A MATHEMATICAL MODEL OF BUILDING DAYLIGHTING BASED ON FIRST PRINCIPLES OF ASTROMETRY, SOLID GEOMETRY AND OPTICAL RADIATION TRANSFER

by

Chia-Peng Chou

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APPROVED:

Benjamin Evans, Chairman

Francis T. Ventre

Robert P. Schubert

Thomas Koontz

Guy J-M. Indebetouw

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(ABSTRACT)

There is a growing recognition in design professions that lighting is a significant factor in energy consideration. This has generated an interest in daylighting; the bringing of direct and diffuse daylight into buildings to reduce the use of artificial lighting. Many methods exist for quantifying diffuse daylight distribution for use in the design of buildings, but the methods vary widely both in technique and capability. Moreover, no present method deals with direct daylight (sunshine) distribution. Additionally, none have taken advantage of improvements in computer technology that make feasible more complex mathematical computational models for dealing with direct and diffuse daylight together.

This dissertation describes the theoretical development and computer implementation of a new mathematical approach to analyzing the distribution of direct and diffuse daylight. This approach examines light transfer from extraterrestrial space to the inside of a room based on the principles of astrometry, solid geometry, and radiation transfer. This study discusses and analyzes certain aspects critical to develop a mathematical model for evaluating daylight performance and compares the results of the proposed model with 48 scale model studies to determine the validity of using this mathematical model to predict the daylight distribution of a room. Subsequent analysis revealed no significant variation between scale model studies and this computer simulation. Consequently, this mathematical model, with the attendant computer program, has demonstrated the ability to predict direct and diffuse daylight distribution. Thus, this approach does indeed have the potential for allowing designers to predict the effect of daylight performance in the schematic design stage.

A microcomputer program has been developed to calculate the diffuse daylight distribution. The computation procedures of the program use the proposed mathematical model method. The program was developed with a menu-driven format, where the input data can be easily chosen, stored, and changed to determine the effects of different parameters. Results can be obtained through two formats. One data format provides complete material for analyzing the aperture size and location, glass transmission, reflectance factors, and room orientation. The other provides the graphic displays which represent the illuminance in plan, section, and 3-dimensional contour. The program not only offers a design tool for determining the effects of various daylighting options quickly and accurately in the early design stage, but also presents the daylight distribution with less explanation and with more rapid communication with the clients. The program is written in BASICA language and can be used with the IBM microcomputer system.

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CHAPTER 1 INTRODUCTION

1.1 Problems

Fenestration is a significant factor affecting architecture, whether from the view point of aesthetics, function, or economy. Most building designers are well trained in aesthetics and building function in architectural design. International events and the resultant energy crisis in the 70's forced a reexamination of energy use patterns in building design. Consequently, the concerns of energy consciousness also apply to the design profession. The building design professions need to examine their current curriculums and available resources to determine the extent of the need for adaptation of energy-related training for assisting in their decision-making on energy related design.

Lighting accounts for 20 percent of the total electrical energy consumption in the United States, or 420 billion kWh per *year*.[1] This represents over 5 percent of the total national energy consumption. Therefore, effective use of daylighting is considered one of most promising energy conservation strategies in building design.

Daylight and the view from windows have always been desired by building occupants for a variety of reasons. Building designers responded to these desires but also have used fenestration as a formal element of design expression. When efficient energy utilization recently became an important national concern, new design issues emerged which suggested that reduced fenestration was the appropriate response to diminishing energy supplies and rising utility bills. Today this response is recognized as simplistic and frequently incorrect, but definitive daylighting predicting methods are not available to provide for appropriate architectural solutions.

Unlike other elements which can be exactly determined building, daylight is constantly changing. The designers can fix the dimensions of solids and cavities, the orientation of the buildings, the arrangement of the interior, etc. Daylight is an element that designers cannot control easily. Its intensity changes from hour to hour, day to day, and season to season. How can this unstable element be predicted correctly to assist designers in their decision-making? How can it be utilized efficiently and appropriately when the artificial lighting is also involved?

1.2 Background and Need for Study

Daylight, like other natural resources, is free. Many reasons have been offered for admitting daylight into buildings such as energy conservation, the promotion of health, the psychological response, and the belief that daylight is inexhaustible.

