1311	994	411
february	8	7	13	1094	878	389	1161	933	456	1472	1239	506
march	8	9	14	1150	1150	500	1267	1100	533	1633	1483	600
april	8	9	13	1222	1222	489	1311	1189	533	1633	1544	600
may	7	11	13	1294	1294	478	1356	1278	533	1633	1606	600
june	7	12	11	1367	1367	467	1400	1367	533	1633	1667	600
july	7	13	11	1294	1294	478	1356	1278	533	1633	1605	600
august	8	12	11	1222	1222	489	1311	1189	533	1633	1544	600
september	10	9	11	1150	1150	500	1267	1100	533	1633	1483	600
october	13	7	11	1094	878	389	1161	933	455	1472	1239	506
november	9	8	13	1039	606	278	1056	767	378	1311	994	411
december	9	8	14	983	333	167	950	600	300	1150	750	317
annual	102	113	151	13950	12000	4900	14651	12500	5699	18149	16149	6350

ANNUAL ILLUMINANCE x DAYS (lx*days)									
EXISTING BLINDS				PATENTED BLINDS			NEW BLINDS		
month	clear	partly clou	cloudy	clear	partly clou	cloudy	clear	partly clou	cloudy
january	8311	4844	4167	8444	6133	5667	10489	7956	6167
february	8756	6144	5056	9289	6533	5922	11778	8672	6572
march	9200	10350	7000	10133	9900	7467	13067	13350	8400
april	9778	11000	6356	10489	10700	6933	13067	13900	7800
may	9061	14239	6211	9489	14056	6933	11433	17661	7800
june	9567	16400	5133	9800	16400	5867	11433	20000	6600
july	9061	16828	5256	9490	16611	5865	11433	20871	6600
august	9778	14667	5378	10491	14267	5864	13065	18531	6600
september	11500	10350	5500	12670	9900	5863	16330	13347	6600
october	14228	6144	4278	15097	6533	5009	19136	8671	5561
november	9350	4844	3611	9501	6133	4910	11799	7955	5944
december	8850	2667	2333	8550	4800	4200	10350	6000	4433
annual	117439	118478	60278	123443	121967	70500	153379	156913	78478

ANNUAL ILLUMINANCE x DAYS (lx*days)			
	clear	partly clou	cloudy
existing	117439	118478	60278
patented	123443	121967	70500
new	153379	156913	78478
min stand	90000	90000	90000
max stand	504000	504000	504000

ANNUAL ILLUMINANCE x DAYS (lx*days)			
	clear	partly clou	cloudy
existing	117	118	60
patented	123	122	71
new	153	157	78
min stand	90	90	90
max stand	504	504	504



SKY CONDITIONS		NUMBER OF DAYS	
month	clear	partly	cloudy
january	8	8	15
february	8	7	13
march	8	9	14
april	8	9	13
may	7	11	13
june	7	12	11
july	7	13	11
august	8	12	11
september	10	9	11
october	13	7	11
november	9	8	13
december	9	8	14
annual	102	113	151

COMPARISON AT THE POINT CLOSE TO THE WINDOW CORNER									
EXISTING BLINDS			PATENTED BLINDS			NEW BLINDS			
month	clear	partly cloudy	cloudy	clear	partly cloudy	cloudy	clear	partly cloudy	cloudy
january	234	96	33	229	131	51	364	240	64
february	179	104	50	278	145	91	346	263	86
march	123	113	67	327	159	132	327	287	107
april	130	125	77	265	149	115	293	273	119
may	136	137	87	204	140	97	260	260	131
june	143	149	97	143	130	80	227	247	143
july	136	137	87	204	140	97	260	260	131
august	130	125	77	266	149	115	294	274	119
september	123	113	67	327	159	132	327	287	107
october	179	104	50	278	145	91	346	264	86
november	234	95	33	229	131	51	365	240	65
december	290	87	17	180	117	10	383	217	43
annual	2037	1387	741	2929	1693	1062	3791	3111	1201

		EXISTING BLINDS			PATENTED BLINDS			NEW BLINDS		
month	clear	partly clou	cloudy	clear	partly clou	cloudy	clear	partly clou	cloudy	
january	1876	764	500	1831	1045	760	2916	1920	967	
february	1431	731	650	2222	1013	1187	2764	1843	1112	
march	987	1020	933	2613	1428	1848	2613	2580	1493	
april	1038	1128	997	2123	1342	1491	2347	2460	1546	
may	954	1511	1127	1428	1535	1265	1820	2860	1704	
june	999	1792	1063	999	1560	880	1587	2960	1577	
july	953	1784	955	1429	1816	1071	1821	3381	1443	
august	1036	1501	846	2124	1792	1261	2348	3283	1310	
september	1230	1017	737	3270	1431	1452	3270	2583	1177	
october	2323	730	552	3614	1014	1005	4495	1845	944	
november	2109	764	435	2061	1046	659	3281	1921	839	
december	2610	693	233	1620	933	140	3450	1733	607	
annual	17545	13435	9028	25334	15956	13019	32712	29370	14719	

patent	clear	partly clear	cloudy
existing	17545	13435	9028
patented	25324	15956	13019
new	32712	29370	14719
min stand	12000	12000	12000
max stand	102000	102000	102000

ANNUAL LUMINANCE X DAYS (K. GUISH)	clear	partly cloud	cloudy
existing	18	13	9
patented	25	16	13
new	33	29	15
min stand	12	12	12
max stand	102	102	102



LUMINANCE SOUTH

LUMINANCE AT THE POINT CLOSE TO THE INTERIOR PARTITION (cd/sq m)

SKY CONDITIONS NUMBER OF DAYS				EXISTING BLINDS		PATENTED BLINDS		NEW BLINDS	
month	clear	partly cloud	cloudy	clear	partly cloud	clear	partly cloud	clear	partly cloud
january	8	8	15	93	66	122	104	44	157
february	8	7	13	93	74	124	121	48	163
march	8	9	14	93	83	127	139	52	170
april	8	9	13	118	112	132	142	60	176
may	7	11	13	142	141	137	146	68	181
june	7	12	11	166	169	143	150	77	187
july	7	13	11	142	141	137	146	68	181
august	8	12	11	117	112	132	143	60	176
september	10	9	11	93	83	127	139	52	170
october	13	7	11	93	74	125	122	48	183
november	9	8	13	93	65	122	104	44	157
december	9	8	14	93	57	120	87	40	150
annual	102	113	151	1337	1177	1549	1543	661	2030

LUMINANCE x DAYS AT THE POINT CLOSE TO THE INTERIOR PARTITION ((cd/sq m)*days)

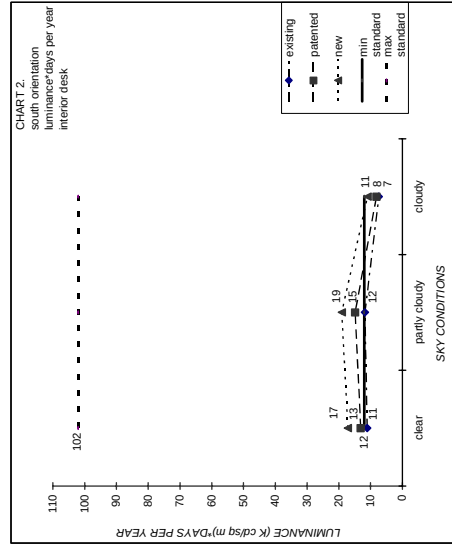
EXISTING BLINDS			PATENTED BLINDS			NEW BLINDS		
month	clear	partly cloud	cloudy	clear	partly cloud	cloudy	clear	partly cloud
january	747	524	375	978	832	658	1253	1147
february	747	521	520	996	849	621	1307	1097
march	747	750	770	1013	1248	723	1360	1530
april	940	1008	838	1056	1282	780	1404	1600
may	992	1547	961	1608	888	1268	2041	1141
june	1162	2032	917	999	1800	843	1307	2320
july	992	1827	813	962	1902	753	1268	2412
august	939	1341	709	1058	1712	662	1404	2133
september	930	747	605	1270	1251	572	1700	1530
october	1210	520	440	1621	851	528	2123	1097
november	838	524	325	1101	833	572	1410	1147
december	840	453	140	1080	693	560	1350	1040
annual	11085	11795	7412	13094	14862	8162	17154	19093

ANNUAL LUMINANCE x DAYS ((cd/sq m)*days)

	clear	partly cloud	cloudy
existing	11085	11795	7412
patented	13094	14862	8162
new	17154	19093	10960
min stand	12000	12000	12000
max stand	102000	102000	102000

ANNUAL LUMINANCE x DAYS ((k cd/sq m)*days)

	clear	partly cloud	cloudy
existing	11	12	7
patented	13	15	8
new	17	19	11
min stand	12	12	12
max stand	102	102	102



LUMINANCE WEST

SKY CONDITIONS NUMBER OF DAYS				LUMINANCE AT THE POINT CLOSE TO THE WINDOW (cd/sq m)			
month	clear	partly cloud	cloudy	EXISTING BLINDS		PATENTED BLINDS	
				clear	partly cloud	clear	partly cloud
january	8	8	15	339	323	47	346
february	8	7	13	258	227	67	258
march	8	9	14	177	130	87	170
april	8	9	13	170	127	86	164
may	7	11	13	163	123	84	158
june	7	12	11	157	120	83	152
july	7	13	11	163	123	85	158
august	8	12	11	170	127	86	164
september	10	9	11	177	130	87	170
october	13	7	11	258	227	67	258
november	9	8	13	339	323	47	346
december	9	8	14	420	420	27	433
annual	102	113	151	2791	2400	851	2776
						NEW BLINDS	
				clear	partly cloud	clear	partly cloud
january				339	323	29	427
february				258	242	48	360
march				177	160	67	293
april				170	158	76	284
may				163	156	84	276
june				157	153	93	267
july				163	156	85	275
august				170	158	76	284
september				177	160	67	293
october				258	242	48	360
november				339	324	29	427
december				420	407	10	483
annual				2791	2640	711	4039
						NEW BLINDS	
				clear	partly cloud	clear	partly cloud
january				339	323	29	427
february				258	242	48	360
march				177	160	67	293
april				170	158	76	284
may				163	156	84	276
june				157	153	93	267
july				163	156	85	275
august				170	158	76	284
september				177	160	67	293
october				258	242	48	360
november				339	324	29	427
december				420	407	10	483
annual				2791	2640	711	4039

LUMINANCE x DAYS AT THE POINT CLOSE TO THE WINDOW ((cd/sq m)*days)

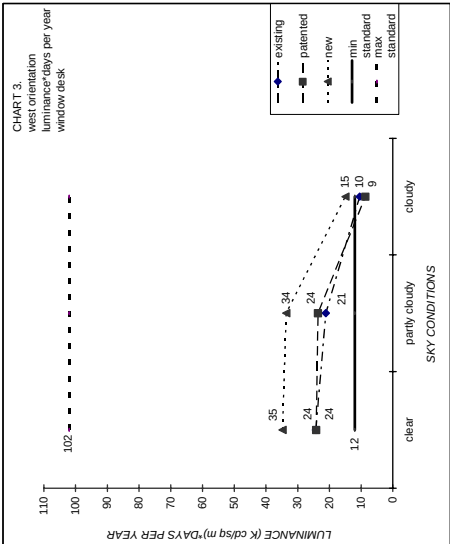
			EXISTING BLINDS			PATENTED BLINDS			NEW BLINDS			
month	clear	partly cloud	cloudy	clear	partly cloud	cloudy	clear	partly cloud	cloudy	clear	partly cloud	cloudy
january	2711	2587	700	2764	2596	433	3413	3040	917			
february	2062	1587	867	2062	1696	621	2880	2147	1199			
march	1413	1170	1213	1360	1440	933	2347	2100	1727			
april	1360	1140	1112	1312	1420	982	2276	2280	1632			
may	1143	1357	1098	1106	1711	1098	1929	3007	1661			
june	1097	1440	917	1064	1840	1027	1867	3520	1430			
july	1144	1603	930	1106	2022	930	1928	3552	1404			
august	1362	1520	944	1312	1893	834	2274	3037	1379			
september	1770	1170	957	1700	1440	737	2930	2097	1353			
october	3354	1587	736	3351	1696	528	4677	2145	1012			
november	3051	2587	608	3110	2596	377	3839	3039	793			
december												
annual	24248	21107	10455	24148	23602	8640	34799	33590	14927			

ANNUAL LUMINANCE x DAYS ((cd/sq m)*days)

	clear	partly cloud	cloudy
existing	24248	21107	10455
patented	24148	23602	8640
new	34799	33590	14927
min stand	12000	12000	12000
max stand	102000	102000	102000

ANNUAL LUMINANCE x DAYS ((k cd/sq m)*days)

	clear	partly cloud	cloudy
existing	24	21	10
patented	24	24	9
new	35	34	15
min stand	12	12	12
max stand	102	102	102



LUMINANCE WEST

SKY CONDITIONS NUMBER OF DAYS			LUMINANCE AT THE POINT CLOSE TO THE INTERIOR PARTITION (cd/sq m)								
month	clear	partly cloudy	clear	partly cloudy	clear	partly cloudy	clear	partly cloudy	clear	partly cloudy	
january	8	8	139	134	43	141	111	32	178	131	41
february	8	7	151	146	63	142	132	54	182	146	59
march	8	9	163	157	83	143	153	77	187	160	77
april	8	9	159	161	81	142	147	81	189	168	81
may	7	11	154	166	79	140	140	84	191	176	86
june	7	12	150	170	77	139	133	88	193	183	90
july	7	13	154	166	79	140	140	85	191	176	86
august	8	12	159	161	81	142	146	81	189	168	81
september	10	9	163	157	83	143	153	77	187	160	77
october	13	7	151	146	63	142	132	55	182	146	59
november	9	8	139	135	43	141	111	32	178	131	41
december	9	8	127	123	23	140	90	10	173	117	23
annual	102	113	1809	1821	799	1695	1589	756	2221	1860	801

LUMINANCE x DAYS AT THE POINT CLOSE TO THE INTERIOR PARTITION ((cd/sq m)*days)

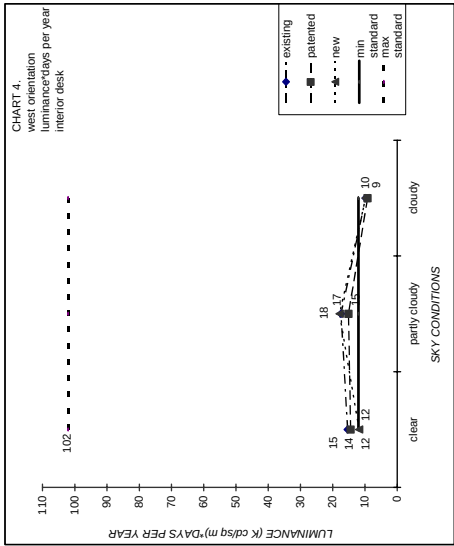
EXISTING BLINDS			PATENTED BLINDS			NEW BLINDS			
month	clear	partly clou cloudy	clear	partly clou cloudy	clear	partly clou cloudy	clear	partly clou cloudy	
january	1111	1076	650	1129	889	483	1422	1049	617
february	1209	1019	823	1138	926	708	1458	1019	766
march	1307	1410	1167	1147	1380	1073	1493	1440	1073
april	1271	1450	1054	1134	1320	1047	1511	1510	1054
may	1081	1821	1026	982	1540	1098	1338	1931	1112
june	1050	2040	843	971	1600	972	1353	2200	990
july	1080	2154	867	981	1819	930	1339	2282	942
august	1269	1936	890	1132	1757	889	1513	2013	895
september	1630	1413	913	1430	1377	847	1870	1440	847
october	1962	1020	694	1846	924	601	2372	1019	650
november	1249	1076	562	1269	888	420	1601	1049	536
december	1140	987	327	1260	720	140	1560	933	327
annual	15359	17402	9815	14418	15139	9208	18830	17886	9809

ANNUAL LUMINANCE x DAYS ((cd/sq m)*days)

	clear	partly clou cloudy
existing	15359	17402
patented	14418	15139
new	11830	17886
min stand	12000	12000
max stand	102000	102000

ANNUAL LUMINANCE x DAYS ((k cd/sq m)*days)

	clear	partly clou cloudy
existing	15	17
patented	14	15
new	12	18
min stand	12	12
max stand	102	102



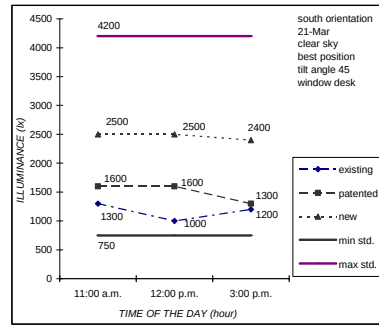
B.3. CHARTS OF RESULTS--USED JUST IN THE DISSERTATION

ILLUMINANCE- effect of the time -for different dates-for different sky conditions

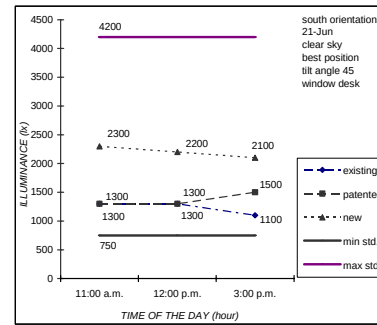
	existing	patented	new
BEST POSITION	inside	between	between

SOUTH SHEET 1
ILLUMINANCE SET 1
WINDOW

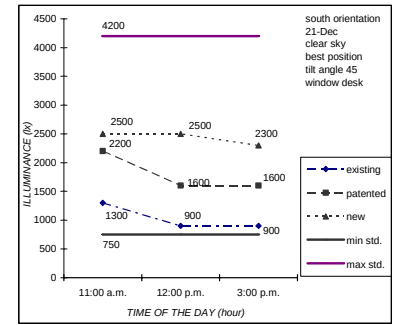
	11:00 a.m.	12:00 p.m.	3:00 p.m.
illuminance south orientation 21-Mar clear sky	existing 1300	1000	1200
patented	1600	1600	1300
new	2500	2500	2400
best position	min std. 750	750	750
tilt angle 45	max std. 4200	4200	4200
window desk			



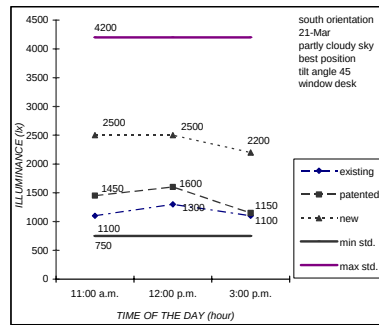
	11:00 a.m.	12:00 p.m.	3:00 p.m.
illuminance south orientation 21-Jun clear sky	existing 1300	1300	1100
patented	1300	1300	1500
new	2300	2200	2100
best position	min std. 750	750	750
tilt angle 45	max std. 4200	4200	4200
window desk			



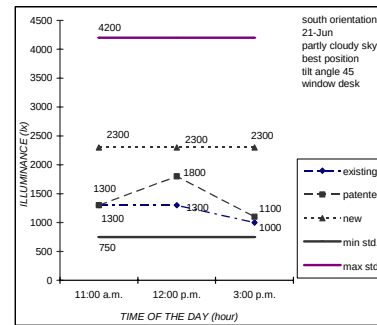
	11:00 a.m.	12:00 p.m.	3:00 p.m.
illuminance south orientation 21-Dec clear sky	existing 1300	900	900
patented	2200	1600	1600
new	2500	2500	2300
best position	min std. 750	750	750
tilt angle 45	max std. 4200	4200	4200
window desk			



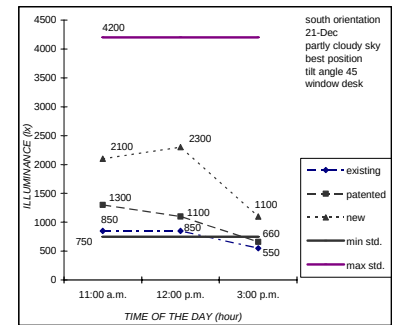
	11:00 a.m.	12:00 p.m.	3:00 p.m.
illuminance south orientation 21-Mar partly cloudy sky	existing 1100	1300	1100
patented	1450	1600	1150
new	2500	2500	2200
best position	min std. 750	750	750
tilt angle 45	max std. 4200	4200	4200
window desk			



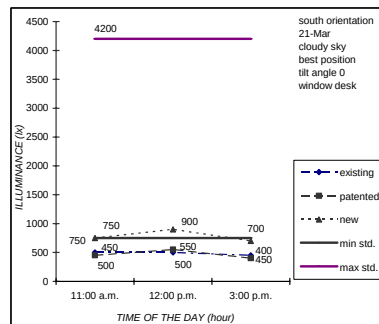
	11:00 a.m.	12:00 p.m.	3:00 p.m.
illuminance south orientation 21-Jun partly cloudy sky	existing 1300	1300	1100
patented	1300	1800	1100
new	2300	2300	2300
best position	min std. 750	750	750
tilt angle 45	max std. 4200	4200	4200
window desk			



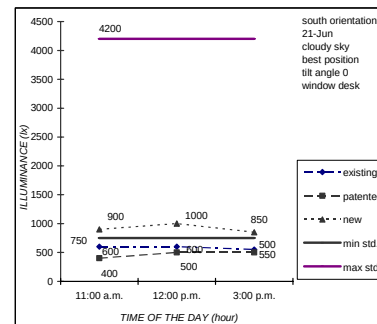
	11:00 a.m.	12:00 p.m.	3:00 p.m.
illuminance south orientation 21-Dec partly cloudy sky	existing 850	850	550
patented	1300	1100	660
new	2100	2300	1100
best position	min std. 750	750	750
tilt angle 45	max std. 4200	4200	4200
window desk			



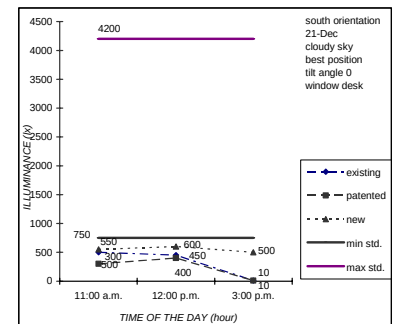
	11:00 a.m.	12:00 p.m.	3:00 p.m.
illuminance south orientation 21-Mar cloudy sky	existing 500	500	450
patented	450	550	400
new	750	900	700
best position	min std. 750	750	750
tilt angle 0	max std. 4200	4200	4200
window desk			



	11:00 a.m.	12:00 p.m.	3:00 p.m.
illuminance south orientation 21-Jun cloudy sky	existing 600	600	550
patented	400	500	500
new	900	1000	850
best position	min std. 750	750	750
tilt angle 0	max std. 4200	4200	4200
window desk			



	11:00 a.m.	12:00 p.m.	3:00 p.m.
illuminance south orientation 21-Dec cloudy sky	existing 500	450	10
patented	300	400	10
new	550	600	500
best position	min std. 750	750	750
tilt angle 0	max std. 4200	4200	4200
window desk			

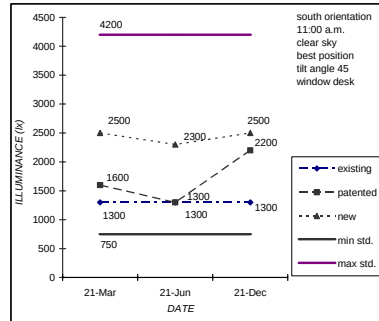


ILLUMINANCE- effect of the date-for different times-for different sky conditions

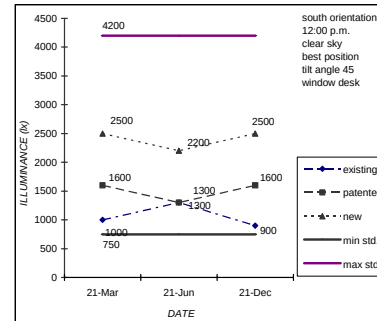
SOUTH SHEET 2
ILLUMINANCE SET 1
WINDOW

	existing	patented	new
BEST POSITION	inside	between	between

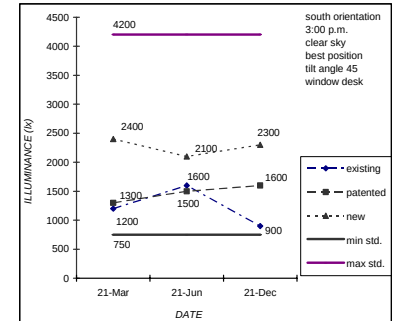
	21-Mar	21-Jun	21-Dec
illuminance			
south orientation			
11:00 a.m.	existing 1300	1300	1300
clear sky	patented 1600	1300	2200
best position	new 2500	2300	2500
tilt angle 45	min std. 750	750	750
window desk	max std. 4200	4200	4200



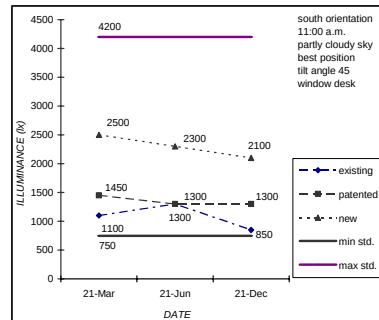
	21-Mar	21-Jun	21-Dec
illuminance			
south orientation			
12:00 p.m.	existing 1000	1300	900
clear sky	patented 1600	1300	1600
best position	new 2500	2200	2500
tilt angle 45	min std. 750	750	750
window desk	max std. 4200	4200	4200



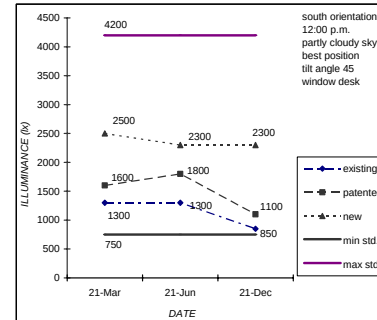
	21-Mar	21-Jun	21-Dec
illuminance			
south orientation			
3:00 p.m.	existing 1200	1600	900
clear sky	patented 1300	1500	1600
best position	new 2400	2100	2300
tilt angle 45	min std. 750	750	750
window desk	max std. 4200	4200	4200



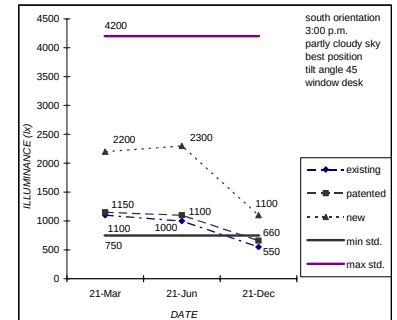
	21-Mar	21-Jun	21-Dec
illuminance			
south orientation			
11:00 a.m.	existing 1100	1300	850
partly cloudy sky	patented 1450	1300	1300
best position	new 2500	2300	2100
tilt angle 45	min std. 750	750	750
window desk	max std. 4200	4200	4200



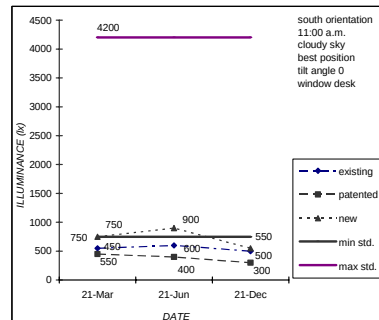
	21-Mar	21-Jun	21-Dec
illuminance			
south orientation			
12:00 p.m.	existing 1300	1300	850
partly cloudy sky	patented 1600	1800	1100
best position	new 2500	2300	2300
tilt angle 45	min std. 750	750	750
window desk	max std. 4200	4200	4200



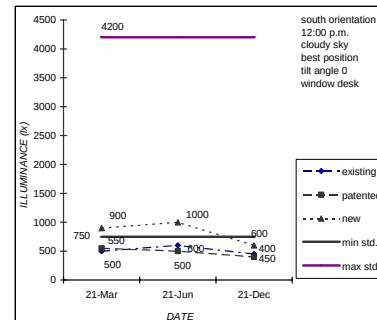
	21-Mar	21-Jun	21-Dec
illuminance			
south orientation			
3:00 p.m.	existing 1100	1000	550
partly cloudy sky	patented 1150	1100	660
best position	new 2200	2300	1100
tilt angle 45	min std. 750	750	750
window desk	max std. 4200	4200	4200



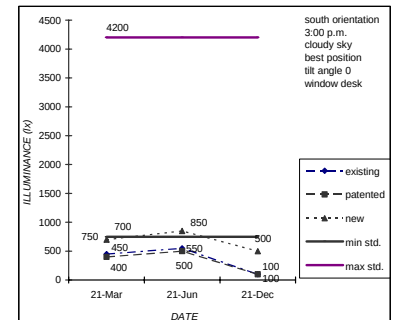
	21-Mar	21-Jun	21-Dec
illuminance			
south orientation			
11:00 a.m.	existing 550	600	500
cloudy sky	patented 450	400	300
best position	new 750	900	550
tilt angle 0	min std. 750	750	750
window desk	max std. 4200	4200	4200



	21-Mar	21-Jun	21-Dec
illuminance			
south orientation			
12:00 p.m.	existing 500	600	450
cloudy sky	patented 550	500	400
best position	new 900	1000	600
tilt angle 0	min std. 750	750	750
window desk	max std. 4200	4200	4200



	21-Mar	21-Jun	21-Dec
illuminance			
south orientation			
3:00 p.m.	existing 450	550	100
cloudy sky	patented 400	500	100
best position	new 700	850	500
tilt angle 0	min std. 750	750	750
window desk	max std. 4200	4200	4200



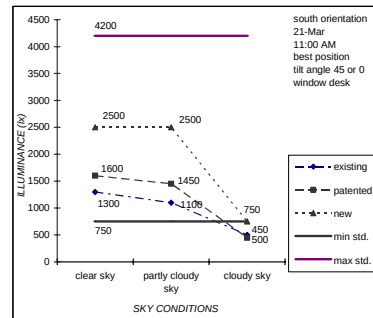
ILLUMINANCE - effect of sky conditions-for different times for different dates

existing blinds - tilt angle 45 for clear sky and partly cloudy sky and 0 for cloudy sky
 patented blinds - tilt angle 0 always
 new blinds - tilt angle 45 for clear sky and partly cloudy sky and 0 for cloudy sky

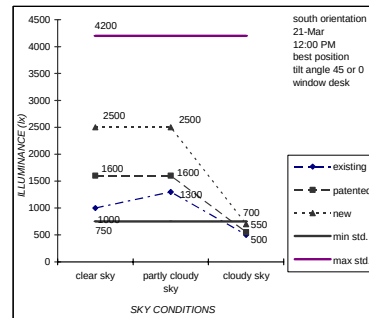
	existing	patented	new
BEST POSITION	inside	between	between

SOUTH SHEET 3
 ILLUMINANCE SET 1
 WINDOW

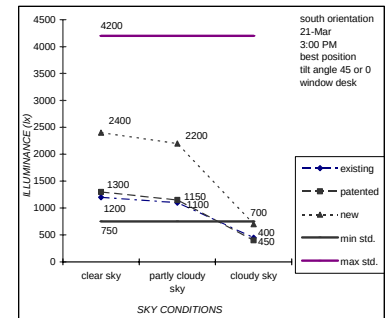
	clear sky	partly cloudy sky	cloudy sky
illumination			
south orientation			
21-Mar			
11:00 AM			
best position			
tilt angle 45 or 0			
window desk			
existing	1300	1100	500
patented	1600	1450	450
new	2500	2500	750
min std.	750	750	750
max std.	4200	4200	4200



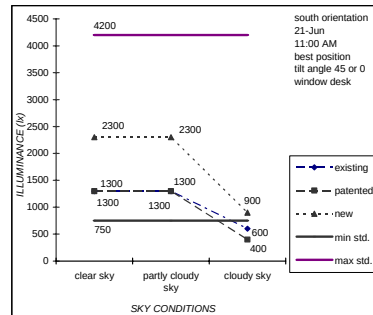
	clear sky	partly cloudy sky	cloudy sky
illumination			
south orientation			
21-Mar			
12:00 PM			
best position			
tilt angle 45 or 0			
window desk			
existing	1000	1300	500
patented	1600	1600	550
new	2500	2500	700
min std.	750	750	750
max std.	4200	4200	4200



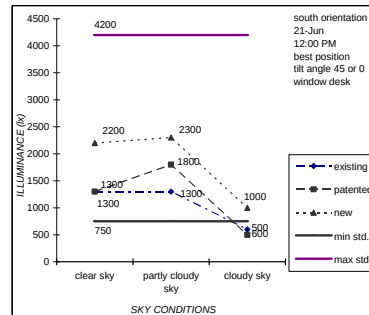
	clear sky	partly cloudy sky	cloudy sky
illumination			
south orientation			
21-Mar			
3:00 PM			
best position			
tilt angle 45 or 0			
window desk			
existing	1200	1100	450
patented	1300	1150	400
new	2400	2200	700
min std.	750	750	750
max std.	4200	4200	4200



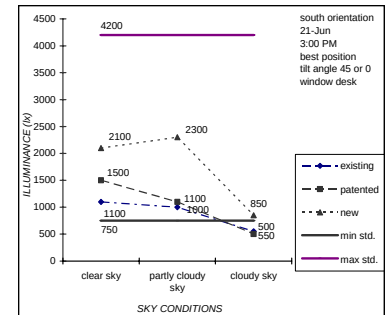
	clear sky	partly cloudy sky	cloudy sky
illumination			
south orientation			
21-Jun			
11:00 AM			
best position			
tilt angle 45 or 0			
window desk			
existing	1300	1300	600
patented	1300	1300	400
new	2300	2300	900
min std.	750	750	750
max std.	4200	4200	4200



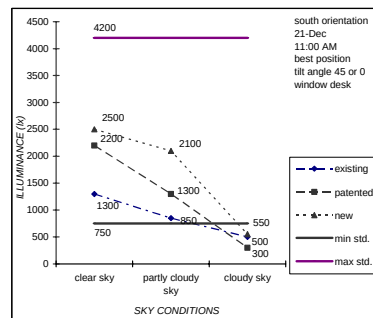
	clear sky	partly cloudy sky	cloudy sky
illumination			
south orientation			
21-Jun			
12:00 PM			
best position			
tilt angle 45 or 0			
window desk			
existing	1300	1300	600
patented	1300	1800	500
new	2200	2300	1000
min std.	750	750	750
max std.	4200	4200	4200



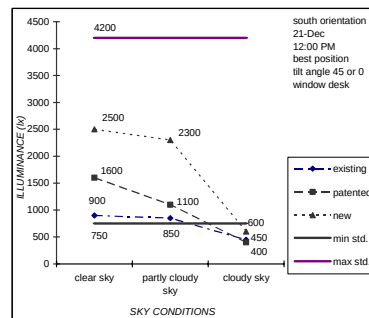
	clear sky	partly cloudy sky	cloudy sky
illumination			
south orientation			
21-Jun			
3:00 PM			
best position			
tilt angle 45 or 0			
window desk			
existing	1100	1000	550
patented	1500	1100	500
new	2100	2300	850
min std.	750	750	750
max std.	4200	4200	4200



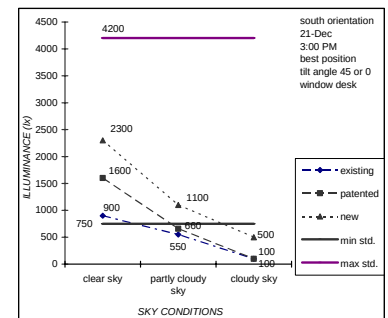
	clear sky	partly cloudy sky	cloudy sky
illumination			
south orientation			
21-Dec			
11:00 AM			
best position			
tilt angle 45 or 0			
window desk			
existing	1300	850	500
patented	2200	1300	300
new	2500	2100	550
min std.	750	750	750
max std.	4200	4200	4200



	clear sky	partly cloudy sky	cloudy sky
illumination			
south orientation			
21-Dec			
12:00 PM			
best position			
tilt angle 45 or 0			
window desk			
existing	900	850	450
patented	1600	1100	400
new	2500	2300	600
min std.	750	750	750
max std.	4200	4200	4200



	clear sky	partly cloudy sky	cloudy sky
illumination			
south orientation			
21-Dec			
3:00 PM			
best position			
tilt angle 45 or 0			
window desk			
existing	900	550	100
patented	1600	660	100
new	2300	1100	500
min std.	750	750	750
max std.	4200	4200	4200

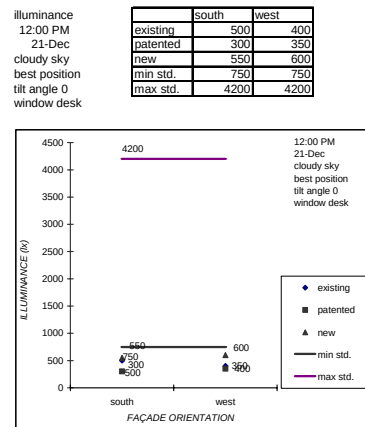
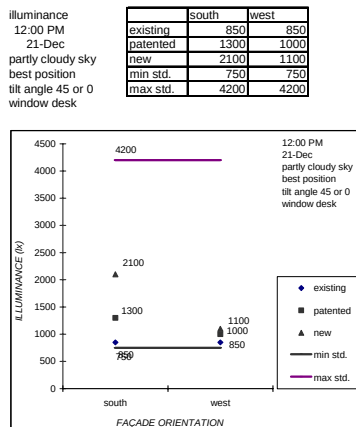
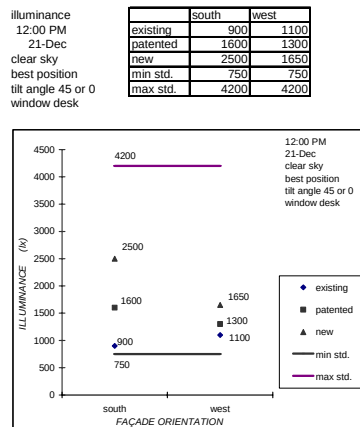
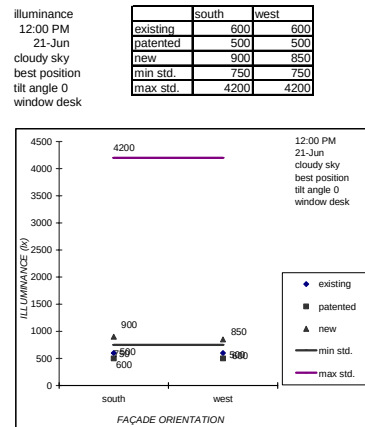
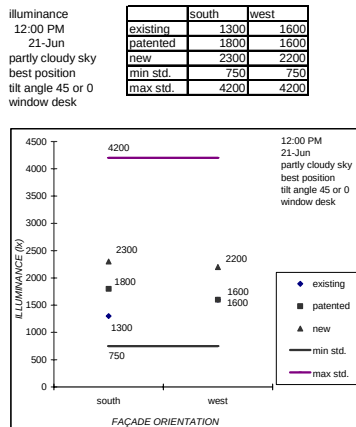
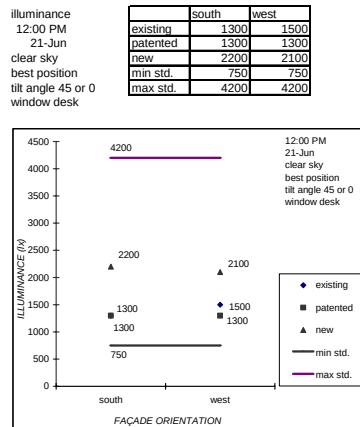
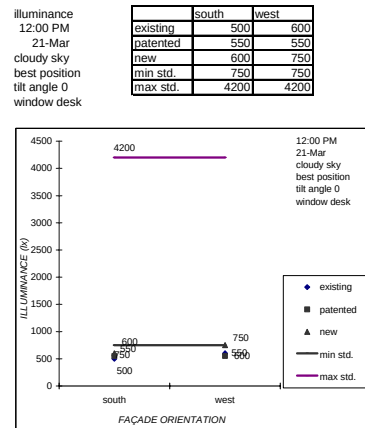
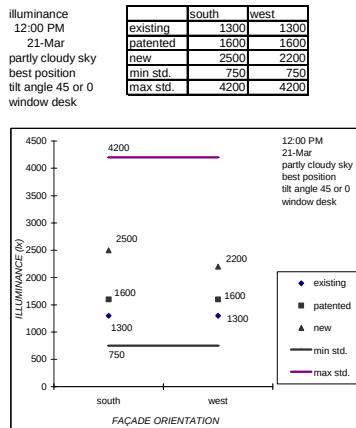
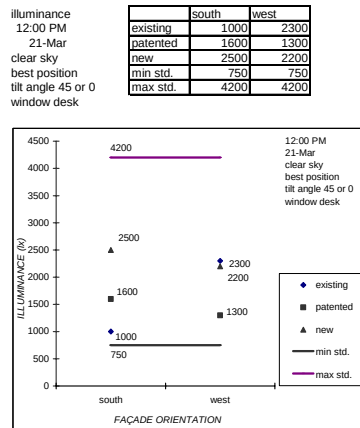


ILLUMINANCE - effect of façade orientation - for different dates - for different times

existing blinds - tilt angle 45 for clear sky and partly cloudy sky and 0 for cloudy sky
 patented blinds - tilt angle 0 always
 new blinds - tilt angle 45 for clear sky and partly cloudy sky and 0 for cloudy sky

	existing	patented	new
BEST POSITION	inside	between	between

SOUTH SHEET 4
 ILLUMINANCE SET 1
 WINDOW

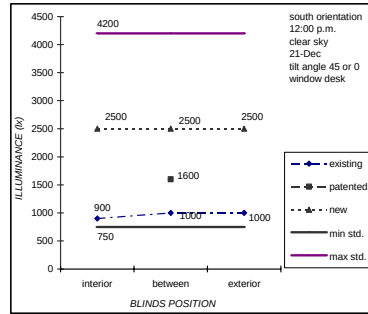


ILLUMINANCE- effect of the blinds position-for different dates -for different sky conditions

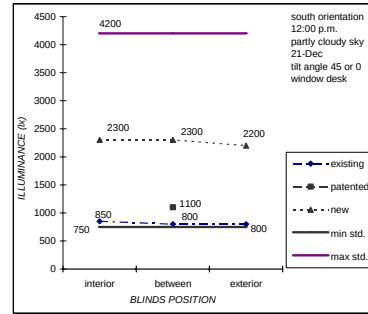
existing blinds - tilt angle 45 for clear sky and partly cloudy sky and 0 for cloudy sky
patented blinds - tilt angle 0 always
new blinds - tilt angle 45 for clear sky and partly cloudy sky and 0 for cloudy sky

SOUTH SHEET 5
ILLUMINANCE SET 1
WINDOW

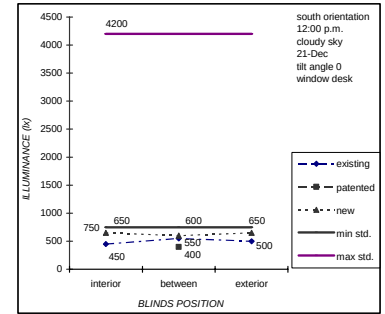
	interior	between	exterior
illuminance			
south orientation			
12:00 p.m.			
clear sky			
21-Dec			
tilt angle 45 or 0			
window desk			
existing	900	1000	1000
patented		1600	
new	2500	2500	2500
min std.	750	750	750
max std.	4200	4200	4200



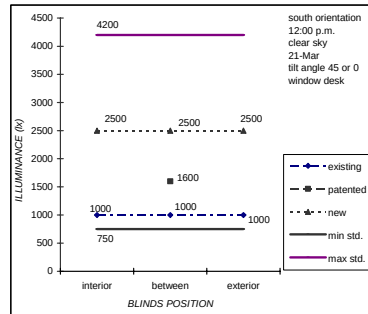
	interior	between	exterior
illuminance			
south orientation			
12:00 p.m.			
partly cloudy sky			
21-Dec			
tilt angle 45 or 0			
window desk			
existing	850	800	800
patented		1100	
new	2300	2300	2200
min std.	750	750	750
max std.	4200	4200	4200



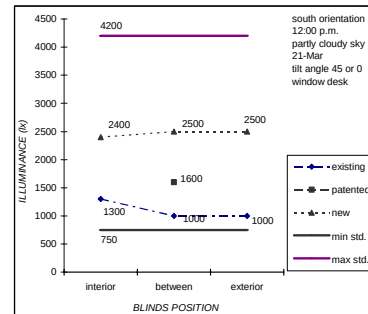
	interior	between	exterior
illuminance			
south orientation			
12:00 p.m.			
cloudy sky			
21-Dec			
tilt angle 45 or 0			
window desk			
existing	450	550	500
patented		400	
new	650	600	650
min std.	750	750	750
max std.	4200	4200	4200



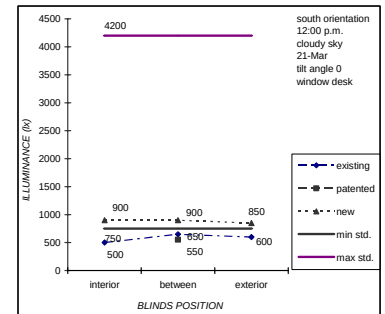
	interior	between	exterior
illuminance			
south orientation			
12:00 p.m.			
clear sky			
21-Mar			
tilt angle 45 or 0			
window desk			
existing	1000	1000	1000
patented		1600	
new	2500	2500	2500
min std.	750	750	750
max std.	4200	4200	4200



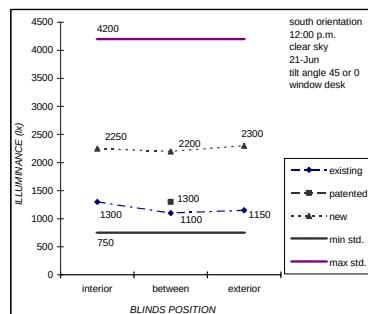
	interior	between	exterior
illuminance			
south orientation			
12:00 p.m.			
partly cloudy sky			
21-Mar			
tilt angle 45 or 0			
window desk			
existing	1300	1000	1000
patented		1600	
new	2400	2500	2500
min std.	750	750	750
max std.	4200	4200	4200



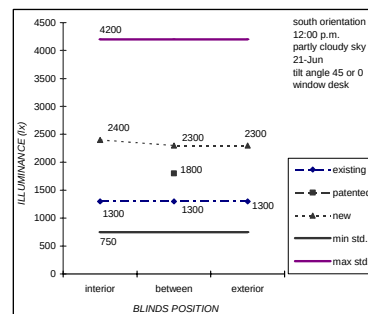
	interior	between	exterior
illuminance			
south orientation			
12:00 p.m.			
cloudy sky			
21-Mar			
tilt angle 45 or 0			
window desk			
existing	500	650	600
patented		550	
new	900	900	850
min std.	750	750	750
max std.	4200	4200	4200



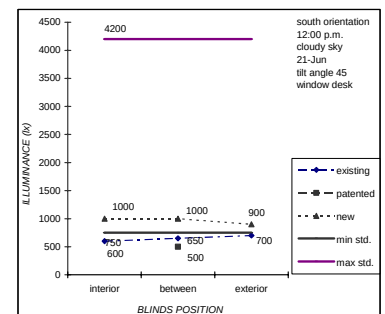
	interior	between	exterior
illuminance			
south orientation			
12:00 p.m.			
clear sky			
21-Jun			
tilt angle 45 or 0			
window desk			
existing	1300	1100	1150
patented		1300	
new	2250	2200	2300
min std.	750	750	750
max std.	4200	4200	4200



	interior	between	exterior
illuminance			
south orientation			
12:00 p.m.			
partly cloudy sky			
21-Jun			
tilt angle 45 or 0			
window desk			
existing	1300	1300	1300
patented		1800	
new	2400	2300	2300
min std.	750	750	750
max std.	4200	4200	4200



	interior	between	exterior
illuminance			
south orientation			
12:00 p.m.			
cloudy sky			
21-Jun			
tilt angle 45			
window desk			
existing	600	650	700
patented		500	
new	1000	1000	900
min std.	750	750	750
max std.	4200	4200	4200



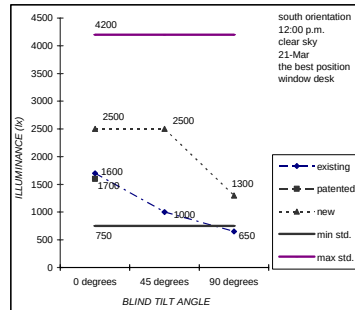
ILLUMINANCE- effect of the blind tilt angle -for different dates-for different sky conditions

SOUTH
ILLUMINANCE
WINDOW

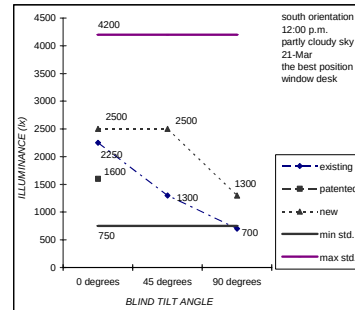
SHEET 6
SET 1

	existing	patented	new
BEST POSITION	inside	between	between

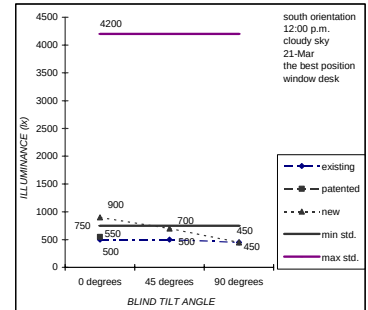
	0 degrees	45 degree	90 degrees
illumination			
south orientation			
12:00 p.m.	existing 1700	1000	650
clear sky	patented 1600		
21-Mar	new 2500	2500	1300
the best position	min std. 750	750	750
window desk	max std. 4200	4200	4200



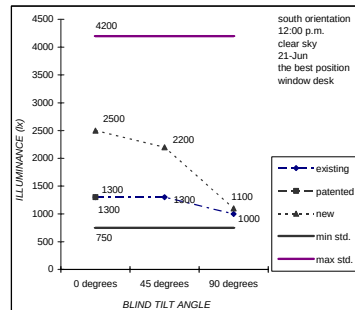
	0 degrees	45 degree	90 degrees
illumination			
south orientation			
12:00 p.m.	existing 2250	1300	700
partly cloudy sky	patented 1600		
21-Mar	new 2500	2500	1300
the best position	min std. 750	750	750
window desk	max std. 4200	4200	4200



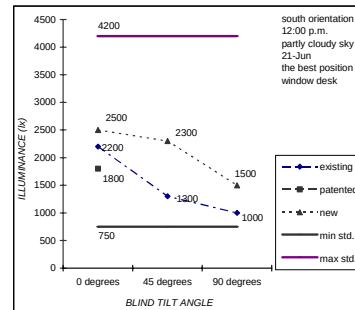
	0 degrees	45 degree	90 degrees
illumination			
south orientation			
12:00 p.m.	existing 500	500	450
cloudy sky	patented 550		
21-Mar	new 900	700	450
the best position	min std. 750	750	750
window desk	max std. 4200	4200	4200



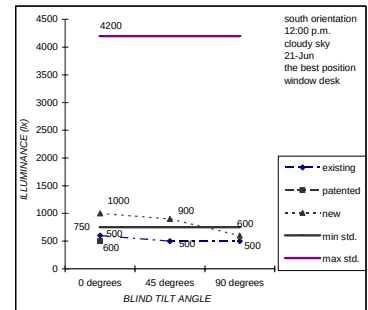
	0 degrees	45 degree	90 degrees
illumination			
south orientation			
12:00 p.m.	existing 1300	1300	1000
clear sky	patented 1300		
21-Jun	new 2500	2200	1100
the best position	min std. 750	750	750
window desk	max std. 4200	4200	4200



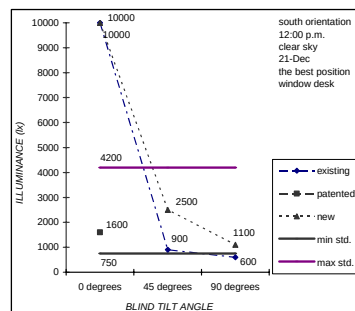
	0 degrees	45 degree	90 degrees
illumination			
south orientation			
12:00 p.m.	existing 2200	1300	1000
partly cloudy sky	patented 1800		
21-Jun	new 2500	2300	1500
the best position	min std. 750	750	750
window desk	max std. 4200	4200	4200



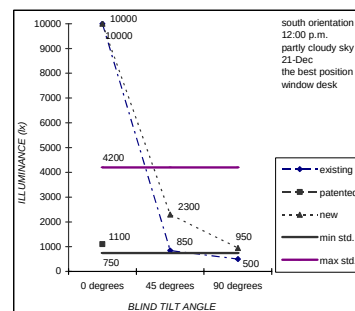
	0 degrees	45 degree	90 degrees
illumination			
south orientation			
12:00 p.m.	existing 600	500	500
cloudy sky	patented 500		
21-Jun	new 1000	900	600
the best position	min std. 750	750	750
window desk	max std. 4200	4200	4200



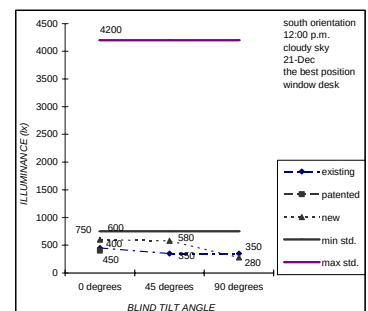
	0 degrees	45 degree	90 degrees
illumination			
south orientation			
12:00 p.m.	existing 10000	900	600
clear sky	patented 16000		
21-Dec	new 10000	2500	1100
the best position	min std. 750	750	750
window desk	max std. 4200	4200	4200



	0 degrees	45 degree	90 degrees
illumination			
south orientation			
12:00 p.m.	existing 10000	850	500
partly cloudy sky	patented 11000		
21-Dec	new 10000	2300	950
the best position	min std. 750	750	750
window desk	max std. 4200	4200	4200



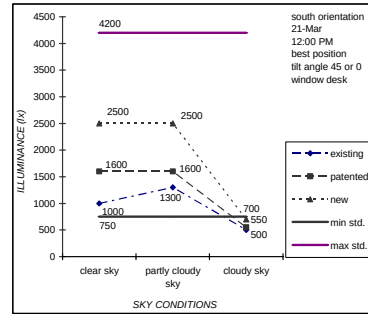
	0 degrees	45 degree	90 degrees
illumination			
south orientation			
12:00 p.m.	existing 450	350	350
cloudy sky	patented 400		
21-Dec	new 600	580	280
the best position	min std. 750	750	750
window desk	max std. 4200	4200	4200



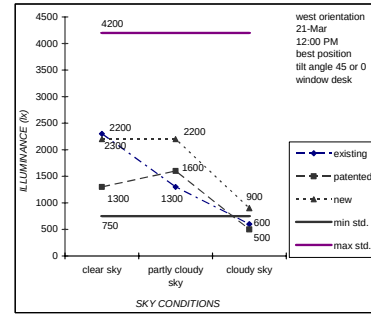
existing blinds - tilt angle 45 for clear sky and partly cloudy sky and 0 for cloudy sky
 patented blinds - tilt angle 0 always
 new blinds - tilt angle 45 for clear sky and partly cloudy sky and 0 for cloudy sky

	plastic	patented	new
BEST POSITION	inside	between	between

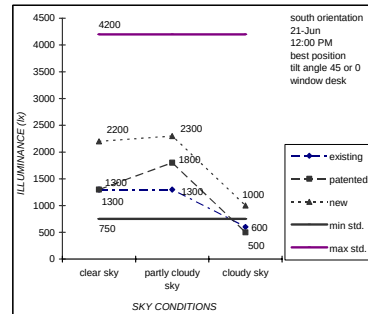
illumiance	clear sky	partly cloud	cloudy sky
existing	1000	1300	500
21-Mar			
12:00 PM			
best position			
tilt angle 45 or 0			
window desk			
patented	1600	1600	550
new	2500	2500	700
min std.	750	750	750
max std.	4200	4200	4200