Although the value of daylight has been appreciated for centuries, little was done to predict its behavior and how it transits into the interior until the end of the nineteen century. In 1885, L. Weber recorded the practical significance of the ratio of internal to external illuminance, and this ratio was explained in rule-of-thumb calculations of window *size*.[2] In 1895, A.P. Trotter who became in 1909 (one of the founders of the Illuminating Engineering Society), devised a portable photometer for measuring light intensities and suggested that it would be useful in understanding the daylight coefficients of certain buildings; Trotter's "coefficients" are today's **daylight factors**.[2]

Many researchers have contributed results to the definition and measurement or prediction of both quantity and quality of the daylighting conditions in architecture. These researchers include P.J. Waldram, J.M. Waldram, and J. Swarbrick in the architectural profession from 1920's to 1960's; the remarkable group of workers led by Allen, Beckett, Dufton, Hopkinson and Petherbridge at the Building Research Station in Britain; the team at the Texas Engineering Experiment Station led by W. W. Caudill, B. H. Reed, and E. E. Vezey; the group at Southern Methodist University led by Arner, Conover, and Griffith who developed the lumen method, the most accepted method to predict daylight distribution in United States; and many others across the world.

Existing methods for prediction of daylight can be analytic or computational or graphic; they can be in the form of graphic tables and computer programs or protractors and physical models. Fifty-eight recognized daylight design methods are listed in the 1970 CIE *publication*.[3] Most were originated in European countries where cloudy skies are the typical minimum brightness condition, and few are well suited to United States where clear skies prevail and direct sunlight is involved.

These existing methods for calculating and analysing daylight distribution can be divided into two categories: those that use assumptions which may reduce flexibility and accuracy; and those that use large-scale computer programs, which, although they may be more flexible and accurate, require the preparation of detailed input data, not user friendly, and access to computers or time-sharing computer facilities. Some of these methods are limited to schemes of maximum utilization of daylight and only predict illuminance levels at certain points in building interior.

Computers may be useful in daylighting design, but daylighting analysis techniques need further development to take advantage of their tremendous potential. Most of the current computer modeling techniques are based on an oversimplified idea of the window or on oversimplified experimentally established empirical relationships. Some are useful in energy analysis for the statistical determination of the number of hours that lights could be off. A number of computer programs have been developed for energy analysis, but they are based on certain assumptions about the thermal design of a building. Daylight performance has been incorporated experimentally into several of these programs, but the results have yet to be validated by comparison with actual conditions. None is at a state where a designer could use it with confidence. The problems of validation and the implications of the simplified data used in these computer programs have yet to be resolved.

Design is not a one-way, linear problem-defining, decision-making, and solution-finding process. Building designers move back and forth between defining problems, making decisions, finding solutions, and some other elements of this iterative design process until an acceptable configuration has been reached. It is also probable that the criteria and conditions of design problems change constantly and cannot be well defined.

The design process requires an analytical tool capable of quick responding, affordable, and repeatable, is user friendly, and has the ability to interact with the designers at different levels of specificity. Most existing methods for daylight analysis tend to be either incomplete, too complex in calculation procedures, or require long periods of expensive design time, and consequently have not been broadly accepted in the design profession. Therefore, there is a need for an mathematical model with a microcomputer appropriate for the process of designing. The mathematical model, developed in theoretical from the viewpoint of the physics of light and processed with mathematical relations, should provide the reliability, accuracy, and generalization in daylight analysis that will sufficiently assist designers in their dynamic design process.

1.3 Purpose and Objectives of Study

The purpose of this study is to develop a user friendly, quickly responsive, computer-aided daylighting design tool for use by building designers in schematic design phase, and thereby advance the utilization of daylight in the built environment. This tool can provide designers an idea of the daylighting performance of their designs, case by case. and provide them a better opportunity through self-training to develop intuitive understanding of daylight situations.

The primary objectives of this study are: (1) to develop a mathematical model which has the ability to separately calculate the illuminance influences of exterior sources both directly and from the inter-reflection phenomenon to any reference point in a rectangular room. This analytical model has the ability not only to predict the total illuminance received for any interior point, but also has the ability to analyze the influences of reflectance factors; and (2) to develop a microcomputer program based on the above mathematical model which has the ability to predict daylight distribution, to produce graphic representations, and to interact with a designer at different stages of specificity.

1.4 Limitations of study

This study has been pursued under the following assumptions:

1. In a certain time and place, all the sun's rays are considered parallel.

2. There is no loss of luminance or illuminance when light travels through the air.(actual loss of luminance is so small as to be insignificant)

3. The illuminance directly from the sky vault and indirectly from the exterior ground is assumed to be homogeneous and isotropic; that is, the entire sky vault and the ground are uniform with constant physical properties in all directions.

4. The daylight availability models used in this study are correct; in other words, the errors of the models in predicting available daylight are outside the scope of this study.

5. The shape of any room to be analyzed must be a rectangular solid with six surfaces, and with rectangular windows.

6. The windows are a secondary source of diffuse daylight instead of the primary source(sky vault or exterior ground) under the diffuse daylight situation.

7. The sky vault and the exterior ground appear to merge at an infinite distance from the opening of a room. This defines the boundary, determined by the height of the point being calculated, which separates the exterior sources of diffuse daylight as being either the sky vault or the ground when calculating the luminance directly incident from the exterior to the calculated point.

1.5 Methodology

Achieving the objectives and purposes previously stated is dependent upon the methodology for determining the natural light from extraterrestrial space that reaches a room and the inside of a room, and the knowledge of related microcomputer hardware and software. The approach in each stage of this study follows.

Based on the knowledge of the sun-earth relationship, the solar altitude, the solar azimuth, and the related profile angles are calculated. These angles are used for determining the direction of direct sunlight incident to a room and is the major factor in deciding diffuse daylight availability.

A celestial sphere and a 3-dimensional rectangular coordinate system is established to ain in describing the relationship between the sun and a room, and the plane and solid geometry of a room. The direct sunlight distribution inside a room is calculated via trigonometry and 3-dimensional geometry. The unit-sphere method with the inverse-square and cosine laws of light are employed to analyze the inter-reflection phenomenon caused by the direct sunlight penetrating the windows and to calculate both the direct and inter-reflective illuminance for any point in the reference plane.

The diffuse daylight distribution, excluding the inter-reflection phenomenon inside a room, is obtained with the assumption that the windows are a secondary source of diffuse daylight. A unit hemisphere, Lambert's cosine law, and the inverse-square law are used to obtain the relation between the window area and any point in a room. Using the known exterior luminance with the double integration method, the illuminance for points in a room are calculated. The method for obtaining the illuminance increase caused by the inter-reflection of diffuse daylight is the same as the method used for direct sunlight.

The computer simulation for the proposed mathematical model was written with a high level language---BASICA. The zoning method was used to develop the computer program for calculating the illuminance caused by the inter-reflection phenomenon both in direct and diffuse daylight situations. The Bicubic Spline Surface fitting mathematical *method*[4] was used to develop a user friendly program for the 3-dimensional graphic representation.

A 16-channel photo-sensor and an analog-signal to digital-code interface board were designed to overcome the simultaneous photometry problem in the process of data acquisition with scale model studies. The polynomial correlation coefficient function test for calibration of photocells and the difference analysis for validation of the mathematical model under the statistics analysis system in CMS at Virginia Tech were executed to verify the acceptability of this study.

1.6 Organization of the Remainder of the Study

The results of this study are presented in the following order: Chapter 2 treats past research related to this study in the areas of daylight availability, daylighting design methods, scale model studies and photometry, and computer-aided daylighting analysis.

Chapter 3 and 4 present the process of developing the mathematical model to predict the illuminance for any point in a rectangular room under different sky conditions for both direct and diffuse daylight situations. The structure of the computer program for diffuse daylight simulation is also presented to explain daylighting prediction and representation in computer-aided design of daylighting.