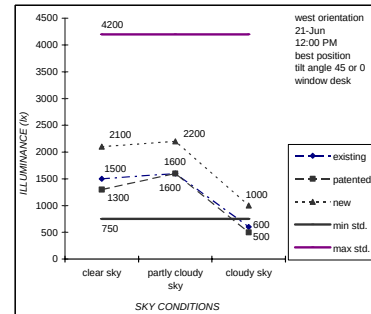
illumiance	clear sky	partly cloud	cloudy sky
existing	2300	1300	600
21-Mar			
12:00 PM			
best position			
tilt angle 45 or 0			
window desk			
patented	1300	1600	500
new	2200	2200	900
min std.	750	750	750
max std.	4200	4200	4200



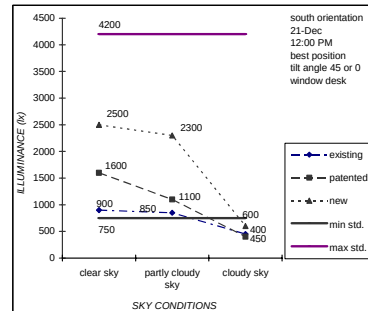
illumiance	clear sky	partly cloud	cloudy sky
existing	1300	1300	600
21-Jun			
12:00 PM			
best position			
tilt angle 45 or 0			
window desk			
patented	1300	1800	500
new	2200	2300	1000
min std.	750	750	750
max std.	4200	4200	4200



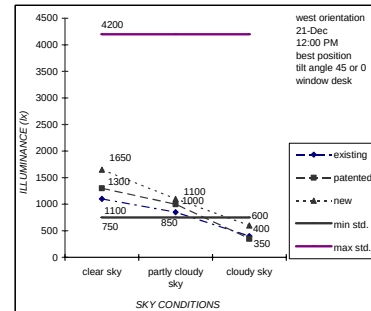
illumiance	clear sky	partly cloud	cloudy sky
existing	1500	1600	600
21-Jun			
12:00 PM			
best position			
tilt angle 45 or 0			
window desk			
patented	1300	1600	500
new	2100	2200	1000
min std.	750	750	750
max std.	4200	4200	4200



illumiance	clear sky	partly cloud	cloudy sky
existing	900	850	450
21-Dec			
12:00 PM			
best position			
tilt angle 45 or 0			
window desk			
patented	1600	1100	400
new	2500	2300	600
min std.	750	750	750
max std.	4200	4200	4200

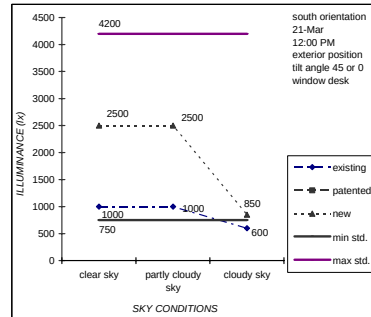


illumiance	clear sky	partly cloud	cloudy sky
existing	1100	850	400
21-Dec			
12:00 PM			
best position			
tilt angle 45 or 0			
window desk			
patented	1300	1000	350
new	1650	1100	600
min std.	750	750	750
max std.	4200	4200	4200

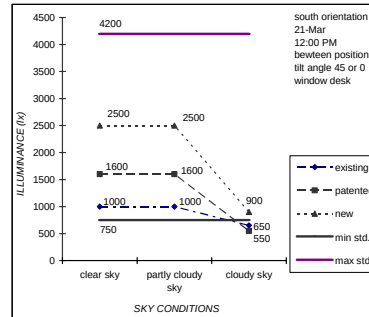


existing blinds - tilt angle 45 for clear sky and partly cloudy sky and 0 for cloudy sky
 patented blinds - tilt angle 0 always
 new blinds - tilt angle 45 for clear sky and partly cloudy sky and 0 for cloudy sky

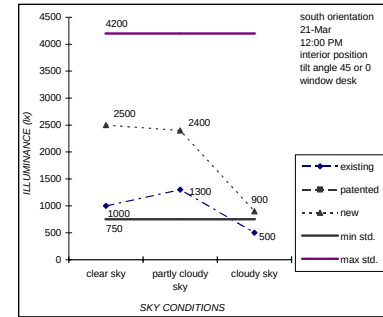
illuminance		clear sky	partly cloudy	cloudy sky
south orientation	existing	1000	1000	600
21-Mar	patented			
12:00 PM	new	2500	2500	850
exterior position	min std.	750	750	750
tilt angle 45 or 0	max std.	4200	4200	4200
window desk				



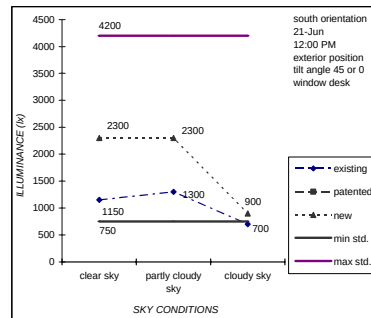
illuminance		clear sky	partly cloudy	cloudy sky
south orientation	existing	1000	1000	650
21-Mar	patented	1600	1600	550
12:00 PM	new	2500	2500	900
between position	min std.	750	750	750
tilt angle 45 or 0	max std.	4200	4200	4200
window desk				



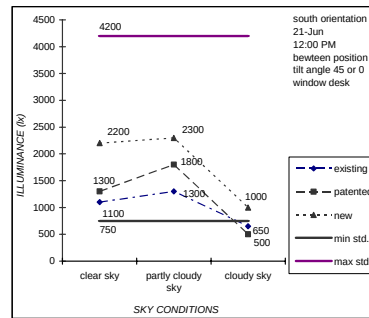
illuminance		clear sky	partly cloudy	cloudy sky
south orientation	existing	1000	1300	500
21-Mar	patented			
12:00 PM	new	2500	2400	900
interior position	min std.	750	750	750
tilt angle 45 or 0	max std.	4200	4200	4200
window desk				



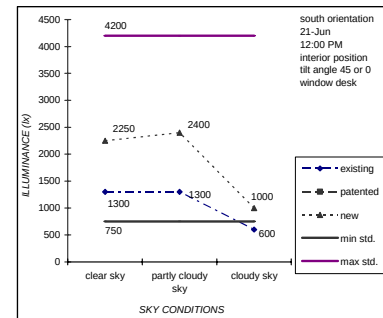
illuminance		clear sky	partly cloudy	cloudy sky
south orientation	existing	1150	1300	700
21-Jun	patented			
12:00 PM	new	2300	2300	900
exterior position	min std.	750	750	750
tilt angle 45 or 0	max std.	4200	4200	4200
window desk				



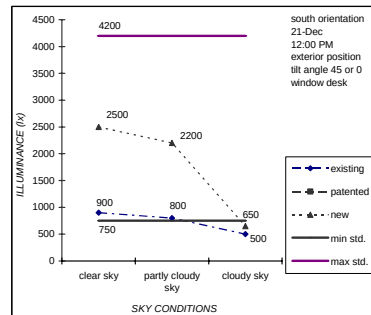
illuminance		clear sky	partly cloudy	cloudy sky
south orientation	existing	1100	1300	650
21-Jun	patented	1300	1800	500
12:00 PM	new	2200	2300	1000
between position	min std.	750	750	750
tilt angle 45 or 0	max std.	4200	4200	4200
window desk				



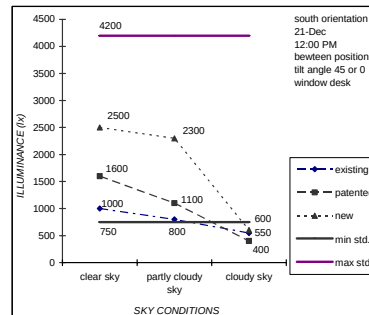
illuminance		clear sky	partly cloudy	cloudy sky
south orientation	existing	1300	1300	600
21-Jun	patented			
12:00 PM	new	2250	2400	1000
interior position	min std.	750	750	750
tilt angle 45 or 0	max std.	4200	4200	4200
window desk				



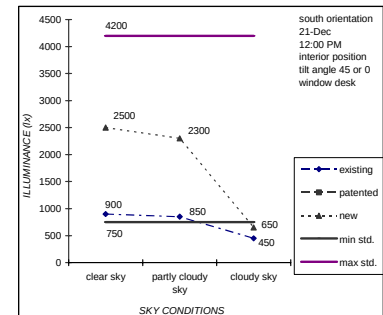
illuminance		clear sky	partly cloudy	cloudy sky
south orientation	existing	900	800	500
21-Dec	patented			
12:00 PM	new	2500	2200	650
exterior position	min std.	750	750	750
tilt angle 45 or 0	max std.	4200	4200	4200
window desk				



illuminance		clear sky	partly cloudy	cloudy sky
south orientation	existing	1000	800	550
21-Dec	patented	1600	1100	400
12:00 PM	new	2500	2300	600
between position	min std.	750	750	750
tilt angle 45 or 0	max std.	4200	4200	4200
window desk				



illuminance		clear sky	partly cloudy	cloudy sky
south orientation	existing	900	850	450
21-Dec	patented			
12:00 PM	new	2500	2300	650
interior position	min std.	750	750	750
tilt angle 45 or 0	max std.	4200	4200	4200
window desk				

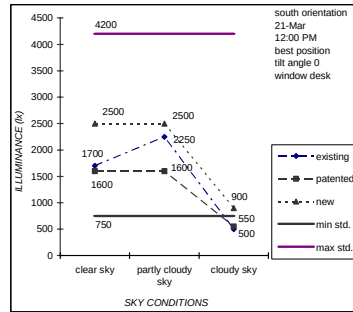


ILLUMINANCE - effect of sky conditions - for different dates - for different blind tilt angles

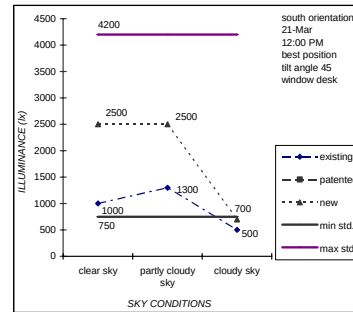
SOUTH SHEET 9
ILLUMINANCE SET 1
WINDOW

	existing	patented	new
BEST POSITION	inside	between	between

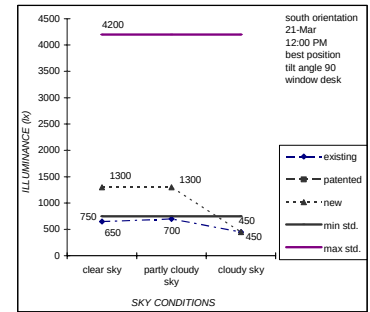
	clear sky	partly cloud	cloudy sky
illuminance south orientation			
21-Mar	existing 1700	2250	500
12:00 PM	patented 1600	1600	550
best position	new 2500	2500	900
tilt angle 0	min std. 750	750	750
window desk	max std. 4200	4200	4200



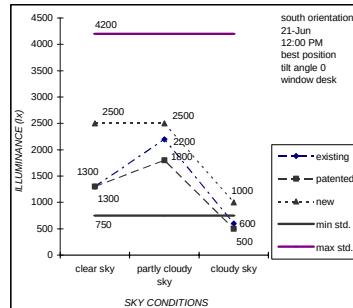
	clear sky	partly cloud	cloudy sky
illuminance south orientation			
21-Mar	existing 1000	1300	500
12:00 PM	patented 2500	2500	700
best position	new 2500	2500	750
tilt angle 45	min std. 750	750	750
window desk	max std. 4200	4200	4200



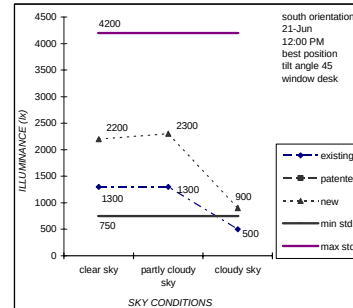
	clear sky	partly cloud	cloudy sky
illuminance south orientation			
21-Mar	existing 650	700	450
12:00 PM	patented 1300	1300	450
best position	new 750	750	750
tilt angle 90	min std. 4200	4200	4200
window desk	max std. 4200	4200	4200



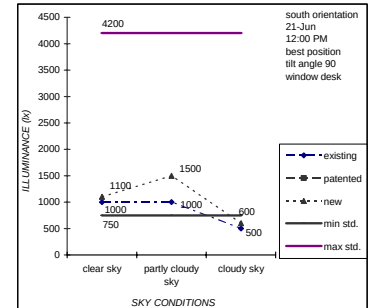
	clear sky	partly cloud	cloudy sky
illuminance south orientation			
21-Jun	existing 1300	1800	500
12:00 PM	patented 2500	2500	1000
best position	new 750	750	750
tilt angle 0	min std. 4200	4200	4200
window desk	max std. 4200	4200	4200



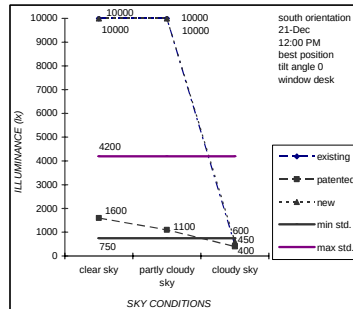
	clear sky	partly cloud	cloudy sky
illuminance south orientation			
21-Jun	existing 1300	1300	500
12:00 PM	patented 2200	2300	900
best position	new 750	750	750
tilt angle 45	min std. 4200	4200	4200
window desk	max std. 4200	4200	4200



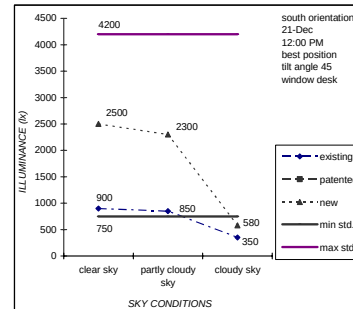
	clear sky	partly cloud	cloudy sky
illuminance south orientation			
21-Jun	existing 1000	1000	500
12:00 PM	patented 1100	1500	600
best position	new 750	750	750
tilt angle 90	min std. 4200	4200	4200
window desk	max std. 4200	4200	4200



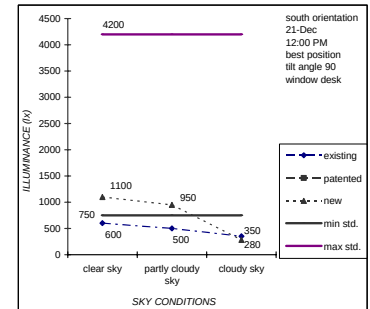
	clear sky	partly cloud	cloudy sky
illuminance south orientation			
21-Dec	existing 10000	10000	450
12:00 PM	patented 1600	1100	400
best position	new 10000	10000	600
tilt angle 0	min std. 750	750	750
window desk	max std. 4200	4200	4200



	clear sky	partly cloud	cloudy sky
illuminance south orientation			
21-Dec	existing 900	850	350
12:00 PM	patented 2500	2300	580
best position	new 750	750	750
tilt angle 45	min std. 4200	4200	4200
window desk	max std. 4200	4200	4200



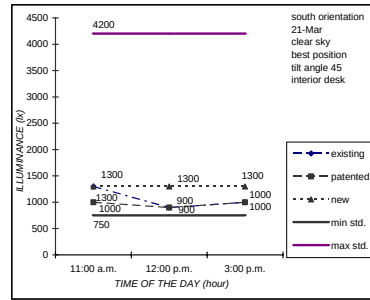
	clear sky	partly cloud	cloudy sky
illuminance south orientation			
21-Dec	existing 600	500	350
12:00 PM	patented 1100	950	280
best position	new 750	750	750
tilt angle 90	min std. 4200	4200	4200
window desk	max std. 4200	4200	4200



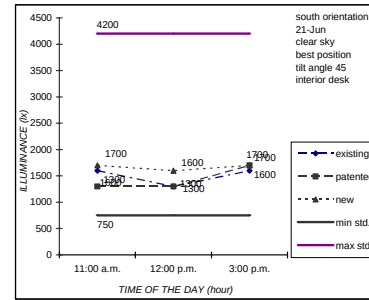
existing blinds - tilt angle 45 for clear sky and partly cloudy sky and 0 for cloudy sky
 patented blinds - tilt angle 0 always
 new blinds - tilt angle 45 for clear sky and partly cloudy sky and 0 for cloudy sky

	existing	patented	new
BEST POSITION	inside	between	between

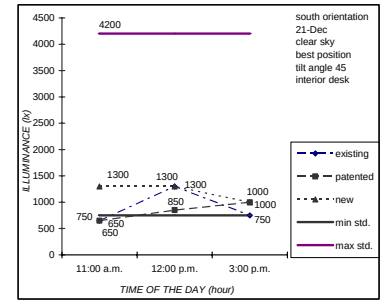
	11:00 a.m.	12:00 p.m.	3:00 p.m.
illumination			
south orientation			
21-Mar			
clear sky			
best position			
tilt angle 45			
interior desk			
existing	1300	900	1000
patented	1000	900	1000
new	1300	1300	1300
min std.	750	750	750
max std.	4200	4200	4200



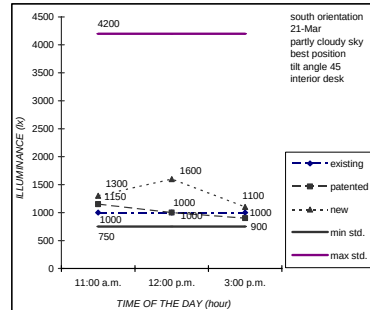
	11:00 a.m.	12:00 p.m.	3:00 p.m.
illumination			
south orientation			
21-Jun			
clear sky			
best position			
tilt angle 45			
interior desk			
existing	1600	1300	1600
patented	1300	1300	1700
new	1700	1600	1700
min std.	750	750	750
max std.	4200	4200	4200



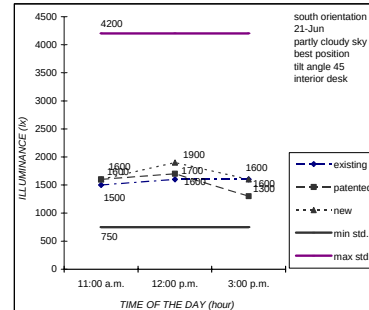
	11:00 a.m.	12:00 p.m.	3:00 p.m.
illumination			
south orientation			
21-Dec			
clear sky			
best position			
tilt angle 45			
interior desk			
existing	650	1300	750
patented	650	850	1000
new	1300	1300	1000
min std.	750	750	750
max std.	4200	4200	4200



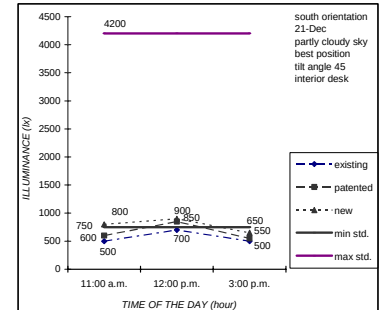
	11:00 a.m.	12:00 p.m.	3:00 p.m.
illumination			
south orientation			
21-Mar			
partly cloudy sky			
best position			
tilt angle 45			
interior desk			
existing	1000	1000	1000
patented	1150	1000	900
new	1300	1600	1100
min std.	750	750	750
max std.	4200	4200	4200



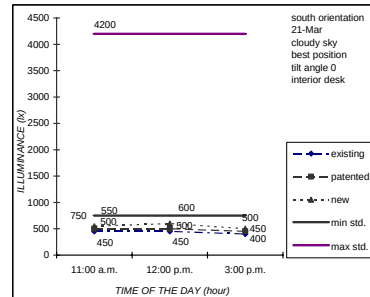
	11:00 a.m.	12:00 p.m.	3:00 p.m.
illumination			
south orientation			
21-Jun			
partly cloudy sky			
best position			
tilt angle 45			
interior desk			
existing	1500	1600	1600
patented	1500	1700	1300
new	1600	1900	1600
min std.	750	750	750
max std.	4200	4200	4200



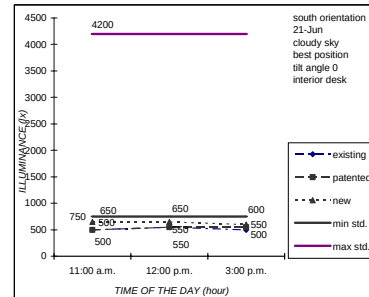
	11:00 a.m.	12:00 p.m.	3:00 p.m.
illumination			
south orientation			
21-Dec			
partly cloudy sky			
best position			
tilt angle 45			
interior desk			
existing	500	700	500
patented	600	850	550
new	800	900	650
min std.	750	750	750
max std.	4200	4200	4200



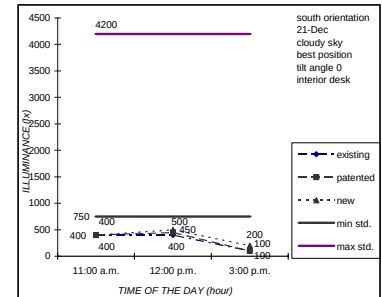
	11:00 a.m.	12:00 p.m.	3:00 p.m.
illumination			
south orientation			
21-Mar			
cloudy sky			
best position			
tilt angle 0			
interior desk			
existing	450	450	400
patented	500	500	450
new	550	600	500
min std.	750	750	750
max std.	4200	4200	4200



	11:00 a.m.	12:00 p.m.	3:00 p.m.
illumination			
south orientation			
21-Jun			
cloudy sky			
best position			
tilt angle 0			
interior desk			
existing	500	550	500
patented	500	550	550
new	650	650	600
min std.	750	750	750
max std.	4200	4200	4200



	11:00 a.m.	12:00 p.m.	3:00 p.m.
illumination			
south orientation			
21-Dec			
cloudy sky			
best position			
tilt angle 0			
interior desk			
existing	400	400	100
patented	400	450	100
new	400	500	200
min std.	750	750	750
max std.	4200	4200	4200



ILLUMINANCE - effect of the date - for different times - for different sky conditions

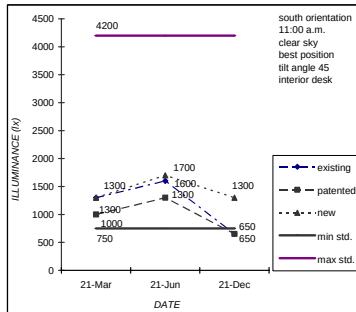
SOUTH
ILLUMINANCE
INTERIOR

SHEET 2
SET 2

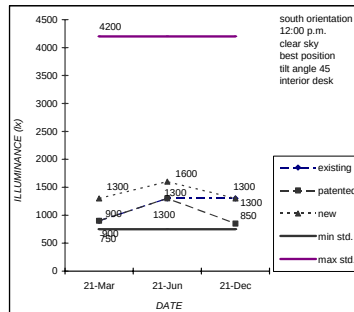
existing blinds - tilt angle 45 for clear sky and partly cloudy sky and 0 for cloudy sky
patented blinds - tilt angle 0 always
new blinds - tilt angle 45 for clear sky and partly cloudy sky and 0 for cloudy sky

	plastic	patented	new
BEST POSITION	inside	between	between

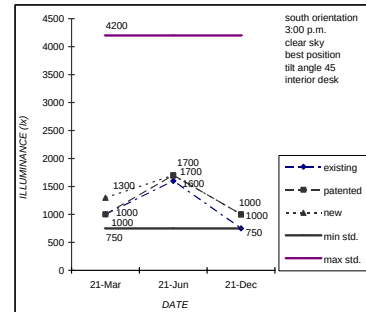
illumination		21-Mar	21-Jun	21-Dec
illumination	existing	1300	1600	650
illumination	patented	1000	1300	650
illumination	new	1300	1700	1300
illumination	min std.	750	750	750
illumination	max std.	4200	4200	4200



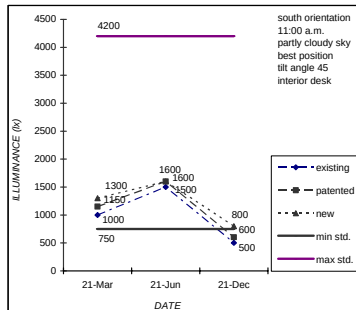
illumination		21-Mar	21-Jun	21-Dec
illumination	existing	900	1300	1300
illumination	patented	900	1300	850
illumination	new	1300	1600	1300
illumination	min std.	750	750	750
illumination	max std.	4200	4200	4200



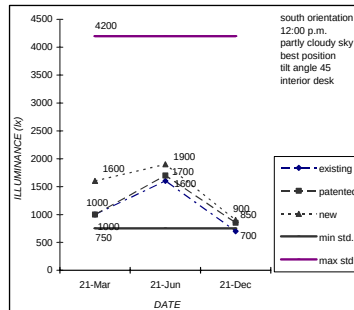
illumination		21-Mar	21-Jun	21-Dec
illumination	existing	1000	1600	750
illumination	patented	1000	1700	1000
illumination	new	1300	1700	1000
illumination	min std.	750	750	750
illumination	max std.	4200	4200	4200



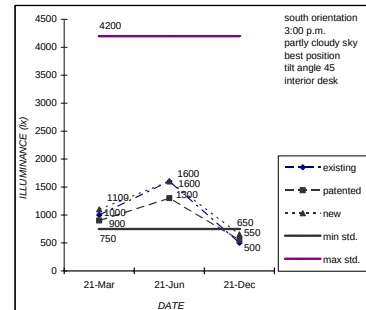
illumination		21-Mar	21-Jun	21-Dec
illumination	existing	1000	1500	500
illumination	patented	1150	1600	600
illumination	new	1300	1600	800
illumination	min std.	750	750	750
illumination	max std.	4200	4200	4200



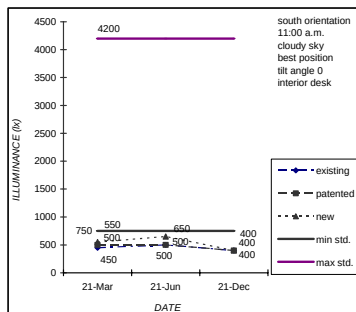
illumination		21-Mar	21-Jun	21-Dec
illumination	existing	1000	1600	700
illumination	patented	1000	1700	850
illumination	new	1600	1900	900
illumination	min std.	750	750	750
illumination	max std.	4200	4200	4200



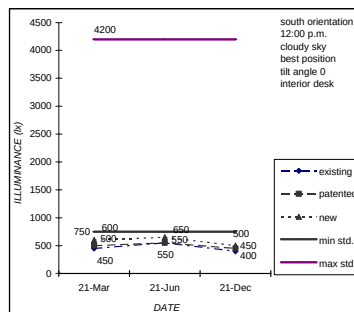
illumination		21-Mar	21-Jun	21-Dec
illumination	existing	1000	1600	500
illumination	patented	900	1300	550
illumination	new	1100	1600	650
illumination	min std.	750	750	750
illumination	max std.	4200	4200	4200



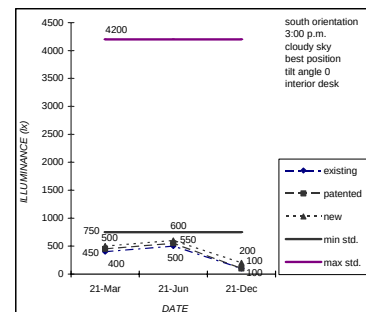
illumination		21-Mar	21-Jun	21-Dec
illumination	existing	450	500	400
illumination	patented	500	500	400
illumination	new	550	650	400
illumination	min std.	750	750	750
illumination	max std.	4200	4200	4200



illumination		21-Mar	21-Jun	21-Dec
illumination	existing	450	550	400
illumination	patented	500	550	450
illumination	new	600	650	500
illumination	min std.	750	750	750
illumination	max std.	4200	4200	4200



illumination		21-Mar	21-Jun	21-Dec
illumination	existing	400	500	100
illumination	patented	450	550	100
illumination	new	500	600	200
illumination	min std.	750	750	750
illumination	max std.	4200	4200	4200

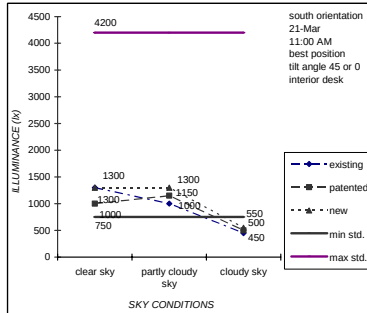


ILLUMINANCE - effect of sky conditions - for different times - for different dates

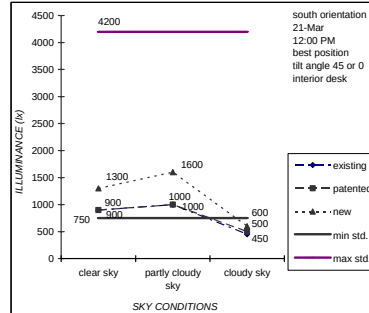
existing blinds - tilt angle 45 for clear sky and partly cloudy sky and 0 for cloudy sky
 patented blinds - tilt angle 0 always
 new blinds - tilt angle 45 for clear sky and partly cloudy sky and 0 for cloudy sky

SOUTH ILLUMINANCE
 INTERIOR
 SHEET 3
 SET 2

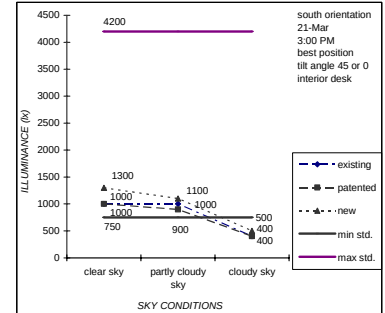
	clear sky	partly cloud	cloudy sky
illuminance			
south orientation			
21-Mar			
11:00 AM			
best position			
tilt angle 45 or 0			
interior desk			
existing	1300	1000	450
patented	1000	1150	500
new	1300	1300	550
min std.	750	750	750
max std.	4200	4200	4200



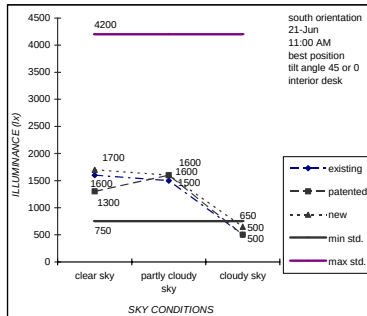
	clear sky	partly cloud	cloudy sky
illuminance			
south orientation			
21-Mar			
12:00 PM			
best position			
tilt angle 45 or 0			
interior desk			
existing	900	1000	450
patented	900	1000	500
new	1300	1600	600
min std.	750	750	750
max std.	4200	4200	4200



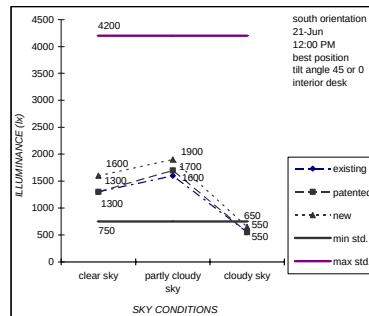
	clear sky	partly cloud	cloudy sky
illuminance			
south orientation			
21-Mar			
3:00 PM			
best position			
tilt angle 45 or 0			
interior desk			
existing	1000	1000	400
patented	1000	900	400
new	1300	1100	500
min std.	750	750	750
max std.	4200	4200	4200



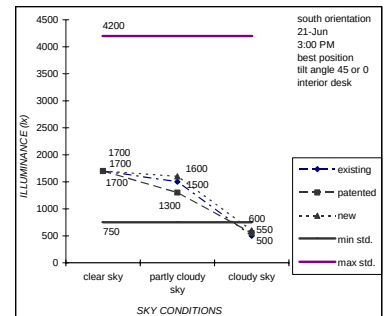
	clear sky	partly cloud	cloudy sky
illuminance			
south orientation			
21-Jun			
11:00 AM			
best position			
tilt angle 45 or 0			
interior desk			
existing	1600	1500	500
patented	1300	1600	500
new	1700	1600	650
min std.	750	750	750
max std.	4200	4200	4200



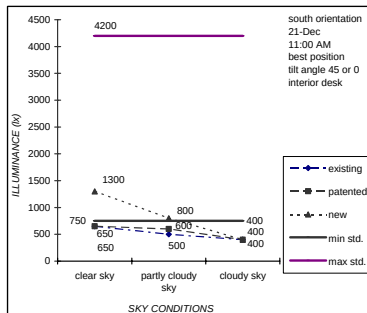
	clear sky	partly cloud	cloudy sky
illuminance			
south orientation			
21-Jun			
12:00 PM			
best position			
tilt angle 45 or 0			
interior desk			
existing	1300	1600	550
patented	1300	1700	550
new	1600	1900	650
min std.	750	750	750
max std.	4200	4200	4200



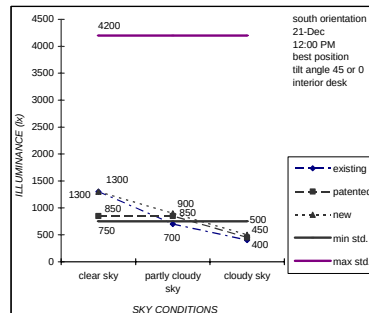
	clear sky	partly cloud	cloudy sky
illuminance			
south orientation			
21-Jun			
3:00 PM			
best position			
tilt angle 45 or 0			
interior desk			
existing	1700	1500	500
patented	1700	1300	550
new	1700	1600	600
min std.	750	750	750
max std.	4200	4200	4200



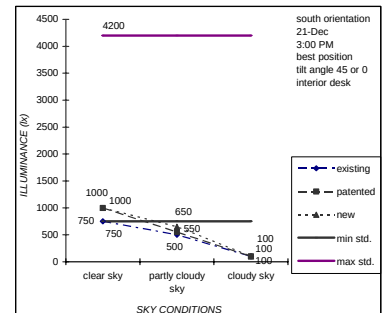
	clear sky	partly cloud	cloudy sky
illuminance			
south orientation			
21-Dec			
11:00 AM			
best position			
tilt angle 45 or 0			
interior desk			
existing	650	500	400
patented	650	600	400
new	1300	800	400
min std.	750	750	750
max std.	4200	4200	4200



	clear sky	partly cloud	cloudy sky
illuminance			
south orientation			
21-Dec			
12:00 PM			
best position			
tilt angle 45 or 0			
interior desk			
existing	1300	700	400
patented	850	850	450
new	1300	900	500
min std.	750	750	750
max std.	4200	4200	4200



	clear sky	partly cloud	cloudy sky
illuminance			
south orientation			
21-Dec			
3:00 PM			
best position			
tilt angle 45 or 0			
interior desk			
existing	750	500	100
patented	1000	550	100
new	1000	650	100
min std.	750	750	750
max std.	4200	4200	4200



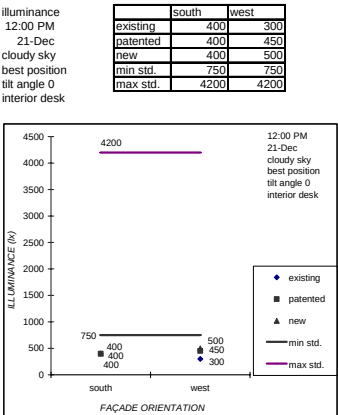
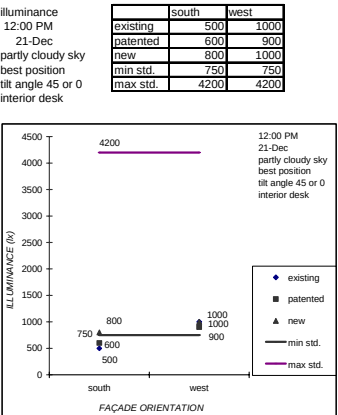
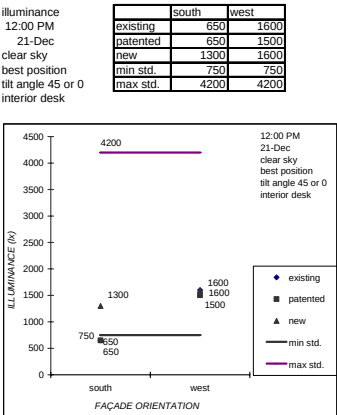
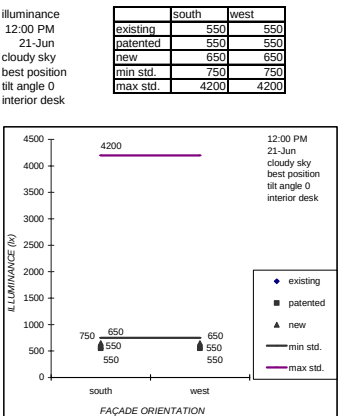
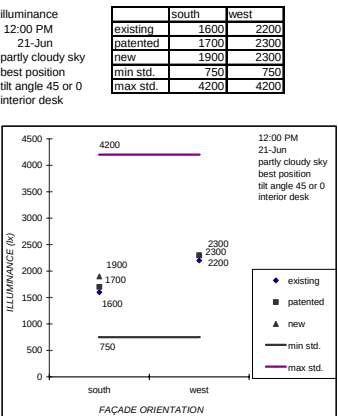
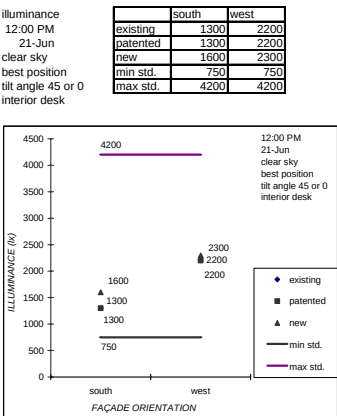
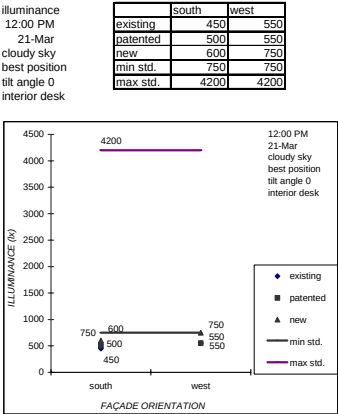
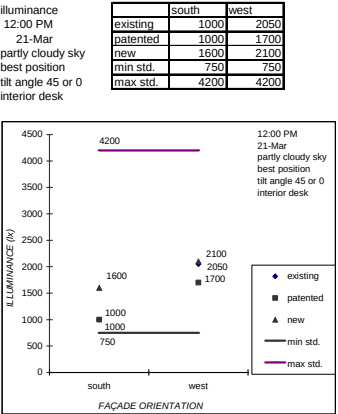
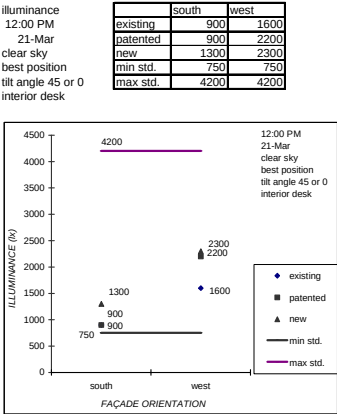
ILLUMINANCE - effect of façade orientation -for different sky conditions - for different dates
12:00 p.m. for different sky conditions

existing blinds - tilt angle 45 for clear sky and partly cloudy sky and 0 for cloudy sky
patented blinds - tilt angle 0 always
new blinds - tilt angle 45 for clear sky and partly cloudy sky and 0 for cloudy sky

	existing	patented	new
BEST POSITION	inside	between	between

SOUTH
ILLUMINANCE
INTERIOR

SHEET 4
SET 2



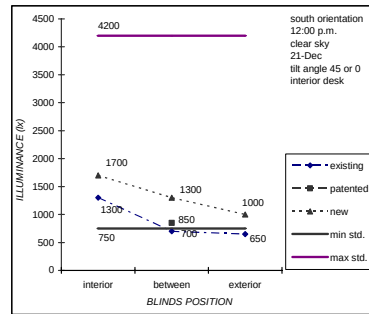
ILLUMINANCE- effect of the blinds position - for different dates - for different sky conditions

SOUTH
ILLUMINANCE
INTERIOR

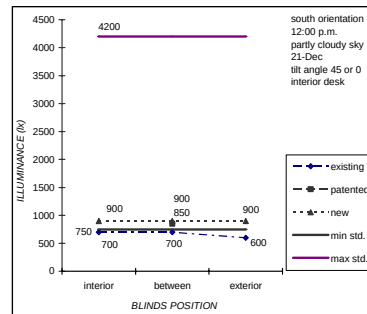
SHEET 5
SET 2

existing blinds - tilt angle 45 for clear sky and partly cloudy sky and 0 for cloudy sky
patented blinds - tilt angle 0 always
new blinds - tilt angle 45 for clear sky and partly cloudy sky and 0 for cloudy sky

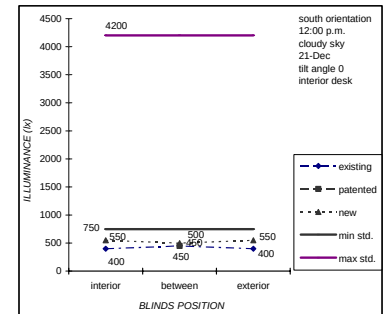
	interior	between	exterior
illuminance			
south orientation			
12:00 p.m.			
clear sky			
21-Dec			
tilt angle 45 or 0			
interior desk			
existing	1300	700	650
patented		850	
new	1700	1300	1000
min std.	750	750	750
max std.	4200	4200	4200



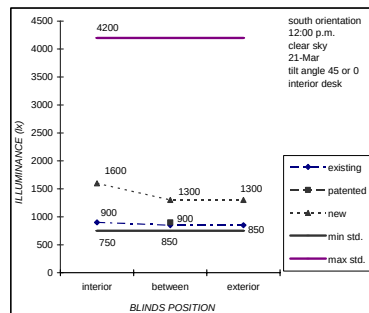
	interior	between	exterior
illuminance			
south orientation			
12:00 p.m.			
partly cloudy sky			
21-Dec			
tilt angle 45 or 0			
interior desk			
existing	700	700	600
patented		850	
new	900	900	900
min std.	750	750	750
max std.	4200	4200	4200



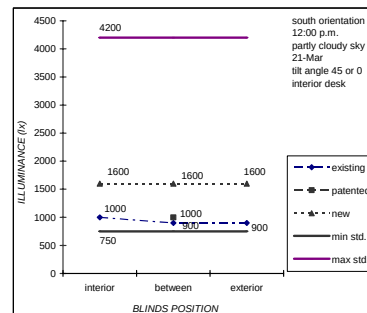
	interior	between	exterior
illuminance			
south orientation			
12:00 p.m.			
cloudy sky			
21-Dec			
tilt angle 0			
interior desk			
existing	400	450	400
patented		450	
new	550	550	550
min std.	750	750	750
max std.	4200	4200	4200



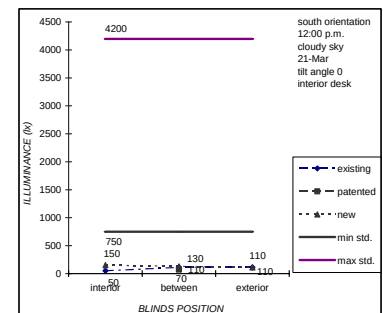
	interior	between	exterior
illuminance			
south orientation			
12:00 p.m.			
clear sky			
21-Mar			
tilt angle 45 or 0			
interior desk			
existing	900	850	850
patented		900	
new	1600	1300	1300
min std.	750	750	750
max std.	4200	4200	4200



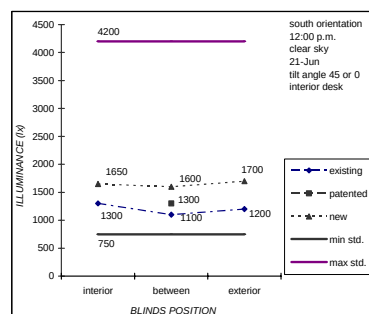
	interior	between	exterior
illuminance			
south orientation			
12:00 p.m.			
partly cloudy sky			
21-Mar			
tilt angle 45 or 0			
interior desk			
existing	1000	900	900
patented		1000	
new	1600	1600	1600
min std.	750	750	750
max std.	4200	4200	4200



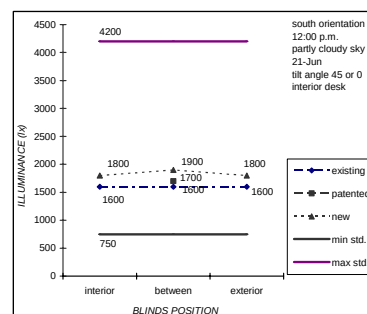
	interior	between	exterior
illuminance			
south orientation			
12:00 p.m.			
cloudy sky			
21-Mar			
tilt angle 0			
interior desk			
existing	50	110	110
patented		70	
new	150	130	110
min std.	750	750	750
max std.	4200	4200	4200



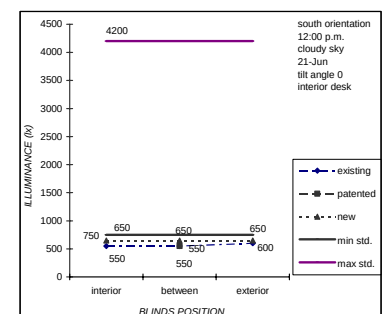
	interior	between	exterior
illuminance			
south orientation			
12:00 p.m.			
clear sky			
21-Jun			
tilt angle 45 or 0			
interior desk			
existing	1300	1100	1200
patented		1300	
new	1650	1600	1700
min std.	750	750	750
max std.	4200	4200	4200



	interior	between	exterior
illuminance			
south orientation			
12:00 p.m.			
partly cloudy sky			
21-Jun			
tilt angle 45 or 0			
interior desk			
existing	1600	1600	1600
patented		1700	
new	1800	1900	1800
min std.	750	750	750
max std.	4200	4200	4200

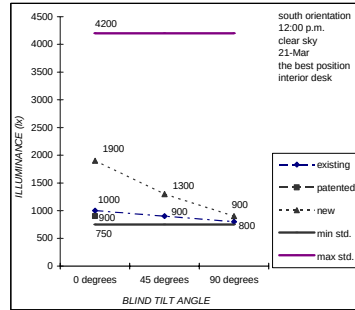


	interior	between	exterior
illuminance			
south orientation			
12:00 p.m.			
cloudy sky			
21-Jun			
tilt angle 0			
interior desk			
existing	550	550	600
patented		550	
new	650	650	650
min std.	750	750	750
max std.	4200	4200	4200

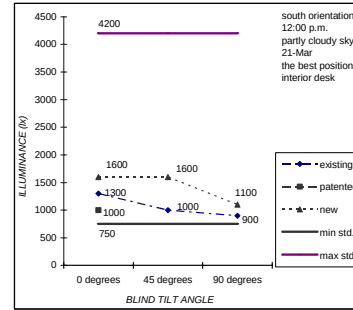


	existing	patented	new
BEST POSITION	inside	between	between

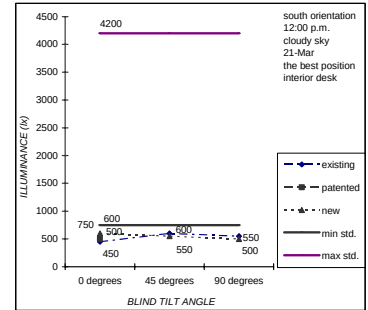
illumination		0 degrees	45 degree	90 degrees
illumination	existing	1000	900	800
12:00 p.m.	patented	900		
clear sky	new	1900	1300	900
21-Mar	min std.	750	750	750
the best position	max std.	4200	4200	4200
interior desk				



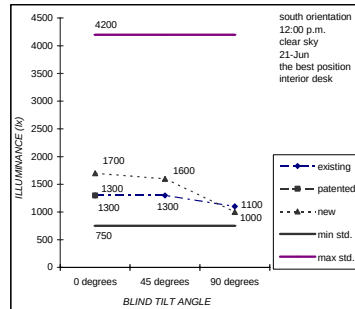
illumination		0 degrees	45 degree	90 degrees
south orientation	existing	1300	1000	900
12:00 p.m.	patented	1000		
partly cloudy sky	new	1600	1600	1100
21-Mar	min std.	750	750	750
the best position	max std.	4200	4200	4200
interior desk				



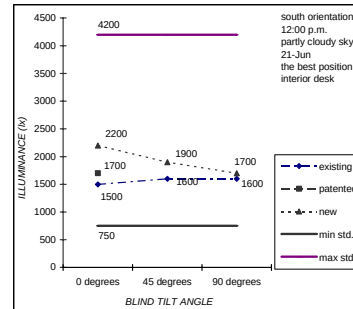
		0 degrees	45 degree	90 degrees
illumination	existing	450	600	550
south orientation	patented	500		
12:00 p.m.				
cloudy sky	new	600	550	500
21-Mar	min std.	750	750	750
the best position	max std.	4200	4200	4200
interior desk				



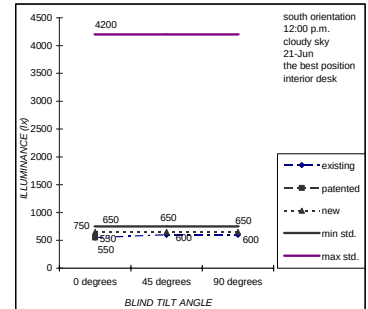
illumination		0 degrees	45 degree	90 degrees
south orientation	existing	1300	1300	1100
12:00 p.m.	patented	1300		
clear sky	new	1700	1600	1000
21-Jun	min std.	750	750	750
the best position	max std.	4200	4200	4200
interior desk				



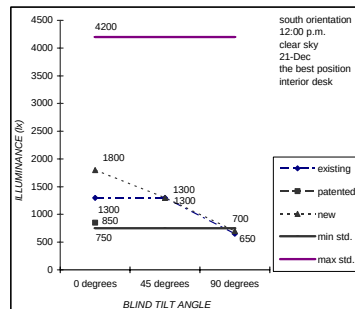
illumination		0 degrees	45 degree	90 degrees
south orientation	existing	1500	1600	1600
12:00 p.m.	patented	1700		
partly cloudy sky	new	2200	1900	1700
21-Jun	min std.	750	750	750
the best position	max std.	4200	4200	4200
interior desk				



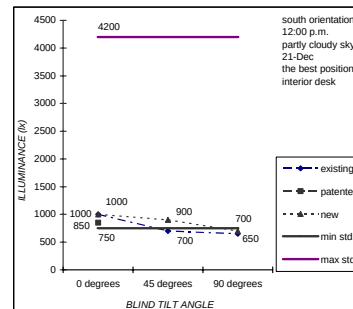
illumination		0 degrees	45 degrees	90 degrees
south orientation	existing	550	600	600
12:00 p.m.	patented	550		
cloudy sky	new	650	650	650
21-Jun	min std.	750	750	750
the best position	max std.	4200	4200	4200
interior desk				



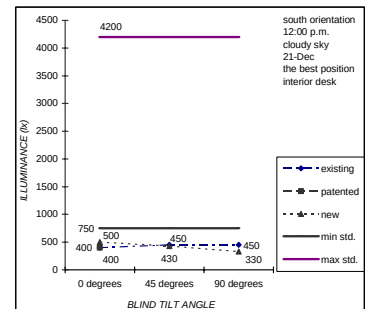
illumination		0 degrees	45 degree	90 degrees
south orientation	existing	1300	1300	650
12:00 p.m.	patented	850		
clear sky	new	1800	1300	700
21-Dec	min std.	750	750	750
the best position	max std.	4200	4200	4200
interior desk				



illumination		0 degrees	45 degree	90 degrees
south orientation	existing	1000	700	650
12:00 p.m.	patented	850		
partly cloudy sky	new	1000	900	700
21-Dec	min std.	750	750	750
the best position	max std.	4200	4200	4200
interior desk				



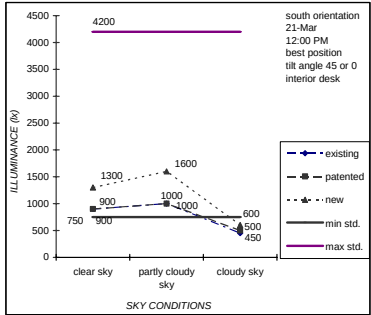
illumination		0 degrees	45 degree	90 degrees
south orientation	existing	400	450	450
12:00 p.m.	patented	400		
cloudy sky	new	500	430	330
21-Dec	min std.	750	750	750
the best position	max std.	4200	4200	4200
interior desk				



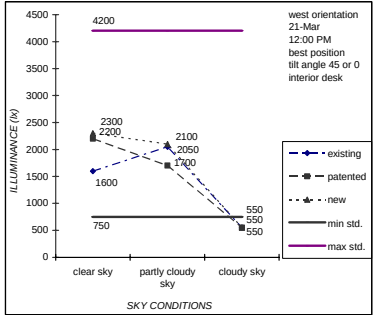
existing blinds - tilt angle 45 for clear sky and partly cloudy sky and 0 for cloudy sky
patented blinds - tilt angle 0 always
new blinds - tilt angle 45 for clear sky and partly cloudy sky and 0 for cloudy sky

	existing	patented	new
BEST POSITION	inside	between	between

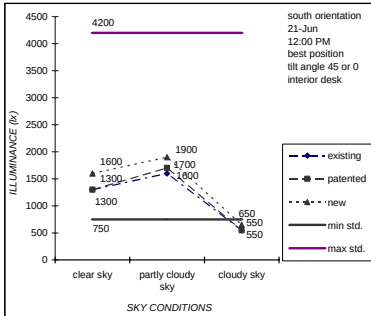
illumiance		clear sky	partly cloud	cloudy sky
south orientation	existing	900	1000	450
21-Mar	patented	900	1000	500
12:00 PM	new	1300	1600	600
best position	min std.	750	750	750
tilt angle 45 or 0	max std.	4200	4200	4200
interior desk				



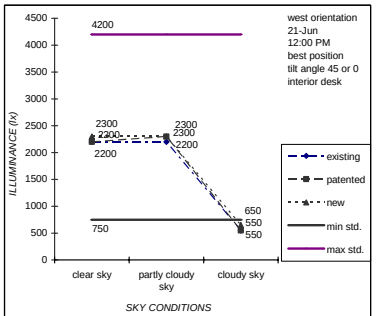
		clear sky	partly cloud	cloudy sky
illumiance				
west orientation	existing	1600	2050	550
21-Mar	patented	2200	1700	550
12:00 PM	new	2300	2100	550
best position	min std.	750	750	750
tilt angle 45 or 0	max std.	4200	4200	4200
interior desk				



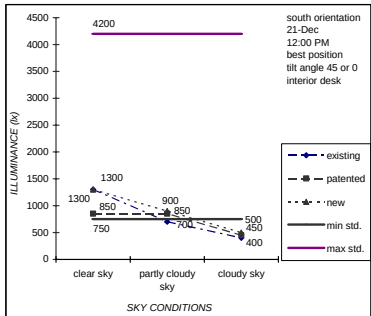
illumiance		clear sky	partly cloud	cloudy sky
south orientation	existing	1300	1600	550
21-Jun	patented	1300	1700	550
12:00 PM	new	1600	1900	650
best position	min std.	750	750	750
tilt angle 45 or 0	max std.	4200	4200	4200
interior desk				