Chapter 5 presents procedures of validation. A brief explanation of the procedures are as follows: It begins with design of the instruments, which includes a 16-channel photocell, an A/D converter card, and a computer program, for use in collect data simultaneously in scale models. The polynomial correlation coefficient functions have been developed via the statistical analysis for calibrating and building look-up tables of each photocell. Second, the study of scale models, which includes model building, measuring positions, and data collecting under the Skydome Daylight Simulator in the Price's Fork Research Center (PFRC) at Virginia Polytechnic Institute and State University (VPI&SU), are introduced. Third, the analysis of difference is used to verify the relationship between the mathematical model and the experimental data. Fourth, the P-value and the confidence coefficient are employed as the critical values to verify the reliability and acceptability of the proposed mathematical model.

Chapter 6 contains the findings and an analysis of the mathematical model, and discusses the implications of this study.

Chapter 7 summarizes the important features of this study, presents conclusions arising from the research, and recommends areas for further work.

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CHAPTER 2 REVIEW OF RELATED LITERATURE

2.1 Introduction

Although the daylight mathematical model developed herein is relatively new, many studies provide background and direction for the proposed study. They include publications in daylight availability, design methods, instrumentation, physical modeling, and computer-aided daylighting analysis related to energy concerns. An appropriate model for predicting the daylight available at a given site is necessary for estimating the original source of daylight in developing this proposed mathematical model study. Understanding of the existing calculation methods of predicting daylight distribution, the techniques for scale model studies, and the characteristics of photometry, will give direction to research in both the conceptual approach and the empirical validation. Understanding use of the computer-aided program in daylighting helps designers to realize the potential and recognize the direction of computer-aided design in the future and the specifications which the design profession needs for the design process. Each of the aspects mentioned above is discussed in this review.

2.2 Daylight Availability

Daylight availability can be defined in terms of the amount of light reaching a point in the earth's surface at a specific location, date, time, and sky *condition*.[1] Available references suggest a member of approaches which can be divided into three categories. Type one is the meteorological model which is based on continuous measurements of global and diffuse illuminance on an unobstructed horizontal plane, such as the models of *Secker*,[2] *Kingsbury*,[3] *Hunt*,[4] *Ruck*,[5] and *Gillette*.[6] Type two consists of the models usually employed in illumination engineering research and which assume some conditions to typify the daylight climate such as the works of *CIE*,[7,8,9] *and IES*[1,10,11] (Illuminating Engineering Society). Type three includes the theoretical or synthetic models which attempt to characterize prevailing, average daylight availability for definite locations or climatic zones and time periods according to practical requirements, such as described in *Tregenza*,[12]*Littlefair*,[13]*Kittler*,[14]*Oki*,[15] *Nakamura*,[16] *andSelkowitz*.[17] (See Figure 1 on page 13 , Figure 2 on page 15 , and Figure 3 on page 18)

Meteorological models are limited by location and provide no general case or formula to predict daylight availability in any specific area. Theoretical or synthetic models are not suitable for comparing daylight designs, since their use is for quantifying the energy effects of daylighting.

In daylight design, the usual concern is to determine the minimum daylight availability conditions to meet the design criteria. Thus, the typical standard approach is to predict the illuminance of the standard clear sky, partly cloudy sky, and cloudy sky. To meet the minimum daylight distribution requirements, the standard sky conditions can be very helpful for designers when they put daylight factors to use in building designs. *Gillette*,[6] found that these approaches can also be used in North America with a fair amount of confidence because the predictions of type two approaches were found to be similar to actual measurements recently made in the United States. Thus, reasonably accurate comparisons can be made of daylighting design alternatives without further information of the local sky luminance data. This means that daylight availability can be predicted under different standard sky conditions with such variables as optical air mass, atmospheric extinction coefficient, cloud ratios, time, and *season.*[1]

A portion of the incident light radiated from the sun is scattered by water vapor, dust, and other particles when passing through the atmosphere. This scattered radiation provides a substantial amount of daylight and normally is divided into three sky conditions: clear, partly cloudy, and cloudy. The National Bureau of Standards (NBS) uses the Sky Ratio *Method*[22] and the National Oceanic and Atmospheric Administration (NOAA) uses the Sky Cover Method to describe these three sky conditions. Both methods defining sky conditions as follows:

clear sky = sky ratio $\leq$ 0.3 or sky cover between 0 to 3 tenths

partly cloudy sky = $0.3 < \textit{sky ratio} < 0.8$ or sky cover between 4 to 7 tenths

cloudy sky = sky ratio $\geq$ 0.8 or sky cover between 8 to 10 tenths.

The sky ratio is the ratio of horizontal sky irradiance to global horizontal irradiance. The sky cover is determined by visual observation of the amount of cloud cover. Cloud cover is reported in tenths and is expressed in a range from 0 for no clouds to 10 for complete sky cover. The sky ratio method is inaccurate at low solar altitudes, requiring some corrections of diffuse daylight availability at sunrise and sunset.

IES General Equations

Researchers propose different equations within different models for each of the three conditions of diffuse sky. Solar altitude is the factor which most affects these equations. Other factors such as atmospheric turbidity, sea level, cloud type, cloud amount, and snow cover are also recognized as affecting the sky illuminance. But these factors also appear to have only a slight affect on sky illuminance, thus, can usually be ignored. The IES Calculation Procedures Committee (IES-CPC) proposed the following general *equation*[1] (Equation 2.2.1) based on the horizontal illuminance from the sky (excluding direct sunlight) versus solar altitude:

$$E_d = A + B(\sin A_t)^c \quad [2.2.1]$$

where A, B, and c are the daylight availability constants, and A_t is the solar altitude.

The general equation form comes from many equations which were presented by different researchers (see Figure 1 on page 13 , Figure 2 on page 15 , and Figure 3 on page 18). Though these researchers have proposed different equations to predict diffuse daylight availability, their plots are similar and all fall within the approximate range of the *measurements*.[6] The IES-CPC claims that this general equation form works well for all three sky conditions, with different values for the constants depending on whether the sky is clear, partly cloudy, or cloudy.

Clear Sky Condition

Gillette, Pierpoint, and *Treado*[6] compare the equations of *Lynes*,[23] *Chroscicki*,[33] *Hopkinson*,[24] *Krochmann*,[25] *Nakamura and Oki*,[26] Elvegard and *Sjosteddt*,[27] and Jones and *Condit*[28] and plot the diffuse clear sky illuminance as a function of solar altitude in some of these equations. They found that not only a consistency for such sky condition, but also a consistency for other locations. One important fact that appears from Gillette et. al's comparison is that all the equations and measurements fall within the same approximate range (Figure 1 on page 13). Therefore, because most of the suggested equations plot the idea in a similar way, and because the general equation 2.1.1 is still apparent among these equations, Gillette recommended that the general equation for clear sky condition be:

$$E_{dclr} = 0.8 + 15.5(\sin A_t)^{0.5} \quad (in KLux) \quad [2.2.2]$$

Gillette's equation is virtually the same as the Krochmann *equation*[25] with a slight adjustment for the sunrise and sunset hour illuminance. Figure 1 on page 13 shows the clear sky diffuse illuminance as a function of solar altitude for several equations.