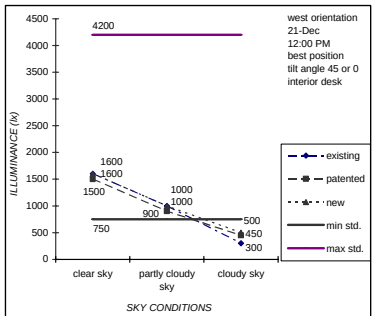
illumiance		clear sky	partly cloud	cloudy sky
west orientation	existing	2200	2200	550
21-Jun	patented	2200	2300	550
12:00 PM	new	2300	2300	650
best position	min std.	750	750	750
tilt angle 45 or 0	max std.	4200	4200	4200
interior desk				



illumiance		clear sky	partly cloud	cloudy sky
south orientation	existing	1300	700	400
21-Dec	patented	850	850	450
12:00 PM	new	1300	900	500
best position	min std.	750	750	750
tilt angle 45 or 0	max std.	4200	4200	4200
interior desk				



		clear sky	partly cloud	cloudy sky
illumiance				
west orientation	existing	1600	1000	300
21-Dec	patented	1500	900	450
12:00 PM	new	1600	1000	500
best position	min std.	750	750	750
tilt angle 45 or 0	max std.	4200	4200	4200
interior desk				



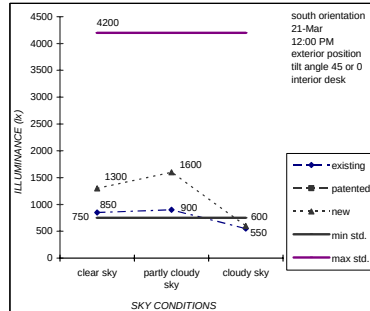
ILLUMINANCE - effect of sky conditions - for different blind positions - for different dates
for different positions of blinds

existing blinds - tilt angle 45 for clear sky and partly cloudy sky and 0 for cloudy sky
patented blinds - tilt angle 0 always
new blinds - tilt angle 45 for clear sky and partly cloudy sky and 0 for cloudy sky

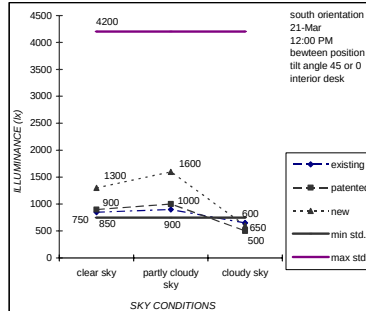
SOUTH
ILLUMINANCE
INTERIOR

SHEET 8
SET 2

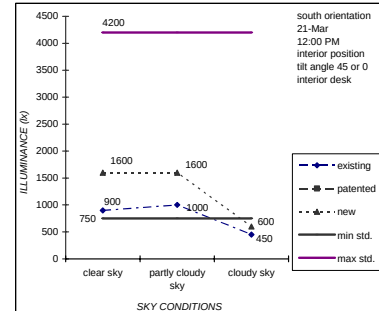
	clear sky	partly cloud	cloudy sky
illuminance			
south orientation			
21-Mar			
12:00 PM			
exterior position			
tilt angle 45 or 0			
interior desk			
existing	850	900	550
patented			
new	1300	1600	600
min std.	750	750	750
max std.	4200	4200	4200



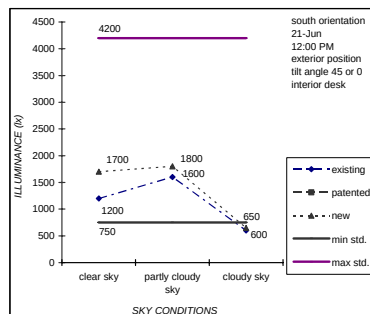
	clear sky	partly cloud	cloudy sky
illuminance			
south orientation			
21-Mar			
12:00 PM			
between position			
tilt angle 45 or 0			
interior desk			
existing	850	900	650
patented	900	1000	500
new	1300	1600	600
min std.	750	750	750
max std.	4200	4200	4200



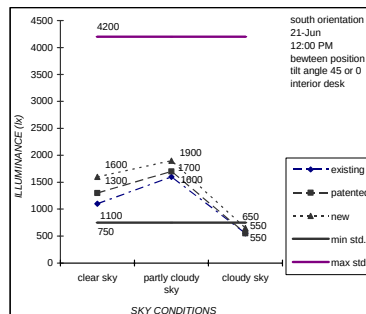
	clear sky	partly cloud	cloudy sky
illuminance			
south orientation			
21-Mar			
12:00 PM			
interior position			
tilt angle 45 or 0			
interior desk			
existing	900	1000	450
patented			
new	1600	1600	600
min std.	750	750	750
max std.	4200	4200	4200



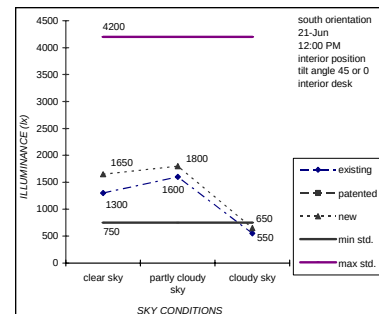
	clear sky	partly cloud	cloudy sky
illuminance			
south orientation			
21-Jun			
12:00 PM			
exterior position			
tilt angle 45 or 0			
interior desk			
existing	1200	1600	600
patented			
new	1700	1800	650
min std.	750	750	750
max std.	4200	4200	4200



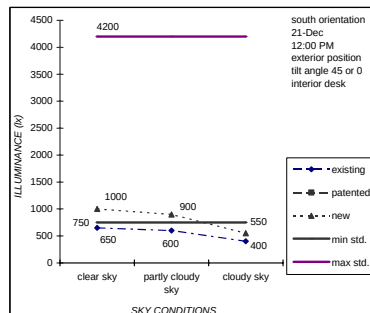
	clear sky	partly cloud	cloudy sky
illuminance			
south orientation			
21-Jun			
12:00 PM			
between position			
tilt angle 45 or 0			
interior desk			
existing	1100	1600	550
patented	1300	1700	550
new	1600	1900	650
min std.	750	750	750
max std.	4200	4200	4200



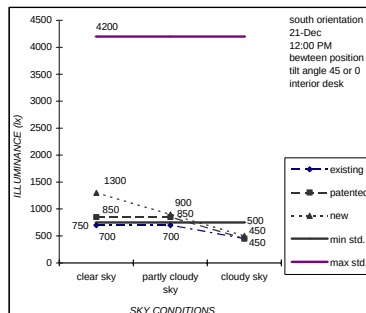
	clear sky	partly cloud	cloudy sky
illuminance			
south orientation			
21-Jun			
12:00 PM			
interior position			
tilt angle 45 or 0			
interior desk			
existing	1300	1600	550
patented			
new	1650	1800	650
min std.	750	750	750
max std.	4200	4200	4200



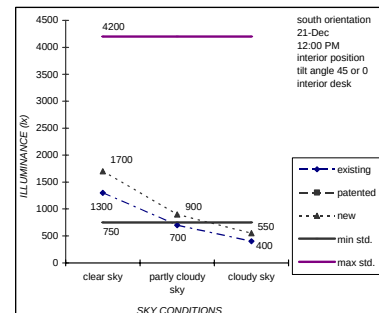
	clear sky	partly cloud	cloudy sky
illuminance			
south orientation			
21-Dec			
12:00 PM			
exterior position			
tilt angle 45 or 0			
interior desk			
existing	650	600	400
patented			
new	1000	900	550
min std.	750	750	750
max std.	4200	4200	4200



	clear sky	partly cloud	cloudy sky
illuminance			
south orientation			
21-Dec			
12:00 PM			
between position			
tilt angle 45 or 0			
interior desk			
existing	700	700	450
patented	850	850	450
new	1300	900	500
min std.	750	750	750
max std.	4200	4200	4200



	clear sky	partly cloud	cloudy sky
illuminance			
south orientation			
21-Dec			
12:00 PM			
interior position			
tilt angle 45 or 0			
interior desk			
existing	1300	700	400
patented			
new	1700	900	550
min std.	750	750	750
max std.	4200	4200	4200



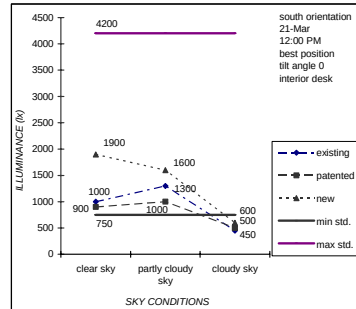
ILLUMINANCE - effect of sky conditions - for different blind tilt angles - for different dates

SOUTH
ILLUMINANCE
INTERIOR

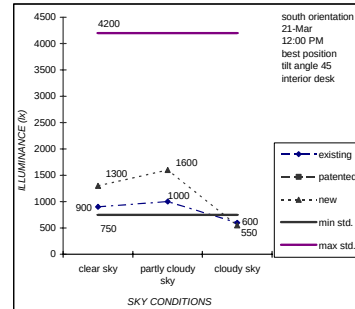
SHEET 9
SET 2

	existing	patented	new
BEST POSITION	inside	between	between

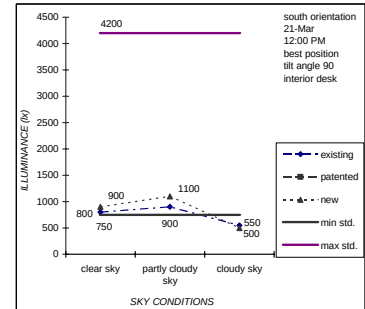
illumiance		clear sky	partly clou	cloudy sky
south orientation	existing	1000	1300	450
21-Mar	patented	900	1000	500
12:00 PM	new	1900	1600	600
best position	min std.	750	750	750
tilt angle 0	max std.	4200	4200	4200
interior desk				



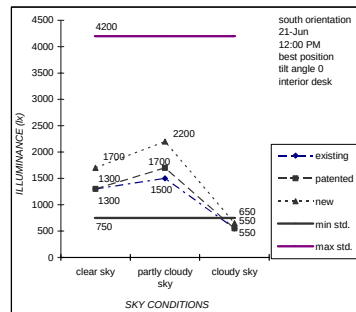
illumiance		clear sky	partly clou	cloudy sky
south orientation	existing	900	1000	600
21-Mar	patented			
12:00 PM	new	1300	1600	550
best position	min std.	750	750	750
tilt angle 45	max std.	4200	4200	4200
interior desk				



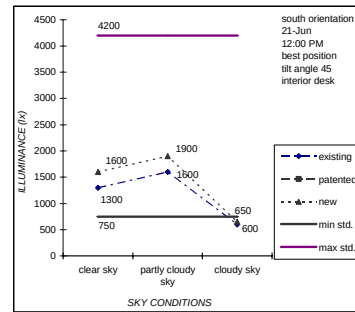
illumiance		clear sky	partly clou	cloudy sky
south orientation	existing	800	900	550
21-Mar	patented			
12:00 PM	new	900	1100	500
best position	min std.	750	750	750
tilt angle 90	max std.	4200	4200	4200
interior desk				



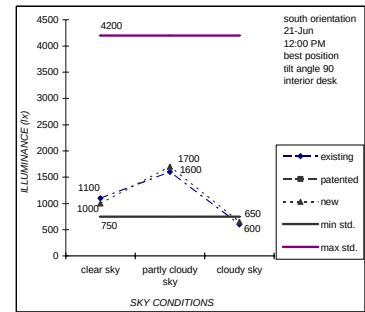
illumiance		clear sky	partly clou	cloudy sky
south orientation	existing	1300	1500	550
21-Jun	patented	1300	1700	550
12:00 PM	new	1700	2200	650
best position	min std.	750	750	750
tilt angle 0	max std.	4200	4200	4200
interior desk				



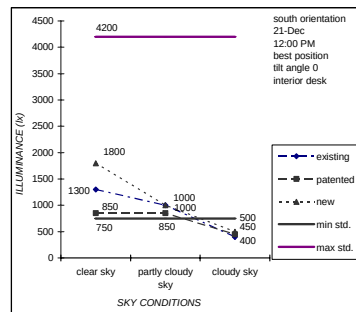
illumiance		clear sky	partly clou	cloudy sky
south orientation	existing	1300	1600	600
21-Jun	patented			
12:00 PM	new	1600	1900	650
best position	min std.	750	750	750
tilt angle 45	max std.	4200	4200	4200
interior desk				



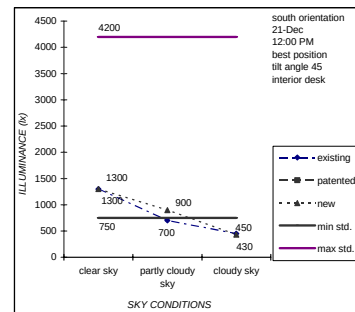
illumiance		clear sky	partly clou	cloudy sky
south orientation	existing	1100	1600	600
21-Jun	patented			
12:00 PM	new	1000	1700	650
best position	min std.	750	750	750
tilt angle 90	max std.	4200	4200	4200
interior desk				



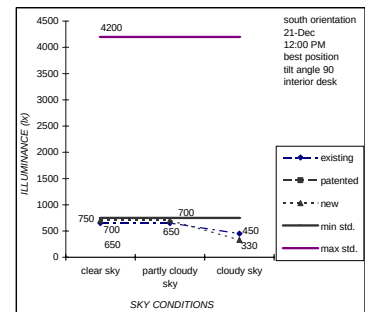
illumiance		clear sky	partly clou	cloudy sky
south orientation	existing	1300	1000	400
21-Dec	patented	850	850	450
12:00 PM	new	1800	1000	500
best position	min std.	750	750	750
tilt angle 0	max std.	4200	4200	4200
interior desk				



illumiance		clear sky	partly clou	cloudy sky
south orientation	existing	1300	700	450
21-Dec	patented			
12:00 PM	new	1300	900	430
best position	min std.	750	750	750
tilt angle 45	max std.	4200	4200	4200
interior desk				



illumiance		clear sky	partly clou	cloudy sky
south orientation	existing	650	650	450
21-Dec	patented			
12:00 PM	new	700	700	330
best position	min std.	750	750	750
tilt angle 90	max std.	4200	4200	4200
interior desk				

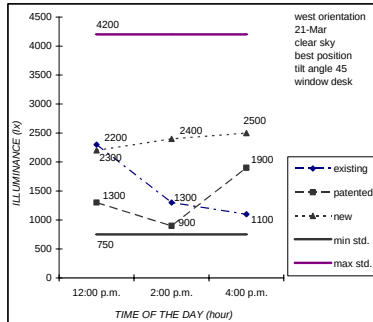


ILLUMINANCE- effect of the time -for different dates-for different sky conditions

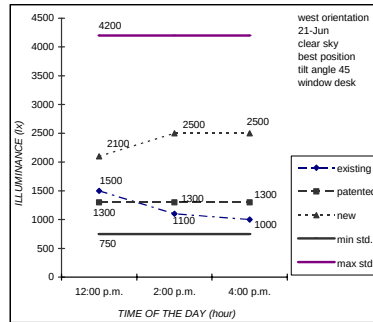
existing blinds - tilt angle 45 for clear sky and partly cloudy sky and 0 for cloudy sky
 patented blinds - tilt angle 0 always
 new blinds - tilt angle 45 for clear sky and partly cloudy sky and 0 for cloudy sky

WEST SHEET 1
 ILLUMINANCE SET 3
 WINDOW

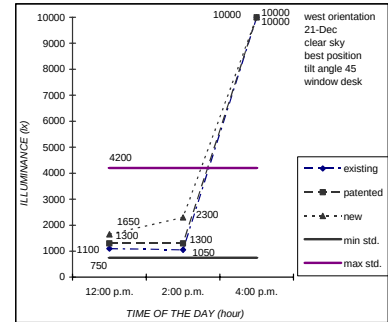
illumance west orientation 21-Mar clear sky best position tilt angle 45 window desk		12:00 p.m.	2:00 p.m.	4:00 p.m.
existing		2300	1300	1100
patented		1300	900	1900
new		2200	2400	2500
min std.		750	750	750
max std.		4200	4200	4200



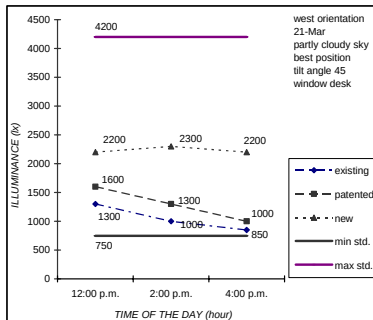
illumance west orientation 21-Jun clear sky best position tilt angle 45 window desk		12:00 p.m.	2:00 p.m.	4:00 p.m.
existing		1500	1100	1000
patented		1300	1300	1300
new		2100	2500	2500
min std.		750	750	750
max std.		4200	4200	4200



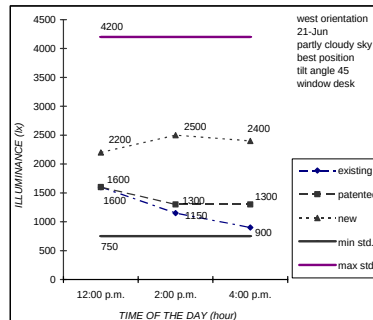
illumance west orientation 21-Dec clear sky best position tilt angle 45 window desk		12:00 p.m.	2:00 p.m.	4:00 p.m.
existing		1100	1050	10000
patented		1300	1300	10000
new		1650	2300	10000
min std.		750	750	750
max std.		4200	4200	4200



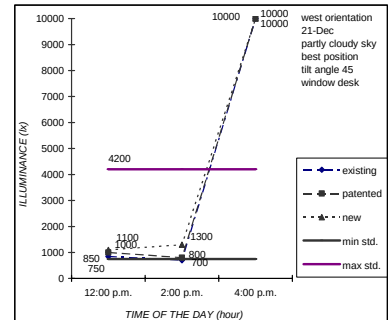
illumance west orientation 21-Mar partly cloudy sky best position tilt angle 45 window desk		12:00 p.m.	2:00 p.m.	4:00 p.m.
existing		1300	1000	850
patented		1600	1300	1000
new		2200	2300	2200
min std.		750	750	750
max std.		4200	4200	4200



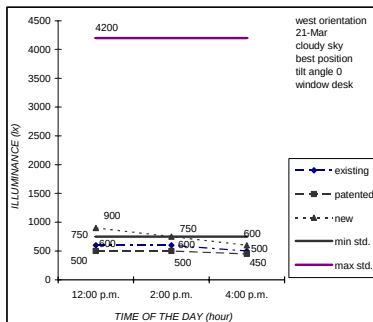
illumance west orientation 21-Jun partly cloudy sky best position tilt angle 45 window desk		12:00 p.m.	2:00 p.m.	4:00 p.m.
existing		1600	1150	900
patented		1600	1300	1300
new		2200	2500	2400
min std.		750	750	750
max std.		4200	4200	4200



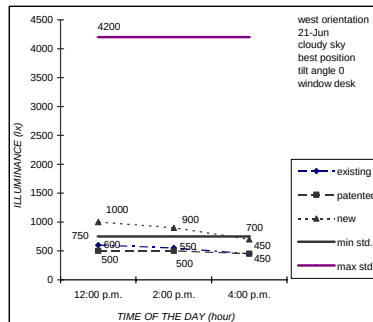
illumance west orientation 21-Dec partly cloudy sky best position tilt angle 45 window desk		12:00 p.m.	2:00 p.m.	4:00 p.m.
existing		850	700	10000
patented		1000	800	10000
new		1100	1300	10000
min std.		750	750	750
max std.		4200	4200	4200



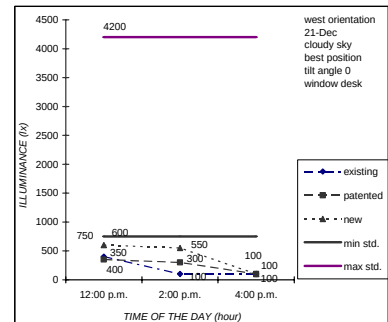
illumance west orientation 21-Mar cloudy sky best position tilt angle 0 window desk		12:00 p.m.	2:00 p.m.	4:00 p.m.
existing		600	600	500
patented		500	500	450
new		900	750	600
min std.		750	750	750
max std.		4200	4200	4200



illumance west orientation 21-Jun cloudy sky best position tilt angle 0 window desk		12:00 p.m.	2:00 p.m.	4:00 p.m.
existing		600	550	450
patented		500	500	450
new		1000	900	700
min std.		750	750	750
max std.		4200	4200	4200



illumance west orientation 21-Dec cloudy sky best position tilt angle 0 window desk		12:00 p.m.	2:00 p.m.	4:00 p.m.
existing		400	100	100
patented		350	300	100
new		600	550	100
min std.		750	750	750
max std.		4200	4200	4200

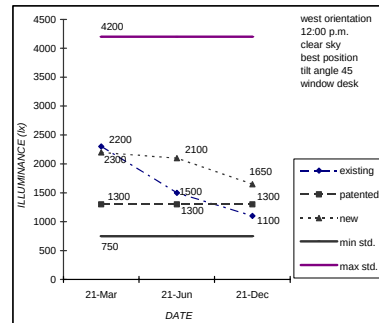


ILLUMINANCE- effect of the date-for different times-for different sky conditions

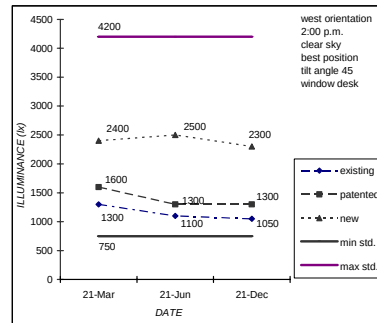
existing blinds - tilt angle 45 for clear sky and partly cloudy sky and 0 for cloudy sky
 patented blinds - tilt angle 0 always
 new blinds - tilt angle 45 for clear sky and partly cloudy sky and 0 for cloudy sky

WEST SHEET 2
 ILLUMINANCE SET 3
 WINDOW

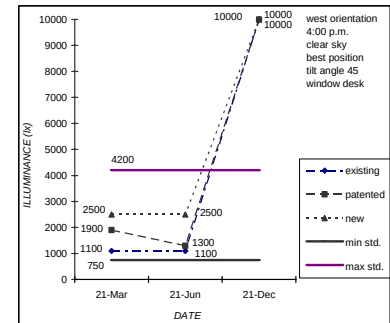
	21-Mar	21-Jun	21-Dec
illuminance west orientation 12:00 p.m. clear sky best position tilt angle 45 window desk			
existing	2300	1500	1100
patented	1300	1300	1300
new	2200	2100	1650
min std.	750	750	750
max std.	4200	4200	4200



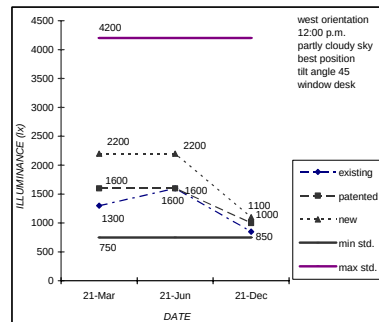
	21-Mar	21-Jun	21-Dec
illuminance west orientation 2:00 p.m. clear sky best position tilt angle 45 window desk			
existing	1300	1100	1050
patented	1600	1300	1300
new	2400	2500	2300
min std.	750	750	750
max std.	4200	4200	4200



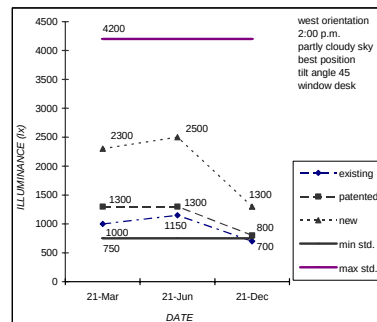
	21-Mar	21-Jun	21-Dec
illuminance west orientation 4:00 p.m. clear sky best position tilt angle 45 window desk			
existing	1100	1100	10000
patented	1900	1300	10000
new	2500	2500	10000
min std.	750	750	750
max std.	4200	4200	4200



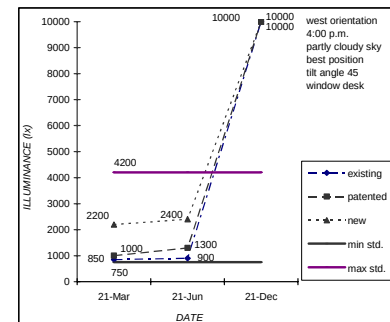
	21-Mar	21-Jun	21-Dec
illuminance west orientation 12:00 p.m. partly cloudy sky best position tilt angle 45 window desk			
existing	1300	1600	850
patented	1600	1600	1000
new	2200	2200	1100
min std.	750	750	750
max std.	4200	4200	4200



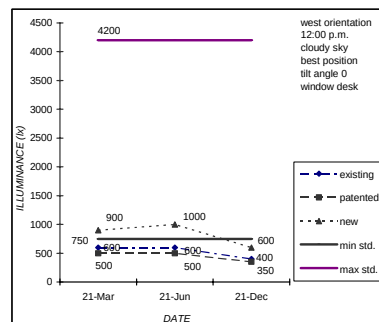
	21-Mar	21-Jun	21-Dec
illuminance west orientation 2:00 p.m. partly cloudy sky best position tilt angle 45 window desk			
existing	1000	1150	700
patented	1300	1300	800
new	2300	2500	1300
min std.	750	750	750
max std.	4200	4200	4200



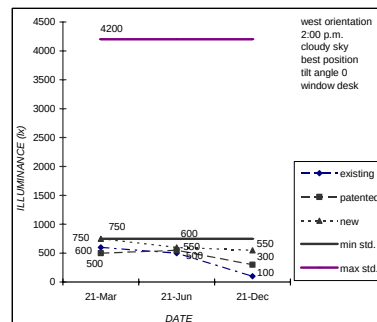
	21-Mar	21-Jun	21-Dec
illuminance west orientation 4:00 p.m. partly cloudy sky best position tilt angle 45 window desk			
existing	850	900	10000
patented	1000	1300	10000
new	2200	2400	10000
min std.	750	750	750
max std.	4200	4200	4200



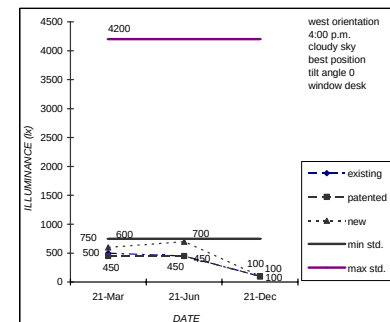
	21-Mar	21-Jun	21-Dec
illuminance west orientation 12:00 p.m. cloudy sky best position tilt angle 0 window desk			
existing	600	600	400
patented	500	500	350
new	900	1000	600
min std.	750	750	750
max std.	4200	4200	4200



	21-Mar	21-Jun	21-Dec
illuminance west orientation 2:00 p.m. cloudy sky best position tilt angle 0 window desk			
existing	600	500	100
patented	500	550	300
new	750	600	550
min std.	750	750	750
max std.	4200	4200	4200



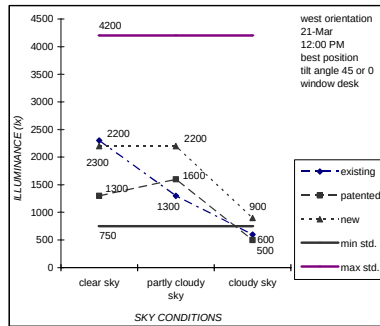
	21-Mar	21-Jun	21-Dec
illuminance west orientation 4:00 p.m. cloudy sky best position tilt angle 0 window desk			
existing	500	450	100
patented	450	450	100
new	600	700	100
min std.	750	750	750
max std.	4200	4200	4200



ILLUMINANCE - effect of sky conditions-for different times - for different dates

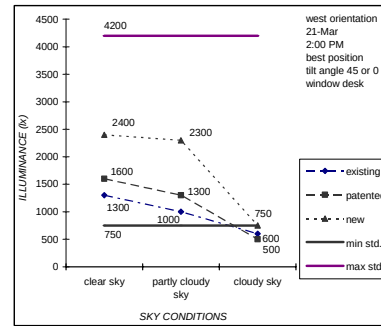
existing blinds - tilt angle 45 for clear sky and partly cloudy sky and 0 for cloudy sky
 patented blinds - tilt angle 0 always
 new blinds - tilt angle 45 for clear sky and partly cloudy sky and 0 for cloudy sky

	clear sky	partly cloud	cloudy sky
illumination			
west orientation			
21-Mar			
12:00 PM			
best position			
tilt angle 45 or 0			
window desk			
existing	2300	1300	600
patented	1300	1600	500
new	2200	2200	900
min std.	750	750	750
max std.	4200	4200	4200

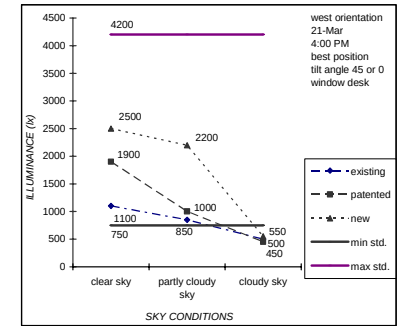


	existing	patented	new
BEST POSITION	inside	between	between

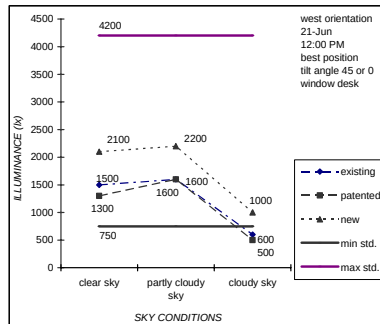
	clear sky	partly cloud	cloudy sky
illumination			
west orientation			
21-Mar			
2:00 PM			
best position			
tilt angle 45 or 0			
window desk			
existing	1300	1000	600
patented	1600	1300	500
new	2400	2300	750
min std.	750	750	750
max std.	4200	4200	4200



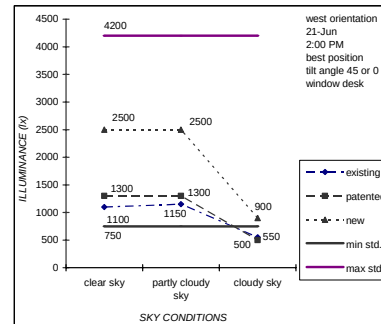
	clear sky	partly cloud	cloudy sky
illumination			
west orientation			
21-Mar			
4:00 PM			
best position			
tilt angle 45 or 0			
window desk			
existing	1100	850	500
patented	1900	1000	450
new	2500	2200	550
min std.	750	750	750
max std.	4200	4200	4200



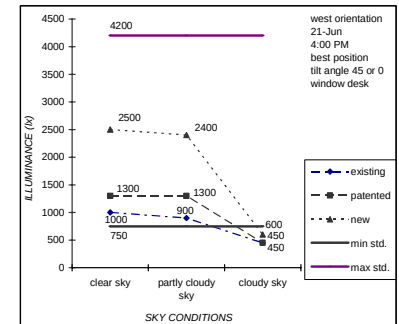
	clear sky	partly cloud	cloudy sky
illumination			
west orientation			
21-Jun			
12:00 PM			
best position			
tilt angle 45 or 0			
window desk			
existing	1500	1600	600
patented	1300	1600	500
new	2100	2200	1000
min std.	750	750	750
max std.	4200	4200	4200



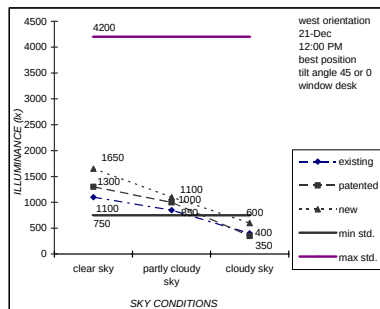
	clear sky	partly cloud	cloudy sky
illumination			
west orientation			
21-Jun			
2:00 PM			
best position			
tilt angle 45 or 0			
window desk			
existing	1100	1150	550
patented	1300	1300	500
new	2500	2500	900
min std.	750	750	750
max std.	4200	4200	4200



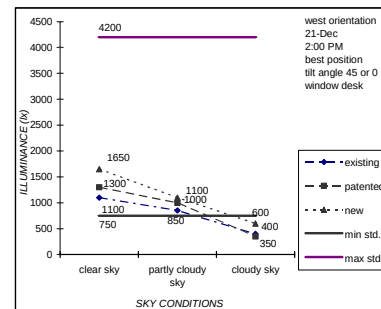
	clear sky	partly cloud	cloudy sky
illumination			
west orientation			
21-Jun			
4:00 PM			
best position			
tilt angle 45 or 0			
window desk			
existing	1000	900	450
patented	1300	1300	450
new	2500	2400	600
min std.	750	750	750
max std.	4200	4200	4200



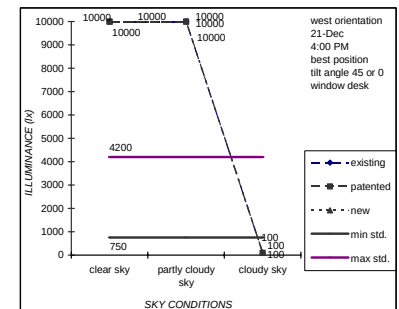
	clear sky	partly cloud	cloudy sky
illumination			
west orientation			
21-Dec			
12:00 PM			
best position			
tilt angle 45 or 0			
window desk			
existing	1100	850	400
patented	1300	1000	350
new	1650	1100	600
min std.	750	750	750
max std.	4200	4200	4200



	clear sky	partly cloud	cloudy sky
illumination			
west orientation			
21-Dec			
2:00 PM			
best position			
tilt angle 45 or 0			
window desk			
existing	1100	850	400
patented	1300	1000	350
new	1650	1100	600
min std.	750	750	750
max std.	4200	4200	4200



	clear sky	partly cloud	cloudy sky
illumination			
west orientation			
21-Dec			
4:00 PM			
best position			
tilt angle 45 or 0			
window desk			
existing	10000	10000	100
patented	10000	10000	100
new	10000	10000	100
min std.	750	750	750
max std.	4200	4200	4200

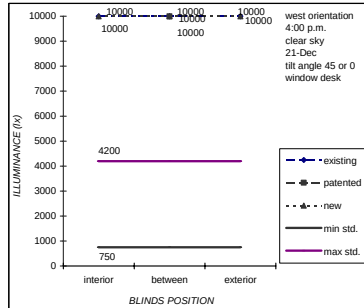


ILLUMINANCE- effect of the blinds position-for different dates-for different sky conditions

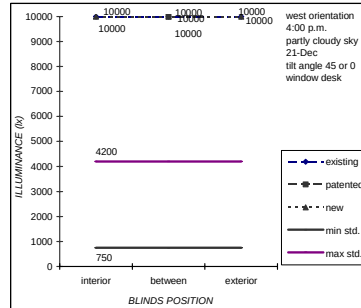
WEST SHEET 4
ILLUMINANCE SET 3
WINDOW

existing blinds - tilt angle 45 for clear sky and partly cloudy sky and 0 for cloudy sky
patented blinds - tilt angle 0 always
new blinds - tilt angle 45 for clear sky and partly cloudy sky and 0 for cloudy sky

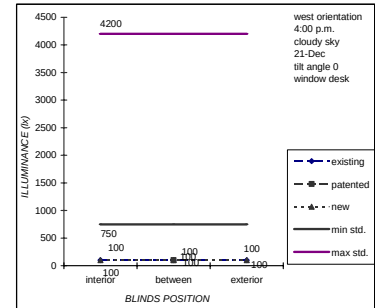
illumina		interior	between	exterior
west orientation	existing	10000	10000	10000
4:00 p.m.	patented			
clear sky	new	10000	10000	10000
21-Dec	min std.	750	750	750
tilt angle 45 or 0	max std.	4200	4200	4200
window desk				



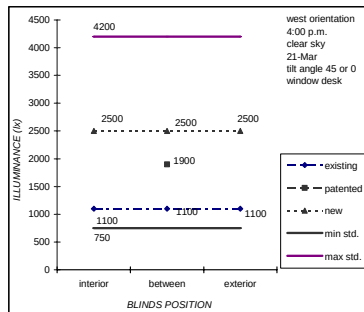
illumina		interior	between	exterior
west orientation	existing	10000	10000	10000
4:00 p.m.	patented			
partly cloudy sky	new	10000	10000	10000
21-Dec	min std.	750	750	750
tilt angle 45 or 0	max std.	4200	4200	4200
window desk				



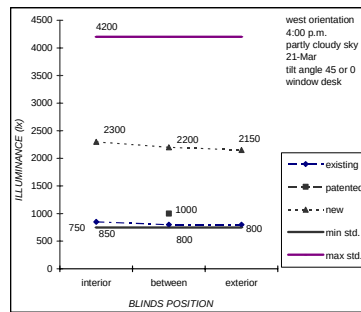
illumina		interior	between	exterior
west orientation	existing	100	100	100
4:00 p.m.	patented			
cloudy sky	new	100	100	100
21-Dec	min std.	750	750	750
tilt angle 0	max std.	4200	4200	4200
window desk				



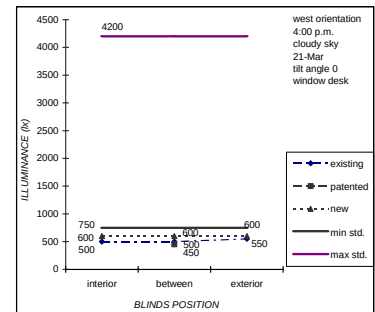
illumina		interior	between	exterior
west orientation	existing	1100	1100	1100
4:00 p.m.	patented			
clear sky	new	2500	2500	2500
21-Mar	min std.	750	750	750
tilt angle 45 or 0	max std.	4200	4200	4200
window desk				



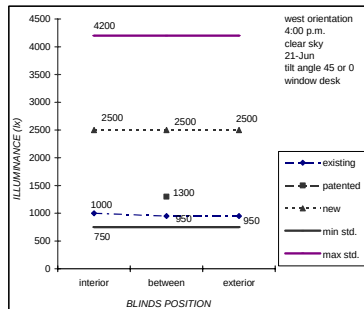
illumina		interior	between	exterior
west orientation	existing	850	1000	800
4:00 p.m.	patented			
partly cloudy sky	new	2300	2200	2150
21-Mar	min std.	750	750	750
tilt angle 45 or 0	max std.	4200	4200	4200
window desk				



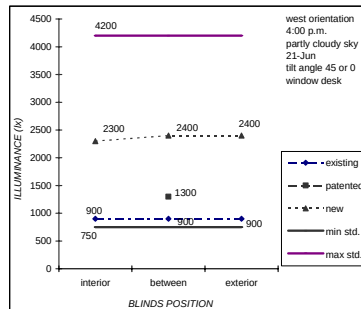
illumina		interior	between	exterior
west orientation	existing	500	500	550
4:00 p.m.	patented			
cloudy sky	new	600	600	600
21-Mar	min std.	750	750	750
tilt angle 0	max std.	4200	4200	4200
window desk				



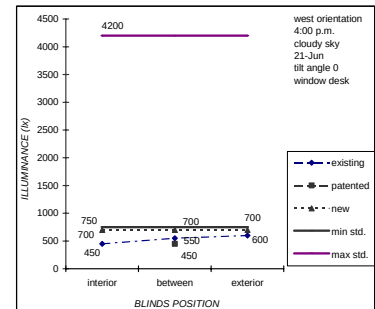
illumina		interior	between	exterior
west orientation	existing	1000	950	950
4:00 p.m.	patented			
clear sky	new	2500	2500	2500
21-Jun	min std.	750	750	750
tilt angle 45 or 0	max std.	4200	4200	4200
window desk				



illumina		interior	between	exterior
west orientation	existing	900	900	900
4:00 p.m.	patented			
partly cloudy sky	new	2300	2400	2400
21-Jun	min std.	750	750	750
tilt angle 45 or 0	max std.	4200	4200	4200
window desk				



illumina		interior	between	exterior
west orientation	existing	450	550	600
4:00 p.m.	patented			
cloudy sky	new	700	700	700
21-Jun	min std.	750	750	750
tilt angle 0	max std.	4200	4200	4200
window desk				

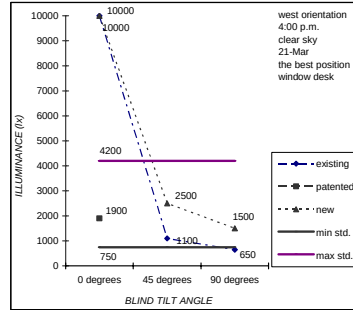


ILLUMINANCE - effect of blinds tilt angle - for different sky conditions - for different dates

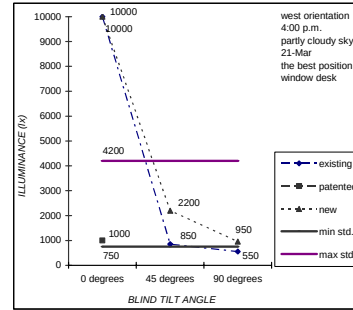
	existing	patented	new
BEST POSITION	inside	between	between

WEST SHEET 5
ILLUMINANCE SET 3
WINDOW

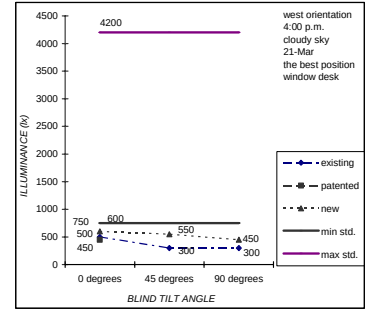
	0 degrees	45 degree	90 degrees
illuminance			
west orientation			
4:00 p.m.			
clear sky			
21-Mar			
the best position			
window desk			
existing	10000	1100	650
patented	1900		
new	10000	2500	1500
min std.	750	750	750
max std.	4200	4200	4200



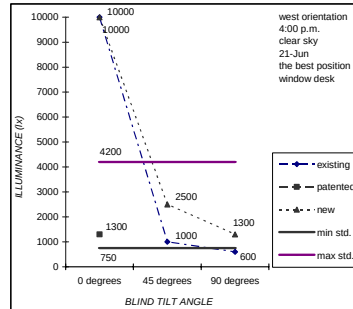
	0 degrees	45 degree	90 degrees
illuminance			
west orientation			
4:00 p.m.			
partly cloudy sky			
21-Mar			
the best position			
window desk			
existing	10000	850	550
patented	1000		
new	10000	2200	950
min std.	750	750	750
max std.	4200	4200	4200



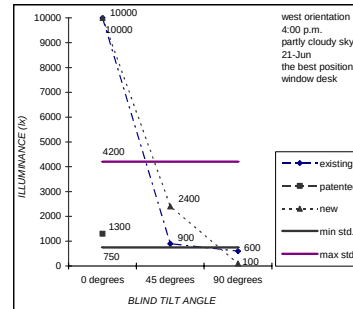
	0 degrees	45 degree	90 degrees
illuminance			
west orientation			
4:00 p.m.			
cloudy sky			
21-Mar			
the best position			
window desk			
existing	500	300	300
patented	450		
new	600	550	450
min std.	750	750	750
max std.	4200	4200	4200



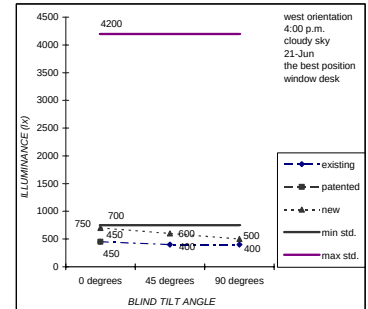
	0 degrees	45 degree	90 degrees
illuminance			
west orientation			
4:00 p.m.			
clear sky			
21-Jun			
the best position			
window desk			
existing	10000	1000	600
patented	1300		
new	10000	2500	1300
min std.	750	750	750
max std.	4200	4200	4200



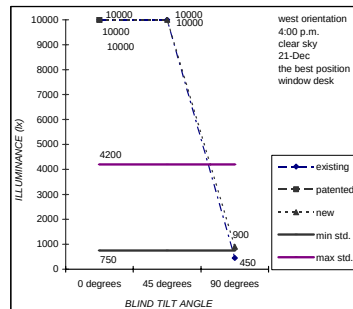
	0 degrees	45 degree	90 degrees
illuminance			
west orientation			
4:00 p.m.			
partly cloudy sky			
21-Jun			
the best position			
window desk			
existing	10000	900	600
patented	1300		
new	10000	2400	100
min std.	750	750	750
max std.	4200	4200	4200



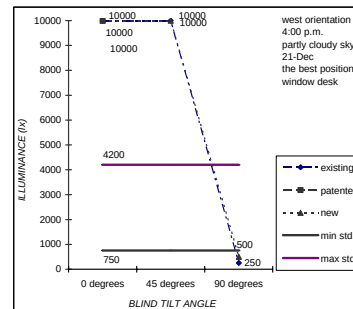
	0 degrees	45 degree	90 degrees
illuminance			
west orientation			
4:00 p.m.			
cloudy sky			
21-Jun			
the best position			
window desk			
existing	450	400	400
patented	450		
new	700	600	500
min std.	750	750	750
max std.	4200	4200	4200



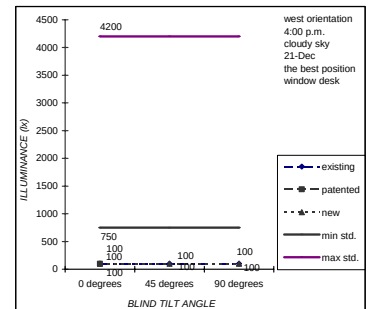
	0 degrees	45 degree	90 degrees
illuminance			
west orientation			
4:00 p.m.			
clear sky			
21-Dec			
the best position			
window desk			
existing	10000	10000	450
patented	10000		
new	10000	10000	900
min std.	750	750	750
max std.	4200	4200	4200



	0 degrees	45 degree	90 degrees
illuminance			
west orientation			
4:00 p.m.			
partly cloudy sky			
21-Dec			
the best position			
window desk			
existing	10000	10000	250
patented	10000		
new	10000	10000	500
min std.	750	750	750
max std.	4200	4200	4200



	0 degrees	45 degree	90 degrees
illuminance			
west orientation			
4:00 p.m.			
cloudy sky			
21-Dec			
the best position			
window desk			
existing	100	100	100
patented	100		
new	100	100	100
min std.	750	750	750
max std.	4200	4200	4200

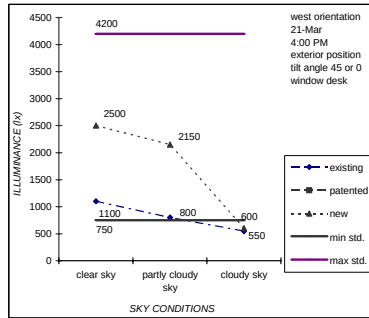


ILLUMINANCE - effect of sky conditions-for different blind positions - for different dates

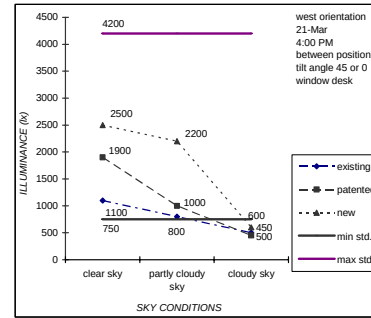
existing blinds - tilt angle 45 for clear sky and partly cloudy sky and 0 for cloudy sky
 patented blinds - tilt angle 0 always
 new blinds - tilt angle 45 for clear sky and partly cloudy sky and 0 for cloudy sky

WEST SHEET 6
 ILLUMINANCE SET 3
 WINDOW

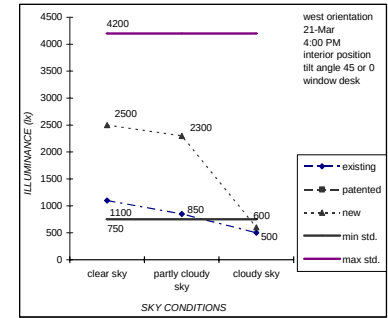
illumiance		clear sky	partly cloud	cloudy sky
west orientation				
21-Mar				
4:00 PM				
exterior position				
tilt angle 45 or 0				
window desk				
existing		1100	800	550
patented				
new		2500	2150	600
min std.		750	750	750
max std.		4200	4200	4200



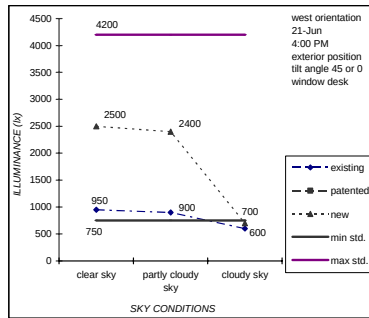
illumiance		clear sky	partly cloud	cloudy sky
west orientation				
21-Mar				
4:00 PM				
between position				
tilt angle 45 or 0				
window desk				
existing		1100	800	500
patented		1900	1000	450
new		2500	2200	600
min std.		750	750	750
max std.		4200	4200	4200



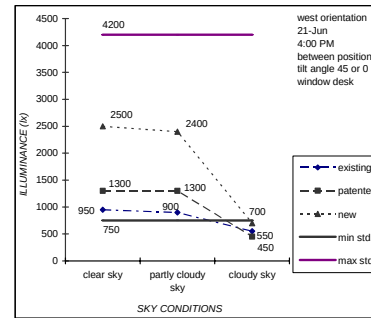
illumiance		clear sky	partly cloud	cloudy sky
west orientation				
21-Mar				
4:00 PM				
interior position				
tilt angle 45 or 0				
window desk				
existing		1100	850	500
patented				
new		2500	2300	600
min std.		750	750	750
max std.		4200	4200	4200



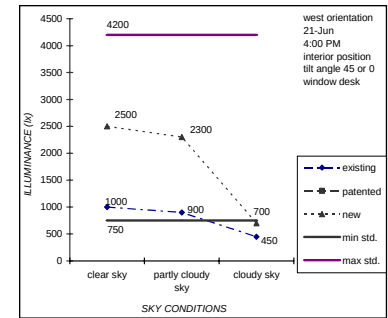
illumiance		clear sky	partly cloud	cloudy sky
west orientation				
21-Jun				
4:00 PM				
exterior position				
tilt angle 45 or 0				
window desk				
existing		950	900	600
patented				
new		2500	2400	700
min std.		750	750	750
max std.		4200	4200	4200



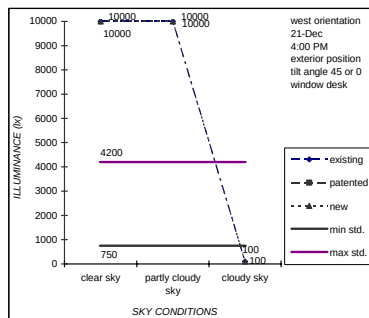
illumiance		clear sky	partly cloud	cloudy sky
west orientation				
21-Jun				
4:00 PM				
between position				
tilt angle 45 or 0				
window desk				
existing		950	900	550
patented		1300	1300	450
new		2500	2400	700
min std.		750	750	750
max std.		4200	4200	4200



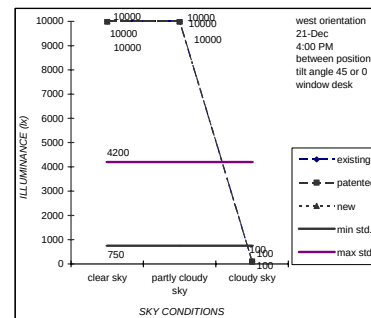
illumiance		clear sky	partly cloud	cloudy sky
west orientation				
21-Jun				
4:00 PM				
interior position				
tilt angle 45 or 0				
window desk				
existing		1000	900	450
patented				
new		2500	2300	700
min std.		750	750	750
max std.		4200	4200	4200



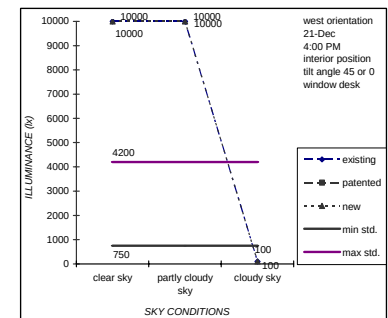
illumiance		clear sky	partly cloud	cloudy sky
west orientation				
21-Dec				
4:00 PM				
exterior position				
tilt angle 45 or 0				
window desk				
existing		10000	10000	100
patented				
new		10000	10000	100
min std.		750	750	750
max std.		4200	4200	4200



illumiance		clear sky	partly cloud	cloudy sky
west orientation				
21-Dec				
4:00 PM				
between position				
tilt angle 45 or 0				
window desk				
existing		10000	10000	100
patented		10000	10000	100
new		10000	10000	100
min std.		750	750	750
max std.		4200	4200	4200



illumiance		clear sky	partly cloud	cloudy sky
west orientation				
21-Dec				
4:00 PM				
interior position				
tilt angle 45 or 0				
window desk				
existing		10000	10000	100
patented				
new		10000	10000	100
min std.		750	750	750
max std.		4200	4200	4200

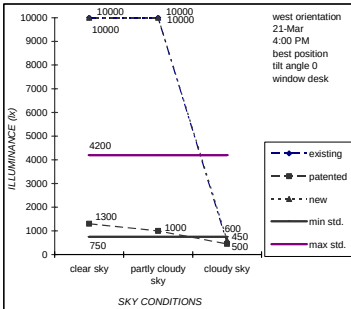


ILLUMINANCE - effect of sky conditions - for blind tilt angles - for different dates

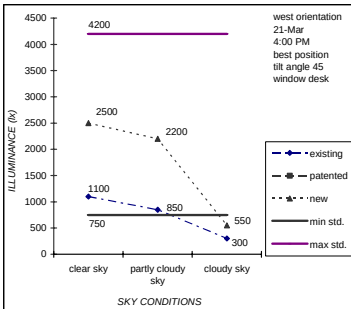
WEST SHEET 7
ILLUMINANCE SET 3
WINDOW

	existing	patented	new
BEST POSITION	inside	between	between

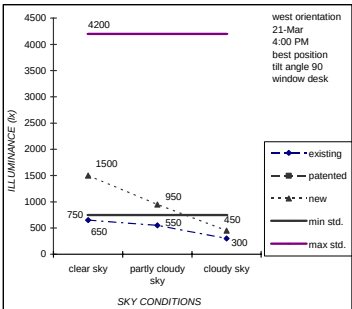
	clear sky	partly cloudy sky	cloudy sky
illumination			
west orientation			
21-Mar	existing 10000	10000	500
4:00 PM	patented 1300	1000	450
best position	new 10000	10000	600
tilt angle 0	min std. 750	750	750
window desk	max std. 4200	4200	4200



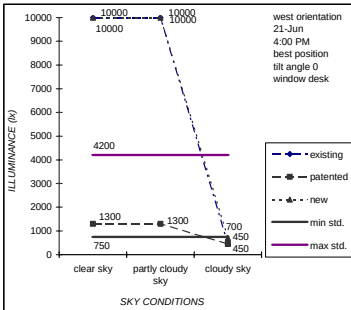
	clear sky	partly cloudy sky	cloudy sky
illumination			
west orientation			
21-Mar	existing 1100	850	300
4:00 PM	patented 2500	2200	550
best position	new 750	750	750
tilt angle 45	min std. 4200	4200	4200
window desk	max std. 4200	4200	4200



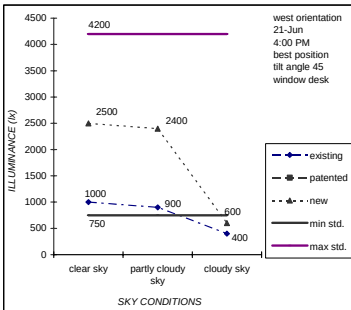
	clear sky	partly cloudy sky	cloudy sky
illumination			
west orientation			
21-Mar	existing 650	550	300
4:00 PM	patented 1500	950	450
best position	new 750	750	750
tilt angle 90	min std. 4200	4200	4200
window desk	max std. 4200	4200	4200



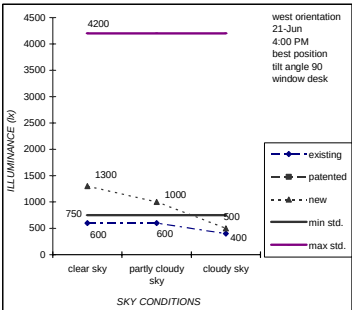
	clear sky	partly cloudy sky	cloudy sky
illumination			
west orientation			
21-Jun	existing 10000	10000	450
4:00 PM	patented 1300	1300	450
best position	new 10000	10000	700
tilt angle 0	min std. 750	750	750
window desk	max std. 4200	4200	4200



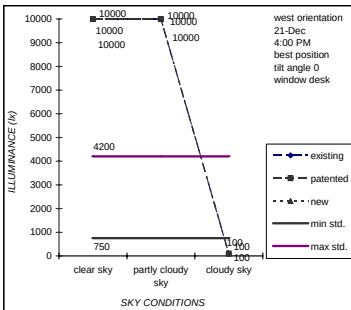
	clear sky	partly cloudy sky	cloudy sky
illumination			
west orientation			
21-Jun	existing 1000	900	400
4:00 PM	patented 2500	2400	600
best position	new 750	750	750
tilt angle 45	min std. 4200	4200	4200
window desk	max std. 4200	4200	4200



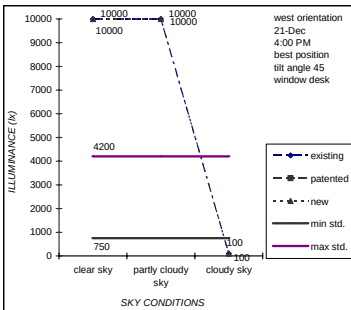
	clear sky	partly cloudy sky	cloudy sky
illumination			
west orientation			
21-Jun	existing 600	600	400
4:00 PM	patented 1300	1000	500
best position	new 750	750	750
tilt angle 90	min std. 4200	4200	4200
window desk	max std. 4200	4200	4200



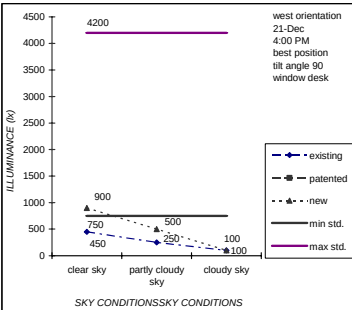
	clear sky	partly cloudy sky	cloudy sky
illumination			
west orientation			
21-Dec	existing 10000	10000	100
4:00 PM	patented 10000	10000	100
best position	new 10000	10000	100
tilt angle 0	min std. 750	750	750
window desk	max std. 4200	4200	4200



	clear sky	partly cloudy sky	cloudy sky
illumination			
west orientation			
21-Dec	existing 10000	10000	100
4:00 PM	patented 10000	10000	100
best position	new 750	750	750
tilt angle 45	min std. 4200	4200	4200
window desk	max std. 4200	4200	4200



	clear sky	partly cloudy sky	cloudy sky
illumination			
west orientation			
21-Dec	existing 450	250	100
4:00 PM	patented 900	500	100
best position	new 750	750	750
tilt angle 90	min std. 4200	4200	4200
window desk	max std. 4200	4200	4200



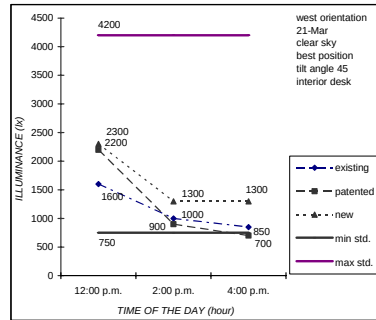
ILLUMINANCE- effect of the time - for different dates - for different sky conditions

WEST SHEET 1
ILLUMINANCE SET 4
INTERIOR

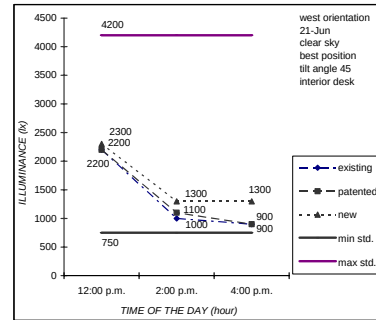
existing blinds - tilt angle 45 for clear sky and partly cloudy sky and 0 for cloudy sky
patented blinds - tilt angle 0 always
new blinds - tilt angle 45 for clear sky and partly cloudy sky and 0 for cloudy sky

	existing	patented	new
BEST POSITION	inside	between	between

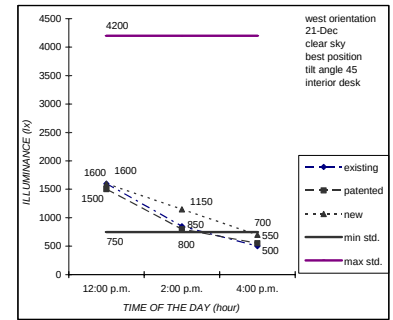
illumiance		12:00 p.m.	2:00 p.m.	4:00 p.m.
west orientation				
21-Mar	existing	1600	1000	850
	patented	2200	900	700
clear sky	new	2300	1300	1300
best position	min std.	750	750	750
tilt angle 45	max std.	4200	4200	4200
interior desk				



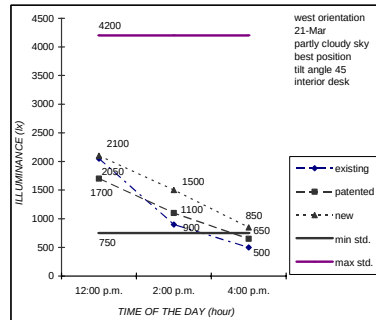
illumiance		12:00 p.m.	2:00 p.m.	4:00 p.m.
west orientation				
21-Jun	existing	2200	1000	900
	patented	2200	1100	900
clear sky	new	2300	1300	1300
best position	min std.	750	750	750
tilt angle 45	max std.	4200	4200	4200
interior desk				



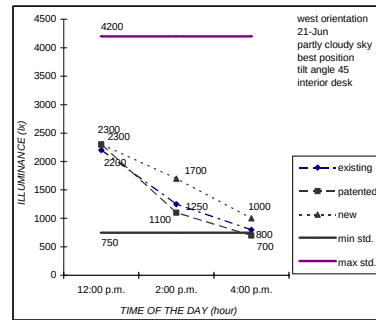
illumiance		12:00 p.m.	2:00 p.m.	4:00 p.m.
west orientation				
21-Dec	existing	1600	850	500
	patented	1500	800	550
clear sky	new	1600	1150	700
best position	min std.	750	750	750
tilt angle 45	max std.	4200	4200	4200
interior desk				



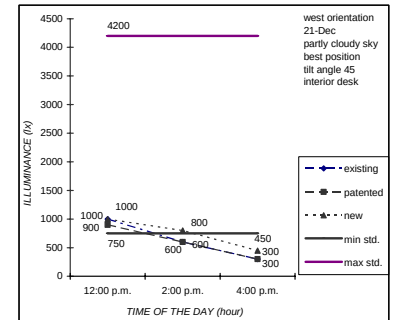
illumiance		12:00 p.m.	2:00 p.m.	4:00 p.m.
west orientation				
21-Mar	existing	2050	900	500
	patented	1700	1100	650
partly cloudy sky	new	2100	1500	850
best position	min std.	750	750	750
tilt angle 45	max std.	4200	4200	4200
interior desk				



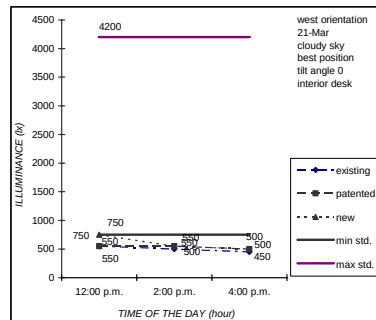
illumiance		12:00 p.m.	2:00 p.m.	4:00 p.m.
west orientation				
21-Jun	existing	2200	1250	800
	patented	2300	1100	700
partly cloudy sky	new	2300	1700	1000
best position	min std.	750	750	750
tilt angle 45	max std.	4200	4200	4200
interior desk				



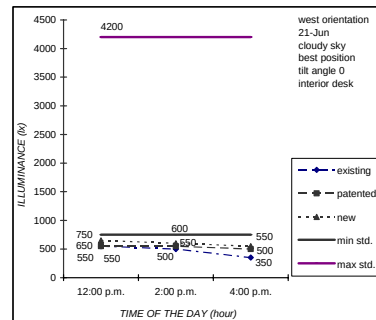
illumiance		12:00 p.m.	2:00 p.m.	4:00 p.m.
west orientation				
21-Dec	existing	1000	600	300
	patented	900	600	300
partly cloudy sky	new	1000	800	450
best position	min std.	750	750	750
tilt angle 45	max std.	4200	4200	4200
interior desk				



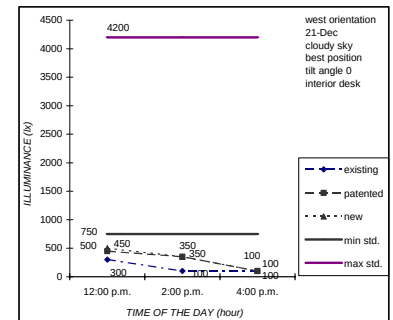
illumiance		12:00 p.m.	2:00 p.m.	4:00 p.m.
west orientation				
21-Mar	existing	550	500	450
	patented	550	550	500
cloudy sky	new	750	550	500
best position	min std.	750	750	750
tilt angle 0	max std.	4200	4200	4200
interior desk				



illumiance		12:00 p.m.	2:00 p.m.	4:00 p.m.
west orientation				
21-Jun	existing	550	500	350
	patented	550	550	500
cloudy sky	new	650	600	550
best position	min std.	750	750	750
tilt angle 0	max std.	4200	4200	4200
interior desk				



illumiance		12:00 p.m.	2:00 p.m.	4:00 p.m.
west orientation				
21-Dec	existing	300	100	100
	patented	450	350	100
cloudy sky	new	500	350	100
best position	min std.	750	750	750
tilt angle 0	max std.	4200	4200	4200
interior desk				



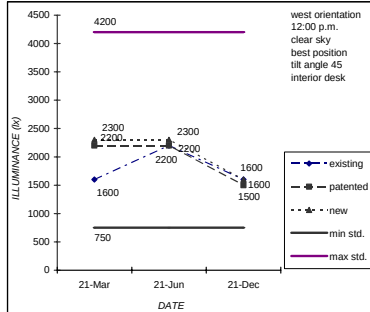
ILLUMINANCE - effect of the date - for different times - for different sky conditions

existing blinds - tilt angle 45 for clear sky and partly cloudy sky and 0 for cloudy sky
 patented blinds - tilt angle 0 always
 new blinds - tilt angle 45 for clear sky and partly cloudy sky and 0 for cloudy sky

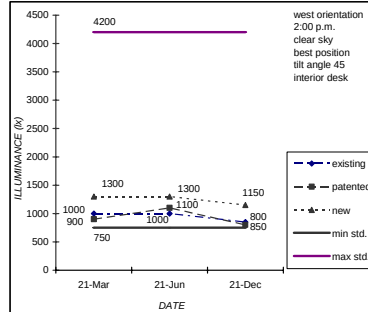
WEST SHEET 2
 ILLUMINANCE SET 4
 INTERIOR

	existing	patented	new
BEST POSITION	inside	between	between

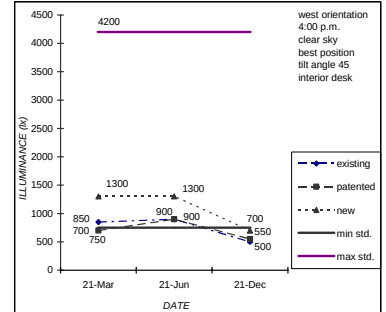
	21-Mar	21-Jun	21-Dec
illuminance west orientation 12:00 p.m. clear sky best position tilt angle 45 interior desk			
existing	1600	2200	1600
patented	2200	2200	1500
new	2300	2300	1600
min std.	750	750	750
max std.	4200	4200	4200



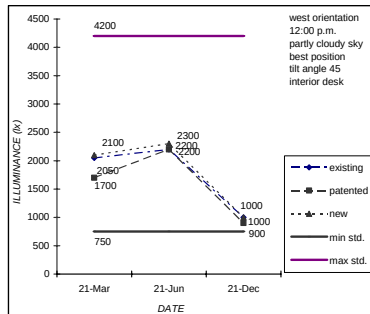
	21-Mar	21-Jun	21-Dec
illuminance west orientation 2:00 p.m. clear sky best position tilt angle 45 interior desk			
existing	1000	1000	850
patented	900	1100	800
new	1300	1300	1150
min std.	750	750	750
max std.	4200	4200	4200



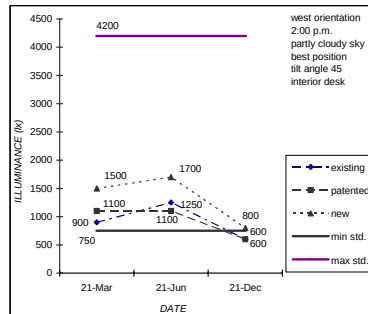
	21-Mar	21-Jun	21-Dec
illuminance west orientation 4:00 p.m. clear sky best position tilt angle 45 interior desk			
existing	850	900	500
patented	700	900	550
new	1300	1300	700
min std.	750	750	750
max std.	4200	4200	4200



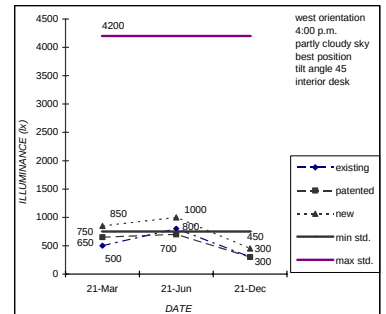
	21-Mar	21-Jun	21-Dec
illuminance west orientation 12:00 p.m. partly cloudy sky best position tilt angle 45 interior desk			
existing	2050	2200	1000
patented	1700	2200	900
new	2100	2300	1000
min std.	750	750	750
max std.	4200	4200	4200



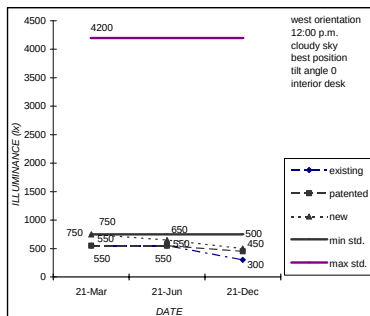
	21-Mar	21-Jun	21-Dec
illuminance west orientation 2:00 p.m. partly cloudy sky best position tilt angle 45 interior desk			
existing	900	1250	600
patented	1100	1100	600
new	1500	1700	800
min std.	750	750	750
max std.	4200	4200	4200



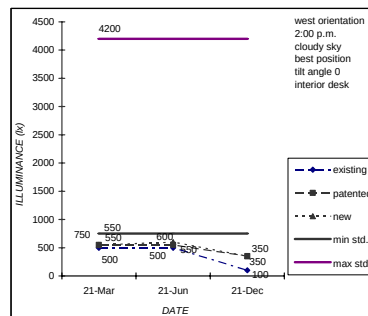
	21-Mar	21-Jun	21-Dec
illuminance west orientation 4:00 p.m. partly cloudy sky best position tilt angle 45 interior desk			
existing	500	800	300
patented	650	700	300
new	850	1000	450
min std.	750	750	750
max std.	4200	4200	4200



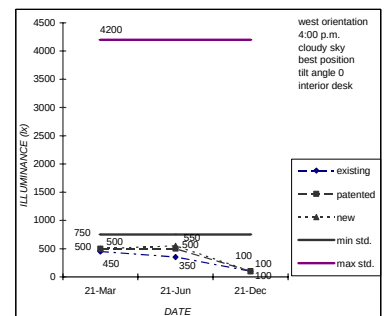
	21-Mar	21-Jun	21-Dec
illuminance west orientation 12:00 p.m. cloudy sky best position tilt angle 0 interior desk			
existing	550	550	300
patented	550	550	450
new	750	650	500
min std.	750	750	750
max std.	4200	4200	4200



	21-Mar	21-Jun	21-Dec
illuminance west orientation 2:00 p.m. cloudy sky best position tilt angle 0 interior desk			
existing	500	500	100
patented	550	550	350
new	550	600	350
min std.	750	750	750
max std.	4200	4200	4200



	21-Mar	21-Jun	21-Dec
illuminance west orientation 4:00 p.m. cloudy sky best position tilt angle 0 interior desk			
existing	450	350	100
patented	500	500	100
new	500	550	100
min std.	750	750	750
max std.	4200	4200	4200



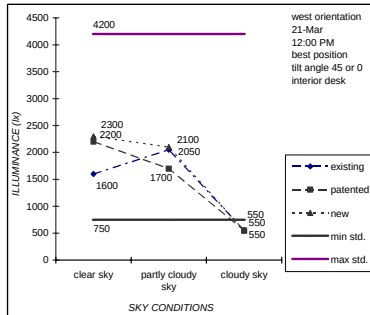
ILLUMINANCE - effect of sky conditions - for different times - for different dates

existing blinds - tilt angle 45 for clear sky and partly cloudy sky and 0 for cloudy sky
 patented blinds - tilt angle 0 always
 new blinds - tilt angle 45 for clear sky and partly cloudy sky and 0 for cloudy sky

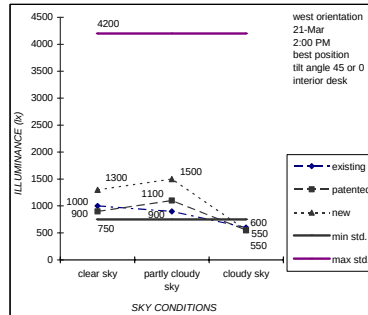
WEST SHEET 3
 ILLUMINANCE SET 4
 INTERIOR

	existing	patented	new
BEST POSITION	inside	between	between

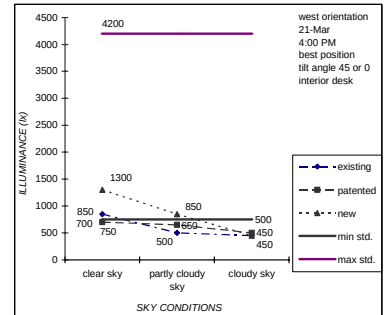
	clear sky	partly cloud	cloudy sky
illuminance			
west orientation			
21-Mar			
12:00 PM			
best position			
tilt angle 45 or 0			
interior desk			
existing	1600	2050	550
patented	2200	1700	550
new	2300	2100	550
min std.	750	750	750
max std.	4200	4200	4200



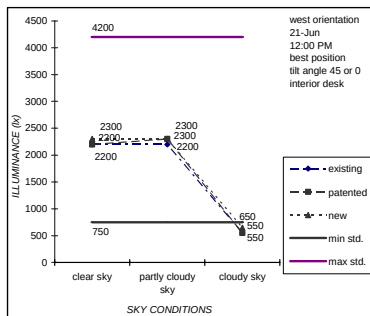
	clear sky	partly cloud	cloudy sky
illuminance			
west orientation			
21-Mar			
2:00 PM			
best position			
tilt angle 45 or 0			
interior desk			
existing	1000	900	600
patented	900	1100	550
new	1300	1500	550
min std.	750	750	750
max std.	4200	4200	4200



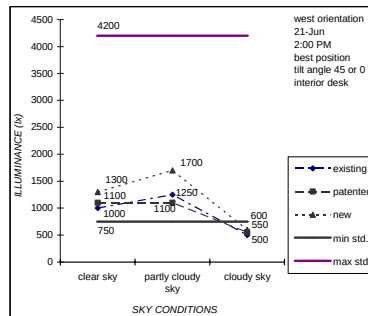
	clear sky	partly cloud	cloudy sky
illuminance			
west orientation			
21-Mar			
4:00 PM			
best position			
tilt angle 45 or 0			
interior desk			
existing	850	500	450
patented	700	650	500
new	1300	850	450
min std.	750	750	750
max std.	4200	4200	4200



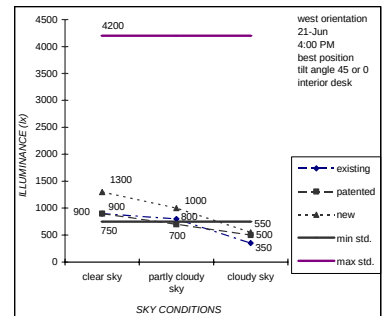
	clear sky	partly cloud	cloudy sky
illuminance			
west orientation			
21-Jun			
12:00 PM			
best position			
tilt angle 45 or 0			
interior desk			
existing	2200	2300	550
patented	2200	2300	550
new	2300	2300	550
min std.	750	750	750
max std.	4200	4200	4200



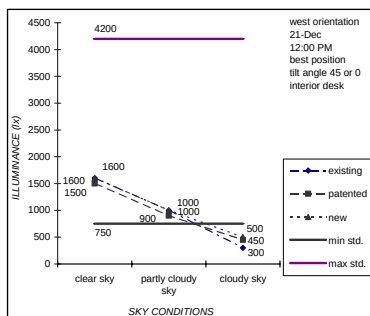
	clear sky	partly cloud	cloudy sky
illuminance			
west orientation			
21-Jun			
2:00 PM			
best position			
tilt angle 45 or 0			
interior desk			
existing	1000	1250	500
patented	1100	1100	550
new	1300	1700	600
min std.	750	750	750
max std.	4200	4200	4200



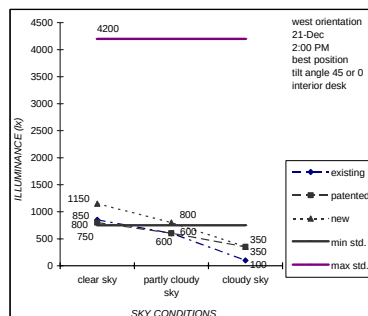
	clear sky	partly cloud	cloudy sky
illuminance			
west orientation			
21-Jun			
4:00 PM			
best position			
tilt angle 45 or 0			
interior desk			
existing	900	800	350
patented	900	700	500
new	1300	1000	550
min std.	750	750	750
max std.	4200	4200	4200



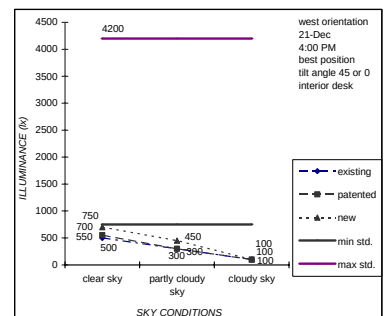
	clear sky	partly cloud	cloudy sky
illuminance			
west orientation			
21-Dec			
12:00 PM			
best position			
tilt angle 45 or 0			
interior desk			
existing	1600	1000	300
patented	1500	900	450
new	1600	1000	500
min std.	750	750	750
max std.	4200	4200	4200



	clear sky	partly cloud	cloudy sky
illuminance			
west orientation			
21-Dec			
2:00 PM			
best position			
tilt angle 45 or 0			
interior desk			
existing	850	600	100
patented	800	600	350
new	1150	800	350
min std.	750	750	750
max std.	4200	4200	4200



	clear sky	partly cloud	cloudy sky
illuminance			
west orientation			
21-Dec			
4:00 PM			
best position			
tilt angle 45 or 0			
interior desk			
existing	500	300	100
patented	550	300	100
new	700	450	100
min std.	750	750	750
max std.	4200	4200	4200



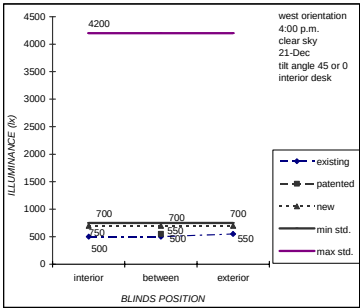
ILLUMINANCE - effect of the blinds position - for different dates - for different sky conditions

WEST SHEET 4
ILLUMINANCE SET 4
INTERIOR

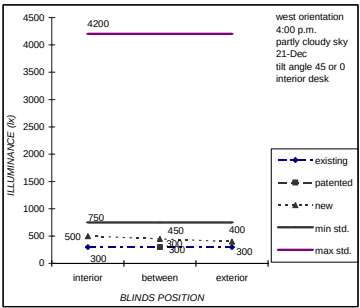
existing blinds - tilt angle 45 for clear sky and partly cloudy sky and 0 for cloudy sky
patented blinds - tilt angle 0 always
new blinds - tilt angle 45 for clear sky and partly cloudy sky and 0 for cloudy sky

	existing	patented	new
BEST POSITION	inside	between	between

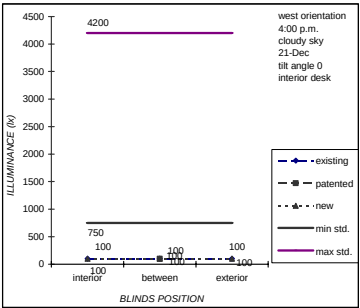
	interior	between	exterior
illumination			
west orientation			
4:00 p.m.			
clear sky	existing	500	500
21-Dec	patented	550	
tilt angle 45 or 0	new	700	700
interior desk	min std.	750	750
	max std.	4200	4200



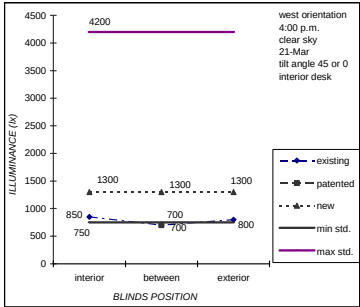
	interior	between	exterior
illumination			
west orientation			
4:00 p.m.			
partly cloudy sky	existing	300	300
21-Dec	patented	300	
tilt angle 45 or 0	new	500	400
interior desk	min std.	750	750
	max std.	4200	4200



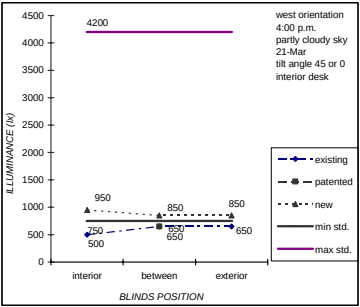
	interior	between	exterior
illumination			
west orientation			
4:00 p.m.			
cloudy sky	existing	100	100
21-Dec	patented	100	
tilt angle 0	new	100	100
interior desk	min std.	750	750
	max std.	4200	4200



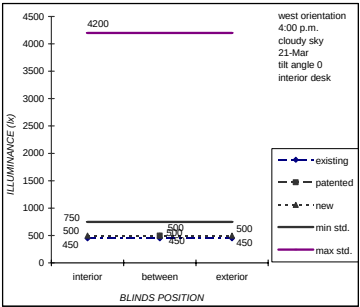
	interior	between	exterior
illumination			
west orientation			
4:00 p.m.			
clear sky	existing	850	800
21-Mar	patented	700	
tilt angle 45 or 0	new	1300	1300
interior desk	min std.	750	750
	max std.	4200	4200



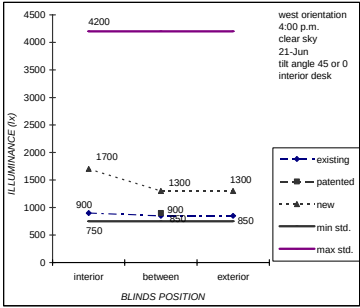
	interior	between	exterior
illumination			
west orientation			
4:00 p.m.			
partly cloudy sky	existing	500	650
21-Mar	patented	650	
tilt angle 45 or 0	new	950	850
interior desk	min std.	750	750
	max std.	4200	4200



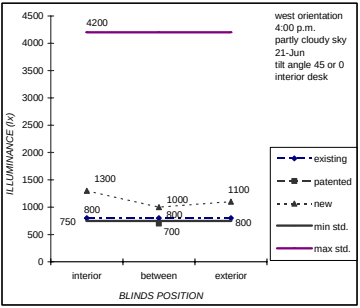
	interior	between	exterior
illumination			
west orientation			
4:00 p.m.			
cloudy sky	existing	450	450
21-Mar	patented	500	
tilt angle 0	new	500	500
interior desk	min std.	750	750
	max std.	4200	4200



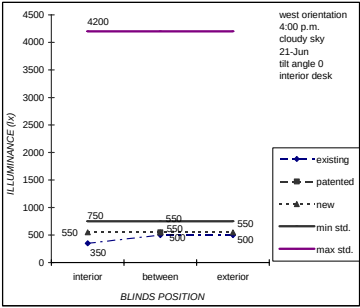
	interior	between	exterior
illumination			
west orientation			
4:00 p.m.			
clear sky	existing	900	850
21-Jun	patented	900	
tilt angle 45 or 0	new	1700	1300
interior desk	min std.	750	750
	max std.	4200	4200



	interior	between	exterior
illumination			
west orientation			
4:00 p.m.			
partly cloudy sky	existing	800	800
21-Jun	patented	700	
tilt angle 45 or 0	new	1300	1100
interior desk	min std.	750	750
	max std.	4200	4200



	interior	between	exterior
illumination			
west orientation			
4:00 p.m.			
cloudy sky	existing	350	500
21-Jun	patented	550	
tilt angle 0	new	550	550
interior desk	min std.	750	750
	max std.	4200	4200

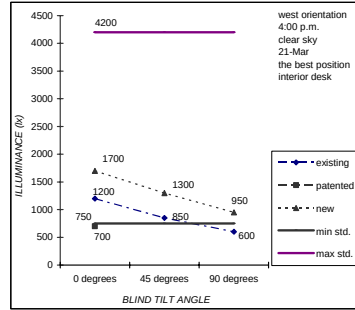


ILLUMINANCE- effect of the blind tilt angle - for different dates - for different sky conditions

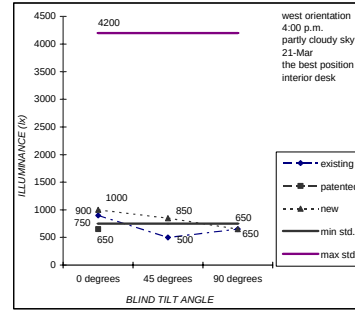
WEST SHEET 5
ILLUMINANCE SET 4
INTERIOR

	existing	patented	new
BEST POSITION	inside	between	between

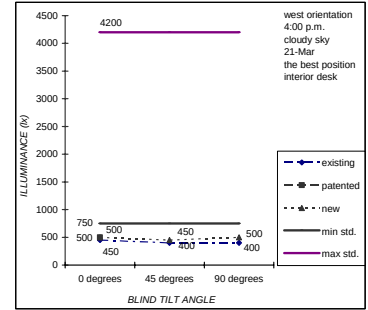
	0 degrees	45 degree	90 degrees
illuminance			
west orientation			
4:00 p.m.			
clear sky			
21-Mar			
the best position			
interior desk			
existing	1200	850	600
patented	700		
new	1700	1300	950
min std.	750	750	750
max std.	4200	4200	4200



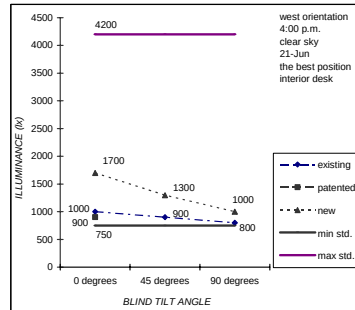
	0 degrees	45 degree	90 degrees
illuminance			
west orientation			
4:00 p.m.			
partly cloudy sky			
21-Mar			
the best position			
interior desk			
existing	900	500	650
patented	650		
new	1000	850	650
min std.	750	750	750
max std.	4200	4200	4200



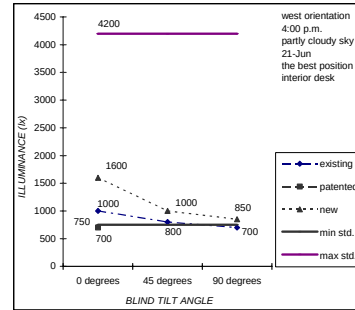
	0 degrees	45 degree	90 degrees
illuminance			
west orientation			
4:00 p.m.			
cloudy sky			
21-Mar			
the best position			
interior desk			
existing	450	400	400
patented	500		
new	500	450	500
min std.	750	750	750
max std.	4200	4200	4200



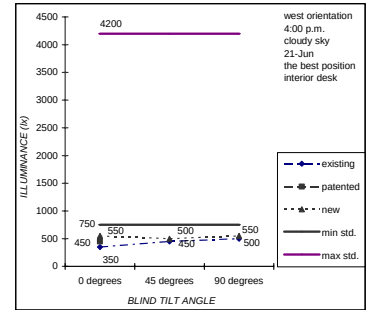
	0 degrees	45 degree	90 degrees
illuminance			
west orientation			
4:00 p.m.			
clear sky			
21-Jun			
the best position			
interior desk			
existing	1000	900	800
patented	900		
new	1700	1300	1000
min std.	750	750	750
max std.	4200	4200	4200



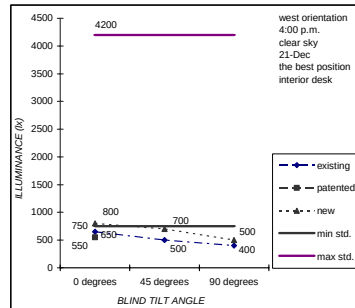
	0 degrees	45 degree	90 degrees
illuminance			
west orientation			
4:00 p.m.			
partly cloudy sky			
21-Jun			
the best position			
interior desk			
existing	1000	800	700
patented	700		
new	1600	1000	850
min std.	750	750	750
max std.	4200	4200	4200



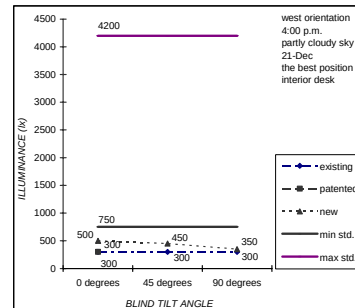
	0 degrees	45 degree	90 degrees
illuminance			
west orientation			
4:00 p.m.			
cloudy sky			
21-Jun			
the best position			
interior desk			
existing	350	450	500
patented	450		
new	550	500	550
min std.	750	750	750
max std.	4200	4200	4200



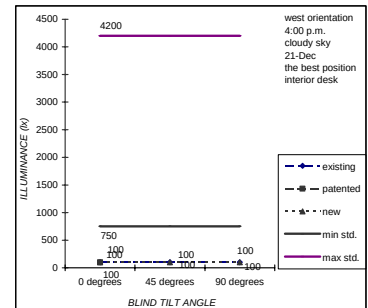
	0 degrees	45 degree	90 degrees
illuminance			
west orientation			
4:00 p.m.			
clear sky			
21-Dec			
the best position			
interior desk			
existing	650	500	400
patented	550		
new	800	700	500
min std.	750	750	750
max std.	4200	4200	4200



	0 degrees	45 degree	90 degrees
illuminance			
west orientation			
4:00 p.m.			
partly cloudy sky			
21-Dec			
the best position			
interior desk			
existing	300	300	300
patented	300		
new	500	450	350
min std.	750	750	750
max std.	4200	4200	4200

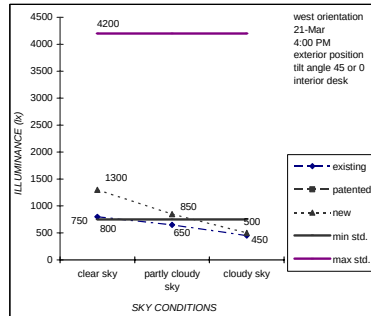


	0 degrees	45 degree	90 degrees
illuminance			
west orientation			
4:00 p.m.			
cloudy sky			
21-Dec			
the best position			
interior desk			
existing	100	100	100
patented	100		
new	100	100	100
min std.	750	750	750
max std.	4200	4200	4200

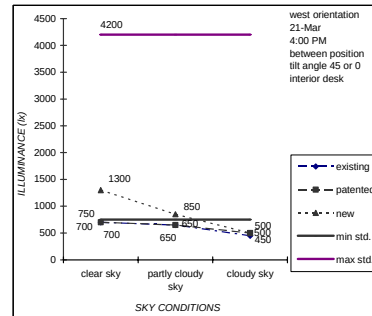


existing blinds - tilt angle 45 for clear sky and partly cloudy sky and 0 for cloudy sky
 patented blinds - tilt angle 0 always
 new blinds - tilt angle 45 for clear sky and partly cloudy sky and 0 for cloudy sky

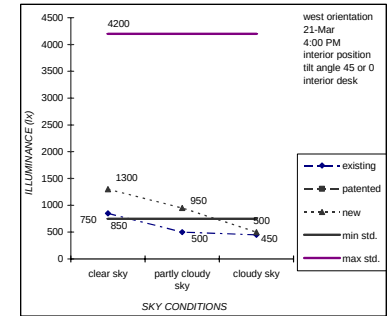
	clear sky	partly cloudy	cloudy sky
illuminance			
west orientation			
21-Mar			
4:00 PM			
exterior position			
tilt angle 45 or 0			
interior desk			
existing	800	650	450
patented			
new	1300	850	500
min std.	750	750	750
max std.	4200	4200	4200



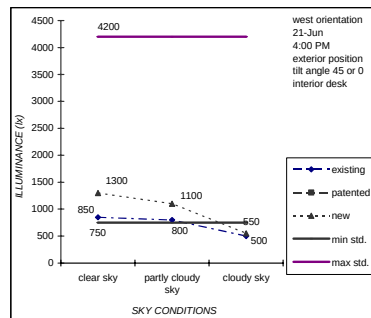
	clear sky	partly cloudy	cloudy sky
illuminance			
west orientation			
21-Mar			
4:00 PM			
between position			
tilt angle 45 or 0			
interior desk			
existing	700	650	450
patented	700	650	500
new	1300	850	500
min std.	750	750	750
max std.	4200	4200	4200



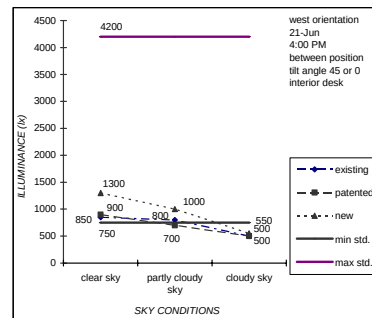
	clear sky	partly cloudy	cloudy sky
illuminance			
west orientation			
21-Mar			
4:00 PM			
interior position			
tilt angle 45 or 0			
interior desk			
existing	850	500	450
patented			
new	1300	950	500
min std.	750	750	750
max std.	4200	4200	4200



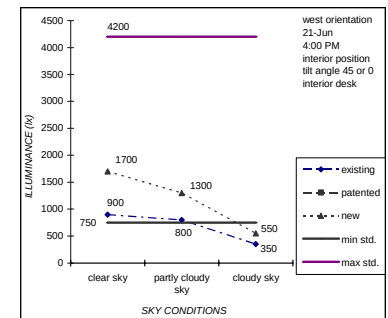
	clear sky	partly cloudy	cloudy sky
illuminance			
west orientation			
21-Jun			
4:00 PM			
exterior position			
tilt angle 45 or 0			
interior desk			
existing	850	800	500
patented			
new	1300	1100	550
min std.	750	750	750
max std.	4200	4200	4200



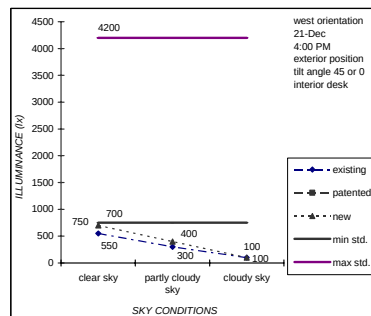
	clear sky	partly cloudy	cloudy sky
illuminance			
west orientation			
21-Jun			
4:00 PM			
between position			
tilt angle 45 or 0			
interior desk			
existing	850	800	500
patented	900	700	500
new	1300	1000	550
min std.	750	750	750
max std.	4200	4200	4200



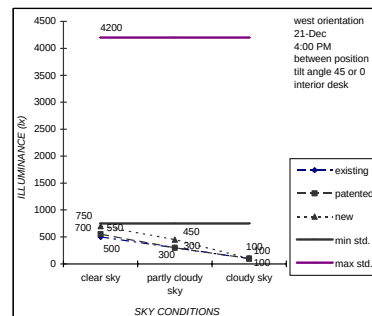
	clear sky	partly cloudy	cloudy sky
illuminance			
west orientation			
21-Jun			
4:00 PM			
interior position			
tilt angle 45 or 0			
interior desk			
existing	900	800	350
patented			
new	1700	1300	550
min std.	750	750	750
max std.	4200	4200	4200



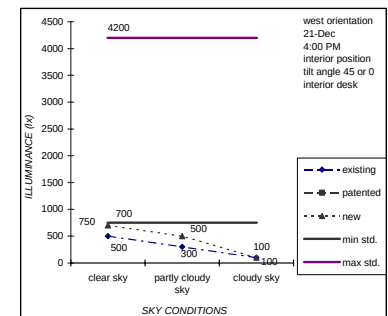
	clear sky	partly cloudy	cloudy sky
illuminance			
west orientation			
21-Dec			
4:00 PM			
exterior position			
tilt angle 45 or 0			
interior desk			
existing	550	300	100
patented			
new	700	400	100
min std.	750	750	750
max std.	4200	4200	4200



	clear sky	partly cloudy	cloudy sky
illuminance			
west orientation			
21-Dec			
4:00 PM			
between position			
tilt angle 45 or 0			
interior desk			
existing	500	300	100
patented	550	300	100
new	700	450	100
min std.	750	750	750
max std.	4200	4200	4200

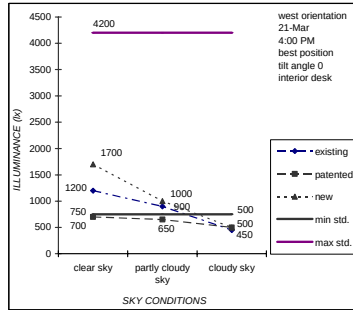


	clear sky	partly cloudy	cloudy sky
illuminance			
west orientation			
21-Dec			
4:00 PM			
interior position			
tilt angle 45 or 0			
interior desk			
existing	500	300	100
patented			
new	700	500	100
min std.	750	750	750
max std.	4200	4200	4200

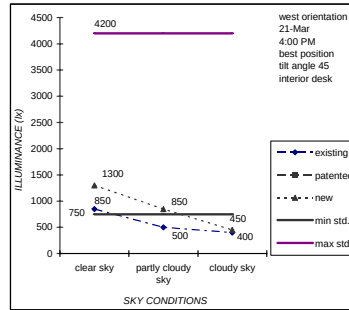


	existing	patented	new
BEST POSITION	inside	between	between

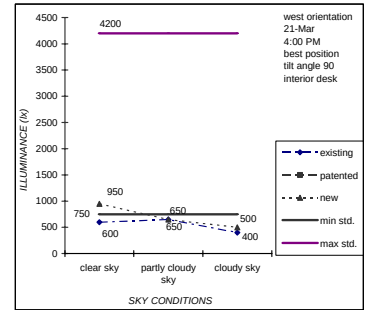
illumination		clear sky	partly cloud	cloudy sky
west orientation	existing	1200	900	450
21-Mar	patented	700	650	500
4:00 PM	new	1700	1000	500
best position	min std.	750	750	750
tilt angle 0	max std.	4200	4200	4200
interior desk				



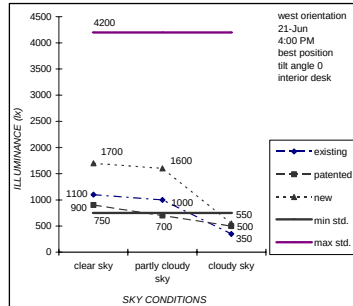
illumination		clear sky	partly cloud	cloudy sky
west orientation	existing	850	500	400
21-Mar	patented			
4:00 PM	new	1300	850	450
best position	min std.	750	750	750
tilt angle 45	max std.	4200	4200	4200
interior desk				



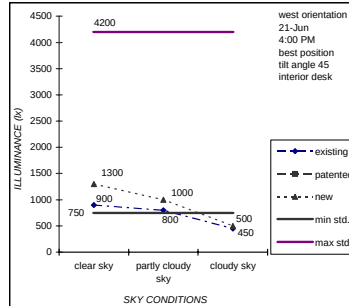
illumination		clear sky	partly cloud	cloudy sky
west orientation	existing	600	650	400
21-Mar	patented			
4:00 PM	new	950	650	500
best position	min std.	750	750	750
tilt angle 90	max std.	4200	4200	4200
interior desk				



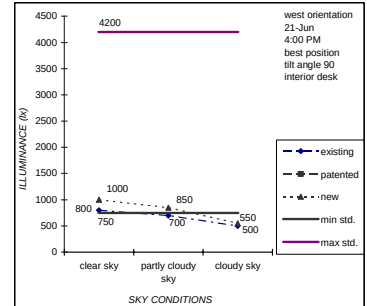
illumination		clear sky	partly cloud	cloudy sky
west orientation	existing	1100	1000	350
21-Jun	patented	900	700	500
4:00 PM	new	1700	1600	550
best position	min std.	750	750	750
tilt angle 0	max std.	4200	4200	4200
interior desk				



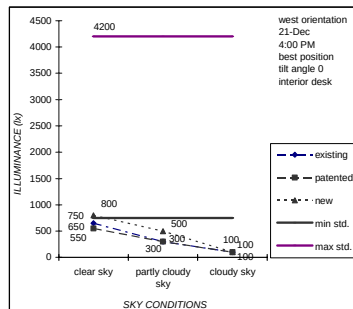
illumination		clear sky	partly cloud	cloudy sky
west orientation	existing	900	800	450
21-Jun	patented			
4:00 PM	new	1300	1000	500
best position	min std.	750	750	750
tilt angle 45	max std.	4200	4200	4200
interior desk				



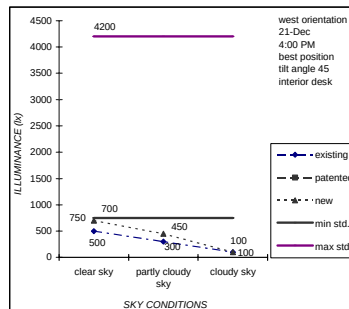
illumination		clear sky	partly cloud	cloudy sky
west orientation	existing	800	700	500
21-Jun	patented			
4:00 PM	new	1000	850	550
best position	min std.	750	750	750
tilt angle 90	max std.	4200	4200	4200
interior desk				



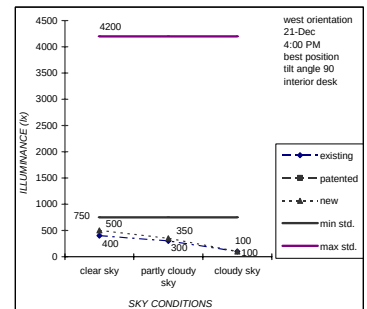
illumination		clear sky	partly cloud	cloudy sky
west orientation	existing	650	300	100
21-Dec	patented	550	300	100
4:00 PM	new	800	500	100
best position	min std.	750	750	750
tilt angle 0	max std.	4200	4200	4200
interior desk				



illumination		clear sky	partly cloud	cloudy sky
west orientation	existing	500	300	100
21-Dec	patented			
4:00 PM	new	700	450	100
best position	min std.	750	750	750
tilt angle 45	max std.	4200	4200	4200
interior desk				



illumination		clear sky	partly cloud	cloudy sky
west orientation	existing	400	300	100
21-Dec	patented			
4:00 PM	new	500	350	100
best position	min std.	750	750	750
tilt angle 90	max std.	4200	4200	4200
interior desk				

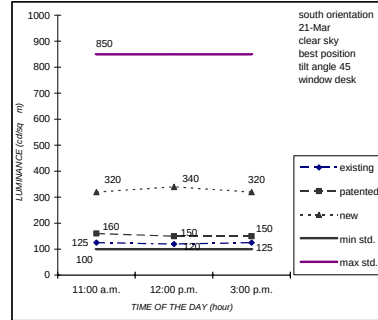


LUMINANCE- effect of the time - for different dates - for different sky conditions

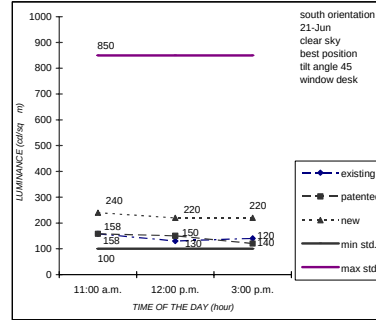
existing blinds - tilt angle 45 for clear sky and partly cloudy sky and 0 for cloudy sky
 patented blinds - tilt angle 0 always
 new blinds - tilt angle 45 for clear sky and partly cloudy sky and 0 for cloudy sky

SOUTH SHEET 1
 LUMINANCE SET 5
 WINDOW

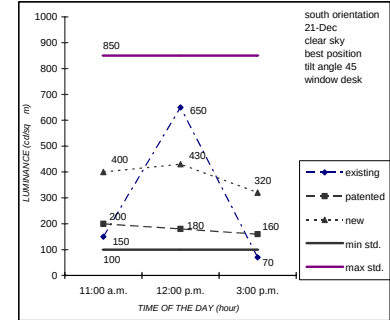
luminance		11:00 a.m.	12:00 p.m.	3:00 p.m.
south orientation				
21-Mar	existing	125	120	125
clear sky	patented	160	150	150
best position	new	320	340	320
tilt angle 45	min std.	100	100	100
window desk	max std.	850	850	850



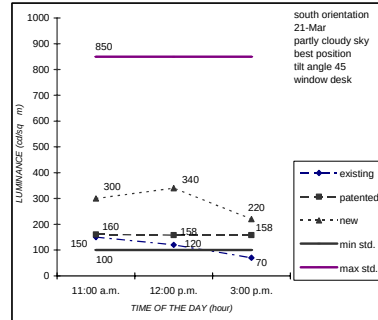
luminance		11:00 a.m.	12:00 p.m.	3:00 p.m.
south orientation				
21-Jun	existing	158	130	140
clear sky	patented	158	150	120
best position	new	240	220	220
tilt angle 45	min std.	100	100	100
window desk	max std.	850	850	850



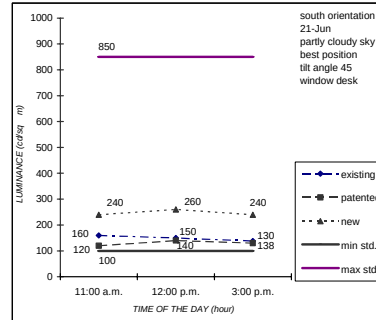
luminance		11:00 a.m.	12:00 p.m.	3:00 p.m.
south orientation				
21-Dec	existing	150	650	70
clear sky	patented	200	180	160
best position	new	400	430	320
tilt angle 45	min std.	100	100	100
window desk	max std.	850	850	850



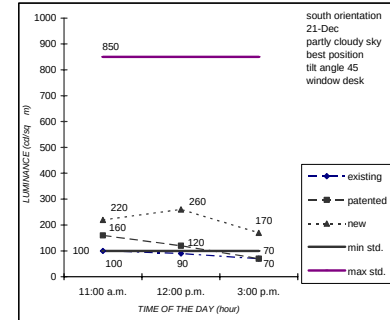
luminance		11:00 a.m.	12:00 p.m.	3:00 p.m.
south orientation				
21-Mar	existing	150	120	70
partly cloudy sky	patented	160	158	158
best position	new	300	340	220
tilt angle 45	min std.	100	100	100
window desk	max std.	850	850	850



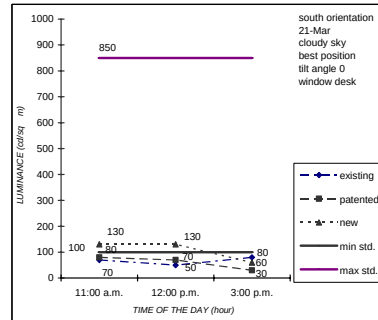
luminance		11:00 a.m.	12:00 p.m.	3:00 p.m.
south orientation				
21-Jun	existing	160	150	138
partly cloudy sky	patented	120	140	130
best position	new	240	260	240
tilt angle 45	min std.	100	100	100
window desk	max std.	850	850	850



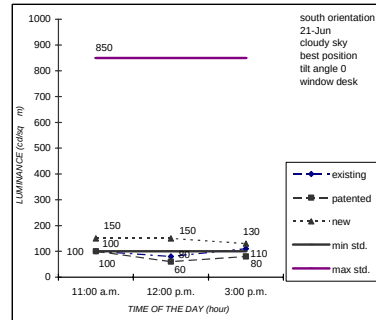
luminance		11:00 a.m.	12:00 p.m.	3:00 p.m.
south orientation				
21-Dec	existing	100	90	70
partly cloudy sky	patented	160	120	70
best position	new	220	260	170
tilt angle 45	min std.	100	100	100
window desk	max std.	850	850	850



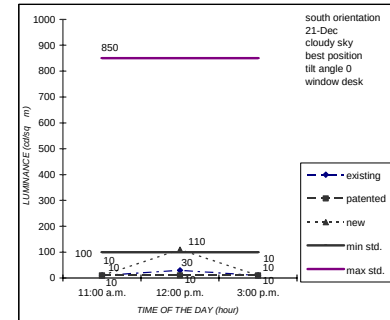
luminance		11:00 a.m.	12:00 p.m.	3:00 p.m.
south orientation				
21-Mar	existing	70	50	80
cloudy sky	patented	80	70	30
best position	new	130	130	60
tilt angle 0	min std.	100	100	100
window desk	max std.	850	850	850



luminance		11:00 a.m.	12:00 p.m.	3:00 p.m.
south orientation				
21-Jun	existing	100	80	110
cloudy sky	patented	100	60	80
best position	new	150	150	130
tilt angle 0	min std.	100	100	100
window desk	max std.	850	850	850



luminance		11:00 a.m.	12:00 p.m.	3:00 p.m.
south orientation				
21-Dec	existing	10	30	10
cloudy sky	patented	10	10	10
best position	new	10	110	10
tilt angle 0	min std.	100	100	100
window desk	max std.	850	850	850

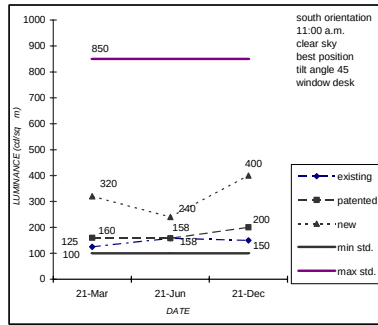


LUMINANCE - effect of the date -for different times - for different sky conditions

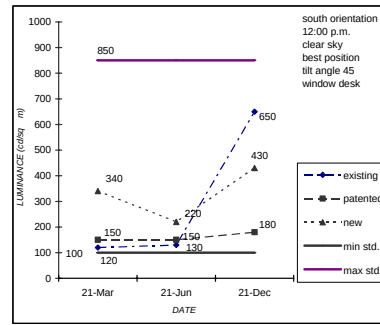
existing blinds - tilt angle 45 for clear sky and partly cloudy sky and 0 for cloudy sky
 patented blinds - tilt angle 0 always
 new blinds - tilt angle 45 for clear sky and partly cloudy sky and 0 for cloudy sky

SOUTH SHEET 2
 LUMINANCE SET 5
 WINDOW

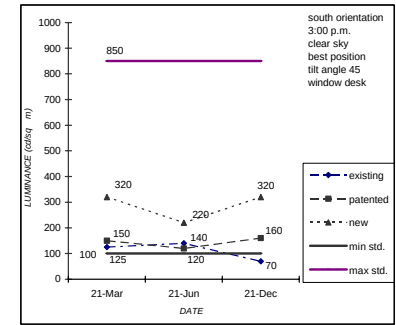
	21-Mar	21-Jun	21-Dec
luminance south orientation			
11:00 a.m.			
clear sky	existing 125	158	150
patented	160	158	200
new	320	240	400
best position	min std. 100	100	100
tilt angle 45	max std. 850	850	850
window desk			



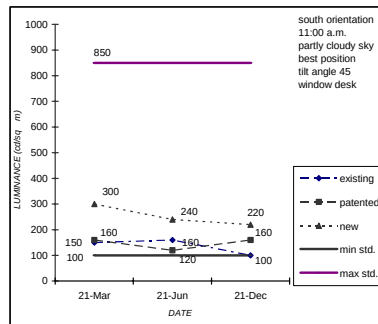
	21-Mar	21-Jun	21-Dec
luminance south orientation			
12:00 p.m.			
clear sky	existing 120	130	650
patented	150	150	180
new	340	220	430
best position	min std. 100	100	100
tilt angle 45	max std. 850	850	850
window desk			



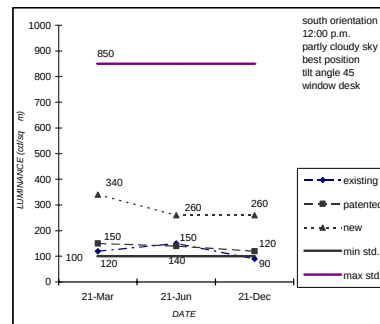
	21-Mar	21-Jun	21-Dec
luminance south orientation			
3:00 p.m.			
clear sky	existing 125	140	70
patented	150	120	160
new	320	220	320
best position	min std. 100	100	100
tilt angle 45	max std. 850	850	850
window desk			



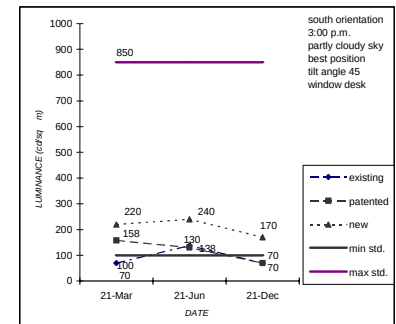
	21-Mar	21-Jun	21-Dec
luminance south orientation			
11:00 a.m.			
partly cloudy sky	existing 150	160	100
patented	160	120	160
new	300	240	220
best position	min std. 100	100	100
tilt angle 45	max std. 850	850	850
window desk			



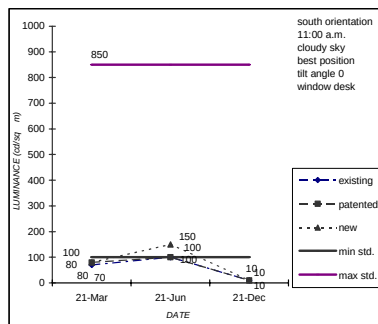
	21-Mar	21-Jun	21-Dec
luminance south orientation			
12:00 p.m.			
partly cloudy sky	existing 120	150	90
patented	150	140	120
new	340	260	260
best position	min std. 100	100	100
tilt angle 45	max std. 850	850	850
window desk			



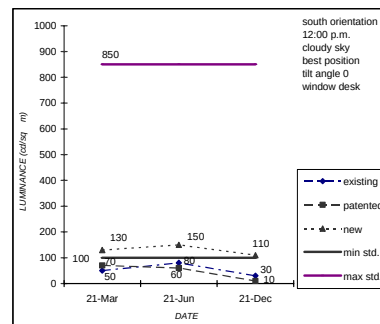
	21-Mar	21-Jun	21-Dec
luminance south orientation			
3:00 p.m.			
partly cloudy sky	existing 70	138	70
patented	158	130	70
new	220	240	170
best position	min std. 100	100	100
tilt angle 45	max std. 850	850	850
window desk			



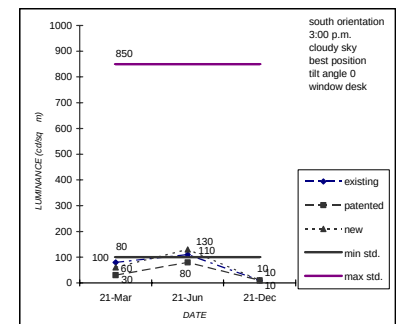
	21-Mar	21-Jun	21-Dec
luminance south orientation			
11:00 a.m.			
cloudy sky	existing 70	100	10
patented	80	100	10
new	80	150	10
best position	min std. 100	100	100
tilt angle 0	max std. 850	850	850
window desk			



	21-Mar	21-Jun	21-Dec
luminance south orientation			
12:00 p.m.			
cloudy sky	existing 50	80	30
patented	70	60	10
new	130	150	110
best position	min std. 100	100	100
tilt angle 0	max std. 850	850	850
window desk			



	21-Mar	21-Jun	21-Dec
luminance south orientation			
3:00 p.m.			
cloudy sky	existing 80	110	10
patented	30	80	10
new	60	130	10
best position	min std. 100	100	100
tilt angle 0	max std. 850	850	850
window desk			



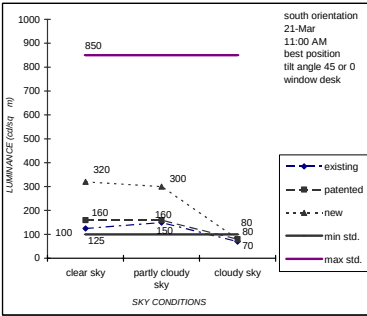
LUMINANCE - effect of sky conditions - for different times - for different dates

existing blinds - tilt angle 45 for clear sky and partly cloudy sky and 0 for cloudy sky
patented blinds - tilt angle 0 always
new blinds - tilt angle 45 for clear sky and partly cloudy sky and 0 for cloudy sky

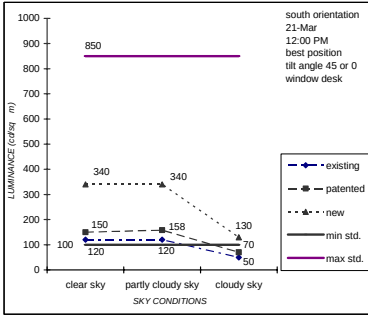
SOUTH SHEET 3
LUMINANCE SET 5
WINDOW

	existing	patented	new
BEST POSITION	inside	between	between

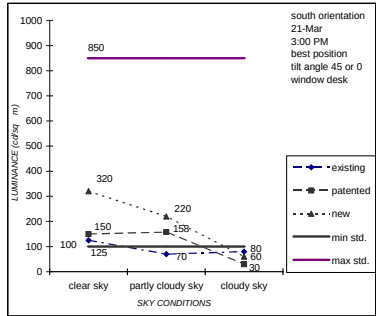
	clear sky	partly cloudy sky	cloudy sky
luminance			
south orientation			
21-Mar			
11:00 AM	existing	125	150
	patented	160	160
	new	320	300
best position	min std.	100	100
tilt angle 45 or 0	max std.	850	850
window desk			



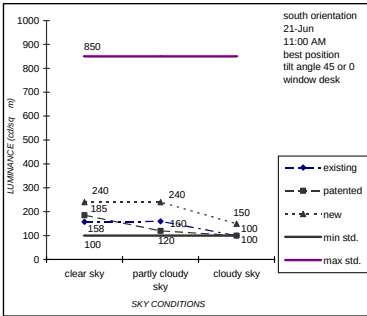
	clear sky	partly cloudy sky	cloudy sky
luminance			
south orientation			
21-Mar			
12:00 PM	existing	120	120
	patented	150	158
	new	340	340
best position	min std.	100	100
tilt angle 45 or 0	max std.	850	850
window desk			



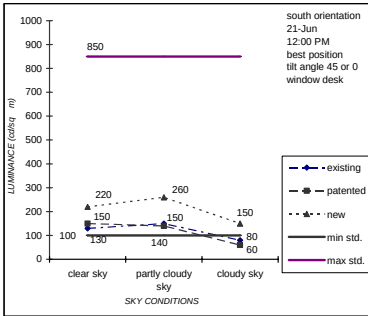
	clear sky	partly cloudy sky	cloudy sky
luminance			
south orientation			
21-Mar			
3:00 PM	existing	125	70
	patented	150	158
	new	320	220
best position	min std.	100	100
tilt angle 45 or 0	max std.	850	850
window desk			



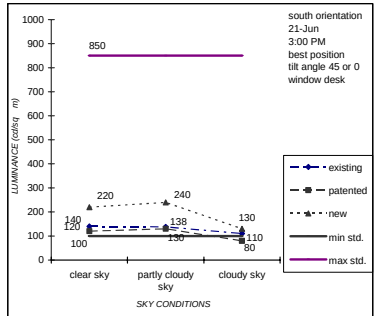
	clear sky	partly cloudy sky	cloudy sky
luminance			
south orientation			
21-Jun			
11:00 AM	existing	158	160
	patented	185	120
	new	240	240
best position	min std.	100	100
tilt angle 45 or 0	max std.	850	850
window desk			



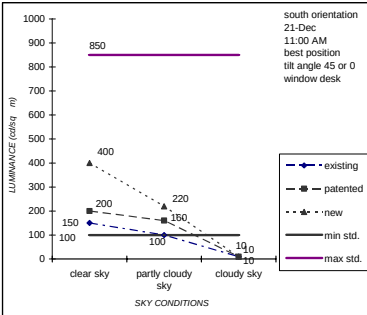
	clear sky	partly cloudy sky	cloudy sky
luminance			
south orientation			
21-Jun			
12:00 PM	existing	130	150
	patented	150	140
	new	220	260
best position	min std.	100	100
tilt angle 45 or 0	max std.	850	850
window desk			



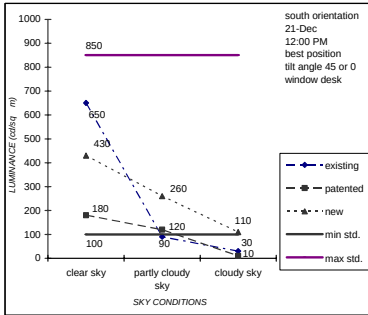
	clear sky	partly cloudy sky	cloudy sky
luminance			
south orientation			
21-Jun			
3:00 PM	existing	140	138
	patented	120	130
	new	220	240
best position	min std.	100	100
tilt angle 45 or 0	max std.	850	850
window desk			



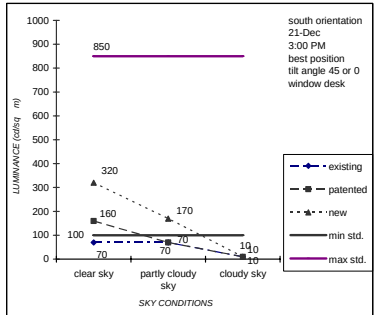
	clear sky	partly cloudy sky	cloudy sky
luminance			
south orientation			
21-Dec			
11:00 AM	existing	150	100
	patented	200	160
	new	400	220
best position	min std.	100	100
tilt angle 45 or 0	max std.	850	850
window desk			



	clear sky	partly cloudy sky	cloudy sky
luminance			
south orientation			
21-Dec			
12:00 PM	existing	650	90
	patented	480	120
	new	430	260
best position	min std.	100	100
tilt angle 45 or 0	max std.	850	850
window desk			



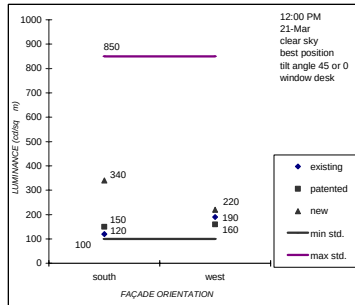
	clear sky	partly cloudy sky	cloudy sky
luminance			
south orientation			
21-Dec			
3:00 PM	existing	70	70
	patented	160	70
	new	320	170
best position	min std.	100	100
tilt angle 45 or 0	max std.	850	850
window desk			



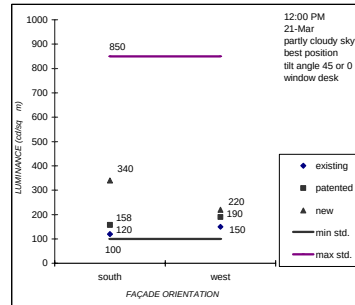
existing blinds - tilt angle 45 for clear sky and partly cloudy sky and 0 for cloudy sky
 patented blinds - tilt angle 0 always
 new blinds - tilt angle 45 for clear sky and partly cloudy sky and 0 for cloudy sky

	existing	patented	new
BEST POSITION	inside	between	between

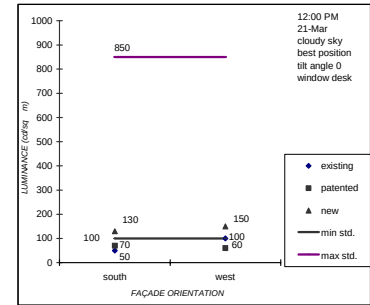
	south	west
luminance		
12:00 PM		
21-Mar		
clear sky		
best position		
tilt angle 45 or 0		
window desk		
existing	120	190
patented	150	160
new	340	220
min std.	100	100
max std.	850	850



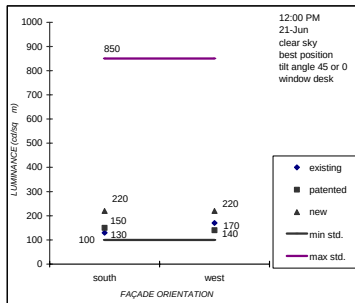
	south	west
luminance		
12:00 PM		
21-Mar		
partly cloudy sky		
best position		
tilt angle 45 or 0		
window desk		
existing	120	150
patented	158	190
new	340	220
min std.	100	100
max std.	850	850



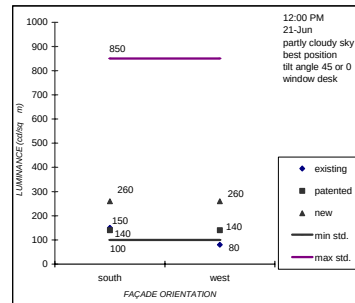
	south	west
luminance		
12:00 PM		
21-Mar		
cloudy sky		
best position		
tilt angle 0		
window desk		
existing	50	100
patented	70	60
new	130	150
min std.	100	100
max std.	850	850



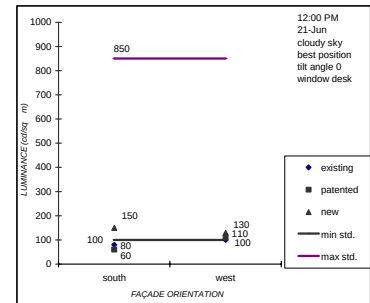
	south	west
luminance		
12:00 PM		
21-Jun		
clear sky		
best position		
tilt angle 45 or 0		
window desk		
existing	130	170
patented	150	140
new	220	220
min std.	100	100
max std.	850	850



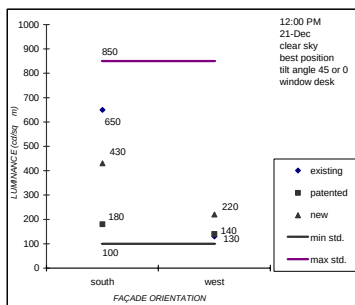
	south	west
luminance		
12:00 PM		
21-Jun		
partly cloudy sky		
best position		
tilt angle 45 or 0		
window desk		
existing	150	80
patented	140	140
new	260	260
min std.	100	100
max std.	850	850



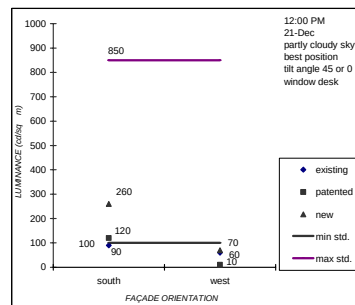
	south	west
luminance		
12:00 PM		
21-Jun		
cloudy sky		
best position		
tilt angle 0		
window desk		
existing	80	100
patented	60	110
new	150	130
min std.	100	100
max std.	850	850



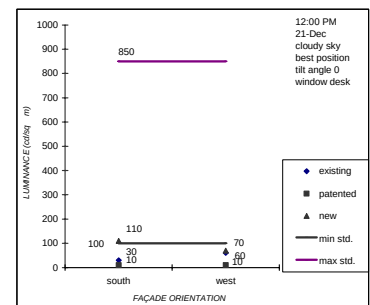
	south	west
luminance		
12:00 PM		
21-Dec		
clear sky		
best position		
tilt angle 45 or 0		
window desk		
existing	650	130
patented	180	140
new	430	220
min std.	100	100
max std.	850	850



	south	west
luminance		
12:00 PM		
21-Dec		
partly cloudy sky		
best position		
tilt angle 45 or 0		
window desk		
existing	90	60
patented	120	10
new	260	70
min std.	100	100
max std.	850	850



	south	west
luminance		
12:00 PM		
21-Dec		
cloudy sky		
best position		
tilt angle 0		
window desk		
existing	30	60
patented	10	10
new	110	70
min std.	100	100
max std.	850	850

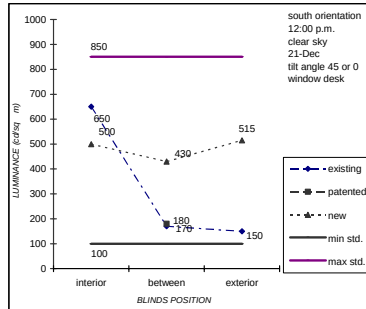


LUMINANCE- effect of the blinds position - for different dates - for different sky conditions

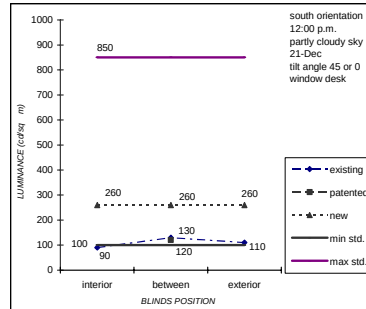
existing blinds - tilt angle 45 for clear sky and partly cloudy sky and 0 for cloudy sky
patented blinds - tilt angle 0 always
new blinds - tilt angle 45 for clear sky and partly cloudy sky and 0 for cloudy sky

SOUTH SHEET 5
LUMINANCE SET 5
WINDOW

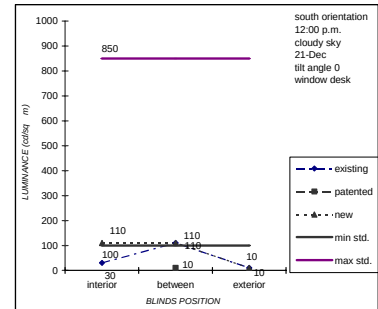
	interior	between	exterior
luminance south orientation 12:00 p.m. clear sky 21-Dec tilt angle 45 or 0 window desk			
existing	650	170	150
patented		180	
new	500	430	515
min std.	100	100	100
max std.	850	850	850



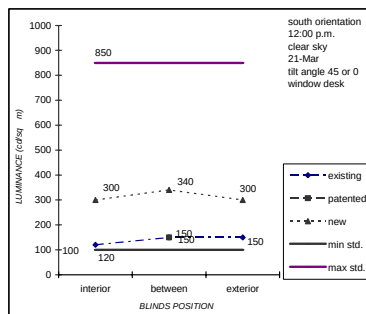
	interior	between	exterior
luminance south orientation 12:00 p.m. partly cloudy sky 21-Dec tilt angle 45 or 0 window desk			
existing	90	130	110
patented		120	
new	260	260	260
min std.	100	100	100
max std.	850	850	850



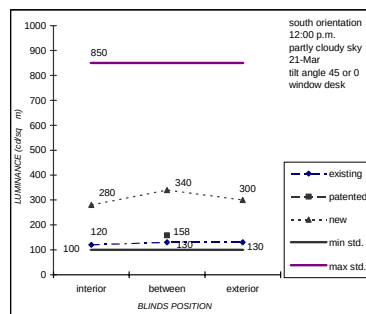
	interior	between	exterior
luminance south orientation 12:00 p.m. cloudy sky 21-Dec tilt angle 0 window desk			
existing	30	110	10
patented		10	
new	110	110	10
min std.	100	100	100
max std.	850	850	850



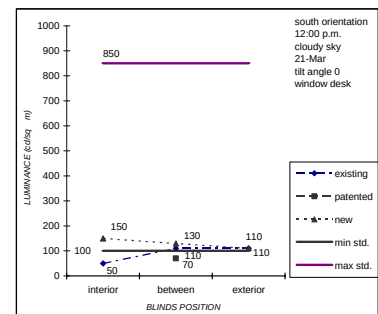
	interior	between	exterior
luminance south orientation 12:00 p.m. clear sky 21-Mar tilt angle 45 or 0 window desk			
existing	120	150	150
patented		150	
new	300	340	300
min std.	100	100	100
max std.	850	850	850



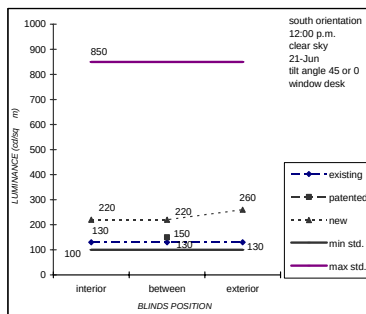
	interior	between	exterior
luminance south orientation 12:00 p.m. partly cloudy sky 21-Mar tilt angle 45 or 0 window desk			
existing	120	130	130
patented		158	
new	280	340	300
min std.	100	100	100
max std.	850	850	850



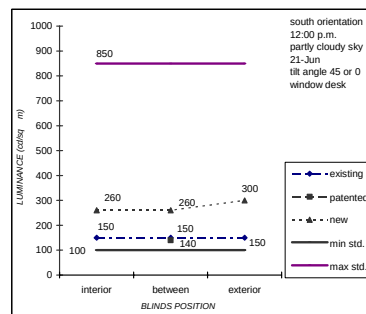
	interior	between	exterior
luminance south orientation 12:00 p.m. cloudy sky 21-Mar tilt angle 0 window desk			
existing	50	110	110
patented		70	
new	150	130	110
min std.	100	100	100
max std.	850	850	850



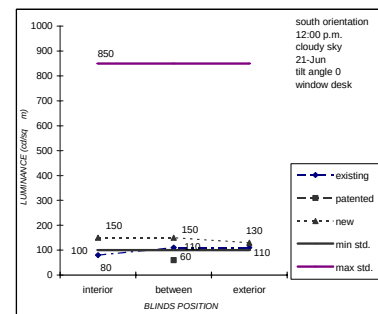
	interior	between	exterior
luminance south orientation 12:00 p.m. clear sky 21-Jun tilt angle 45 or 0 window desk			
existing	130	130	130
patented		150	
new	220	220	260
min std.	100	100	100
max std.	850	850	850



	interior	between	exterior
luminance south orientation 12:00 p.m. partly cloudy sky 21-Jun tilt angle 45 or 0 window desk			
existing	150	150	150
patented		140	
new	260	260	300
min std.	100	100	100
max std.	850	850	850



	interior	between	exterior
luminance south orientation 12:00 p.m. cloudy sky 21-Jun tilt angle 0 window desk			
existing	80	110	110
patented		60	
new	150	150	130
min std.	100	100	100
max std.	850	850	850

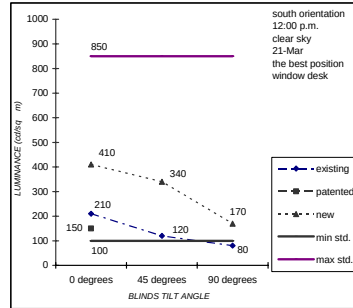


LUMINANCE- effect of the blind tilt angle - for different dates - for different sky conditions

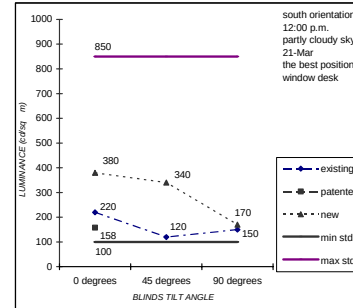
SOUTH SHEET 6
LUMINANCE SET 5
WINDOW

	existing	patented	new
BEST POSITION	inside	between	between

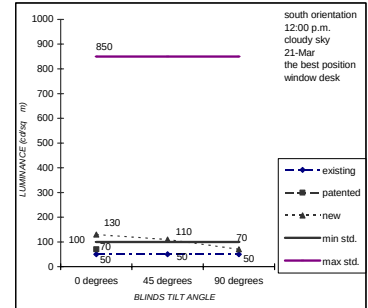
	0 degrees	45 degree	90 degrees
luminance			
south orientation			
12:00 p.m.	existing 210	45 degree 120	90 degrees 80
clear sky	patented 150		
21-Mar	new 410	340	170
the best position	min std. 100	100	100
window desk	max std. 850	850	850



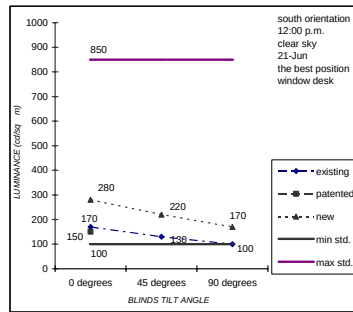
	0 degrees	45 degree	90 degrees
luminance			
south orientation			
12:00 p.m.	existing 220	45 degree 120	90 degrees 150
partly cloudy sky	patented 158		
21-Mar	new 380	340	170
the best position	min std. 100	100	100
window desk	max std. 850	850	850



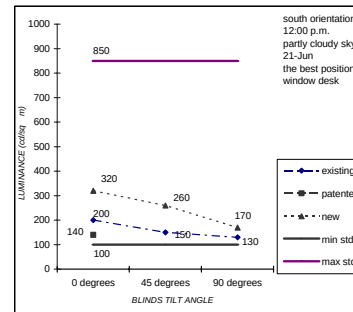
	0 degrees	45 degree	90 degrees
luminance			
south orientation			
12:00 p.m.	existing 50	45 degree 50	90 degrees 50
cloudy sky	patented 70		
21-Mar	new 130	110	70
the best position	min std. 100	100	100
window desk	max std. 850	850	850



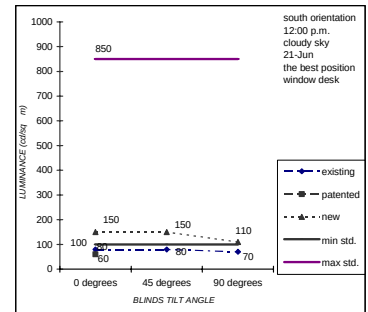
	0 degrees	45 degree	90 degrees
luminance			
south orientation			
12:00 p.m.	existing 170	45 degree 130	90 degrees 100
clear sky	patented 150		
21-Jun	new 280	220	170
the best position	min std. 100	100	100
window desk	max std. 850	850	850



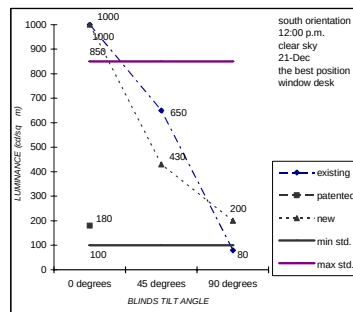
	0 degrees	45 degree	90 degrees
luminance			
south orientation			
12:00 p.m.	existing 200	45 degree 150	90 degrees 130
partly cloudy sky	patented 140		
21-Jun	new 320	260	170
the best position	min std. 100	100	100
window desk	max std. 850	850	850



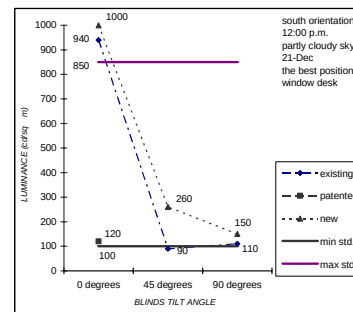
	0 degrees	45 degree	90 degrees
luminance			
south orientation			
12:00 p.m.	existing 80	45 degree 80	90 degrees 70
cloudy sky	patented 60		
21-Jun	new 150	150	110
the best position	min std. 100	100	100
window desk	max std. 850	850	850



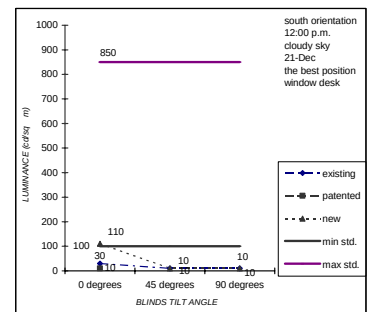
	0 degrees	45 degree	90 degrees
luminance			
south orientation			
12:00 p.m.	existing 1000	45 degree 650	90 degrees 80
clear sky	patented 180		
21-Dec	new 1000	430	200
the best position	min std. 100	100	100
window desk	max std. 850	850	850



	0 degrees	45 degree	90 degrees
luminance			
south orientation			
12:00 p.m.	existing 940	45 degree 90	90 degrees 110
partly cloudy sky	patented 120		
21-Dec	new 1000	260	150
the best position	min std. 100	100	100
window desk	max std. 850	850	850



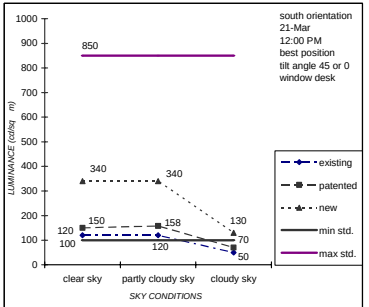
	0 degrees	45 degree	90 degrees
luminance			
south orientation			
12:00 p.m.	existing 30	45 degree 10	90 degrees 10
cloudy sky	patented 10		
21-Dec	new 110	10	10
the best position	min std. 100	100	100
window desk	max std. 850	850	850



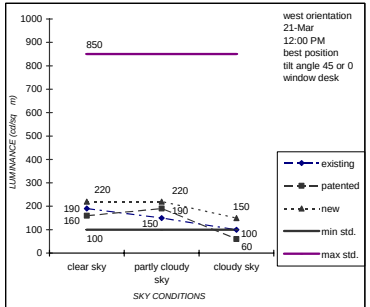
existing blinds - tilt angle 45 for clear sky and partly cloudy sky and 0 for cloudy sky
patented blinds - tilt angle 0 always
new blinds - tilt angle 45 for clear sky and partly cloudy sky and 0 for cloudy sky

	existing	patented	new
BEST POSITION	inside	between	between

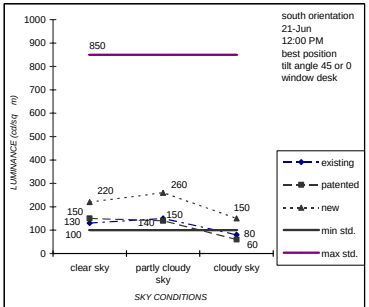
	clear sky	partly cloudy	cloudy sky
luminance			
south orientation			
21-Mar	existing 120	120	50
12:00 PM	patented 150	158	70
best position	new 340	340	130
tilt angle 45 or 0	min std. 100	100	100
window desk	max std. 850	850	850



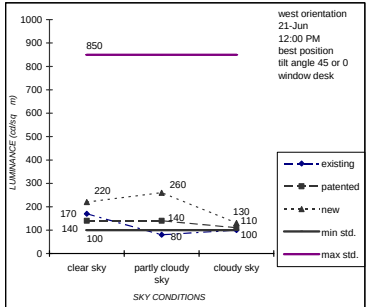
	clear sky	partly cloudy	cloudy sky
luminance			
west orientation			
21-Mar	existing 190	150	100
12:00 PM	patented 160	190	60
best position	new 220	220	150
tilt angle 45 or 0	min std. 100	100	100
window desk	max std. 850	850	850



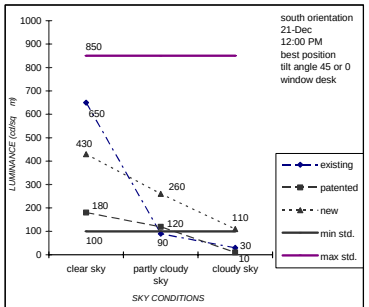
	clear sky	partly cloudy	cloudy sky
luminance			
south orientation			
21-Jun	existing 130	150	80
12:00 PM	patented 150	140	60
best position	new 220	260	150
tilt angle 45 or 0	min std. 100	100	100
window desk	max std. 850	850	850



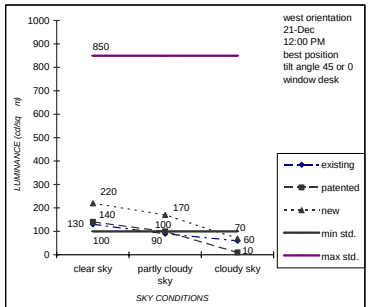
	clear sky	partly cloudy	cloudy sky
luminance			
west orientation			
21-Jun	existing 170	80	100
12:00 PM	patented 140	140	110
best position	new 220	260	130
tilt angle 45 or 0	min std. 100	100	100
window desk	max std. 850	850	850



	clear sky	partly cloudy	cloudy sky
luminance			
south orientation			
21-Dec	existing 650	90	30
12:00 PM	patented 180	120	10
best position	new 430	260	110
tilt angle 45 or 0	min std. 100	100	100
window desk	max std. 850	850	850



	clear sky	partly cloudy	cloudy sky
luminance			
west orientation			
21-Dec	existing 130	90	60
12:00 PM	patented 140	100	10
best position	new 220	170	70
tilt angle 45 or 0	min std. 100	100	100
window desk	max std. 850	850	850

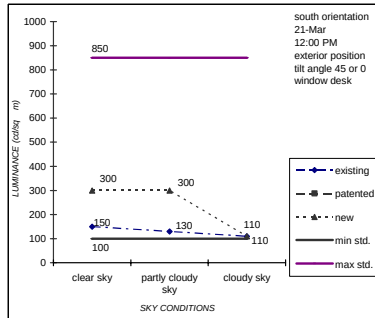


LUMINANCE - effect of sky conditions-for different positions of the blinds - for different dates

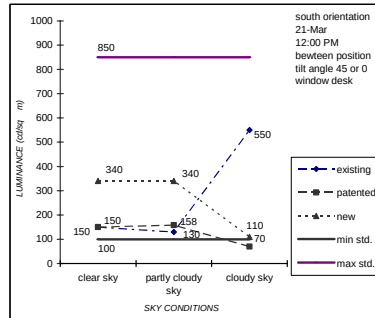
existing blinds - tilt angle 45 for clear sky and partly cloudy sky and 0 for cloudy sky
patented blinds - tilt angle 0 always
new blinds - tilt angle 45 for clear sky and partly cloudy sky and 0 for cloudy sky

SOUTH SHEET 8
LUMINANCE SET 5
WINDOW

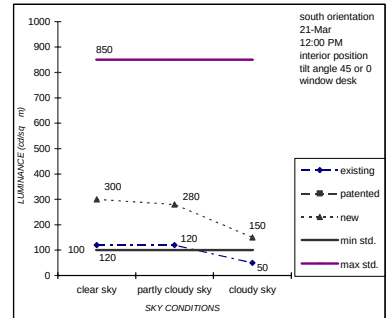
	clear sky	partly cloudy sky	cloudy sky
luminance			
south orientation			
21-Mar			
12:00 PM			
exterior position			
tilt angle 45 or 0			
window desk			
existing	150	130	110
patented			
new	300	300	110
min std.	100	100	100
max std.	850	850	850



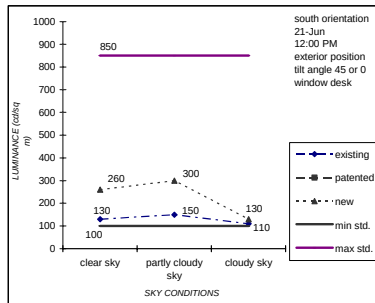
	clear sky	partly cloudy sky	cloudy sky
luminance			
south orientation			
21-Mar			
12:00 PM			
between position			
tilt angle 45 or 0			
window desk			
existing	150	130	550
patented			
new	340	340	110
min std.	100	100	100
max std.	850	850	850



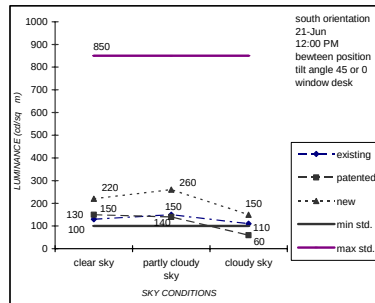
	clear sky	partly cloudy sky	cloudy sky
luminance			
south orientation			
21-Mar			
12:00 PM			
interior position			
tilt angle 45 or 0			
window desk			
existing	120	120	50
patented			
new	300	280	150
min std.	100	100	100
max std.	850	850	850



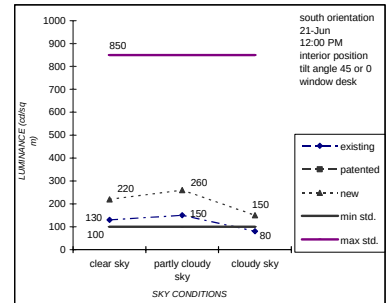
	clear sky	partly cloudy sky	cloudy sky
luminance			
south orientation			
21-Jun			
12:00 PM			
exterior position			
tilt angle 45 or 0			
window desk			
existing	130	150	110
patented			
new	260	300	130
min std.	100	100	100
max std.	850	850	850



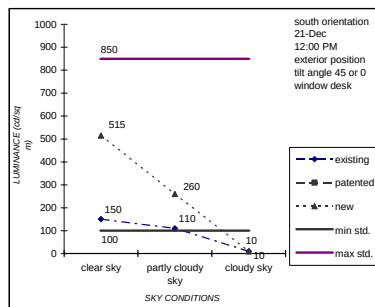
	clear sky	partly cloudy sky	cloudy sky
luminance			
south orientation			
21-Jun			
12:00 PM			
between position			
tilt angle 45 or 0			
window desk			
existing	130	150	110
patented			
new	220	260	150
min std.	100	100	100
max std.	850	850	850



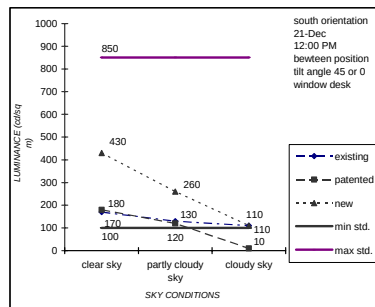
	clear sky	partly cloudy sky	cloudy sky
luminance			
south orientation			
21-Jun			
12:00 PM			
interior position			
tilt angle 45 or 0			
window desk			
existing	130	150	80
patented			
new	220	260	150
min std.	100	100	100
max std.	850	850	850



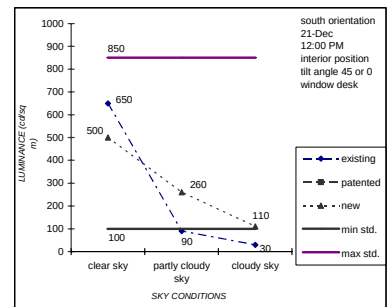
	clear sky	partly cloudy sky	cloudy sky
luminance			
south orientation			
21-Dec			
12:00 PM			
exterior position			
tilt angle 45 or 0			
window desk			
existing	150	110	10
patented			
new	515	260	10
min std.	100	100	100
max std.	850	850	850



	clear sky	partly cloudy sky	cloudy sky
luminance			
south orientation			
21-Dec			
12:00 PM			
between position			
tilt angle 45 or 0			
window desk			
existing	170	130	110
patented			
new	430	260	110
min std.	100	100	100
max std.	850	850	850



	clear sky	partly cloudy sky	cloudy sky
luminance			
south orientation			
21-Dec			
12:00 PM			
interior position			
tilt angle 45 or 0			
window desk			
existing	650	90	30
patented			
new	500	260	110
min std.	100	100	100
max std.	850	850	850

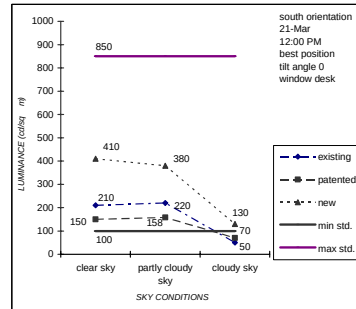


LUMINANCE - effect of sky conditions - for different blind tilt angles - for different dates

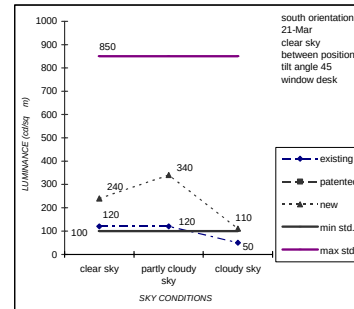
	existing	patented	new
BEST POSITION	inside	between	between

SOUTH SHEET 9
LUMINANCE SET 5
WINDOW

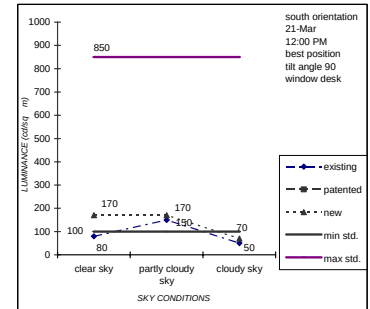
	clear sky	partly cloudy sky	cloudy sky
luminance south orientation			
21-Mar			
12:00 PM			
best position			
tilt angle 0			
window desk			
existing	210	220	50
patented	150	158	70
new	410	380	130
min std.	100	100	100
max std.	850	850	850



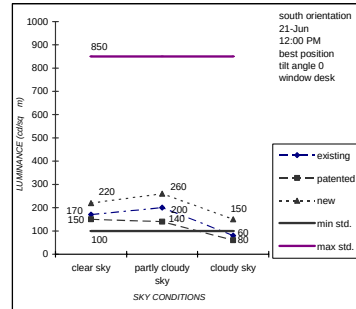
	clear sky	partly cloudy sky	cloudy sky
luminance south orientation			
21-Mar			
12:00 PM			
best position			
tilt angle 45			
window desk			
existing	120	120	50
patented			
new	240	340	110
min std.	100	100	100
max std.	850	850	850



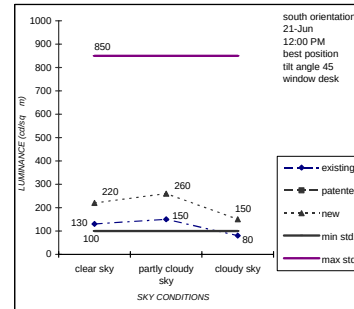
	clear sky	partly cloudy sky	cloudy sky
luminance south orientation			
21-Mar			
12:00 PM			
best position			
tilt angle 90			
window desk			
existing	80	150	50
patented			
new	170	170	70
min std.	100	100	100
max std.	850	850	850



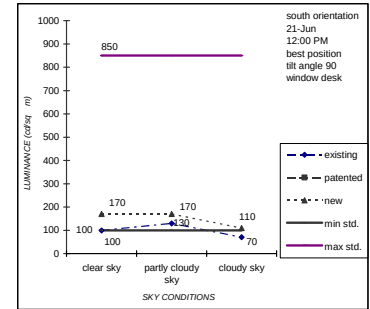
	clear sky	partly cloudy sky	cloudy sky
luminance south orientation			
21-Jun			
12:00 PM			
best position			
tilt angle 0			
window desk			
existing	170	200	80
patented	150	140	60
new	220	260	150
min std.	100	100	100
max std.	850	850	850



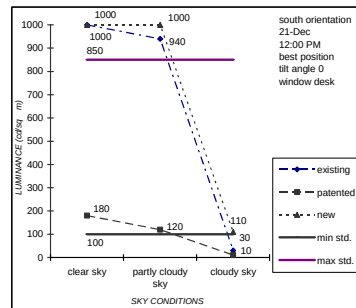
	clear sky	partly cloudy sky	cloudy sky
luminance south orientation			
21-Jun			
12:00 PM			
best position			
tilt angle 45			
window desk			
existing	130	150	80
patented			
new	220	260	150
min std.	100	100	100
max std.	850	850	850



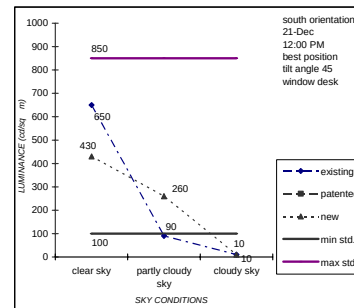
	clear sky	partly cloudy sky	cloudy sky
luminance south orientation			
21-Jun			
12:00 PM			
best position			
tilt angle 90			
window desk			
existing	100	130	70
patented			
new	170	170	110
min std.	100	100	100
max std.	850	850	850



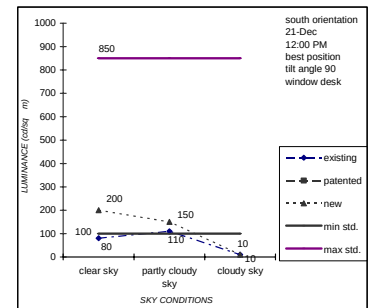
	clear sky	partly cloudy sky	cloudy sky
luminance south orientation			
21-Dec			
12:00 PM			
best position			
tilt angle 0			
window desk			
existing	1000	940	30
patented	180	120	10
new	1000	1000	110
min std.	100	100	100
max std.	850	850	850



	clear sky	partly cloudy sky	cloudy sky
luminance south orientation			
21-Dec			
12:00 PM			
best position			
tilt angle 45			
window desk			
existing	650	90	10
patented			
new	430	260	10
min std.	100	100	100
max std.	850	850	850



	clear sky	partly cloudy sky	cloudy sky
luminance south orientation			
21-Dec			
12:00 PM			
best position			
tilt angle 90			
window desk			
existing	80	110	10
patented			
new	200	150	10
min std.	100	100	100
max std.	850	850	850



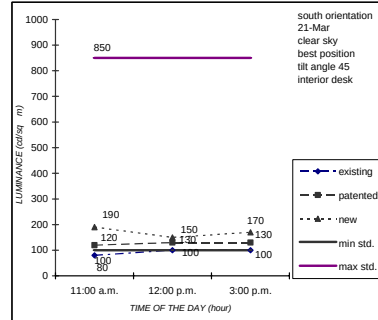
LUMINANCE- effect of the time - for different dates - for different sky conditions

existing blinds - tilt angle 45 for clear sky and partly cloudy sky and 0 for cloudy sky
 patented blinds - tilt angle 0 always
 new blinds - tilt angle 45 for clear sky and partly cloudy sky and 0 for cloudy sky

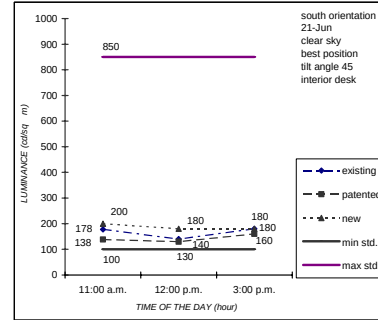
SOUTH SHEET 1
 LUMINANCE SET 6
 INTERIOR

	existing	patented	new
BEST POSITION	inside	between	between

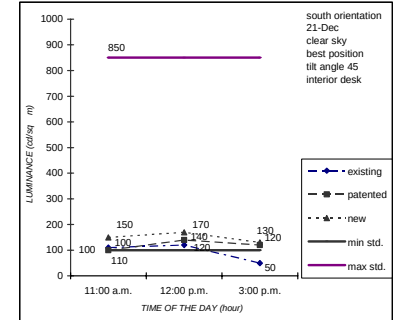
luminance	11:00 a.m.	12:00 p.m.	3:00 p.m.
south orientation			
21-Mar			
clear sky	existing 80	100	100
best position	patented 120	130	130
tilt angle 45	new 190	150	170
interior desk	min std. 100	100	100
	max std. 850	850	850



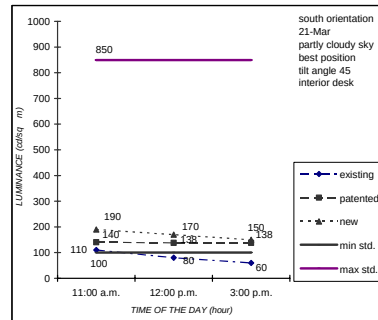
luminance	11:00 a.m.	12:00 p.m.	3:00 p.m.
south orientation			
21-Jun			
clear sky	existing 178	140	180
best position	patented 138	130	160
tilt angle 45	new 200	180	180
interior desk	min std. 100	100	100
	max std. 850	850	850



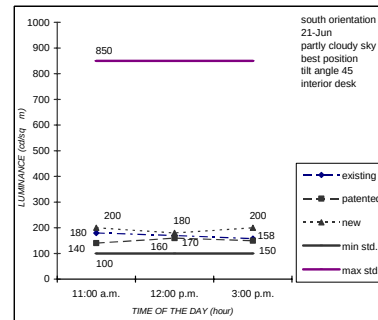
luminance	11:00 a.m.	12:00 p.m.	3:00 p.m.
south orientation			
21-Dec			
clear sky	existing 110	120	50
best position	patented 100	140	120
tilt angle 45	new 150	170	130
interior desk	min std. 100	100	100
	max std. 850	850	850



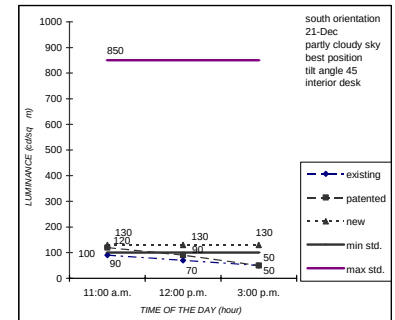
luminance	11:00 a.m.	12:00 p.m.	3:00 p.m.
south orientation			
21-Mar			
partly cloudy sky	existing 110	80	60
best position	patented 140	138	138
tilt angle 45	new 190	170	150
interior desk	min std. 100	100	100
	max std. 850	850	850



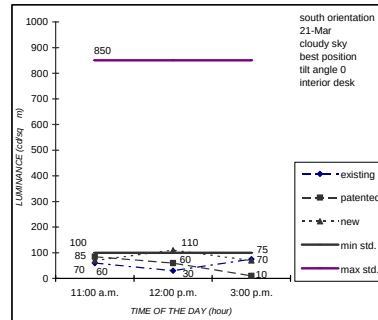
luminance	11:00 a.m.	12:00 p.m.	3:00 p.m.
south orientation			
21-Jun			
partly cloudy sky	existing 180	170	158
best position	patented 140	160	150
tilt angle 45	new 200	180	200
interior desk	min std. 100	100	100
	max std. 850	850	850



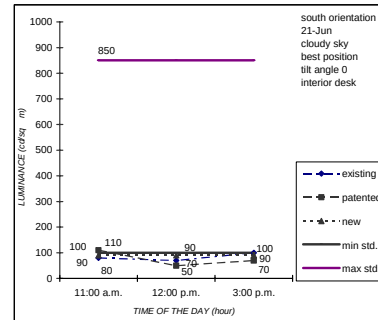
luminance	11:00 a.m.	12:00 p.m.	3:00 p.m.
south orientation			
21-Dec			
partly cloudy sky	existing 90	70	50
best position	patented 120	90	50
tilt angle 45	new 130	130	130
interior desk	min std. 100	100	100
	max std. 850	850	850



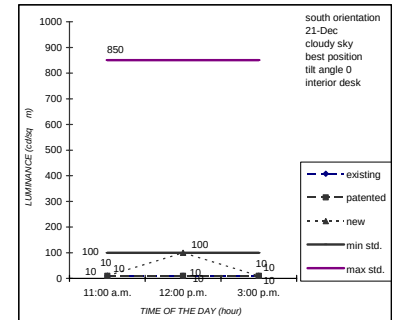
luminance	11:00 a.m.	12:00 p.m.	3:00 p.m.
south orientation			
21-Mar			
cloudy sky	existing 60	30	75
best position	patented 85	60	10
tilt angle 0	new 70	110	70
interior desk	min std. 100	100	100
	max std. 850	850	850



luminance	11:00 a.m.	12:00 p.m.	3:00 p.m.
south orientation			
21-Jun			
cloudy sky	existing 80	70	100
best position	patented 110	50	70
tilt angle 0	new 90	90	90
interior desk	min std. 100	100	100
	max std. 850	850	850



luminance	11:00 a.m.	12:00 p.m.	3:00 p.m.
south orientation			
21-Dec			
cloudy sky	existing 10	10	10
best position	patented 10	10	10
tilt angle 0	new 10	100	10
interior desk	min std. 100	100	100
	max std. 850	850	850



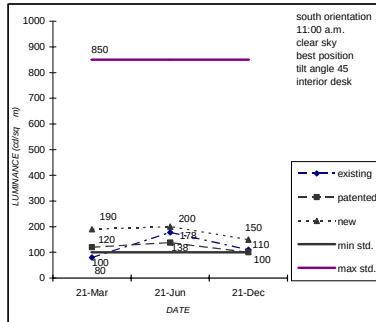
LUMINANCE - effect of the date -for different times - for different sky conditions

existing blinds - tilt angle 45 for clear sky and partly cloudy sky and 0 for cloudy sky
patented blinds - tilt angle 0 always
new blinds - tilt angle 45 for clear sky and partly cloudy sky and 0 for cloudy sky

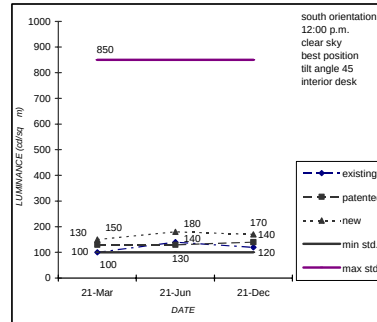
SOUTH SHEET 2
LUMINANCE SET 6
INTERIOR

	existing	patented	new
BEST POSITION	inside	between	between

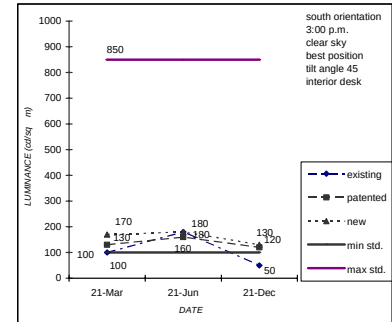
	21-Mar	21-Jun	21-Dec
luminance			
south orientation			
11:00 a.m.			
clear sky	existing 80	178	110
patented	120	138	100
new	190	200	150
best position	min std. 100	100	100
tilt angle 45	max std. 850	850	850
interior desk			



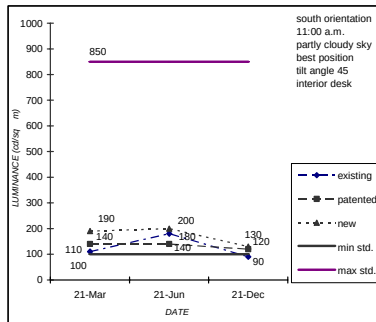
	21-Mar	21-Jun	21-Dec
luminance			
south orientation			
12:00 p.m.			
clear sky	existing 100	140	120
patented	130	130	140
new	150	180	170
best position	min std. 100	100	100
tilt angle 45	max std. 850	850	850
interior desk			



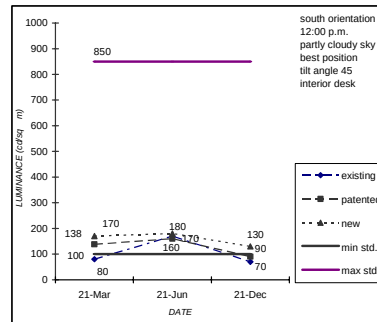
	21-Mar	21-Jun	21-Dec
luminance			
south orientation			
3:00 p.m.			
clear sky	existing 100	180	50
patented	130	160	120
new	170	180	130
best position	min std. 100	100	100
tilt angle 45	max std. 850	850	850
interior desk			



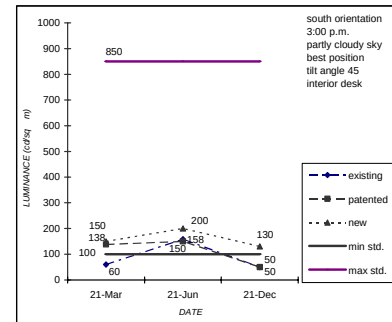
	21-Mar	21-Jun	21-Dec
luminance			
south orientation			
11:00 a.m.			
partly cloudy sky	existing 110	180	90
patented	140	140	120
new	190	200	130
best position	min std. 100	100	100
tilt angle 45	max std. 850	850	850
interior desk			



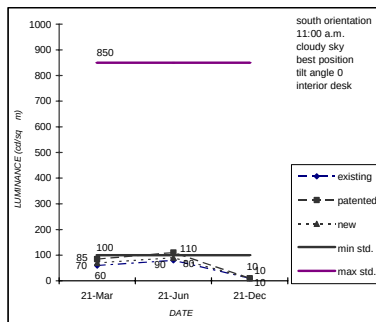
	21-Mar	21-Jun	21-Dec
luminance			
south orientation			
12:00 p.m.			
partly cloudy sky	existing 80	170	70
patented	138	160	90
new	170	180	130
best position	min std. 100	100	100
tilt angle 45	max std. 850	850	850
interior desk			



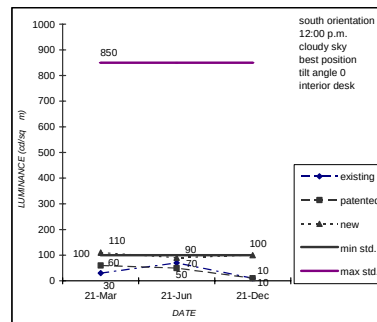
	21-Mar	21-Jun	21-Dec
luminance			
south orientation			
3:00 p.m.			
partly cloudy sky	existing 60	158	50
patented	138	150	50
new	150	200	130
best position	min std. 100	100	100
tilt angle 45	max std. 850	850	850
interior desk			



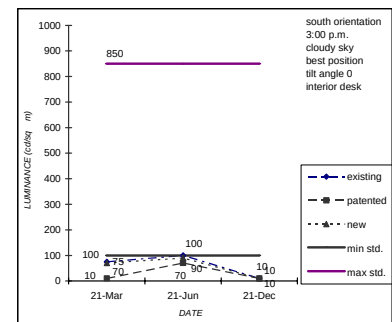
	21-Mar	21-Jun	21-Dec
luminance			
south orientation			
11:00 a.m.			
cloudy sky	existing 60	80	10
patented	85	110	10
new	70	90	10
best position	min std. 100	100	100
tilt angle 0	max std. 850	850	850
interior desk			



	21-Mar	21-Jun	21-Dec
luminance			
south orientation			
12:00 p.m.			
cloudy sky	existing 30	70	10
patented	60	50	10
new	110	90	100
best position	min std. 100	100	100
tilt angle 0	max std. 850	850	850
interior desk			



	21-Mar	21-Jun	21-Dec
luminance			
south orientation			
3:00 p.m.			
cloudy sky	existing 75	100	10
patented	10	70	10
new	70	90	10
best position	min std. 100	100	100
tilt angle 0	max std. 850	850	850
interior desk			



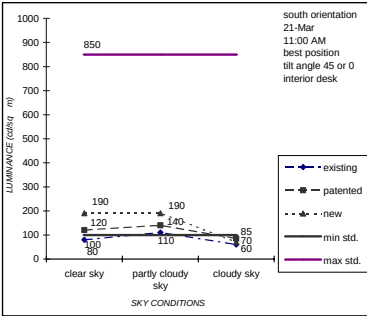
LUMINANCE - effect of sky conditions - for different times - for different dates

existing blinds - tilt angle 45 for clear sky and partly cloudy sky and 0 for cloudy sky
patented blinds - tilt angle 0 always
new blinds - tilt angle 45 for clear sky and partly cloudy sky and 0 for cloudy sky

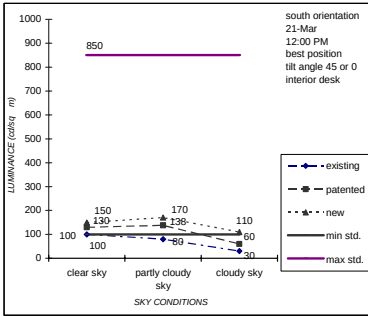
	existing	patented	new
BEST POSITION	inside	between	between

SOUTH SHEET 3
LUMINANCE SET 6
INTERIOR

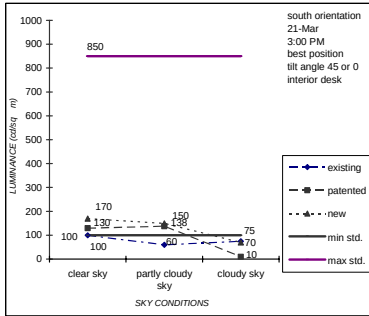
	clear sky	partly cloud	cloudy sky
luminance			
south orientation			
21-Mar			
11:00 AM			
best position			
tilt angle 45 or 0			
interior desk			
existing	80	110	60
patented	120	140	85
new	190	190	70
min std.	100	100	100
max std.	850	850	850



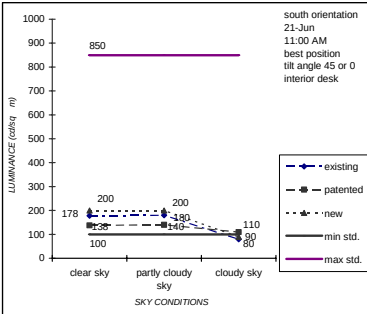
	clear sky	partly cloud	cloudy sky
luminance			
south orientation			
21-Mar			
12:00 PM			
best position			
tilt angle 45 or 0			
interior desk			
existing	100	80	30
patented	130	138	60
new	150	170	110
min std.	100	100	100
max std.	850	850	850



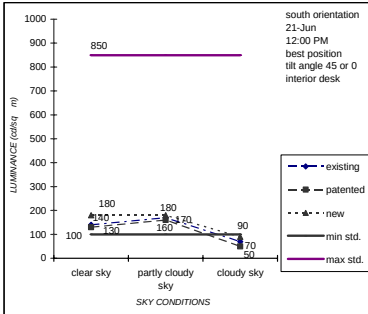
	clear sky	partly cloud	cloudy sky
luminance			
south orientation			
21-Mar			
3:00 PM			
best position			
tilt angle 45 or 0			
interior desk			
existing	100	60	75
patented	130	138	10
new	170	150	70
min std.	100	100	100
max std.	850	850	850



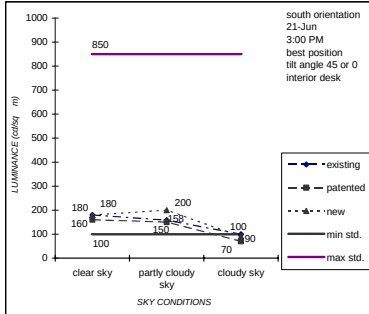
	clear sky	partly cloud	cloudy sky
luminance			
south orientation			
21-Jun			
11:00 AM			
best position			
tilt angle 45 or 0			
interior desk			
existing	178	180	80
patented	138	140	110
new	200	200	90
min std.	100	100	100
max std.	850	850	850



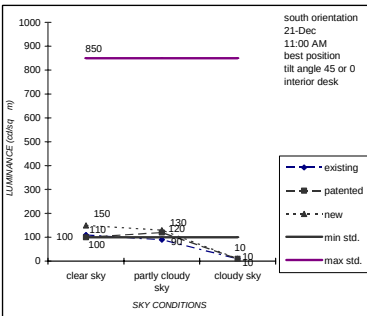
	clear sky	partly cloud	cloudy sky
luminance			
south orientation			
21-Jun			
12:00 PM			
best position			
tilt angle 45 or 0			
interior desk			
existing	140	170	70
patented	130	160	50
new	180	180	90
min std.	100	100	100
max std.	850	850	850



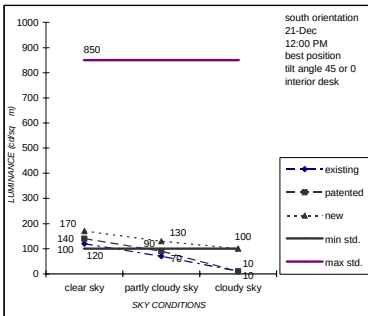
	clear sky	partly cloud	cloudy sky
luminance			
south orientation			
21-Jun			
3:00 PM			
best position			
tilt angle 45 or 0			
interior desk			
existing	180	158	100
patented	160	150	70
new	180	200	90
min std.	100	100	100
max std.	850	850	850



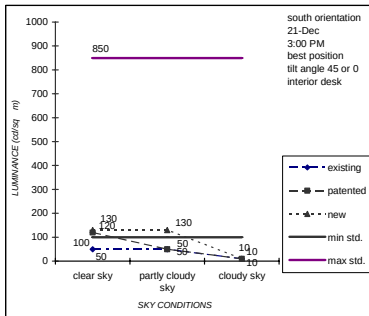
	clear sky	partly cloud	cloudy sky
luminance			
south orientation			
21-Dec			
11:00 AM			
best position			
tilt angle 45 or 0			
interior desk			
existing	110	90	10
patented	100	120	10
new	150	130	10
min std.	100	100	100
max std.	850	850	850



	clear sky	partly cloud	cloudy sky
luminance			
south orientation			
21-Dec			
12:00 PM			
best position			
tilt angle 45 or 0			
interior desk			
existing	120	70	10
patented	140	90	10
new	170	130	100
min std.	100	100	100
max std.	850	850	850



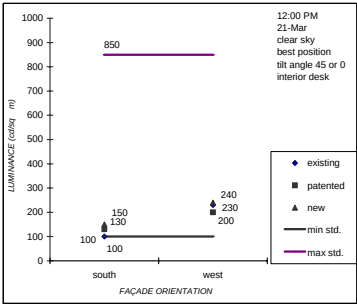
	clear sky	partly cloud	cloudy sky
luminance			
south orientation			
21-Dec			
3:00 PM			
best position			
tilt angle 45 or 0			
interior desk			
existing	50	50	10
patented	120	50	10
new	130	130	10
min std.	100	100	100
max std.	850	850	850



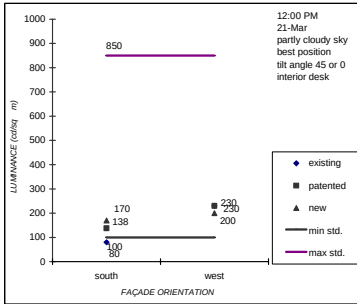
existing blinds - tilt angle 45 for clear sky and partly cloudy sky and 0 for cloudy sky
patented blinds - tilt angle 0 always
new blinds - tilt angle 45 for clear sky and partly cloudy sky and 0 for cloudy sky

	existing	patented	new
BEST POSITION	inside	between	between

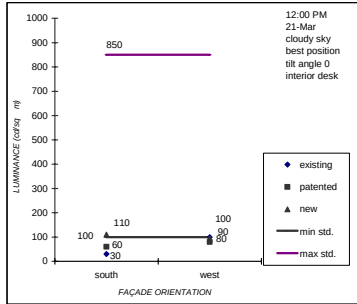
	south	west
luminance		
12:00 PM		
21-Mar		
clear sky	existing 100	230
	patented 130	200
	new 150	240
best position	min std. 100	100
tilt angle 45 or 0	max std. 850	850



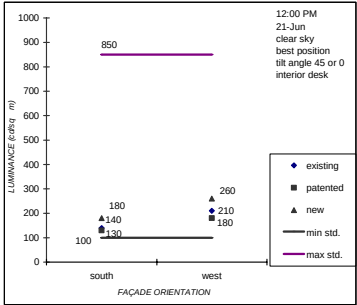
	south	west
luminance		
12:00 PM		
21-Mar		
partly cloudy sky	existing 80	230
	patented 138	230
	new 170	200
best position	min std. 100	100
tilt angle 45 or 0	max std. 850	850



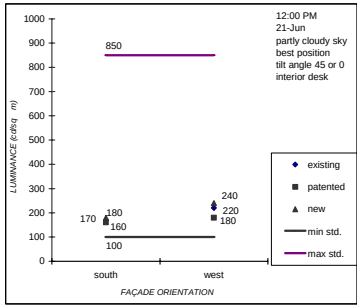
	south	west
luminance		
12:00 PM		
21-Mar		
cloudy sky	existing 30	100
	patented 60	80
	new 110	90
best position	min std. 100	100
tilt angle 0	max std. 850	850



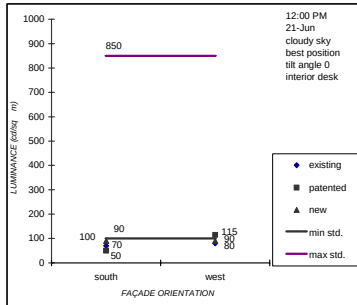
	south	west
luminance		
12:00 PM		
21-Jun		
clear sky	existing 140	210
	patented 130	180
	new 180	250
best position	min std. 100	100
tilt angle 45 or 0	max std. 850	850



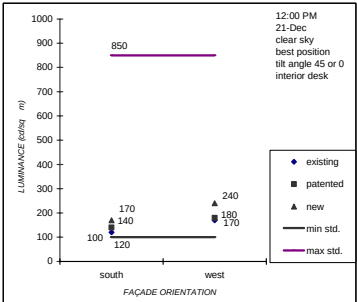
	south	west
luminance		
12:00 PM		
21-Jun		
partly cloudy sky	existing 170	220
	patented 160	180
	new 180	240
best position	min std. 100	100
tilt angle 45 or 0	max std. 850	850



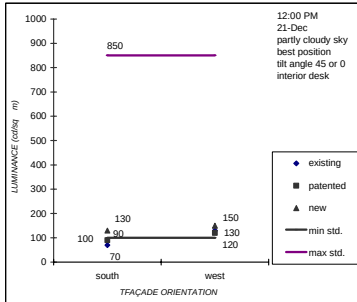
	south	west
luminance		
12:00 PM		
21-Jun		
cloudy sky	existing 70	80
	patented 50	115
	new 90	90
best position	min std. 100	100
tilt angle 0	max std. 850	850



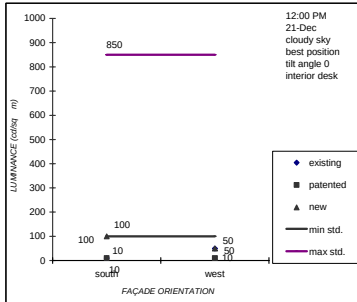
	south	west
luminance		
12:00 PM		
21-Dec		
clear sky	existing 120	170
	patented 140	180
	new 170	240
best position	min std. 100	100
tilt angle 45 or 0	max std. 850	850



	south	west
luminance		
12:00 PM		
21-Dec		
partly cloudy sky	existing 70	130
	patented 90	120
	new 130	150
best position	min std. 100	100
tilt angle 45 or 0	max std. 850	850



	south	west
luminance		
12:00 PM		
21-Dec		
cloudy sky	existing 10	50
	patented 10	10
	new 100	50
best position	min std. 100	100
tilt angle 0	max std. 850	850

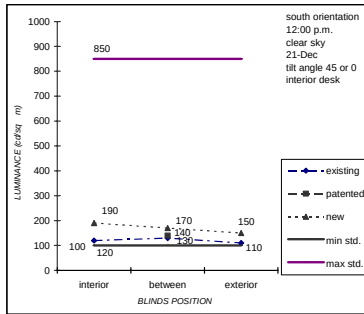


LUMINANCE- effect of the blinds position - for different dates - for different sky conditions

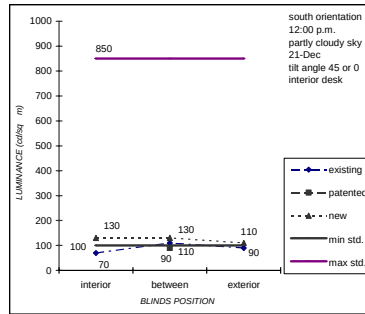
existing blinds - tilt angle 45 for clear sky and partly cloudy sky and 0 for cloudy sky
 patented blinds - tilt angle 0 always
 new blinds - tilt angle 45 for clear sky and partly cloudy sky and 0 for cloudy sky

SOUTH SHEET 5
 LUMINANCE SET 6
 INTERIOR

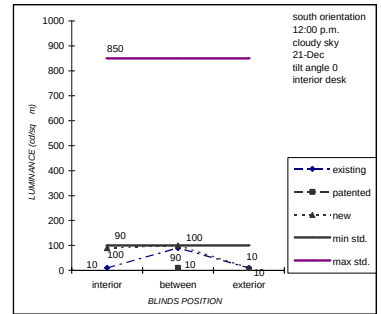
	interior	between	exterior
luminance			
12:00 p.m.			
clear sky			
21-Dec			
tilt angle 45 or 0			
interior desk			
existing	120	130	110
patented	140	170	150
new	190	170	150
min std.	100	100	100
max std.	850	850	850



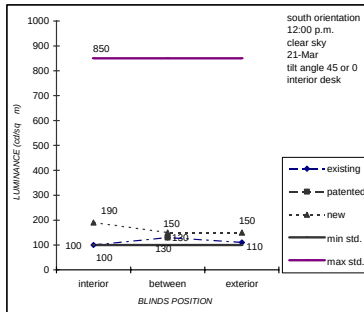
	interior	between	exterior
luminance			
12:00 p.m.			
partly cloudy sky			
21-Dec			
tilt angle 45 or 0			
interior desk			
existing	70	110	90
patented	130	130	110
new	130	130	110
min std.	100	100	100
max std.	850	850	850



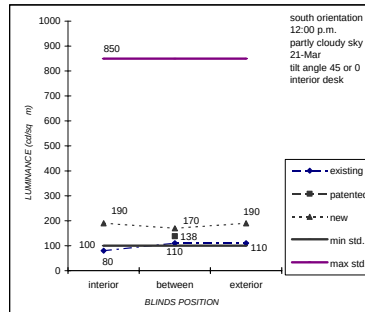
	interior	between	exterior
luminance			
12:00 p.m.			
cloudy sky			
21-Dec			
tilt angle 0			
interior desk			
existing	10	90	10
patented	90	100	100
new	90	100	100
min std.	100	100	100
max std.	850	850	850



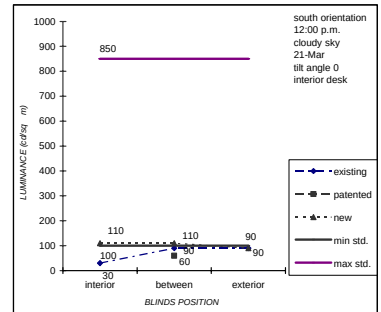
	interior	between	exterior
luminance			
12:00 p.m.			
clear sky			
21-Mar			
tilt angle 45 or 0			
interior desk			
existing	100	130	110
patented	190	150	150
new	190	150	150
min std.	100	100	100
max std.	850	850	850



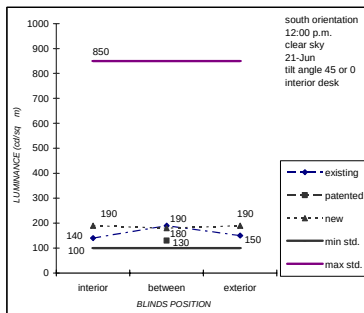
	interior	between	exterior
luminance			
12:00 p.m.			
partly cloudy sky			
21-Mar			
tilt angle 45 or 0			
interior desk			
existing	80	110	110
patented	190	170	190
new	190	170	190
min std.	100	100	100
max std.	850	850	850



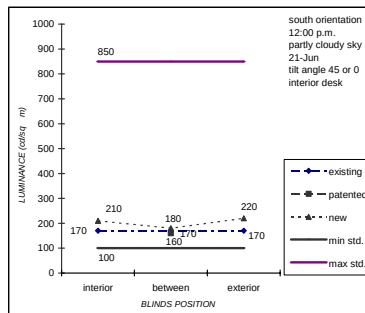
	interior	between	exterior
luminance			
12:00 p.m.			
cloudy sky			
21-Mar			
tilt angle 0			
interior desk			
existing	30	90	90
patented	110	110	90
new	110	110	90
min std.	100	100	100
max std.	850	850	850



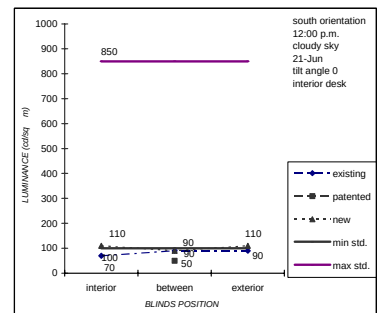
	interior	between	exterior
luminance			
12:00 p.m.			
clear sky			
21-Jun			
tilt angle 45 or 0			
interior desk			
existing	140	190	150
patented	190	180	190
new	190	180	190
min std.	100	100	100
max std.	850	850	850



	interior	between	exterior
luminance			
12:00 p.m.			
partly cloudy sky			
21-Jun			
tilt angle 45 or 0			
interior desk			
existing	170	170	170
patented	210	180	220
new	210	180	220
min std.	100	100	100
max std.	850	850	850



	interior	between	exterior
luminance			
12:00 p.m.			
cloudy sky			
21-Jun			
tilt angle 0			
interior desk			
existing	70	90	90
patented	110	90	110
new	110	90	110
min std.	100	100	100
max std.	850	850	850

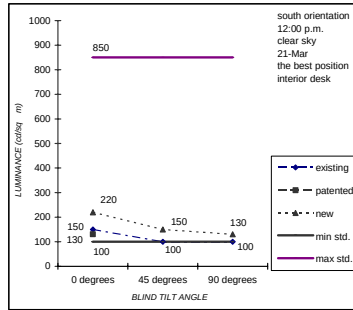


LUMINANCE- effect of the blind tilt angle - for different dates - for different sky conditions

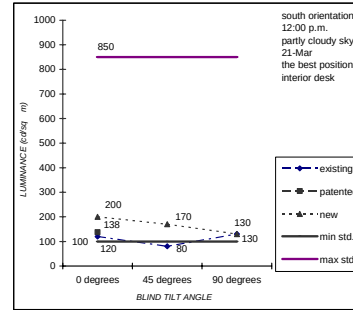
SOUTH SHEET 6
LUMINANCE SET 6
INTERIOR

	existing	patented	new
BEST POSITION	inside	between	between

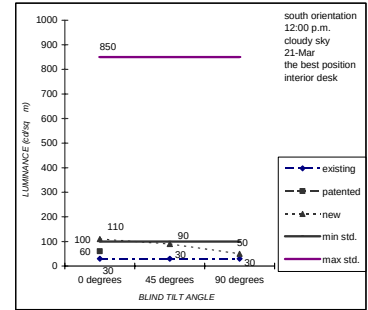
	0 degrees	45 degree	90 degrees
luminance			
south orientation			
12:00 p.m.	existing 150	100	100
clear sky	patented 130		
21-Mar	new 220	150	130
the best position	min std. 100	100	100
interior desk	max std. 850	850	850



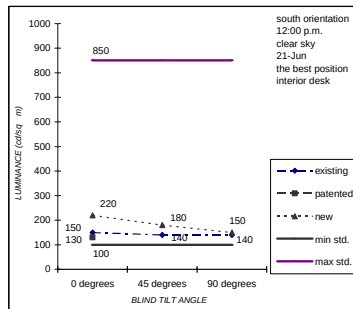
	0 degrees	45 degree	90 degrees
luminance			
south orientation			
12:00 p.m.	existing 120	80	130
partly cloudy sky	patented 138		
21-Mar	new 200	170	130
the best position	min std. 100	100	100
interior desk	max std. 850	850	850



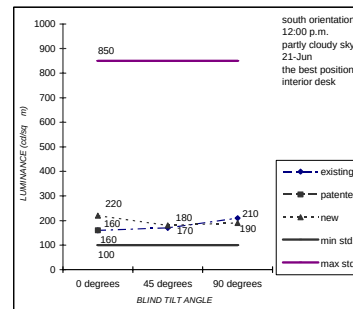
	0 degrees	45 degree	90 degrees
luminance			
south orientation			
12:00 p.m.	existing 30	30	30
cloudy sky	patented 60		
21-Mar	new 110	90	50
the best position	min std. 100	100	100
interior desk	max std. 850	850	850



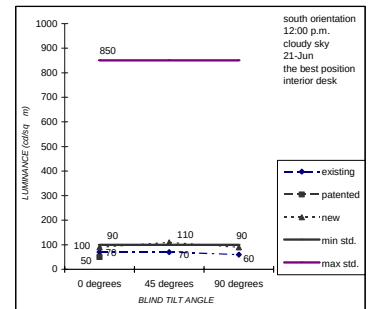
	0 degrees	45 degree	90 degrees
luminance			
south orientation			
12:00 p.m.	existing 150	140	140
clear sky	patented 130		
21-Jun	new 220	180	150
the best position	min std. 100	100	100
interior desk	max std. 850	850	850



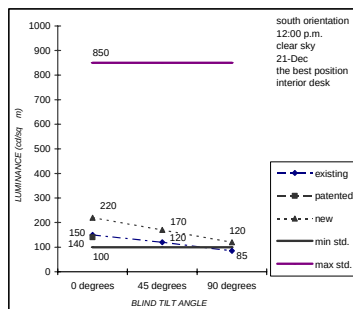
	0 degrees	45 degree	90 degrees
luminance			
south orientation			
12:00 p.m.	existing 160	170	210
partly cloudy sky	patented 160		
21-Jun	new 220	180	190
the best position	min std. 100	100	100
interior desk	max std. 850	850	850



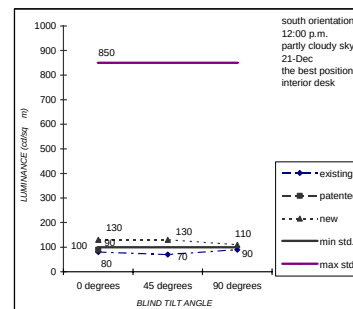
	0 degrees	45 degree	90 degrees
luminance			
south orientation			
12:00 p.m.	existing 70	70	60
cloudy sky	patented 50		
21-Jun	new 90	110	90
the best position	min std. 100	100	100
interior desk	max std. 850	850	850



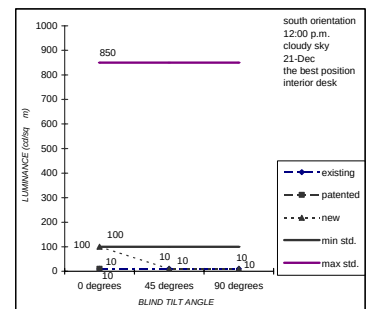
	0 degrees	45 degree	90 degrees
luminance			
south orientation			
12:00 p.m.	existing 150	120	85
clear sky	patented 140		
21-Dec	new 220	170	120
the best position	min std. 100	100	100
interior desk	max std. 850	850	850



	0 degrees	45 degree	90 degrees
luminance			
south orientation			
12:00 p.m.	existing 80	70	90
partly cloudy sky	patented 90		
21-Dec	new 130	130	110
the best position	min std. 100	100	100
interior desk	max std. 850	850	850



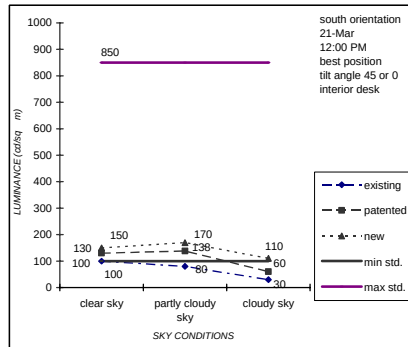
	0 degrees	45 degree	90 degrees
luminance			
south orientation			
12:00 p.m.	existing 10	10	10
cloudy sky	patented 10		
21-Dec	new 100	10	10
the best position	min std. 100	100	100
interior desk	max std. 850	850	850



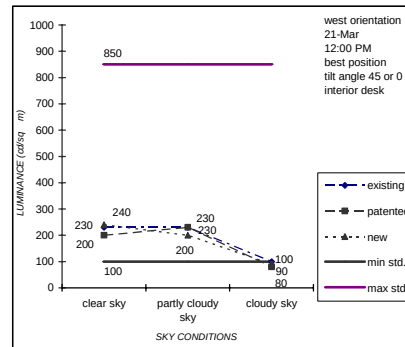
existing blinds - tilt angle 45 for clear sky and partly cloudy sky and 0 for cloudy sky
 patented blinds - tilt angle 0 always
 new blinds - tilt angle 45 for clear sky and partly cloudy sky and 0 for cloudy sky

	existing	patented	new
BEST POSITION	inside	between	between

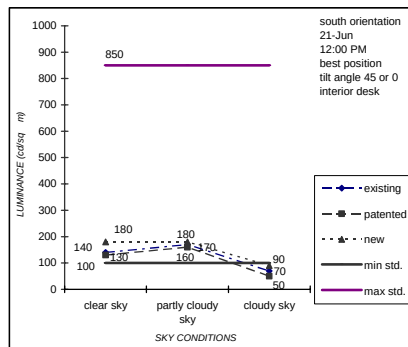
	clear sky	partly cloud	cloudy sky
luminance			
south orientation			
21-Mar			
12:00 PM	existing 100	80	30
	patented 130	138	60
	new 150	170	110
best position	min std. 100	100	100
tilt angle 45 or 0	max std. 850	850	850
interior desk			



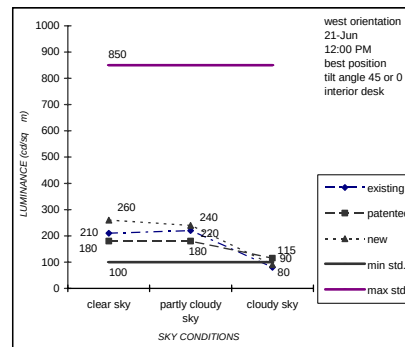
	clear sky	partly cloud	cloudy sky
luminance			
west orientation			
21-Mar			
12:00 PM	existing 230	230	100
	patented 200	230	80
	new 240	200	90
best position	min std. 100	100	100
tilt angle 45 or 0	max std. 850	850	850
interior desk			



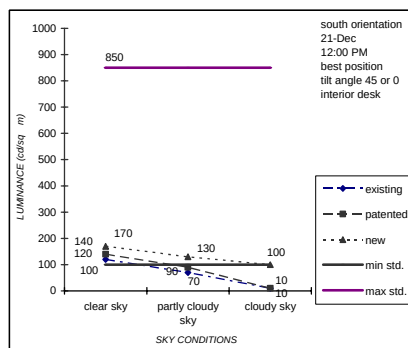
	clear sky	partly cloud	cloudy sky
luminance			
south orientation			
21-Jun			
12:00 PM	existing 140	170	70
	patented 130	160	50
	new 180	180	90
best position	min std. 100	100	100
tilt angle 45 or 0	max std. 850	850	850
interior desk			



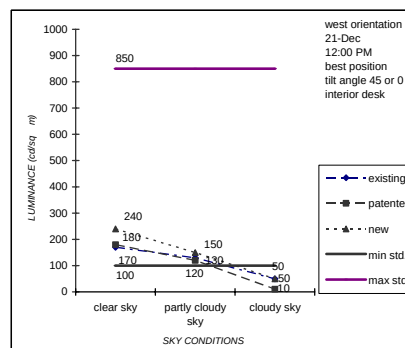
	clear sky	partly cloud	cloudy sky
luminance			
west orientation			
21-Jun			
12:00 PM	existing 210	220	80
	patented 180	180	115
	new 260	240	90
best position	min std. 100	100	100
tilt angle 45 or 0	max std. 850	850	850
interior desk			



	clear sky	partly cloud	cloudy sky
luminance			
south orientation			
21-Dec			
12:00 PM	existing 120	70	10
	patented 140	90	10
	new 170	130	100
best position	min std. 100	100	100
tilt angle 45 or 0	max std. 850	850	850
interior desk			

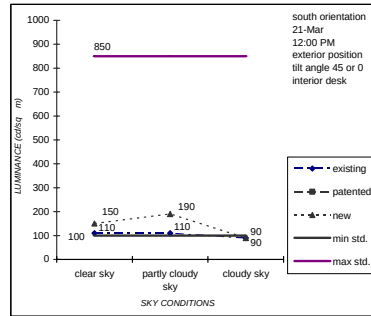


	clear sky	partly cloud	cloudy sky
luminance			
west orientation			
21-Dec			
12:00 PM	existing 170	130	50
	patented 180	120	10
	new 240	150	50
best position	min std. 100	100	100
tilt angle 45 or 0	max std. 850	850	850
interior desk			

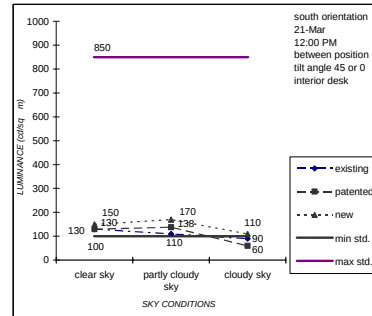


existing blinds - tilt angle 45 for clear sky and partly cloudy sky and 0 for cloudy sky
 patented blinds - tilt angle 0 always
 new blinds - tilt angle 45 for clear sky and partly cloudy sky and 0 for cloudy sky

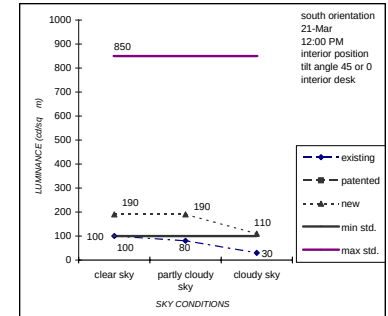
	clear sky	partly cloudy	cloudy sky
luminance			
south orientation			
21-Mar			
12:00 PM			
exterior position			
tilt angle 45 or 0			
interior desk			
existing	110	110	90
patented			
new	150	190	90
min std.	100	100	100
max std.	850	850	850



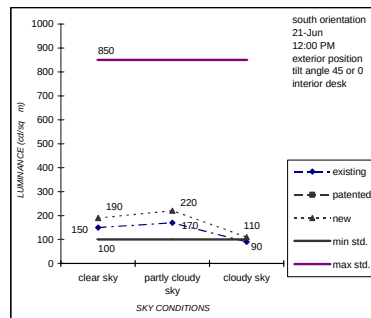
	clear sky	partly cloudy	cloudy sky
luminance			
south orientation			
21-Mar			
12:00 PM			
between position			
tilt angle 45 or 0			
interior desk			
existing	130	110	90
patented	130	138	60
new	150	170	110
min std.	100	100	100
max std.	850	850	850



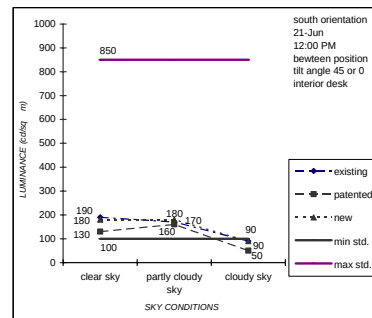
	clear sky	partly cloudy	cloudy sky
luminance			
south orientation			
21-Mar			
12:00 PM			
interior position			
tilt angle 45 or 0			
interior desk			
existing	100	80	30
patented			
new	190	190	110
min std.	100	100	100
max std.	850	850	850



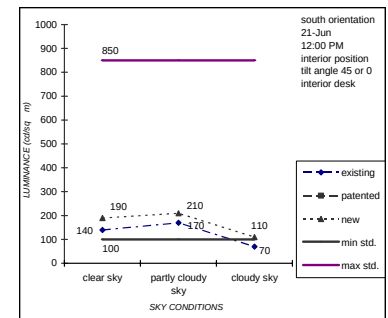
	clear sky	partly cloudy	cloudy sky
luminance			
south orientation			
21-Jun			
12:00 PM			
exterior position			
tilt angle 45 or 0			
interior desk			
existing	150	170	90
patented			
new	190	220	110
min std.	100	100	100
max std.	850	850	850



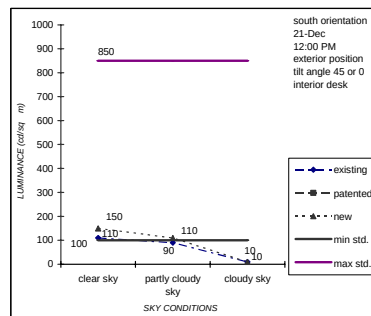
	clear sky	partly cloudy	cloudy sky
luminance			
south orientation			
21-Jun			
12:00 PM			
between position			
tilt angle 45 or 0			
interior desk			
existing	190	170	90
patented	130	160	50
new	180	180	90
min std.	100	100	100
max std.	850	850	850



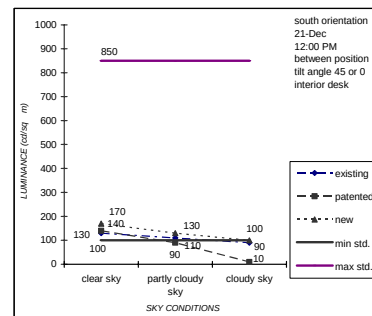
	clear sky	partly cloudy	cloudy sky
luminance			
south orientation			
21-Jun			
12:00 PM			
interior position			
tilt angle 45 or 0			
interior desk			
existing	140	170	70
patented			
new	190	210	110
min std.	100	100	100
max std.	850	850	850



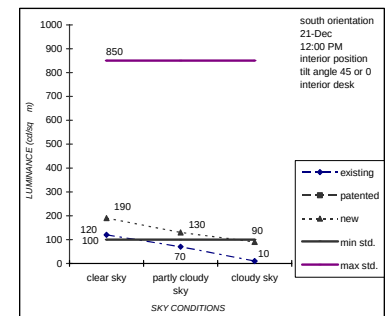
	clear sky	partly cloudy	cloudy sky
luminance			
south orientation			
21-Dec			
12:00 PM			
exterior position			
tilt angle 45 or 0			
interior desk			
existing	110	90	10
patented			
new	150	110	10
min std.	100	100	100
max std.	850	850	850



	clear sky	partly cloudy	cloudy sky
luminance			
south orientation			
21-Dec			
12:00 PM			
between position			
tilt angle 45 or 0			
interior desk			
existing	130	110	90
patented	140	90	10
new	170	130	100
min std.	100	100	100
max std.	850	850	850



	clear sky	partly cloudy	cloudy sky
luminance			
south orientation			
21-Dec			
12:00 PM			
interior position			
tilt angle 45 or 0			
interior desk			
existing	120	70	10
patented			
new	190	130	90
min std.	100	100	100
max std.	850	850	850

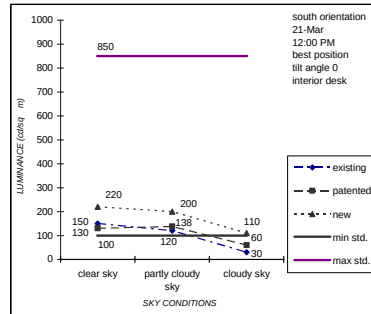


LUMINANCE - effect of sky conditions - for different blind tilt angles - for different dates

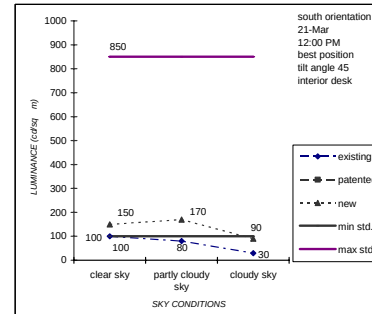
	existing	patented	new
BEST POSITION	inside	between	between

SOUTH SHEET 9
LUMINANCE SET 6
INTERIOR

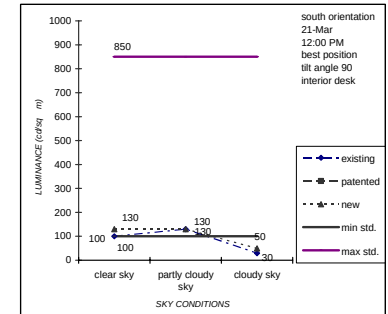
	clear sky	partly cloud	cloudy sky
luminance			
south orientation			
21-Mar			
12:00 PM			
best position			
tilt angle 0			
interior desk			
existing	150	120	30
patented	130	138	60
new	220	200	110
min std.	100	100	100
max std.	850	850	850



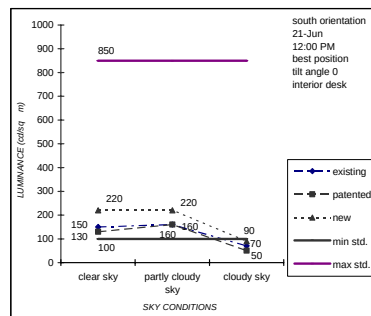
	clear sky	partly cloud	cloudy sky
luminance			
south orientation			
21-Mar			
12:00 PM			
best position			
tilt angle 45			
interior desk			
existing	100	80	30
patented			
new	150	170	90
min std.	100	100	100
max std.	850	850	850



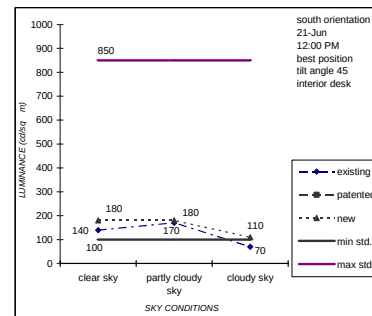
	clear sky	partly cloud	cloudy sky
luminance			
south orientation			
21-Mar			
12:00 PM			
best position			
tilt angle 90			
interior desk			
existing	100	130	30
patented			
new	130	130	50
min std.	100	100	100
max std.	850	850	850



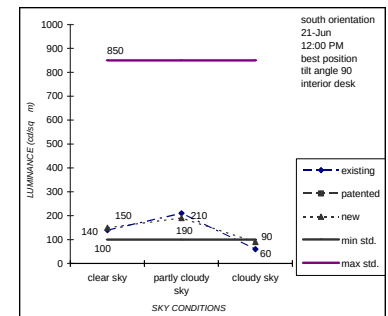
	clear sky	partly cloud	cloudy sky
luminance			
south orientation			
21-Jun			
12:00 PM			
best position			
tilt angle 0			
interior desk			
existing	150	160	70
patented	130	160	50
new	220	220	90
min std.	100	100	100
max std.	850	850	850



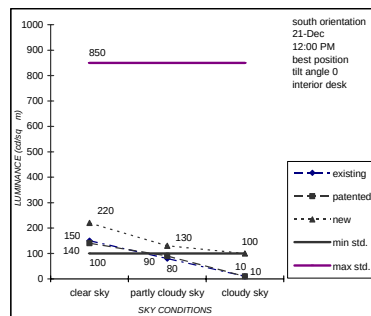
	clear sky	partly cloud	cloudy sky
luminance			
south orientation			
21-Jun			
12:00 PM			
best position			
tilt angle 45			
interior desk			
existing	140	170	70
patented			
new	180	180	110
min std.	100	100	100
max std.	850	850	850



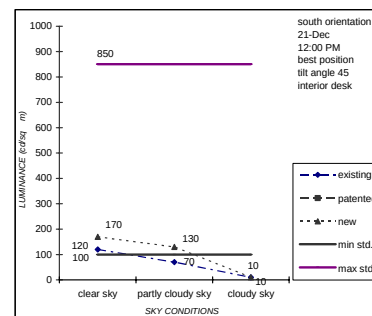
	clear sky	partly cloud	cloudy sky
luminance			
south orientation			
21-Jun			
12:00 PM			
best position			
tilt angle 90			
interior desk			
existing	140	210	60
patented			
new	150	190	90
min std.	100	100	100
max std.	850	850	850



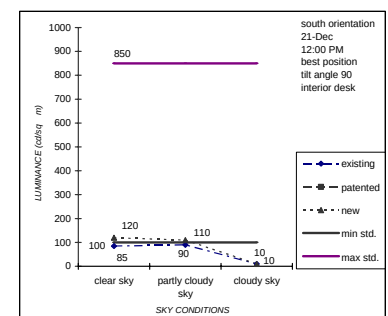
	clear sky	partly cloud	cloudy sky
luminance			
south orientation			
21-Dec			
12:00 PM			
best position			
tilt angle 0			
interior desk			
existing	150	80	10
patented	140	90	10
new	220	130	100
min std.	100	100	100
max std.	850	850	850



	clear sky	partly cloud	cloudy sky
luminance			
south orientation			
21-Dec			
12:00 PM			
best position			
tilt angle 45			
interior desk			
existing	120	70	10
patented			
new	170	130	10
min std.	100	100	100
max std.	850	850	850



	clear sky	partly cloud	cloudy sky
luminance			
south orientation			
21-Dec			
12:00 PM			
best position			
tilt angle 90			
interior desk			
existing	85	90	10
patented			
new	120	110	10
min std.	100	100	100
max std.	850	850	850



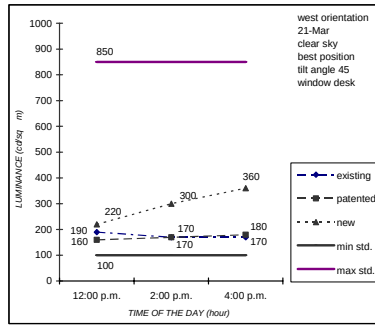
LUMINANCE- effect of the time - for different dates - for different sky conditions

existing blinds - tilt angle 45 for clear sky and partly cloudy sky and 0 for cloudy sky
patented blinds - tilt angle 0 always
new blinds - tilt angle 45 for clear sky and partly cloudy sky and 0 for cloudy sky

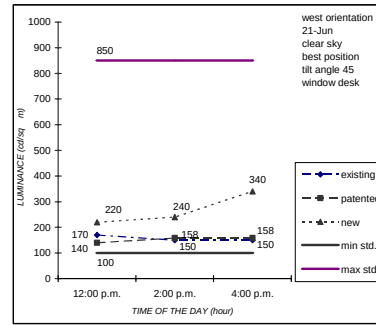
WEST SHEET 1
LUMINANCE SET 7
WINDOW

	existing	patented	new
BEST POSITION	inside	between	between

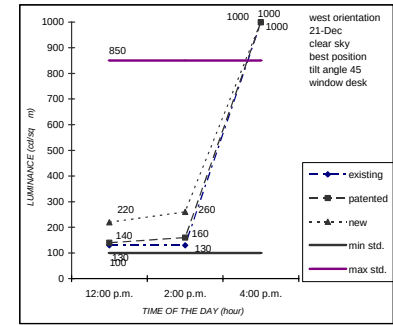
	12:00 p.m.	2:00 p.m.	4:00 p.m.
luminance west orientation 21-Mar clear sky best position tilt angle 45 window desk			
existing	190	170	170
patented	160	170	180
new	220	300	360
min std.	100	100	100
max std.	850	850	850



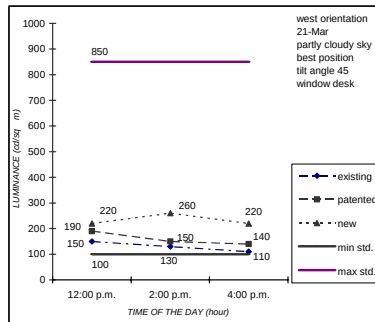
	12:00 p.m.	2:00 p.m.	4:00 p.m.
luminance west orientation 21-Jun clear sky best position tilt angle 45 window desk			
existing	170	150	150
patented	140	158	158
new	220	240	340
min std.	100	100	100
max std.	850	850	850



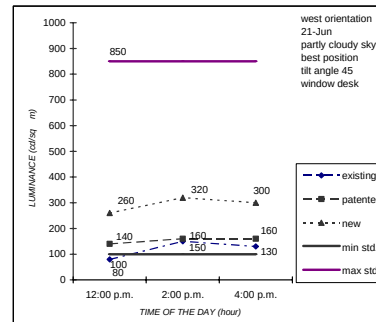
	12:00 p.m.	2:00 p.m.	4:00 p.m.
luminance west orientation 21-Dec clear sky best position tilt angle 45 window desk			
existing	130	130	1000
patented	140	160	1000
new	220	260	1000
min std.	100	100	100
max std.	850	850	850



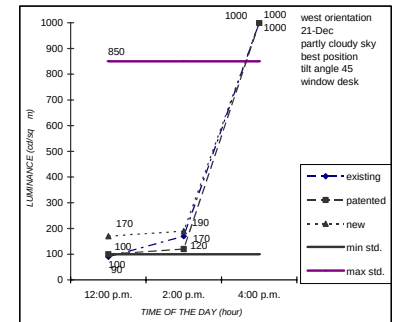
	12:00 p.m.	2:00 p.m.	4:00 p.m.
luminance west orientation 21-Mar partly cloudy sky best position tilt angle 45 window desk			
existing	150	130	110
patented	190	150	140
new	220	260	220
min std.	100	100	100
max std.	850	850	850



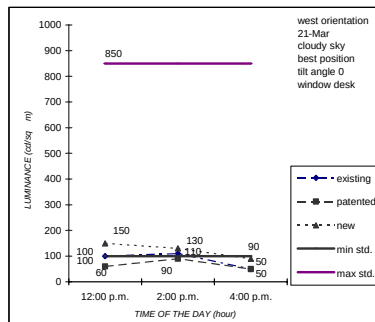
	12:00 p.m.	2:00 p.m.	4:00 p.m.
luminance west orientation 21-Jun partly cloudy sky best position tilt angle 45 window desk			
existing	80	150	130
patented	140	160	160
new	260	320	300
min std.	100	100	100
max std.	850	850	850



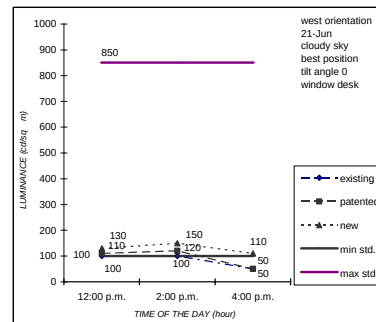
	12:00 p.m.	2:00 p.m.	4:00 p.m.
luminance west orientation 21-Dec partly cloudy sky best position tilt angle 45 window desk			
existing	90	170	1000
patented	100	120	1000
new	170	190	1000
min std.	100	100	100
max std.	850	850	850



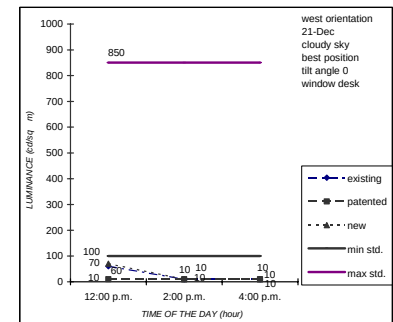
	12:00 p.m.	2:00 p.m.	4:00 p.m.
luminance west orientation 21-Mar cloudy sky best position tilt angle 0 window desk			
existing	100	110	50
patented	60	90	50
new	150	130	90
min std.	100	100	100
max std.	850	850	850



	12:00 p.m.	2:00 p.m.	4:00 p.m.
luminance west orientation 21-Jun cloudy sky best position tilt angle 0 window desk			
existing	100	100	50
patented	110	120	50
new	130	150	110
min std.	100	100	100
max std.	850	850	850



	12:00 p.m.	2:00 p.m.	4:00 p.m.
luminance west orientation 21-Dec cloudy sky best position tilt angle 0 window desk			
existing	60	10	10
patented	10	10	10
new	70	10	10
min std.	100	100	100
max std.	850	850	850



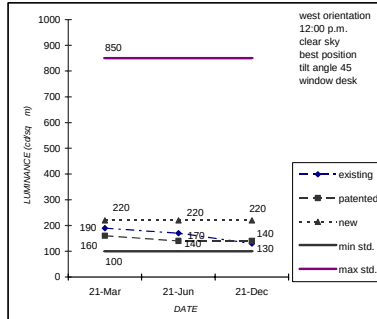
LUMINANCE - effect of the date -for different times - for different sky conditions

existing blinds - tilt angle 45 for clear sky and partly cloudy sky and 0 for cloudy sky
 patented blinds - tilt angle 0 always
 new blinds - tilt angle 45 for clear sky and partly cloudy sky and 0 for cloudy sky

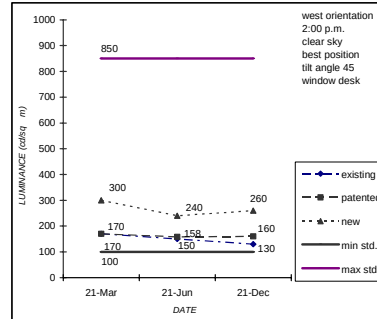
WEST SHEET 2
 LUMINANCE SET 7
 WINDOW

	existing	patented	new
BEST POSITION	inside	between	between

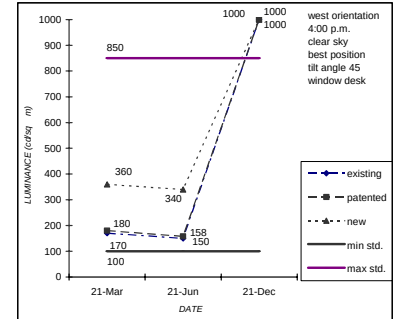
	21-Mar	21-Jun	21-Dec
luminance			
west orientation			
12:00 p.m.			
clear sky			
best position			
tilt angle 45			
window desk			
existing	190	170	130
patented	160	140	140
new	220	220	220
min std.	100	100	100
max std.	850	850	850



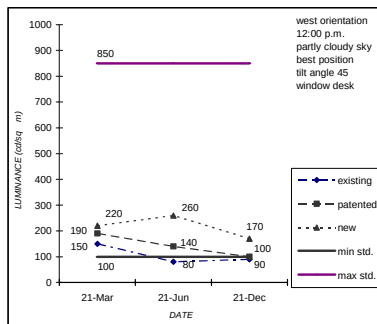
	21-Mar	21-Jun	21-Dec
luminance			
west orientation			
2:00 p.m.			
clear sky			
best position			
tilt angle 45			
window desk			
existing	170	150	130
patented	170	158	160
new	300	240	260
min std.	100	100	100
max std.	850	850	850



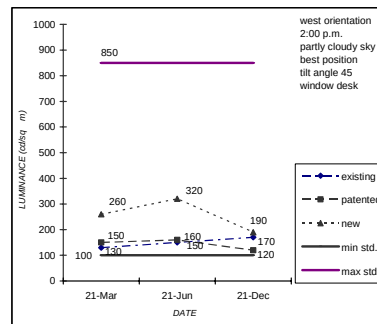
	21-Mar	21-Jun	21-Dec
luminance			
west orientation			
4:00 p.m.			
clear sky			
best position			
tilt angle 45			
window desk			
existing	170	150	1000
patented	180	158	1000
new	360	340	1000
min std.	100	100	100
max std.	850	850	850



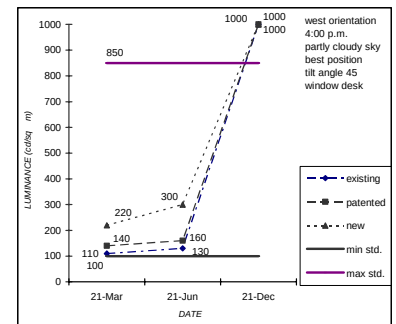
	21-Mar	21-Jun	21-Dec
luminance			
west orientation			
12:00 p.m.			
partly cloudy sky			
best position			
tilt angle 45			
window desk			
existing	150	80	90
patented	190	140	100
new	220	260	170
min std.	100	100	100
max std.	850	850	850



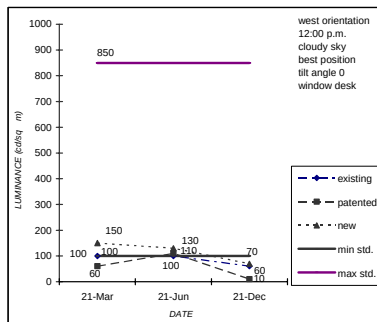
	21-Mar	21-Jun	21-Dec
luminance			
west orientation			
2:00 p.m.			
partly cloudy sky			
best position			
tilt angle 45			
window desk			
existing	130	150	170
patented	150	160	120
new	260	320	190
min std.	100	100	100
max std.	850	850	850



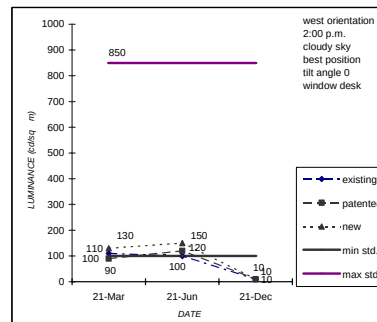
	21-Mar	21-Jun	21-Dec
luminance			
west orientation			
4:00 p.m.			
partly cloudy sky			
best position			
tilt angle 45			
window desk			
existing	110	130	1000
patented	140	160	1000
new	220	300	1000
min std.	100	100	100
max std.	850	850	850



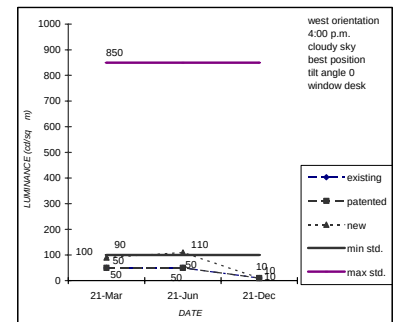
	21-Mar	21-Jun	21-Dec
luminance			
west orientation			
12:00 p.m.			
cloudy sky			
best position			
tilt angle 0			
window desk			
existing	100	100	60
patented	60	110	10
new	150	130	70
min std.	100	100	100
max std.	850	850	850



	21-Mar	21-Jun	21-Dec
luminance			
west orientation			
2:00 p.m.			
cloudy sky			
best position			
tilt angle 0			
window desk			
existing	110	100	10
patented	90	120	10
new	130	150	10
min std.	100	100	100
max std.	850	850	850



	21-Mar	21-Jun	21-Dec
luminance			
west orientation			
4:00 p.m.			
cloudy sky			
best position			
tilt angle 0			
window desk			
existing	50	50	10
patented	50	50	10
new	90	110	10
min std.	100	100	100
max std.	850	850	850



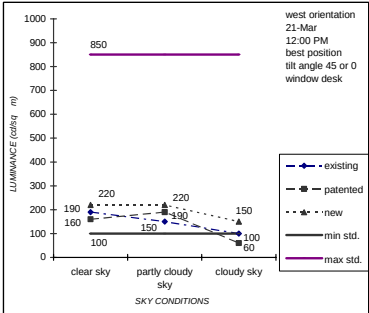
LUMINANCE - effect of sky conditions - for different times - for different dates

existing blinds - tilt angle 45 for clear sky and partly cloudy sky and 0 for cloudy sky
patented blinds - tilt angle 0 always
new blinds - tilt angle 45 for clear sky and partly cloudy sky and 0 for cloudy sky

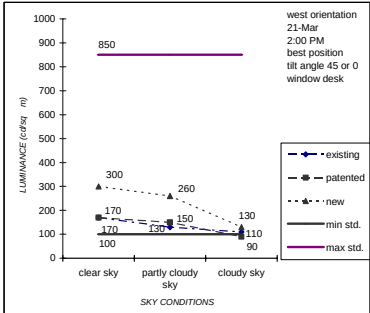
	existing	patented	new
BEST POSITION	inside	between	between

WEST SHEET 3
LUMINANCE SET 7
WINDOW

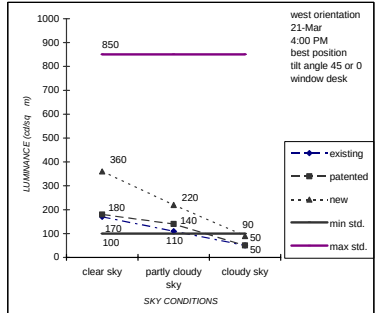
	clear sky	partly cloud	cloudy sky
luminance			
west orientation			
21-Mar			
12:00 PM			
best position			
tilt angle 45 or 0			
window desk			
existing	190	150	100
patented	160	190	60
new	220	220	150
min std.	100	100	100
max std.	850	850	850



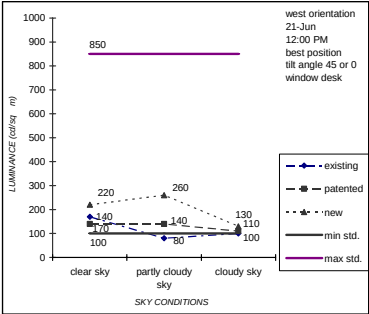
	clear sky	partly cloud	cloudy sky
luminance			
west orientation			
21-Mar			
2:00 PM			
best position			
tilt angle 45 or 0			
window desk			
existing	170	130	110
patented	170	150	90
new	300	260	130
min std.	100	100	100
max std.	850	850	850



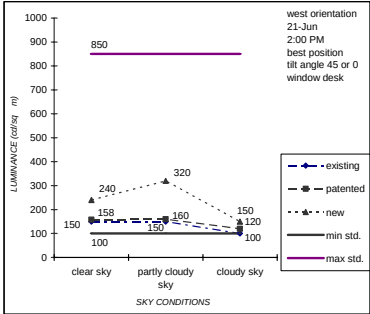
	clear sky	partly cloud	cloudy sky
luminance			
west orientation			
21-Mar			
4:00 PM			
best position			
tilt angle 45 or 0			
window desk			
existing	170	110	50
patented	180	140	50
new	360	220	90
min std.	100	100	100
max std.	850	850	850



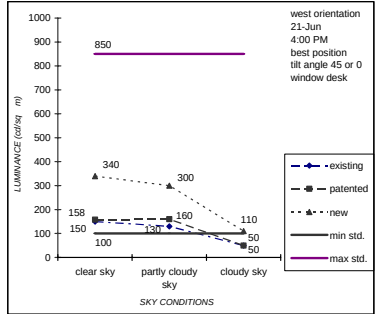
	clear sky	partly cloud	cloudy sky
luminance			
west orientation			
21-Jun			
12:00 PM			
best position			
tilt angle 45 or 0			
window desk			
existing	170	80	100
patented	140	140	110
new	220	260	130
min std.	100	100	100
max std.	850	850	850



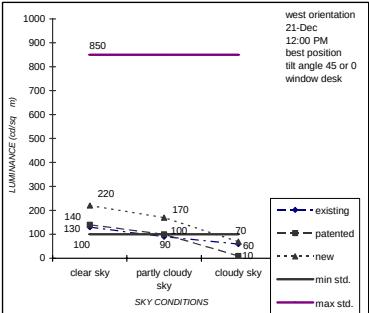
	clear sky	partly cloud	cloudy sky
luminance			
west orientation			
21-Jun			
2:00 PM			
best position			
tilt angle 45 or 0			
window desk			
existing	150	150	100
patented	158	160	120
new	240	320	150
min std.	100	100	100
max std.	850	850	850



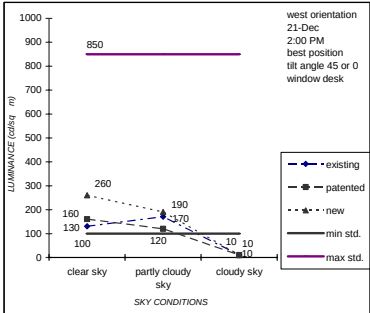
	clear sky	partly cloud	cloudy sky
luminance			
west orientation			
21-Jun			
4:00 PM			
best position			
tilt angle 45 or 0			
window desk			
existing	150	130	50
patented	158	160	50
new	340	300	110
min std.	100	100	100
max std.	850	850	850



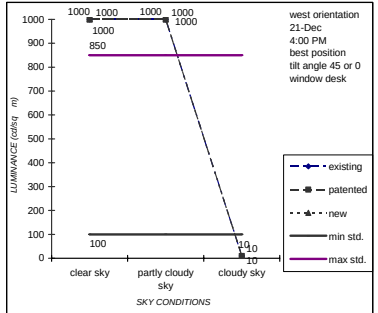
	clear sky	partly cloud	cloudy sky
luminance			
west orientation			
21-Dec			
12:00 PM			
best position			
tilt angle 45 or 0			
window desk			
existing	130	90	60
patented	140	100	10
new	220	170	70
min std.	100	100	100
max std.	850	850	850



	clear sky	partly cloud	cloudy sky
luminance			
west orientation			
21-Dec			
2:00 PM			
best position			
tilt angle 45 or 0			
window desk			
existing	130	170	10
patented	160	120	10
new	260	190	10
min std.	100	100	100
max std.	850	850	850

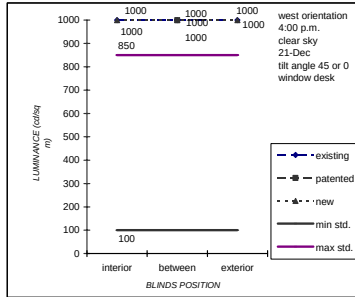


	clear sky	partly cloud	cloudy sky
luminance			
west orientation			
21-Dec			
4:00 PM			
best position			
tilt angle 45 or 0			
window desk			
existing	1000	1000	10
patented	1000	1000	10
new	1000	1000	10
min std.	100	100	100
max std.	850	850	850

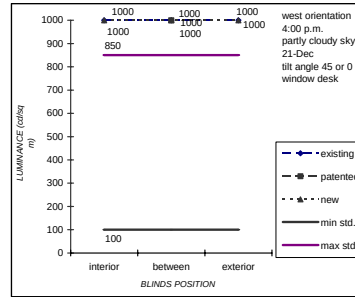


existing blinds - tilt angle 45 for clear sky and partly cloudy sky and 0 for cloudy sky
 patented blinds - tilt angle 0 always
 new blinds - tilt angle 45 for clear sky and partly cloudy sky and 0 for cloudy sky

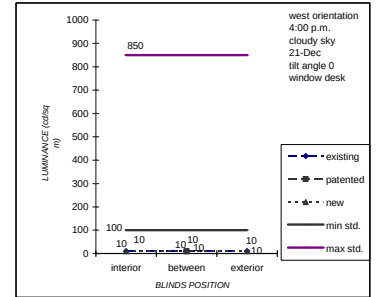
	interior	between	exterior
luminance			
west orientation			
4:00 p.m.			
clear sky			
21-Dec			
tilt angle 45 or 0			
window desk			
existing	1000	1000	1000
patented	1000	1000	1000
new	1000	1000	1000
min std.	100	100	100
max std.	850	850	850



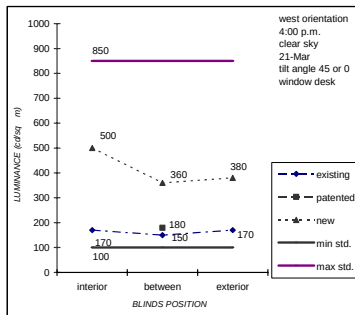
	interior	between	exterior
luminance			
west orientation			
4:00 p.m.			
partly cloudy sky			
21-Dec			
tilt angle 45 or 0			
window desk			
existing	1000	1000	1000
patented	1000	1000	1000
new	1000	1000	1000
min std.	100	100	100
max std.	850	850	850



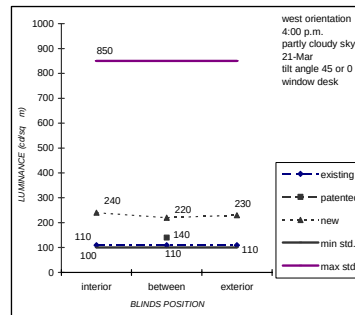
	interior	between	exterior
luminance			
west orientation			
4:00 p.m.			
cloudy sky			
21-Dec			
tilt angle 0			
window desk			
existing	10	10	10
patented	10	10	10
new	10	10	10
min std.	100	100	100
max std.	850	850	850



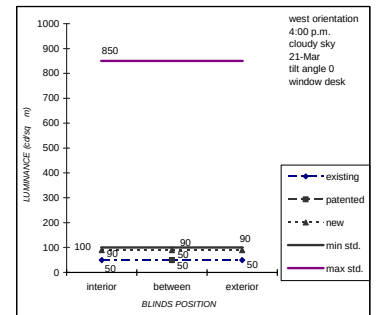
	interior	between	exterior
luminance			
west orientation			
4:00 p.m.			
clear sky			
21-Mar			
tilt angle 45 or 0			
window desk			
existing	170	150	170
patented	180	180	180
new	500	360	380
min std.	100	100	100
max std.	850	850	850



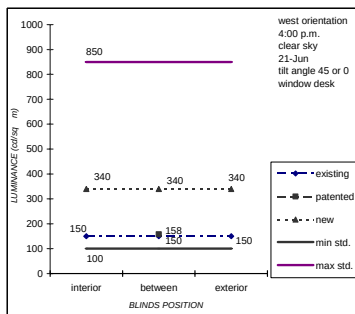
	interior	between	exterior
luminance			
west orientation			
4:00 p.m.			
partly cloudy sky			
21-Mar			
tilt angle 45 or 0			
window desk			
existing	110	110	110
patented	140	140	140
new	240	220	230
min std.	100	100	100
max std.	850	850	850



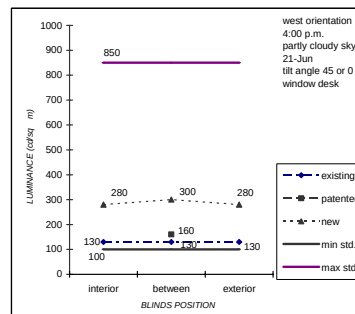
	interior	between	exterior
luminance			
west orientation			
4:00 p.m.			
cloudy sky			
21-Mar			
tilt angle 0			
window desk			
existing	50	50	50
patented	50	50	50
new	90	90	90
min std.	100	100	100
max std.	850	850	850



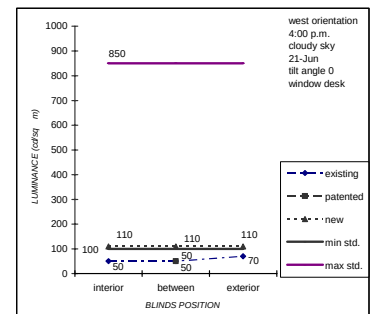
	interior	between	exterior
luminance			
west orientation			
4:00 p.m.			
clear sky			
21-Jun			
tilt angle 45 or 0			
window desk			
existing	150	150	150
patented	158	158	158
new	340	340	340
min std.	100	100	100
max std.	850	850	850



	interior	between	exterior
luminance			
west orientation			
4:00 p.m.			
partly cloudy sky			
21-Jun			
tilt angle 45 or 0			
window desk			
existing	130	130	130
patented	160	160	160
new	280	300	280
min std.	100	100	100
max std.	850	850	850



	interior	between	exterior
luminance			
west orientation			
4:00 p.m.			
cloudy sky			
21-Jun			
tilt angle 0			
window desk			
existing	50	50	70
patented	50	50	70
new	110	110	110
min std.	100	100	100
max std.	850	850	850

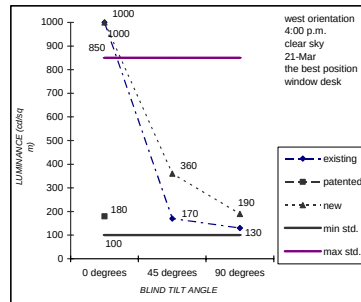


LUMINANCE- effect of the blinds position - for different dates - for different sky conditions

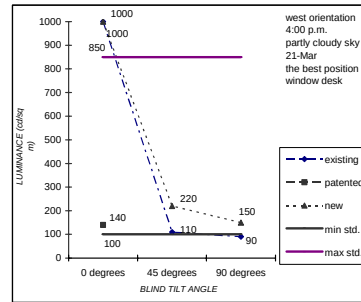
existing blinds - tilt angle 45 for clear sky and partly cloudy sky and 0 for cloudy sky
 patented blinds - tilt angle 0 always
 new blinds - tilt angle 45 for clear sky and partly cloudy sky and 0 for cloudy sky

WEST SHEET 5
 LUMINANCE SET 7
 WINDOW

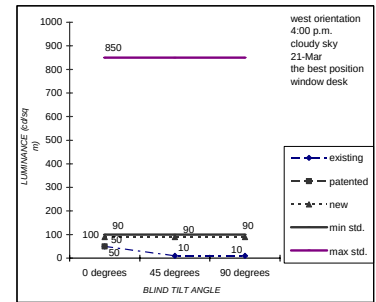
	0 degrees	45 degree	90 degrees
luminance			
west orientation			
4:00 p.m.			
clear sky			
21-Mar			
the best position			
window desk			
existing	1000	170	130
patented	180		
new	1000	360	190
min std.	100	100	100
max std.	850	850	850



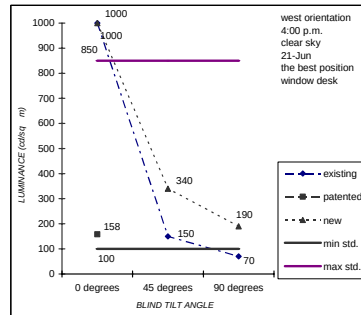
	0 degrees	45 degree	90 degrees
luminance			
west orientation			
4:00 p.m.			
partly cloudy sky			
21-Mar			
the best position			
window desk			
existing	1000	110	90
patented	140		
new	1000	220	150
min std.	100	100	100
max std.	850	850	850



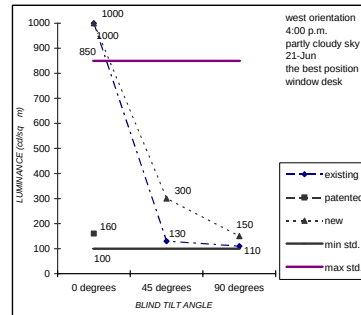
	0 degrees	45 degree	90 degrees
luminance			
west orientation			
4:00 p.m.			
cloudy sky			
21-Mar			
the best position			
window desk			
existing	50	10	10
patented	50		
new	90	90	90
min std.	100	100	100
max std.	850	850	850



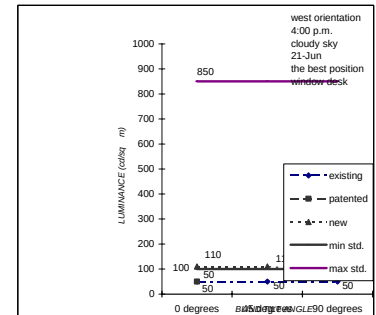
	0 degrees	45 degree	90 degrees
luminance			
west orientation			
4:00 p.m.			
clear sky			
21-Jun			
the best position			
window desk			
existing	1000	150	70
patented	158		
new	1000	340	190
min std.	100	100	100
max std.	850	850	850



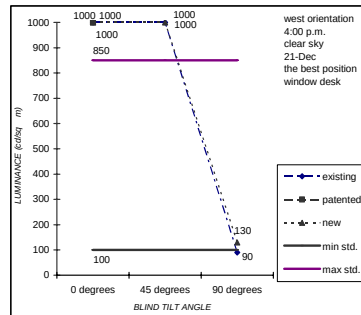
	0 degrees	45 degree	90 degrees
luminance			
west orientation			
4:00 p.m.			
partly cloudy sky			
21-Jun			
the best position			
window desk			
existing	1000	130	110
patented	160		
new	1000	300	150
min std.	100	100	100
max std.	850	850	850



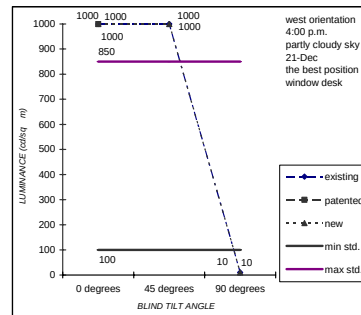
	0 degrees	45 degree	90 degrees
luminance			
west orientation			
4:00 p.m.			
cloudy sky			
21-Jun			
the best position			
window desk			
existing	50	50	50
patented	50		
new	110	110	90
min std.	100	100	100
max std.	850	850	850



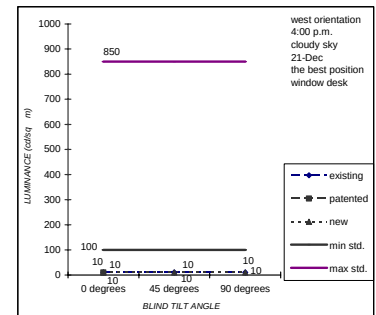
	0 degrees	45 degree	90 degrees
luminance			
west orientation			
4:00 p.m.			
clear sky			
21-Dec			
the best position			
window desk			
existing	1000	1000	90
patented	1000		
new	1000	1000	130
min std.	100	100	100
max std.	850	850	850



	0 degrees	45 degree	90 degrees
luminance			
west orientation			
4:00 p.m.			
partly cloudy sky			
21-Dec			
the best position			
window desk			
existing	1000	1000	10
patented	1000		
new	1000	1000	10
min std.	100	100	100
max std.	850	850	850



	0 degrees	45 degree	90 degrees
luminance			
west orientation			
4:00 p.m.			
cloudy sky			
21-Dec			
the best position			
window desk			
existing	10	10	10
patented	10		
new	10	10	10
min std.	100	100	100
max std.	850	850	850

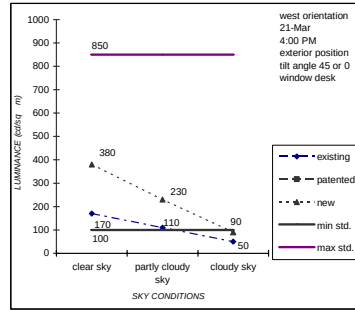


LUMINANCE - effect of sky conditions-for different positions of the blinds - for different dates

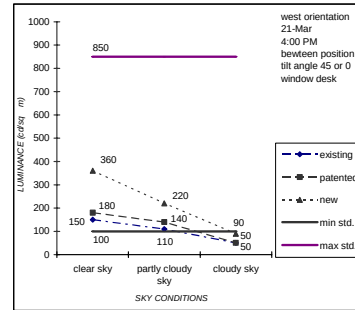
WEST SHEET 6
LUMINANCE SET 7
WINDOW

existing blinds - tilt angle 45 for clear sky and partly cloudy sky and 0 for cloudy sky
patented blinds - tilt angle 0 always
new blinds - tilt angle 45 for clear sky and partly cloudy sky and 0 for cloudy sky

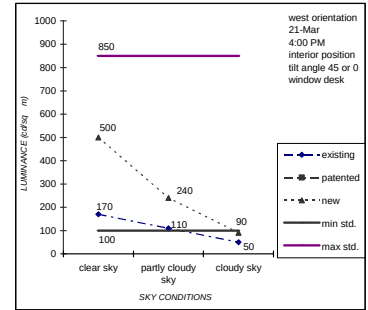
luminance		clear sky	partly cloud	cloudy sky
west orientation				
21-Mar	existing	170	110	50
	patented			
4:00 PM	new	380	230	90
exterior position	min std.	100	100	100
tilt angle 45 or 0	max std.	850	850	850
window desk				



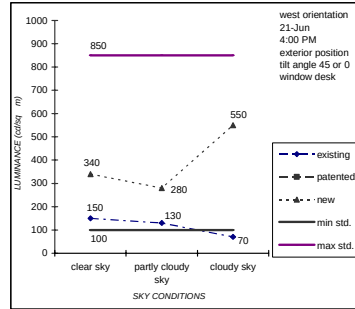
luminance		clear sky	partly cloud	cloudy sky
west orientation				
21-Mar	existing	150	110	50
	patented			
4:00 PM	new	360	220	90
between position	min std.	100	100	100
tilt angle 45 or 0	max std.	850	850	850
window desk				



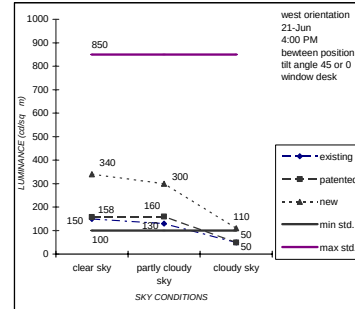
luminance		clear sky	partly cloud	cloudy sky
west orientation				
21-Mar	existing	170	110	50
	patented			
4:00 PM	new	500	240	90
interior position	min std.	100	100	100
tilt angle 45 or 0	max std.	850	850	850
window desk				



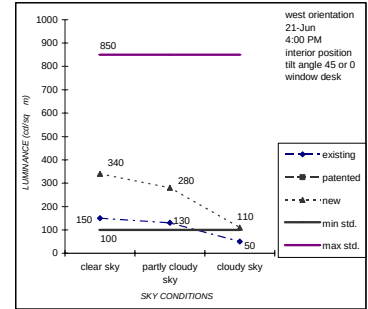
luminance		clear sky	partly cloud	cloudy sky
west orientation				
21-Jun	existing	150	130	70
	patented			
4:00 PM	new	340	280	550
exterior position	min std.	100	100	100
tilt angle 45 or 0	max std.	850	850	850
window desk				



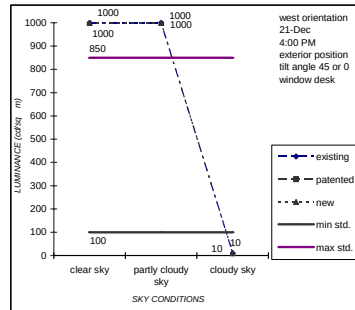
luminance		clear sky	partly cloud	cloudy sky
west orientation				
21-Jun	existing	150	130	50
	patented			
4:00 PM	new	340	300	110
between position	min std.	100	100	100
tilt angle 45 or 0	max std.	850	850	850
window desk				



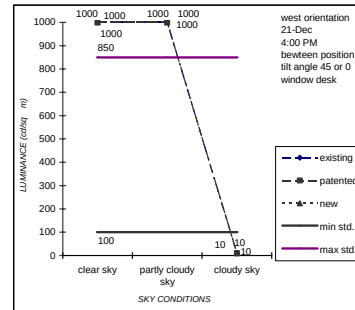
luminance		clear sky	partly cloud	cloudy sky
west orientation				
21-Jun	existing	150	130	50
	patented			
4:00 PM	new	340	280	110
interior position	min std.	100	100	100
tilt angle 45 or 0	max std.	850	850	850
window desk				



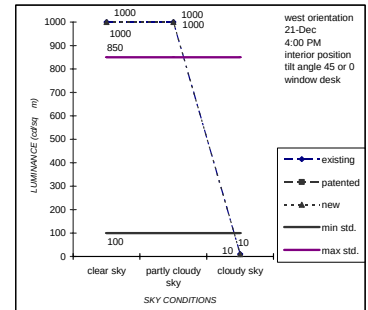
luminance		clear sky	partly cloud	cloudy sky
west orientation				
21-Dec	existing	1000	1000	10
	patented			
4:00 PM	new	1000	1000	10
exterior position	min std.	100	100	100
tilt angle 45 or 0	max std.	850	850	850
window desk				



luminance		clear sky	partly cloud	cloudy sky
west orientation				
21-Dec	existing	1000	1000	10
	patented			
4:00 PM	new	1000	1000	10
between position	min std.	100	100	100
tilt angle 45 or 0	max std.	850	850	850
window desk				



luminance		clear sky	partly cloud	cloudy sky
west orientation				
21-Dec	existing	1000	1000	10
	patented			
4:00 PM	new	1000	1000	10
interior position	min std.	100	100	100
tilt angle 45 or 0	max std.	850	850	850
window desk				

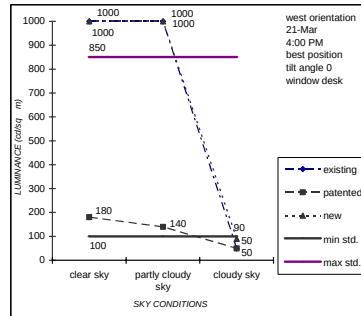


LUMINANCE - effect of sky conditions - for different blind tilt angles - for different dates

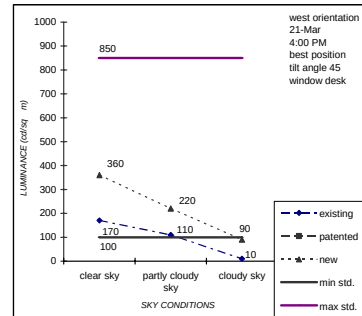
	existing	patented	new
BEST POSITION	inside	between	between

WEST SHEET 7
LUMINANCE SET 7
WINDOW

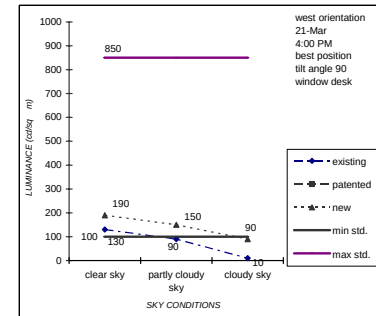
	clear sky	partly cloud	cloudy sky
luminance			
west orientation			
21-Mar			
4:00 PM			
best position			
tilt angle 0			
window desk			
existing	1000	1000	50
patented	180	140	90
new	1000	1000	100
min std.	100	100	100
max std.	850	850	850



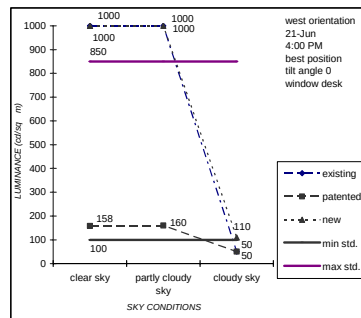
	clear sky	partly cloud	cloudy sky
luminance			
west orientation			
21-Mar			
4:00 PM			
best position			
tilt angle 45			
window desk			
existing	170	110	10
patented	360	220	90
new	100	100	100
min std.	100	100	100
max std.	850	850	850



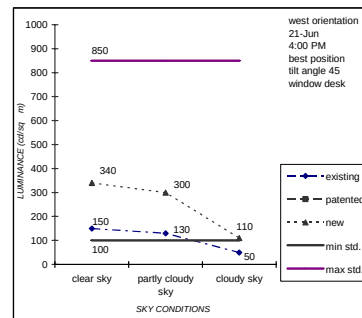
	clear sky	partly cloud	cloudy sky
luminance			
west orientation			
21-Mar			
4:00 PM			
best position			
tilt angle 90			
window desk			
existing	130	90	10
patented	190	150	90
new	100	100	100
min std.	100	100	100
max std.	850	850	850



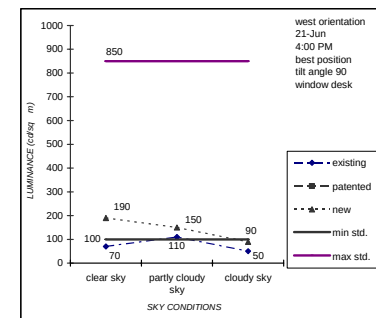
	clear sky	partly cloud	cloudy sky
luminance			
west orientation			
21-Jun			
4:00 PM			
best position			
tilt angle 0			
window desk			
existing	1000	1000	50
patented	158	160	110
new	1000	1000	100
min std.	100	100	100
max std.	850	850	850



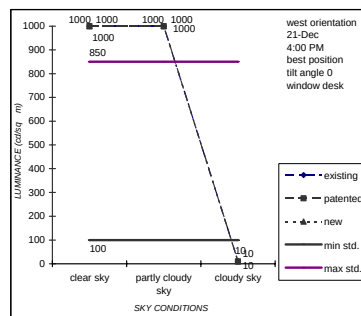
	clear sky	partly cloud	cloudy sky
luminance			
west orientation			
21-Jun			
4:00 PM			
best position			
tilt angle 45			
window desk			
existing	150	130	50
patented	340	300	110
new	100	100	100
min std.	100	100	100
max std.	850	850	850



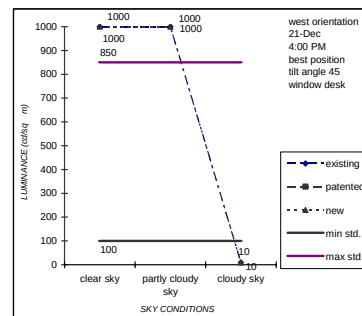
	clear sky	partly cloud	cloudy sky
luminance			
west orientation			
21-Jun			
4:00 PM			
best position			
tilt angle 90			
window desk			
existing	70	110	50
patented	190	150	90
new	100	100	100
min std.	100	100	100
max std.	850	850	850



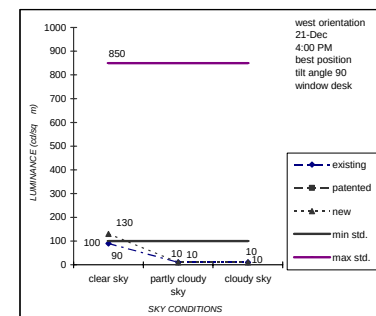
	clear sky	partly cloud	cloudy sky
luminance			
west orientation			
21-Dec			
4:00 PM			
best position			
tilt angle 0			
window desk			
existing	1000	1000	10
patented	1000	1000	10
new	1000	1000	10
min std.	100	100	100
max std.	850	850	850



	clear sky	partly cloud	cloudy sky
luminance			
west orientation			
21-Dec			
4:00 PM			
best position			
tilt angle 45			
window desk			
existing	1000	1000	10
patented	1000	1000	10
new	1000	1000	10
min std.	100	100	100
max std.	850	850	850



	clear sky	partly cloud	cloudy sky
luminance			
west orientation			
21-Dec			
4:00 PM			
best position			
tilt angle 90			
window desk			
existing	90	10	10
patented	130	10	10
new	100	100	100
min std.	100	100	100
max std.	850	850	850



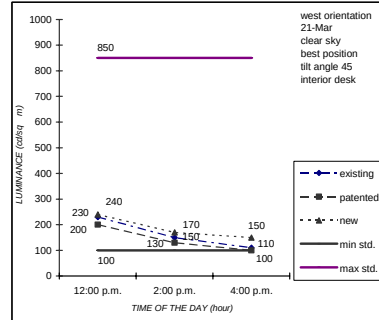
LUMINANCE- effect of the time - for different dates - for different sky conditions

existing blinds - tilt angle 45 for clear sky and partly cloudy sky and 0 for cloudy sky
 patented blinds - tilt angle 0 always
 new blinds - tilt angle 45 for clear sky and partly cloudy sky and 0 for cloudy sky

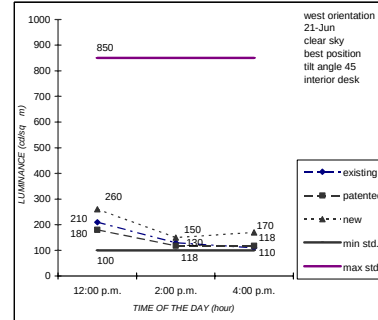
WEST SHEET 1
 LUMINANCE SET 8
 INTERIOR

	existing	patented	new
BEST POSITION	inside	between	between

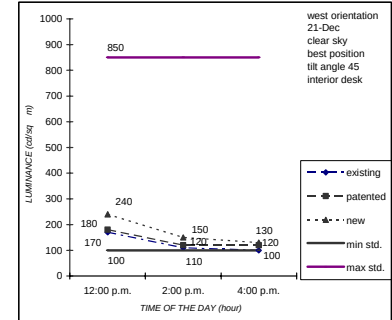
	12:00 p.m.	2:00 p.m.	4:00 p.m.
luminance west orientation			
21-Mar			
existing	230	150	110
patented	200	130	100
clear sky			
new	240	170	150
best position			
min std.	100	100	100
tilt angle 45			
max std.	850	850	850
interior desk			



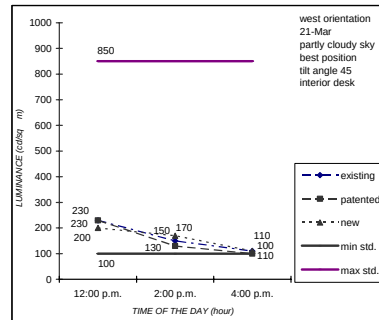
	12:00 p.m.	2:00 p.m.	4:00 p.m.
luminance west orientation			
21-Jun			
existing	210	130	110
patented	180	118	118
clear sky			
new	260	150	170
best position			
min std.	100	100	100
tilt angle 45			
max std.	850	850	850
interior desk			



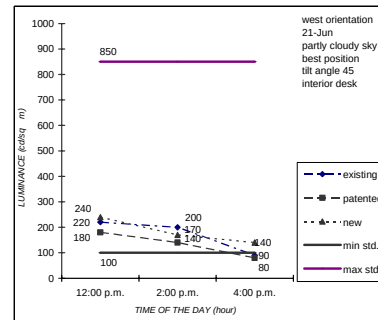
	12:00 p.m.	2:00 p.m.	4:00 p.m.
luminance west orientation			
21-Dec			
existing	170	110	100
patented	180	120	120
clear sky			
new	240	150	130
best position			
min std.	100	100	100
tilt angle 45			
max std.	850	850	850
interior desk			



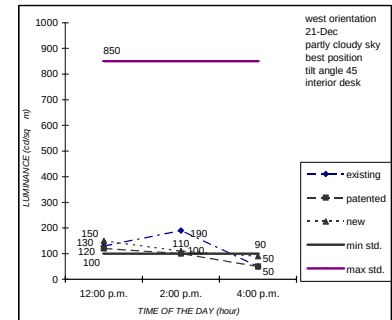
	12:00 p.m.	2:00 p.m.	4:00 p.m.
luminance west orientation			
21-Mar			
existing	230	150	110
patented	230	130	100
partly cloudy sky			
new	200	170	110
best position			
min std.	100	100	100
tilt angle 45			
max std.	850	850	850
interior desk			



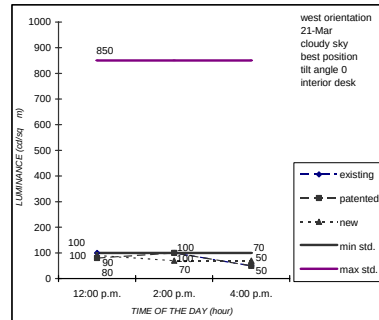
	12:00 p.m.	2:00 p.m.	4:00 p.m.
luminance west orientation			
21-Jun			
existing	220	200	90
patented	180	140	80
partly cloudy sky			
new	240	170	140
best position			
min std.	100	100	100
tilt angle 45			
max std.	850	850	850
interior desk			



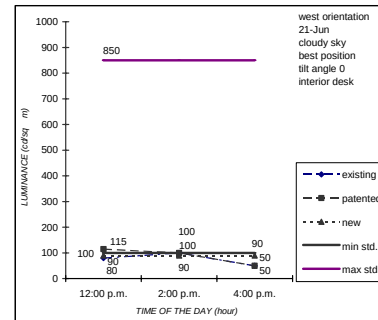
	12:00 p.m.	2:00 p.m.	4:00 p.m.
luminance west orientation			
21-Dec			
existing	130	190	50
patented	120	100	50
partly cloudy sky			
new	150	110	90
best position			
min std.	100	100	100
tilt angle 45			
max std.	850	850	850
interior desk			



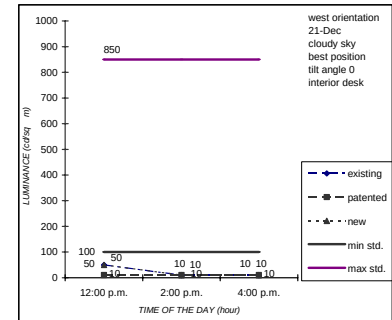
	12:00 p.m.	2:00 p.m.	4:00 p.m.
luminance west orientation			
21-Mar			
existing	100	100	50
patented	80	100	50
cloudy sky			
new	90	70	70
best position			
min std.	100	100	100
tilt angle 0			
max std.	850	850	850
interior desk			



	12:00 p.m.	2:00 p.m.	4:00 p.m.
luminance west orientation			
21-Jun			
existing	80	100	50
patented	115	100	50
cloudy sky			
new	90	90	90
best position			
min std.	100	100	100
tilt angle 0			
max std.	850	850	850
interior desk			



	12:00 p.m.	2:00 p.m.	4:00 p.m.
luminance west orientation			
21-Dec			
existing	50	10	10
patented	10	10	10
cloudy sky			
new	50	10	10
best position			
min std.	100	100	100
tilt angle 0			
max std.	850	850	850
interior desk			



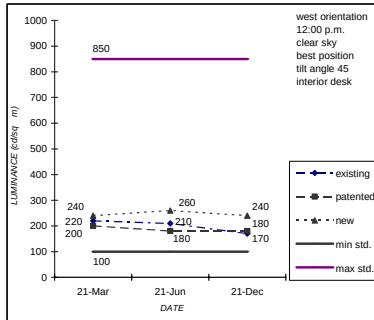
LUMINANCE - effect of the date -for different times - for different sky conditions

existing blinds - tilt angle 45 for clear sky and partly cloudy sky and 0 for cloudy sky
patented blinds - tilt angle 0 always
new blinds - tilt angle 45 for clear sky and partly cloudy sky and 0 for cloudy sky

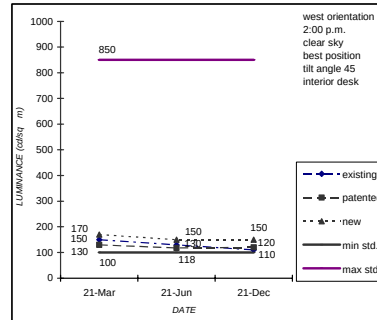
WEST SHEET 2
LUMINANCE SET 8
INTERIOR

	existing	patented	new
BEST POSITION	inside	between	between

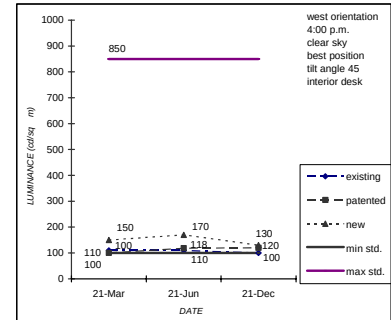
	21-Mar	21-Jun	21-Dec
luminance			
west orientation			
12:00 p.m.			
clear sky	220	210	170
best position	200	180	180
tilt angle 45	240	260	240
min std.	100	100	100
max std.	850	850	850



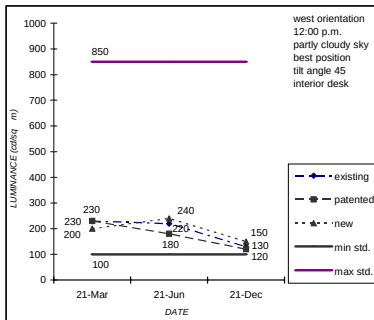
	21-Mar	21-Jun	21-Dec
luminance			
west orientation			
2:00 p.m.			
clear sky	150	130	110
best position	130	118	120
tilt angle 45	170	150	150
min std.	100	100	100
max std.	850	850	850



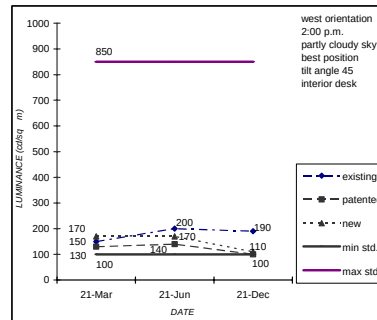
	21-Mar	21-Jun	21-Dec
luminance			
west orientation			
4:00 p.m.			
clear sky	110	110	100
best position	100	118	120
tilt angle 45	150	170	130
min std.	100	100	100
max std.	850	850	850



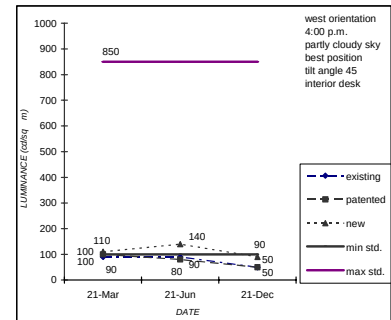
	21-Mar	21-Jun	21-Dec
luminance			
west orientation			
12:00 p.m.			
partly cloudy sky	230	220	130
best position	230	180	120
tilt angle 45	200	240	150
min std.	100	100	100
max std.	850	850	850



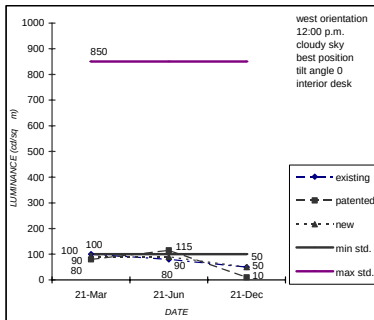
	21-Mar	21-Jun	21-Dec
luminance			
west orientation			
2:00 p.m.			
partly cloudy sky	150	200	190
best position	130	140	100
tilt angle 45	170	170	110
min std.	100	100	100
max std.	850	850	850



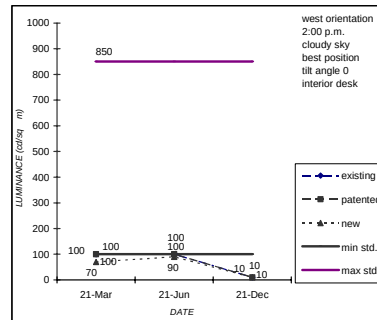
	21-Mar	21-Jun	21-Dec
luminance			
west orientation			
4:00 p.m.			
partly cloudy sky	90	90	50
best position	100	80	50
tilt angle 45	110	140	90
min std.	100	100	100
max std.	850	850	850



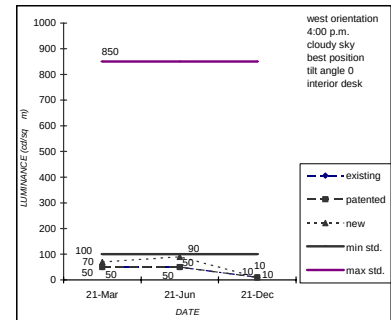
	21-Mar	21-Jun	21-Dec
luminance			
west orientation			
12:00 p.m.			
cloudy sky	100	80	50
best position	80	115	10
tilt angle 0	90	90	50
min std.	100	100	100
max std.	850	850	850



	21-Mar	21-Jun	21-Dec
luminance			
west orientation			
2:00 p.m.			
cloudy sky	100	100	10
best position	100	100	10
tilt angle 0	70	90	10
min std.	100	100	100
max std.	850	850	850



	21-Mar	21-Jun	21-Dec
luminance			
west orientation			
4:00 p.m.			
cloudy sky	50	50	10
best position	50	50	10
tilt angle 0	70	90	10
min std.	100	100	100
max std.	850	850	850



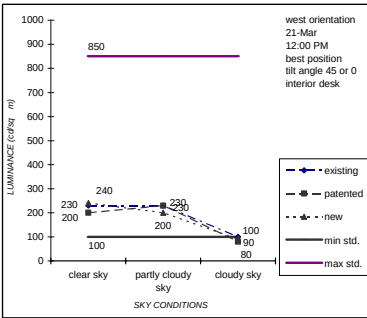
LUMINANCE - effect of sky conditions - for different times - for different dates

existing blinds - tilt angle 45 for clear sky and partly cloudy sky and 0 for cloudy sky
patented blinds - tilt angle 0 always
new blinds - tilt angle 45 for clear sky and partly cloudy sky and 0 for cloudy sky

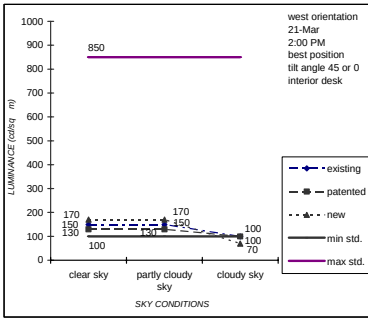
WEST SHEET 3
LUMINANCE SET 8
INTERIOR

	existing	patented	new
BEST POSITION	inside	between	between

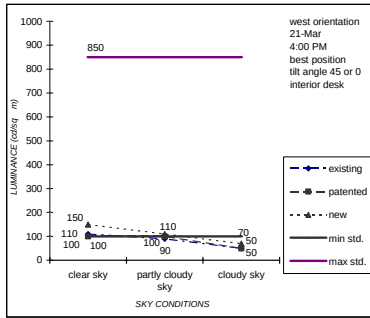
	clear sky	partly cloud	cloudy sky
luminance			
west orientation			
21-Mar			
12:00 PM			
best position			
tilt angle 45 or 0			
interior desk			
existing	230	230	100
patented	200	230	80
new	240	200	90
min std.	100	100	100
max std.	850	850	850



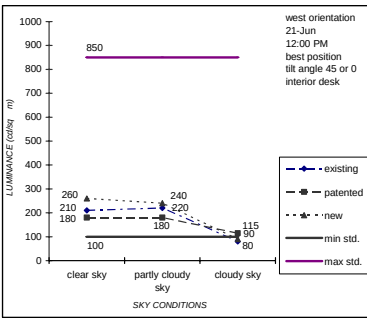
	clear sky	partly cloud	cloudy sky
luminance			
west orientation			
21-Mar			
2:00 PM			
best position			
tilt angle 45 or 0			
interior desk			
existing	150	150	100
patented	130	130	100
new	170	170	70
min std.	100	100	100
max std.	850	850	850



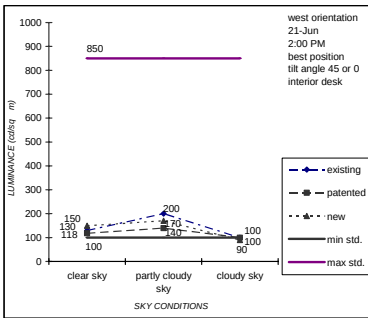
	clear sky	partly cloud	cloudy sky
luminance			
west orientation			
21-Mar			
4:00 PM			
best position			
tilt angle 45 or 0			
interior desk			
existing	110	90	50
patented	100	100	50
new	150	110	70
min std.	100	100	100
max std.	850	850	850



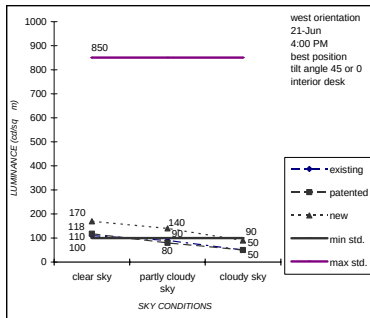
	clear sky	partly cloud	cloudy sky
luminance			
west orientation			
21-Jun			
12:00 PM			
best position			
tilt angle 45 or 0			
interior desk			
existing	210	220	80
patented	180	180	115
new	260	240	90
min std.	100	100	100
max std.	850	850	850



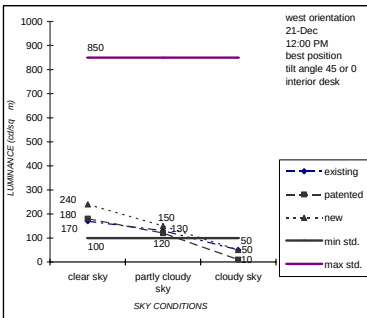
	clear sky	partly cloud	cloudy sky
luminance			
west orientation			
21-Jun			
2:00 PM			
best position			
tilt angle 45 or 0			
interior desk			
existing	130	200	100
patented	118	140	100
new	150	170	90
min std.	100	100	100
max std.	850	850	850



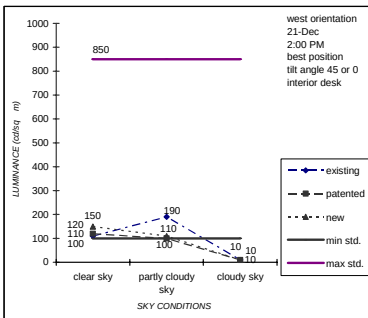
	clear sky	partly cloud	cloudy sky
luminance			
west orientation			
21-Jun			
4:00 PM			
best position			
tilt angle 45 or 0			
interior desk			
existing	110	90	50
patented	118	80	50
new	170	140	90
min std.	100	100	100
max std.	850	850	850



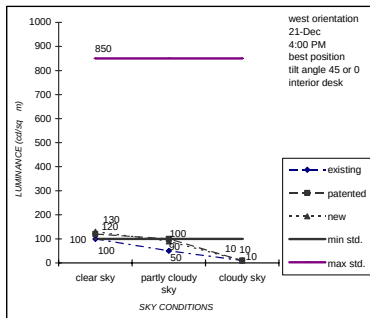
	clear sky	partly cloud	cloudy sky
luminance			
west orientation			
21-Dec			
12:00 PM			
best position			
tilt angle 45 or 0			
interior desk			
existing	170	130	50
patented	180	120	10
new	240	150	50
min std.	100	100	100
max std.	850	850	850



	clear sky	partly cloud	cloudy sky
luminance			
west orientation			
21-Dec			
2:00 PM			
best position			
tilt angle 45 or 0			
interior desk			
existing	110	190	10
patented	120	100	10
new	150	110	10
min std.	100	100	100
max std.	850	850	850



	clear sky	partly cloud	cloudy sky
luminance			
west orientation			
21-Dec			
4:00 PM			
best position			
tilt angle 45 or 0			
interior desk			
existing	100	50	10
patented	120	100	10
new	130	90	10
min std.	100	100	100
max std.	850	850	850

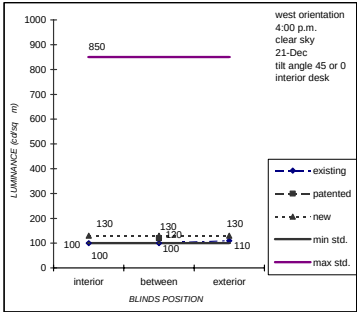


LUMINANCE- effect of the blinds position - for different dates - for different sky conditions

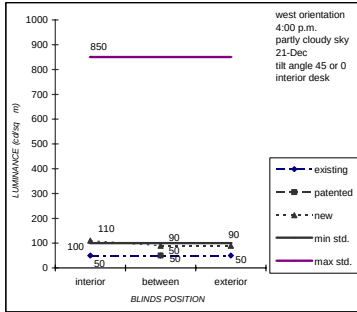
existing blinds - tilt angle 45 for clear sky and partly cloudy sky and 0 for cloudy sky
patented blinds - tilt angle 0 always
new blinds - tilt angle 45 for clear sky and partly cloudy sky and 0 for cloudy sky

WEST SHEET 4
LUMINANCE SET 8
INTERIOR

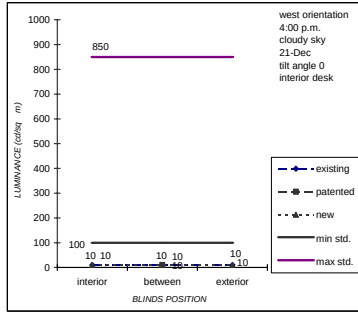
	interior	between	exterior
luminance			
west orientation			
4:00 p.m.	existing 100	100	110
clear sky	patented 130	120	130
21-Dec	new 100	100	100
tilt angle 45 or 0	min std. 850	850	850
interior desk			



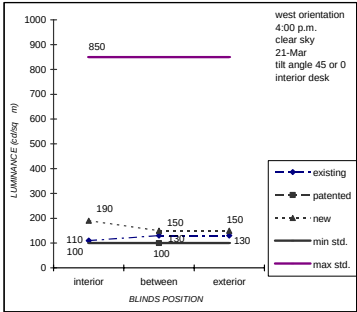
	interior	between	exterior
luminance			
west orientation			
4:00 p.m.	existing 50	50	50
partly cloudy sky	patented 110	90	90
21-Dec	new 100	100	100
tilt angle 45 or 0	min std. 850	850	850
interior desk			



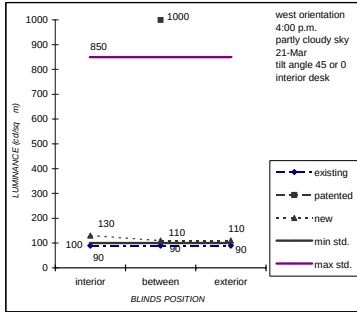
	interior	between	exterior
luminance			
west orientation			
4:00 p.m.	existing 10	10	10
cloudy sky	patented 10	10	10
21-Dec	new 100	100	100
tilt angle 0	min std. 850	850	850
interior desk			



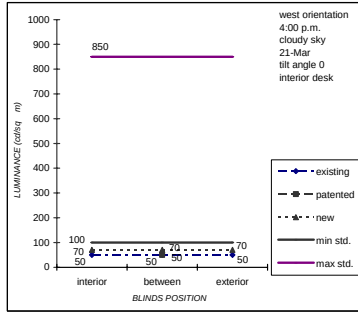
	interior	between	exterior
luminance			
west orientation			
4:00 p.m.	existing 110	130	130
clear sky	patented 100	100	130
21-Mar	new 190	150	150
tilt angle 45 or 0	min std. 100	100	100
interior desk			



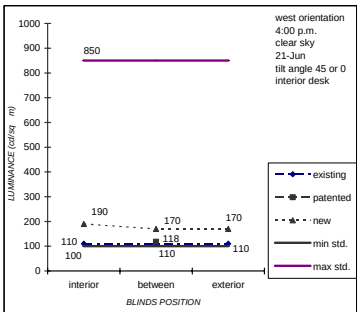
	interior	between	exterior
luminance			
west orientation			
4:00 p.m.	existing 90	90	90
partly cloudy sky	patented 1000	1000	1000
21-Mar	new 130	110	110
tilt angle 45 or 0	min std. 100	100	100
interior desk			



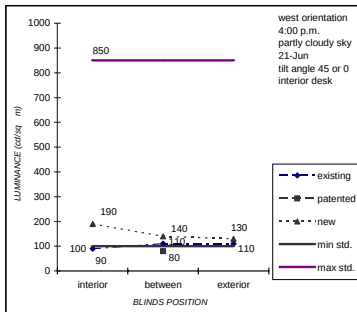
	interior	between	exterior
luminance			
west orientation			
4:00 p.m.	existing 50	50	50
cloudy sky	patented 50	50	50
21-Mar	new 70	70	70
tilt angle 0	min std. 100	100	100
interior desk			



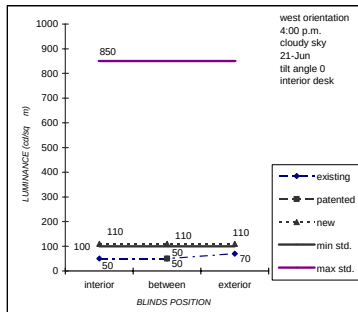
	interior	between	exterior
luminance			
west orientation			
4:00 p.m.	existing 110	110	110
clear sky	patented 118	118	118
21-Jun	new 190	170	170
tilt angle 45 or 0	min std. 100	100	100
interior desk			



	interior	between	exterior
luminance			
west orientation			
4:00 p.m.	existing 90	110	110
partly cloudy sky	patented 80	80	80
21-Jun	new 190	140	130
tilt angle 45 or 0	min std. 100	100	100
interior desk			



	interior	between	exterior
luminance			
west orientation			
4:00 p.m.	existing 50	50	70
cloudy sky	patented 50	50	50
21-Jun	new 110	110	110
tilt angle 0	min std. 100	100	100
interior desk			

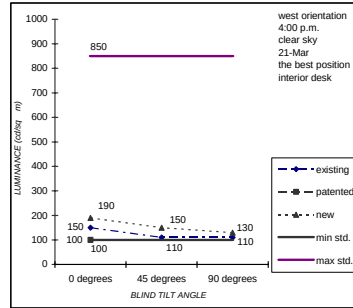


LUMINANCE - effect of the blinds position - for different dates - for different sky conditions

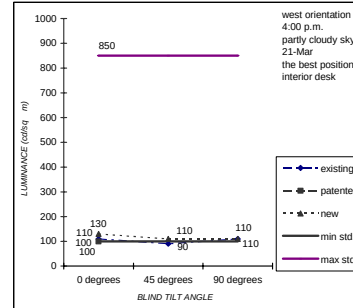
WEST SHEET 5
LUMINANCE SET 8
INTERIOR

existing blinds - tilt angle 45 for clear sky and partly cloudy sky and 0 for cloudy sky
patented blinds - tilt angle 0 always
new blinds - tilt angle 45 for clear sky and partly cloudy sky and 0 for cloudy sky

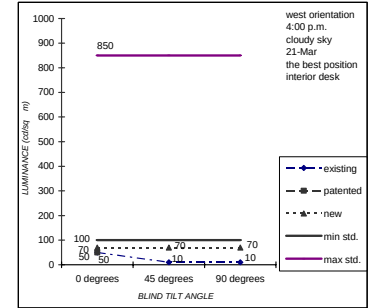
	0 degrees	45 degree	90 degrees
luminance			
west orientation			
4:00 p.m.			
clear sky			
21-Mar			
the best position			
interior desk			
existing	150	110	110
patented	100		
new	190	150	130
min std.	100	100	100
max std.	850	850	850



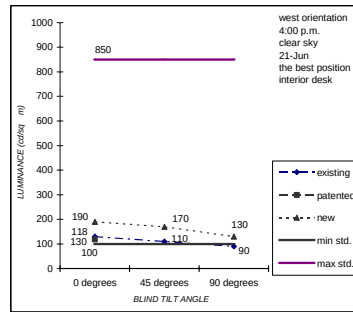
	0 degrees	45 degree	90 degrees
luminance			
west orientation			
4:00 p.m.			
partly cloudy sky			
21-Mar			
the best position			
interior desk			
existing	110	90	110
patented	100		
new	130	110	110
min std.	100	100	100
max std.	850	850	850



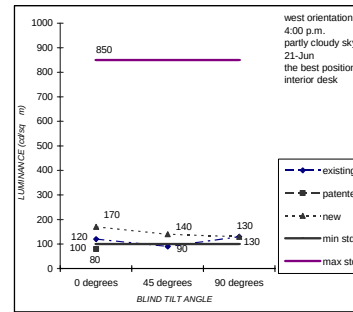
	0 degrees	45 degree	90 degrees
luminance			
west orientation			
4:00 p.m.			
cloudy sky			
21-Mar			
the best position			
interior desk			
existing	50	10	10
patented	50		
new	70	70	70
min std.	100	100	100
max std.	850	850	850



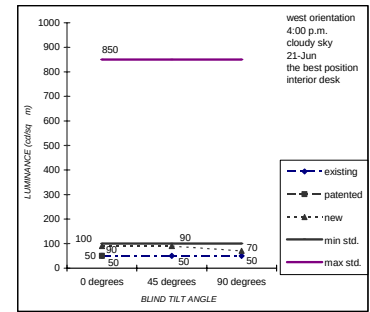
	0 degrees	45 degree	90 degrees
luminance			
west orientation			
4:00 p.m.			
clear sky			
21-Jun			
the best position			
interior desk			
existing	130	110	90
patented	118		
new	190	170	130
min std.	100	100	100
max std.	850	850	850



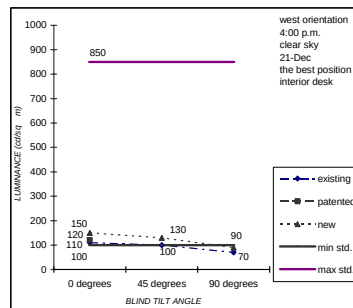
	0 degrees	45 degree	90 degrees
luminance			
west orientation			
4:00 p.m.			
partly cloudy sky			
21-Jun			
the best position			
interior desk			
existing	120	90	130
patented	80		
new	170	140	130
min std.	100	100	100
max std.	850	850	850



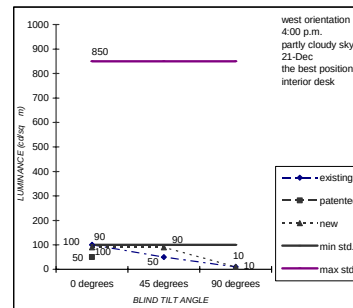
	0 degrees	45 degree	90 degrees
luminance			
west orientation			
4:00 p.m.			
cloudy sky			
21-Jun			
the best position			
interior desk			
existing	50	50	50
patented	50		
new	90	90	70
min std.	100	100	100
max std.	850	850	850



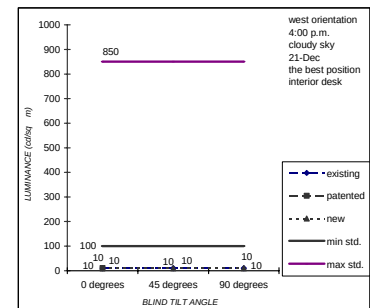
	0 degrees	45 degree	90 degrees
luminance			
west orientation			
4:00 p.m.			
clear sky			
21-Dec			
the best position			
interior desk			
existing	110	100	70
patented	120		
new	150	130	90
min std.	100	100	100
max std.	850	850	850



	0 degrees	45 degree	90 degrees
luminance			
west orientation			
4:00 p.m.			
partly cloudy sky			
21-Dec			
the best position			
interior desk			
existing	100	50	10
patented	50		
new	90	90	10
min std.	100	100	100
max std.	850	850	850



	0 degrees	45 degree	90 degrees
luminance			
west orientation			
4:00 p.m.			
cloudy sky			
21-Dec			
the best position			
interior desk			
existing	10	10	10
patented	10		
new	10	10	10
min std.	100	100	100
max std.	850	850	850

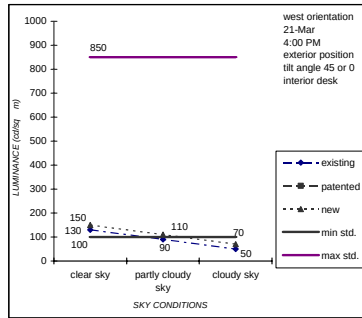


LUMINANCE - effect of sky conditions-for different positions of the blinds - for different dates

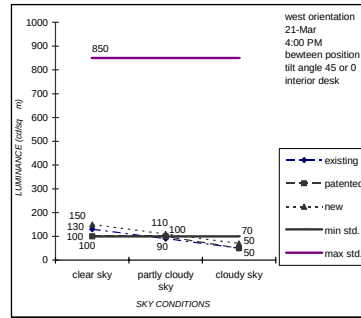
WEST SHEET 6
LUMINANCE SET 8
INTERIOR

existing blinds - tilt angle 45 for clear sky and partly cloudy sky and 0 for cloudy sky
patented blinds - tilt angle 0 always
new blinds - tilt angle 45 for clear sky and partly cloudy sky and 0 for cloudy sky

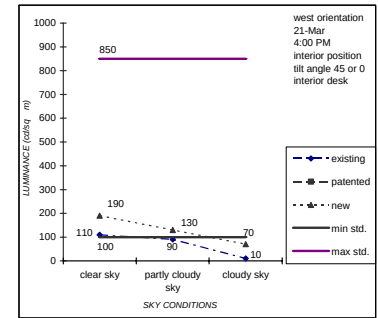
	clear sky	partly clou	cloudy sky
luminance			
west orientation			
21-Mar			
4:00 PM			
exterior position			
tilt angle 45 or 0			
interior desk			
existing	130	90	50
patented			
new	150	110	70
min std.	100	100	100
max std.	850	850	850



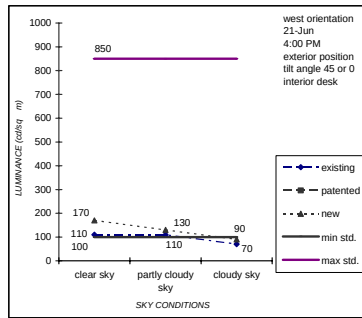
	clear sky	partly clou	cloudy sky
luminance			
west orientation			
21-Mar			
4:00 PM			
between position			
tilt angle 45 or 0			
interior desk			
existing	130	90	50
patented	100	100	50
new	150	110	70
min std.	100	100	100
max std.	850	850	850



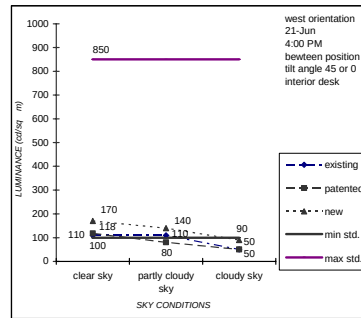
	clear sky	partly clou	cloudy sky
luminance			
west orientation			
21-Mar			
4:00 PM			
interior position			
tilt angle 45 or 0			
interior desk			
existing	110	90	10
patented			
new	190	130	70
min std.	100	100	100
max std.	850	850	850



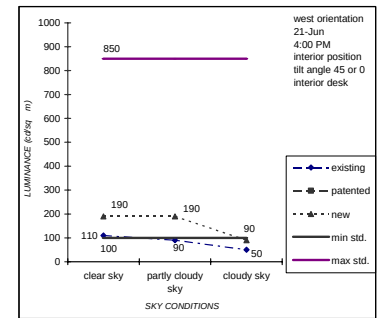
	clear sky	partly clou	cloudy sky
luminance			
west orientation			
21-Jun			
4:00 PM			
exterior position			
tilt angle 45 or 0			
interior desk			
existing	110	110	70
patented			
new	170	130	90
min std.	100	100	100
max std.	850	850	850



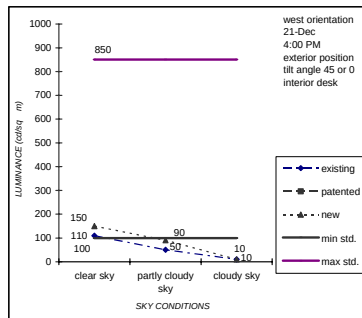
	clear sky	partly clou	cloudy sky
luminance			
west orientation			
21-Jun			
4:00 PM			
between position			
tilt angle 45 or 0			
interior desk			
existing	110	110	50
patented	118	80	50
new	170	140	90
min std.	100	100	100
max std.	850	850	850



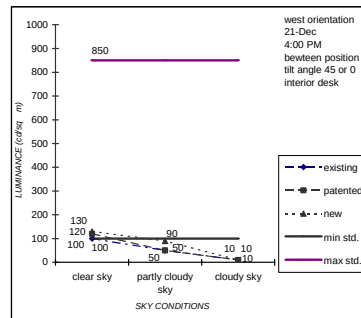
	clear sky	partly clou	cloudy sky
luminance			
west orientation			
21-Jun			
4:00 PM			
interior position			
tilt angle 45 or 0			
interior desk			
existing	110	90	50
patented			
new	190	190	90
min std.	100	100	100
max std.	850	850	850



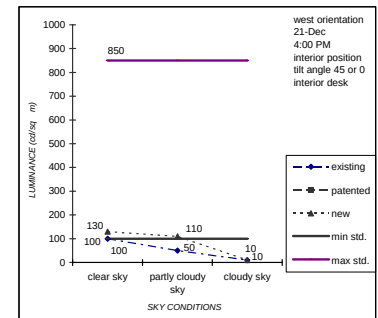
	clear sky	partly clou	cloudy sky
luminance			
west orientation			
21-Dec			
4:00 PM			
exterior position			
tilt angle 45 or 0			
interior desk			
existing	110	50	10
patented			
new	150	90	10
min std.	100	100	100
max std.	850	850	850



	clear sky	partly clou	cloudy sky
luminance			
west orientation			
21-Dec			
4:00 PM			
between position			
tilt angle 45 or 0			
interior desk			
existing	100	50	10
patented	120	50	10
new	130	90	10
min std.	100	100	100
max std.	850	850	850



	clear sky	partly clou	cloudy sky
luminance			
west orientation			
21-Dec			
4:00 PM			
interior position			
tilt angle 45 or 0			
interior desk			
existing	100	50	10
patented			
new	130	110	10
min std.	100	100	100
max std.	850	850	850

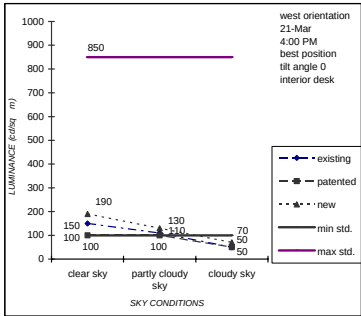


LUMINANCE - effect of sky conditions - for different blind tilt angles - for different dates

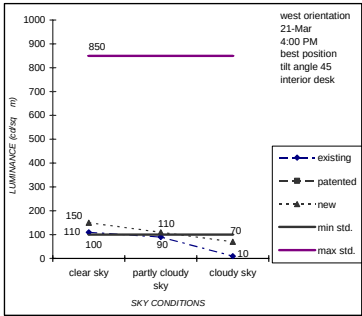
	existing	patented	new
BEST POSITION	inside	between	between

WEST SHEET 7
LUMINANCE SET 8
INTERIOR

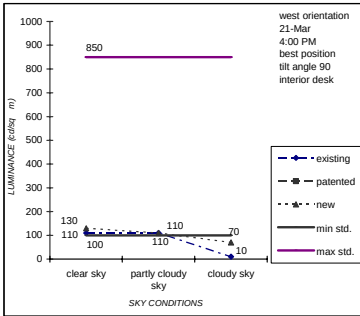
luminance		clear sky	partly clou	cloudy sky
west orientation				
21-Mar	existing	150	110	50
4:00 PM	patented	100	100	50
	new	130	130	70
best position	min std.	100	100	100
tilt angle 0	max std.	850	850	850
interior desk				



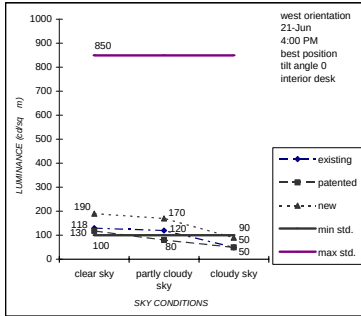
luminance		clear sky	partly clou	cloudy sky
west orientation				
21-Mar	existing	110	90	10
4:00 PM	patented	150	110	70
	new	100	100	100
best position	min std.	850	850	850
tilt angle 45	max std.	850	850	850
interior desk				



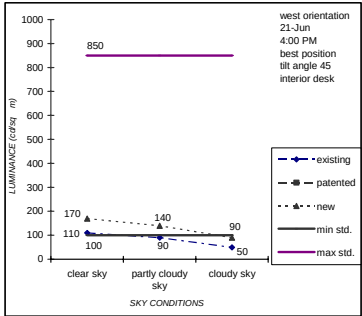
luminance		clear sky	partly clou	cloudy sky
west orientation				
21-Mar	existing	110	110	10
4:00 PM	patented	130	110	70
	new	100	100	100
best position	min std.	850	850	850
tilt angle 90	max std.	850	850	850
interior desk				



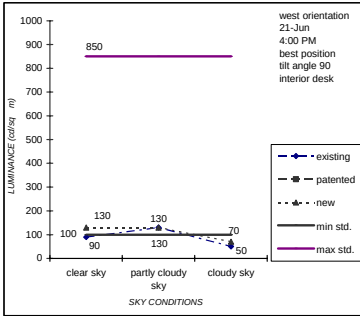
luminance		clear sky	partly clou	cloudy sky
west orientation				
21-Jun	existing	130	120	50
4:00 PM	patented	118	80	50
	new	190	170	90
best position	min std.	100	100	100
tilt angle 0	max std.	850	850	850
interior desk				



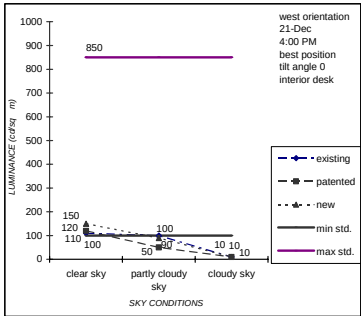
luminance		clear sky	partly clou	cloudy sky
west orientation				
21-Jun	existing	110	90	50
4:00 PM	patented	170	140	90
	new	100	100	100
best position	min std.	850	850	850
tilt angle 45	max std.	850	850	850
interior desk				



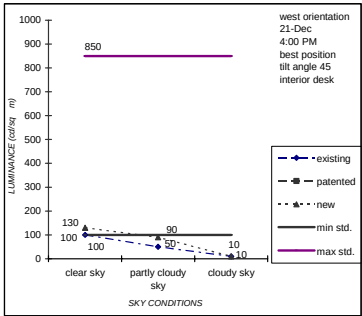
luminance		clear sky	partly clou	cloudy sky
west orientation				
21-Jun	existing	90	130	50
4:00 PM	patented	130	130	70
	new	100	100	100
best position	min std.	850	850	850
tilt angle 90	max std.	850	850	850
interior desk				



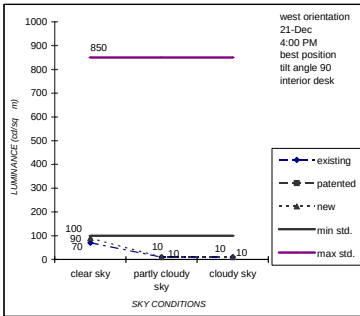
luminance		clear sky	partly clou	cloudy sky
west orientation				
21-Dec	existing	110	100	10
4:00 PM	patented	120	50	10
	new	150	90	10
best position	min std.	100	100	100
tilt angle 0	max std.	850	850	850
interior desk				



luminance		clear sky	partly clou	cloudy sky
west orientation				
21-Dec	existing	100	50	10
4:00 PM	patented	130	90	10
	new	100	100	100
best position	min std.	850	850	850
tilt angle 45	max std.	850	850	850
interior desk				



luminance		clear sky	partly clou	cloudy sky
west orientation				
21-Dec	existing	70	10	10
4:00 PM	patented	90	10	10
	new	100	100	100
best position	min std.	850	850	850
tilt angle 90	max std.	850	850	850
interior desk				



B.4. POSSIBLE PRESENTATION OF THE RESULTS

B.4.1. – CONVERSION OF VALUES

VALUES OF ILLUMINANCE AND LUMINANCE TAKEN FROM THE MATRIXES OF DATA FOR SOUTH (Appendix B.1.)

	21-Dec											
	11:00 a.m.											
	clear sky				partly cloudy sky				cloudy sky			
	illuminance		luminance		illuminance		luminance		illuminance		luminance	
	window	inside wall	window	inside wall	window	inside wall	window	inside wall	window	inside wall	window	inside wall
EXISTING	1300	650	150	110	850	500	100	90	500	400	10	10
PATENTED	2200	650	200	100	1300	600	160	120	300	400	10	10
NEW	2500	1300	400	150	2100	800	220	130	550	400	10	10

	21-Dec											
	12:00 p.m.											
	clear sky				partly cloudy sky				cloudy sky			
	illuminance		luminance		illuminance		luminance		illuminance		luminance	
	window	inside wall	window	inside wall	window	inside wall	window	inside wall	window	inside wall	window	inside wall
EXISTING	2500	1300	650	120	850	700	90	70	450	400	30	10
PATENTED	1600	850	180	140	1100	850	120	90	400	450	10	10
NEW	2500	1300	430	170	2300	900	260	130	600	500	110	100

	21-Dec											
	3:00 p.m.											
	clear sky				partly cloudy sky				cloudy sky			
	illuminance		luminance		illuminance		luminance		illuminance		luminance	
	window	inside wall	window	inside wall	window	inside wall	window	inside wall	window	inside wall	window	inside wall
EXISTING	900	750	70	50	550	500	70	50	101	101	11	11
PATENTED	1600	1000	160	120	660	550	70	50	101	101	11	11
NEW	2300	1000	320	130	1100	650	170	130	500	200	11	11

	21-Mar											
	11:00 a.m.											
	clear sky				partly cloudy sky				cloudy sky			
	illuminance		luminance		illuminance		luminance		illuminance		luminance	
	window	inside wall	window	inside wall	window	inside wall	window	inside wall	window	inside wall	window	inside wall
EXISTING	1300	1300	125	80	1100	1000	150	110	500	450	70	60
PATENTED	1600	1000	160	120	1450	1150	160	140	450	500	80	85
NEW	2500	1300	320	190	2500	1300	300	190	750	550	130	70

	21-Mar											
	12:00 p.m.											
	clear sky				partly cloudy sky				cloudy sky			
	illuminance		luminance		illuminance		luminance		illuminance		luminance	
	window	inside wall	window	inside wall	window	inside wall	window	inside wall	window	inside wall	window	inside wall
EXISTING	1000	900	120	100	1300	1000	120	80	500	450	50	30
PATENTED	1600	900	150	130	1600	1000	158	138	550	500	70	60
NEW	2500	1300	340	150	2500	1600	340	170	900	600	130	110

	21-Mar											
	3:00 p.m.											
	clear sky				partly cloudy sky				cloudy sky			
	illuminance		luminance		illuminance		luminance		illuminance		luminance	
	window	inside wall	window	inside wall	window	inside wall	window	inside wall	window	inside wall	window	inside wall
EXISTING	1200	1000	125	100	1100	1000	70	60	450	400	80	75
PATENTED	1300	1000	150	130	1150	900	158	138	400	450	30	10
NEW	2400	1300	320	170	2200	1100	220	150	700	500	60	70

	21-Jun											
	11:00 a.m.											
	clear sky				partly cloudy sky				cloudy sky			
	illuminance		luminance		illuminance		luminance		illuminance		luminance	
	window	inside wall	window	inside wall	window	inside wall	window	inside wall	window	inside wall	window	inside wall
EXISTING	1300	1600	158	178	1300	1500	160	180	600	500	100	80
PATENTED	1300	1300	158	138	1300	1600	120	140	400	500	100	110
NEW	2300	1700	240	200	2300	1600	240	200	900	650	150	90

	21-Jun											
	12:00 p.m.											
	clear sky				partly cloudy sky				cloudy sky			
	illuminance		luminance		illuminance		luminance		illuminance		luminance	
	window	inside wall	window	inside wall	window	inside wall	window	inside wall	window	inside wall	window	inside wall
EXISTING	1300	1300	130	140	1300	1600	150	170	600	550	80	70
PATENTED	1300	1300	150	130	1800	1700	140	160	500	550	60	50
NEW	2200	1600	220	180	2300	1900	260	180	1000	650	150	90

	21-Jun											
	3:00 p.m.											
	clear sky				partly cloudy sky				cloudy sky			
	illuminance		luminance		illuminance		luminance		illuminance		luminance	
	window	inside wall	window	inside wall	window	inside wall	window	inside wall	window	inside wall	window	inside wall
EXISTING	1100	1600	140	180	1000	1600	138	158	550	500	110	100
PATENTED	1500	1700	120	160	1100	1300	130	150	500	550	80	70
NEW	2100	1700	220	180	2300	1600	240	200	850	600	130	90

VALUES OF ILLUMINANCE AND LUMINANCE FOR SOUTH CONVERTED TO THE SCALE 0-1

	21-Dec											
	11:00 a.m.											
	clear sky				partly cloudy sky				cloudy sky			
	illuminance		luminance		illuminance		luminance		illuminance		luminance	
	window	inside wall	window	inside wall	window	inside wall	window	inside wall	window	inside wall	window	inside wall
EXISTING	0.5	0.25	0.25	0.125	0.375	0.25	0.125	0.125	0.25	0.125	0.125	0.125
PATENTED	0.875	0.25	0.25	0.125	0.5	0.25	0.25	0.125	0.125	0.125	0.125	0.125
NEW	0.875	0.5	0.5	0.25	0.875	0.375	0.25	0.125	0.25	0.125	0.125	0.125

	21-Dec											
	12:00 p.m.											
	clear sky				partly cloudy sky				cloudy sky			
	illuminance		luminance		illuminance		luminance		illuminance		luminance	
	window	inside wall	window	inside wall	window	inside wall	window	inside wall	window	inside wall	window	inside wall
EXISTING	0.875	0.5	0.75	0.125	0.375	0.25	0.125	0.125	0.25	0.125	0.125	0.125
PATENTED	0.625	0.375	0.25	0.25	0.5	0.375	0.125	0.125	0.125	0.25	0.125	0.125
NEW	0.875	0.5	0.5	0.25	0.875	0.375	0.375	0.125	0.25	0.25	0.125	0.125

	21-Dec											
	3:00 p.m.											
	clear sky				partly cloudy sky				cloudy sky			
	illuminance		luminance		illuminance		luminance		illuminance		luminance	
	window	inside wall	window	inside wall	window	inside wall	window	inside wall	window	inside wall	window	inside wall
EXISTING	0.375	0.375	0.125	0.125	0.25	0.25	0.125	0.125	0.125	0.125	0.125	0.125
PATENTED	0.625	0.375	0.25	0.125	0.25	0.25	0.125	0.125	0.125	0.125	0.125	0.125
NEW	0.875	0.375	0.375	0.125	0.5	0.25	0.25	0.125	0.25	0.125	0.125	0.125

	21-Mar											
	11:00 a.m.											
	clear sky				partly cloudy sky				cloudy sky			
	illuminance		luminance		illuminance		luminance		illuminance		luminance	
	window	inside wall	window	inside wall	window	inside wall	window	inside wall	window	inside wall	window	inside wall
EXISTING	0.5	0.5	0.125	0.125	0.5	0.375	0.25	0.125	0.25	0.25	0.125	0.125
PATENTED	0.625	0.375	0.25	0.125	0.625	0.5	0.25	0.25	0.25	0.25	0.125	0.125
NEW	0.875	0.5	0.375	0.25	0.875	0.5	0.375	0.25	0.375	0.25	0.125	0.125

	21-Mar											
	12:00 p.m.											
	clear sky				partly cloudy sky				cloudy sky			
	illuminance		luminance		illuminance		luminance		illuminance		luminance	
	window	inside wall	window	inside wall	window	inside wall	window	inside wall	window	inside wall	window	inside wall
EXISTING	0.375	0.375	0.125	0.125	0.5	0.375	0.125	0.125	0.25	0.25	0.125	0.125
PATENTED	0.625	0.375	0.25	0.125	0.625	0.375	0.25	0.25	0.25	0.25	0.125	0.125
NEW	0.875	0.5	0.375	0.25	0.875	0.625	0.375	0.25	0.375	0.25	0.125	0.125

	21-Mar											
	3:00 p.m.											
	clear sky				partly cloudy sky				cloudy sky			
	illuminance		luminance		illuminance		luminance		illuminance		luminance	
	window	inside wall	window	inside wall	window	inside wall	window	inside wall	window	inside wall	window	inside wall
EXISTING	0.5	0.375	0.125	0.125	0.5	0.375	0.125	0.125	0.25	0.125	0.125	0.125
PATENTED	0.5	0.375	0.25	0.125	0.5	0.375	0.25	0.25	0.125	0.25	0.125	0.125
NEW	0.875	0.5	0.375	0.25	0.875	0.5	0.25	0.25	0.25	0.25	0.125	0.125

	21-Jun											
	11:00 a.m.											
	clear sky				partly cloudy sky				cloudy sky			
	illuminance		luminance		illuminance		luminance		illuminance		luminance	
	window	inside wall	window	inside wall	window	inside wall	window	inside wall	window	inside wall	window	inside wall
EXISTING	0.5	0.625	0.25	0.25	0.5	0.625	0.25	0.25	0.25	0.25	0.125	0.125
PATENTED	0.5	0.5	0.25	0.25	0.5	0.625	0.125	0.25	0.125	0.25	0.125	0.125
NEW	0.875	0.75	0.25	0.25	0.875	0.625	0.25	0.25	0.375	0.25	0.25	0.125

	21-Jun											
	12:00 p.m.											
	clear sky				partly cloudy sky				cloudy sky			
	illuminance		luminance		illuminance		luminance		illuminance		luminance	
	window	inside wall	window	inside wall	window	inside wall	window	inside wall	window	inside wall	window	inside wall
EXISTING	0.5	0.5	0.125	0.25	0.5	0.625	0.25	0.25	0.25	0.25	0.125	0.125
PATENTED	0.5	0.5	0.25	0.125	0.75	0.75	0.25	0.25	0.25	0.25	0.125	0.125
NEW	0.875	0.625	0.25	0.25	0.875	0.75	0.375	0.25	0.375	0.25	0.25	0.125

	21-Jun											
	3:00 p.m.											
	clear sky				partly cloudy sky				cloudy sky			
	illuminance		luminance		illuminance		luminance		illuminance		luminance	
	window	inside wall	window	inside wall	window	inside wall	window	inside wall	window	inside wall	window	inside wall
EXISTING	0.5	0.625	0.25	0.25	0.375	0.625	0.25	0.25	0.25	0.25	0.125	0.125
PATENTED	0.625	0.75	0.125	0.25	0.5	0.5	0.125	0.25	0.25	0.25	0.125	0.125
NEW	0.875	0.75	0.25	0.25	0.875	0.625	0.25	0.25	0.375	0.25	0.125	0.125

B.4.2. DAYLIGHT
AUTONOMY

SOUTH											
ILLUMINANCE - MARCH 21- AT 12:00 P.M.											
BLIND TYPE	BLIND ANGLE	CLEAR SKY			PARTLY CLOUDY SKY			CLOUDY SKY			INTERIOR
		WINDOW	INTERIOR	WINDOW	WINDOW	INTERIOR	WINDOW	WINDOW	INTERIOR	WINDOW	
EXISTING	0	1700	1000	1300	2250	1300	1300	500	900	500	450
	45	1000	900	1300	1300	1000	1000	500	900	500	600
	90	650	800	700	700	900	450	550	500	500	550
PATENTED	0	1600	900	1600	1000	1000	550	500	500	500	500
	0	2500	1900	2500	1600	1600	900	600	600	600	600
	45	2500	1300	2500	1600	1600	700	550	500	500	550
NEW	90	1300	900	1300	1100	1100	450	500	500	500	500

WEST											
ILLUMINANCE - MARCH 21- AT 4:00 P.M.											
BLIND TYPE	BLIND ANGLE	CLEAR SKY			PARTLY CLOUDY SKY			CLOUDY SKY			INTERIOR
		WINDOW	INTERIOR	WINDOW	WINDOW	INTERIOR	WINDOW	WINDOW	INTERIOR	WINDOW	
EXISTING	0	10000	1200	10000	10000	900	500	450	500	500	450
	45	1100	850	850	850	500	300	400	400	400	400
	90	650	600	550	550	650	300	400	400	400	400
PATENTED	0	1900	700	1000	1000	650	450	500	500	500	500
	0	10000	1700	10000	10000	1000	600	500	500	500	500
	45	2500	1300	2200	2200	850	550	450	450	450	450
NEW	90	1500	950	950	950	650	450	500	500	500	500

SOUTH											
ILLUMINANCE - DECEMBER 21- AT 12:00 P.M.											
BLIND TYPE	BLIND ANGLE	CLEAR SKY			PARTLY CLOUDY SKY			CLOUDY SKY			INTERIOR
		WINDOW	INTERIOR	WINDOW	WINDOW	INTERIOR	WINDOW	WINDOW	INTERIOR	WINDOW	
EXISTING	0	10000	1300	10000	1000	1000	450	400	400	400	400
	45	2500	1300	850	700	350	450	450	450	450	450
	90	600	650	500	650	350	450	450	450	450	450
PATENTED	0	1600	850	1100	850	400	450	450	450	450	450
	0	10000	1800	10000	1000	600	500	500	500	500	500
	45	2500	1300	2300	900	580	430	430	430	430	430
NEW	90	1100	700	950	700	280	330	330	330	330	330

WEST											
ILLUMINANCE - DECEMBER 21- AT 4:00 P.M.											
BLIND TYPE	BLIND ANGLE	CLEAR SKY			PARTLY CLOUDY SKY			CLOUDY SKY			INTERIOR
		WINDOW	INTERIOR	WINDOW	WINDOW	INTERIOR	WINDOW	WINDOW	INTERIOR	WINDOW	
EXISTING	0	10000	650	10000	300	100	100	100	100	100	100
	45	10000	500	10000	300	100	100	100	100	100	100
	90	450	400	250	300	100	100	100	100	100	100
PATENTED	0	2500	550	10000	300	100	100	100	100	100	100
	0	10000	800	10000	500	100	100	100	100	100	100
	45	10000	700	10000	450	100	100	100	100	100	100
NEW	90	900	500	500	350	100	100	100	100	100	100

SOUTH											
ILLUMINANCE - JUN 21- AT 12:00 P.M.											
BLIND TYPE	BLIND ANGLE	CLEAR SKY			PARTLY CLOUDY SKY			CLOUDY SKY			INTERIOR
		WINDOW	INTERIOR	WINDOW	WINDOW	INTERIOR	WINDOW	WINDOW	INTERIOR	WINDOW	
EXISTING	0	1300	1300	2200	1500	600	550	550	550	550	550
	45	1300	1300	1300	1600	500	600	600	600	600	600
	90	1000	1100	1000	1600	500	600	600	600	600	600
PATENTED	0	1300	1300	1800	1700	500	550	550	550	550	550
	0	2500	1700	2500	2200	1000	650	650	650	650	650
	45	2200	1600	2300	1900	900	650	650	650	650	650
NEW	90	1100	1000	1500	1700	600	650	650	650	650	650

WEST											
ILLUMINANCE - JUN 21- AT 4:00 P.M.											
BLIND TYPE	BLIND ANGLE	CLEAR SKY			PARTLY CLOUDY SKY			CLOUDY SKY			INTERIOR
		WINDOW	INTERIOR	WINDOW	WINDOW	INTERIOR	WINDOW	WINDOW	INTERIOR	WINDOW	
EXISTING	0	10000	1100	10000	1000	450	350	350	350	350	350
	45	1000	900	800	800	400	450	450	450	450	450
	90	600	800	600	700	400	500	500	500	500	500
PATENTED	0	1300	900	1300	700	450	500	500	500	500	500
	0	10000	1700	10000	1600	700	550	550	550	550	550
	45	2500	1300	2400	1000	600	500	500	500	500	500
NEW	90	1300	1000	1000	850	500	550	550	550	550	550

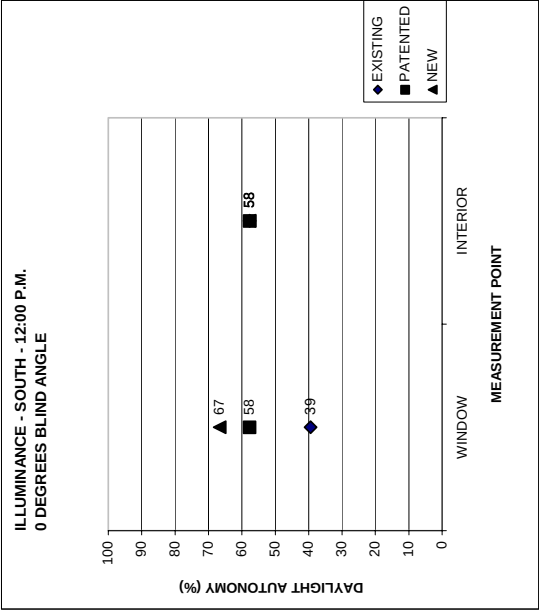
ANGLE 0	ILLUMINANCE - JUN 21-AT 12:00 P.M.						ILLUMINANCE - DECEMBER 21-AT 12:00 P.M.						ILLUMINANCE - MARCH 21-AT 12:00 P.M.					
	CLEAR SKY		PARTLY CLOUDY SKY		CLOUDY SKY		CLEAR SKY		PARTLY CLOUDY SKY		CLOUDY SKY		CLEAR SKY		PARTLY CLOUDY SKY		CLOUDY SKY	
	WINDOW	INTERIOR	WINDOW	INTERIOR	WINDOW	INTERIOR	WINDOW	INTERIOR	WINDOW	INTERIOR	WINDOW	INTERIOR	WINDOW	INTERIOR	WINDOW	INTERIOR	WINDOW	INTERIOR
EXISTING	1300	1300	2200	1500	600	550	10000	1300	10000	1000	450	400	1700	1000	2250	1300	500	450
PATENTED	1300	1300	1800	1700	500	550	1600	850	1100	850	400	450	1600	900	1600	1000	550	500
NEW	2500	1700	2500	2200	1000	650	10000	1800	10000	1000	600	500	2500	1900	2500	1600	900	600

SKY CONDITIONS NUMBER OF DAYS

month	JUNE			DECEMBER			MARCH		
	clear	partly cloud	cloudy	clear	partly cloud	cloudy	clear	partly cloud	cloudy
EXISTING	7	12	11	9	8	14	8	9	14
PATENTED	7	12	11	9	8	14	8	9	14
NEW	7	12	11	9	8	14	8	9	14

	PER YEAR		
	EXISTING	WINDOW	INTERIOR
	58	39	58
PATENTED	58	58	58
NEW	67	67	58

	ILLUM - JUN 21		ILLUM - DEC 21		ILLUM - MAR 21	
	WINDOW	INTERIOR	WINDOW	INTERIOR	WINDOW	INTERIOR
	63	63	0	55	55	55
PATENTED	63	63	55	55	55	55
NEW	100	63	0	55	100	55



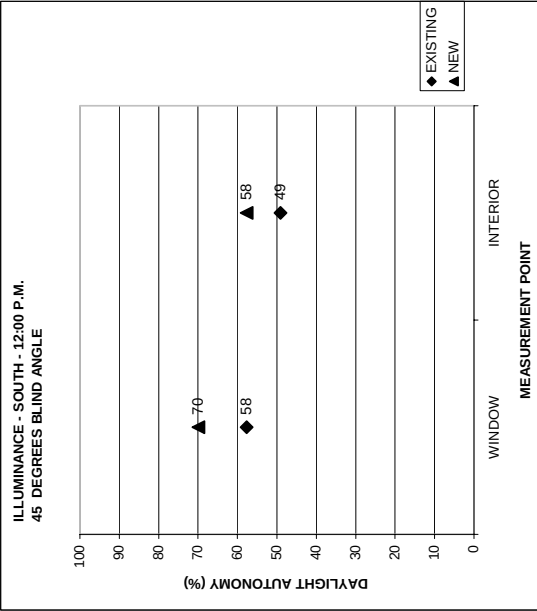
ANGLE 45	ILLUMINANCE - JUN 21- AT 12:00 P.M.						ILLUMINANCE - DECEMBER 21- AT 12:00 P.M.						ILLUMINANCE - MARCH 21- AT 12:00 P.M.					
	CLEAR SKY		PARTLY CLOUDY SKY		CLOUDY SKY		CLEAR SKY		PARTLY CLOUDY SKY		CLOUDY SKY		CLEAR SKY		PARTLY CLOUDY SKY		CLOUDY SKY	
	WINDOW	INTERIOR	WINDOW	INTERIOR	WINDOW	INTERIOR	WINDOW	INTERIOR	WINDOW	INTERIOR	WINDOW	INTERIOR	WINDOW	INTERIOR	WINDOW	INTERIOR	WINDOW	INTERIOR
EXISTING	1300	1300	1300	1600	500	600	2500	1300	850	700	350	450	1000	900	1300	1000	500	600
NEW	2200	1600	2300	1900	900	650	2500	1300	2300	900	580	430	2500	1300	2500	1600	700	550

SKY CONDITIONS NUMBER OF DAYS

month	JUNE			DECEMBER			MARCH		
	clear	partly cloud	cloudy	clear	partly cloud	cloudy	clear	partly cloud	cloudy
EXISTING	7	12	11	9	8	14	8	9	14
NEW	7	12	11	9	8	14	8	9	14

	ILLUM - JUN 21		ILLUM - DEC 21		ILLUM - MAR 21	
	WINDOW	INTERIOR	WINDOW	INTERIOR	WINDOW	INTERIOR
EXISTING	63	63	55	29	55	55
NEW	100	63	55	55	55	55

	PER YEAR	
	EXISTING	INTERIOR
	58	49
	NEW	70
		58



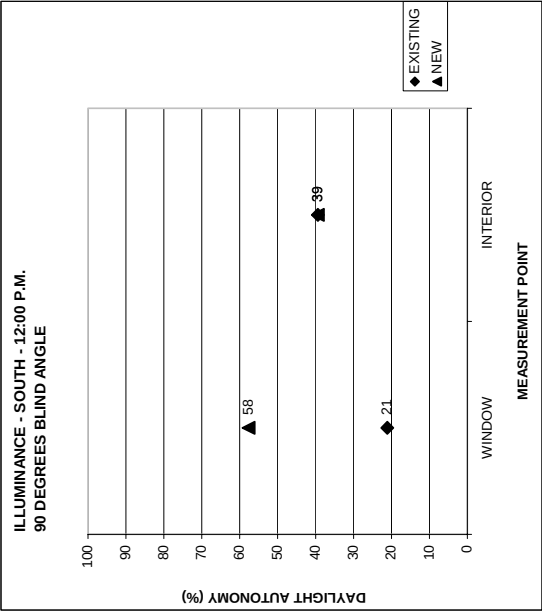
ANGLE 90	ILLUMINANCE - JUN 21- AT 12:00 P.M.						ILLUMINANCE - DECEMBER 21- AT 12:00 P.M.						ILLUMINANCE - MARCH 21- AT 12:00 P.M.					
	CLEAR SKY		PARTLY CLOUDY SKY		CLOUDY SKY		CLEAR SKY		PARTLY CLOUDY SKY		CLOUDY SKY		CLEAR SKY		PARTLY CLOUDY SKY		CLOUDY SKY	
	WINDOW	INTERIOR	WINDOW	INTERIOR	WINDOW	INTERIOR	WINDOW	INTERIOR	WINDOW	INTERIOR	WINDOW	INTERIOR	WINDOW	INTERIOR	WINDOW	INTERIOR	WINDOW	INTERIOR
EXISTING	1000	1100	1000	1600	500	600	600	650	500	650	350	450	650	800	700	900	450	550
NEW	1100	1000	1500	1700	600	650	1100	700	950	700	280	330	1300	900	1300	1100	450	500

SKY CONDITIONS NUMBER OF DAYS

month	JUNE			DECEMBER			MARCH		
	clear	partly cloud	cloudy	clear	partly cloud	cloudy	clear	partly cloud	cloudy
EXISTING	7	12	11	9	8	14	8	9	14
NEW	7	12	11	9	8	14	8	9	14

	ILLUM - JUN 21		ILLUM - DEC 21		ILLUM - MAR 21	
	WINDOW	INTERIOR	WINDOW	INTERIOR	WINDOW	INTERIOR
EXISTING	63	63	0	0	0	55
NEW	63	63	55	0	55	55

	PER YEAR	
	EXISTING	NEW
WINDOW	21	58
INTERIOR	39	39



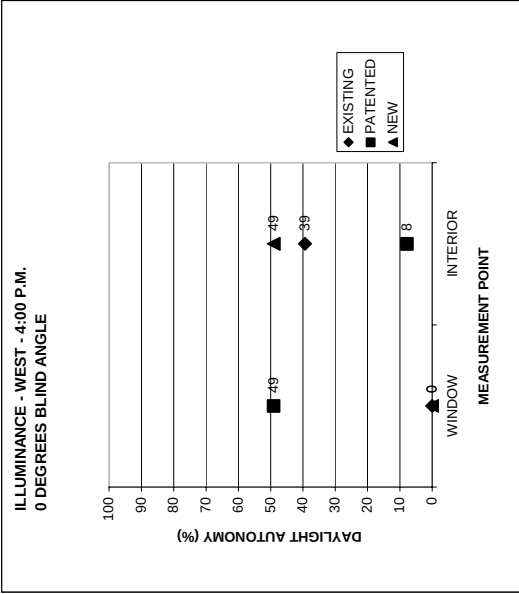
ANGLE 0	ILLUMINANCE - JUN 21- AT 4:00 P.M.						ILLUMINANCE - DECEMBER 21- AT 4:00 P.M.						ILLUMINANCE - MARCH 21- AT 4:00 P.M.					
	CLEAR SKY		PARTLY CLOUDY SKY		CLOUDY SKY		CLEAR SKY		PARTLY CLOUDY SKY		CLOUDY SKY		CLEAR SKY		PARTLY CLOUDY SKY		CLOUDY SKY	
	WINDOW	INTERIOR	WINDOW	INTERIOR	WINDOW	INTERIOR	WINDOW	INTERIOR	WINDOW	INTERIOR	WINDOW	INTERIOR	WINDOW	INTERIOR	WINDOW	INTERIOR	WINDOW	INTERIOR
	EXISTING	10000	1100	10000	1000	1000	10000	650	10000	10000	300	100	10000	1200	10000	900	500	450
PATENTED	1300	900	1300	700	450	500	2500	550	10000	10000	300	100	1900	700	1000	650	450	500
NEW	10000	1700	10000	1600	700	550	10000	800	10000	10000	500	100	10000	1700	10000	1000	600	500

SKY CONDITIONS NUMBER OF DAYS

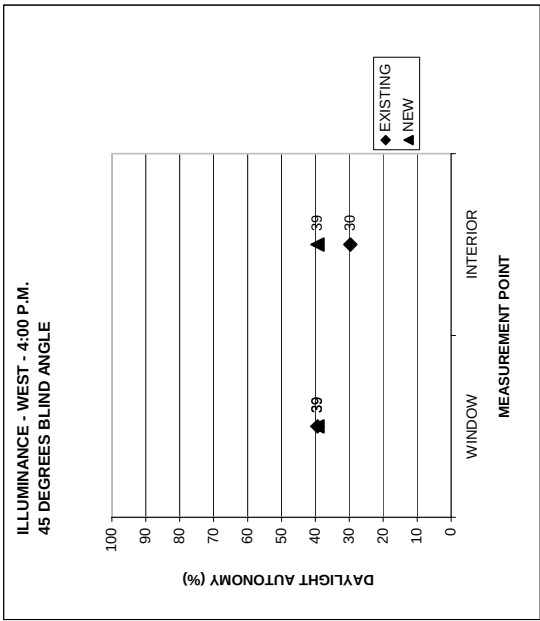
	JUNE			DECEMBER			MARCH		
	clear	partly cloud	cloudy	clear	partly cloud	cloudy	clear	partly cloud	cloudy
EXISTING	7	12	11	9	8	14	8	9	14
PATENTED	7	12	11	9	8	14	8	9	14
NEW	7	12	11	9	8	14	8	9	14

	PER YEAR		
	EXISTING	WINDOW	INTERIOR
	0	0	39
PATENTED	63	29	0
NEW	0	0	49

	ILLUM - JUN 21		ILLUM - DEC 21		ILLUM - MAR 21	
	WINDOW	INTERIOR	WINDOW	INTERIOR	WINDOW	INTERIOR
EXISTING	0	63	0	0	0	55
PATENTED	63	23	0	0	55	0
NEW	0	63	0	29	0	55



ANGLE 45	ILLUMINANCE - JUN 21- AT 4:00 P.M.						ILLUMINANCE - DECEMBER 21- AT 4:00 P.M.						ILLUMINANCE - MARCH 21- AT 4:00 P.M.					
	CLEAR SKY		PARTLY CLOUDY SKY		CLOUDY SKY		CLEAR SKY		PARTLY CLOUDY SKY		CLOUDY SKY		CLEAR SKY		PARTLY CLOUDY SKY		CLOUDY SKY	
	WINDOW	INTERIOR	WINDOW	INTERIOR	WINDOW	INTERIOR	WINDOW	INTERIOR	WINDOW	INTERIOR	WINDOW	INTERIOR	WINDOW	INTERIOR	WINDOW	INTERIOR	WINDOW	INTERIOR
EXISTING	1000	900	900	800	400	450	10000	500	10000	300	100	100	1100	850	850	500	300	400
NEW	2500	1300	2400	1000	600	500	10000	700	10000	450	100	100	2500	1300	2200	850	550	450



SKY CONDITIONS NUMBER OF DAYS

month	JUNE			DECEMBER			MARCH		
	clear	partly cloud	cloudy	clear	partly cloud	cloudy	clear	partly cloud	cloudy
EXISTING	7	12	11	9	8	14	8	9	14
NEW	7	12	11	9	8	14	8	9	14

	ILLUM - JUN 21			ILLUM - DEC 21			ILLUM - MAR 21			PER YEAR	
	WINDOW	INTERIOR	INTERIOR	WINDOW	INTERIOR	INTERIOR	WINDOW	INTERIOR	INTERIOR	WINDOW	INTERIOR
	63	63	0	0	0	26	55	55	30	39	39
EXISTING	63	63	0	0	0	26	55	55	30	39	39
NEW	63	63	0	0	0	26	55	55	30	39	39

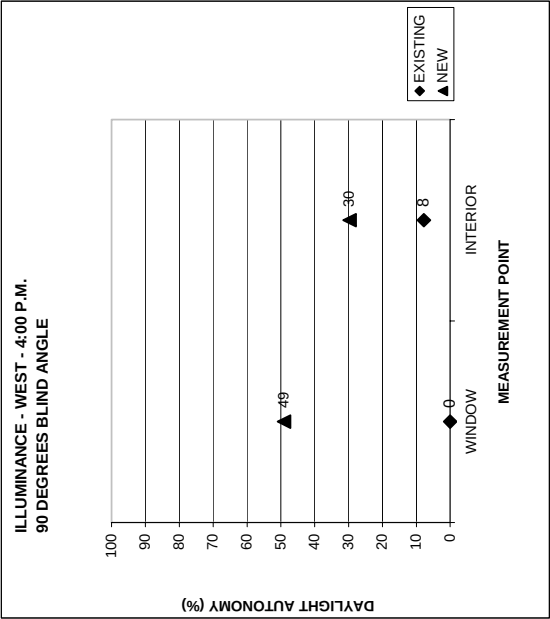
ANGLE 90	ILLUMINANCE - JUN 21- AT 4:00 P.M.						ILLUMINANCE - DECEMBER 21- AT 4:00 P.M.						ILLUMINANCE - MARCH 21- AT 4:00 P.M.					
	CLEAR SKY		PARTLY CLOUDY SKY		CLOUDY SKY		CLEAR SKY		PARTLY CLOUDY SKY		CLOUDY SKY		CLEAR SKY		PARTLY CLOUDY SKY		CLOUDY SKY	
	WINDOW	INTERIOR	WINDOW	INTERIOR	WINDOW	INTERIOR	WINDOW	INTERIOR	WINDOW	INTERIOR	WINDOW	INTERIOR	WINDOW	INTERIOR	WINDOW	INTERIOR	WINDOW	INTERIOR
EXISTING	600	800	600	700	400	500	450	400	250	300	100	100	650	600	550	650	300	400
NEW	1300	1000	1000	850	500	550	900	500	500	350	100	100	1500	950	950	650	450	500

SKY CONDITIONS NUMBER OF DAYS

month	JUNE			DECEMBER			MARCH		
	clear	partly cloud	cloudy	clear	partly cloud	cloudy	clear	partly cloud	cloudy
EXISTING	7	12	11	9	8	14	8	9	14
NEW	7	12	11	9	8	14	8	9	14

	ILLUM - JUN 21		ILLUM - DEC 21		ILLUM - MAR 21	
	WINDOW	INTERIOR	WINDOW	INTERIOR	WINDOW	INTERIOR
EXISTING	0	23	0	0	0	0
NEW	63	63	29	0	55	26

	PER YEAR	
	EXISTING	NEW
	0	49
	8	30



VITAE

Svetlana Olbina was born in Sombor, Yugoslavia. She earned a Bachelor of Architecture degree from the University of Belgrade in June 1990. After graduation, she worked as an architectural manager in the Industry of Metal Constructions in Belgrade. From August 1994 to August 2000, Svetlana was a lecturer at the University of Belgrade, School of Architecture, in the Department of Building Construction. She earned a Masters of Science degree in Architecture from University of Belgrade in June 2000, and then enrolled in the doctorate program at Virginia Polytechnic Institute and State University in the Building Construction Department in August 2000. Svetlana is currently assistant professor in the Rinker School of Building Construction at the University of Florida.