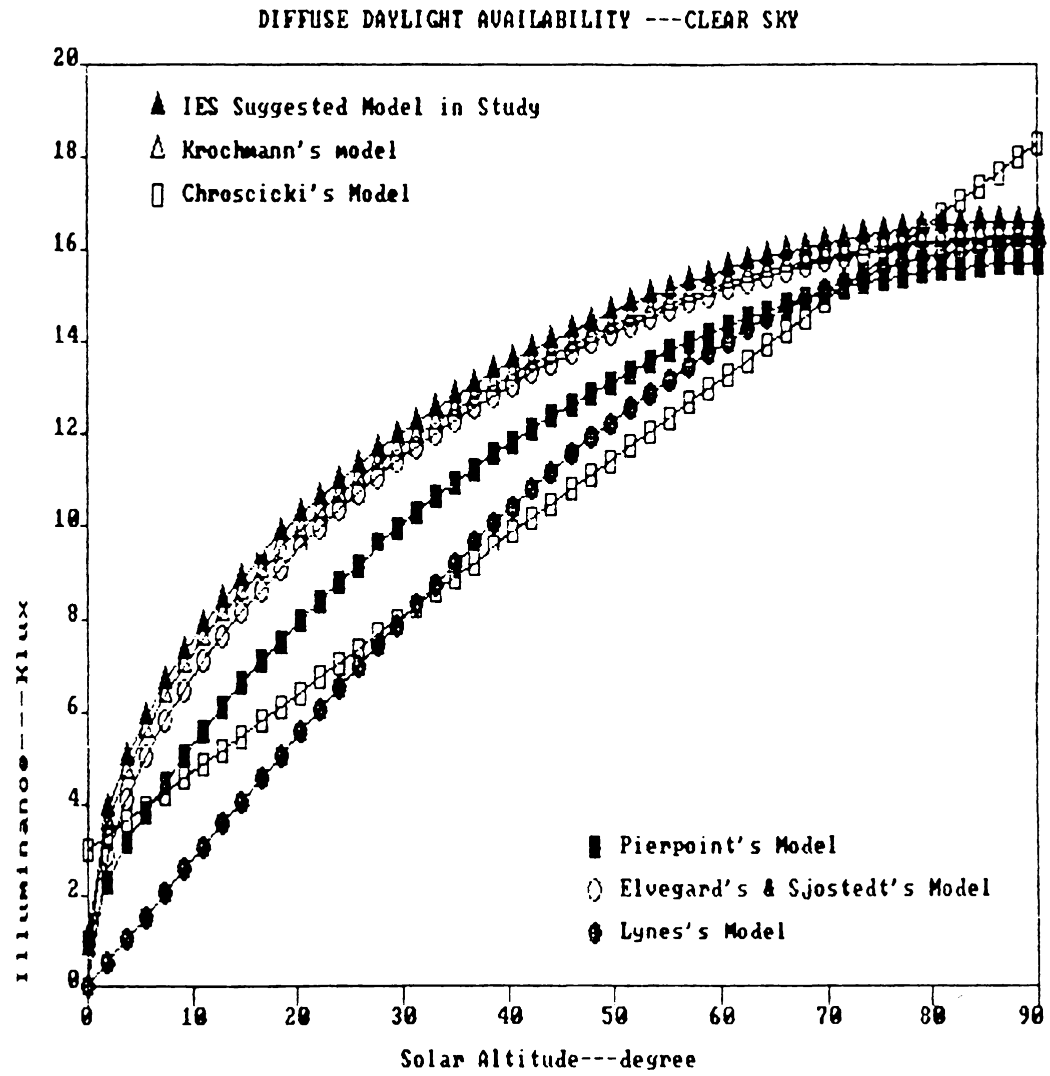

Figure 1. Comparison of Diffuse Daylight Availability Models Under Clear Sky Condition

Gillette compares this equation with the existing values given in the IES Reference *Volume*,[29] and found that these equations are still representative of the larger data base. Nevertheless, equation 2.2.2 shows itself more representative of the larger data base and should be applicable for other locations as well. This equation also was accepted by IES-CPC in 1984.[1]

Partly Cloudy Sky Condition

Much attention in the past twenty years has been directed to resolving the issue of the partly cloudy sky condition. Though many researchers have proposed luminance distributions for the partly cloudy sky condition, it is difficult to attach substantial meaning to any single equation for such an unstable sky condition. Nevertheless, progress has been made in approximating the dynamics of the nonstandard, nonperfect sky and in suggesting ways of dealing with these dynamic skies. *Lynes*[23] and other researchers such as *Hopkinson*,[24] *Elvegard and Sjostedt*,[27] *Nakamura and Oki*,[26] and Gillette et. al. suggest simple equations to predict partly cloudy sky condition. These equations (Figure 2 on page 15) are very similar with the IES's general equation, and most of them fall within the band of the measurement shown in Figure 2 on page 15.[6] Therefore, an expression analogous with the partly cloudy sky can be written as:

$$E_{dpc} = 0.3 + 45.0 \sin A_t \quad (in KLux) \qquad [2.2.3]$$

Equation 2.2.3 may not be commonly experienced under the real sky, but it is fairly representative of these general conditions and provide a means of predicting daylighting design alternatives without being concerned with the dynamics of the natural sky.

Cloudy Sky Condition

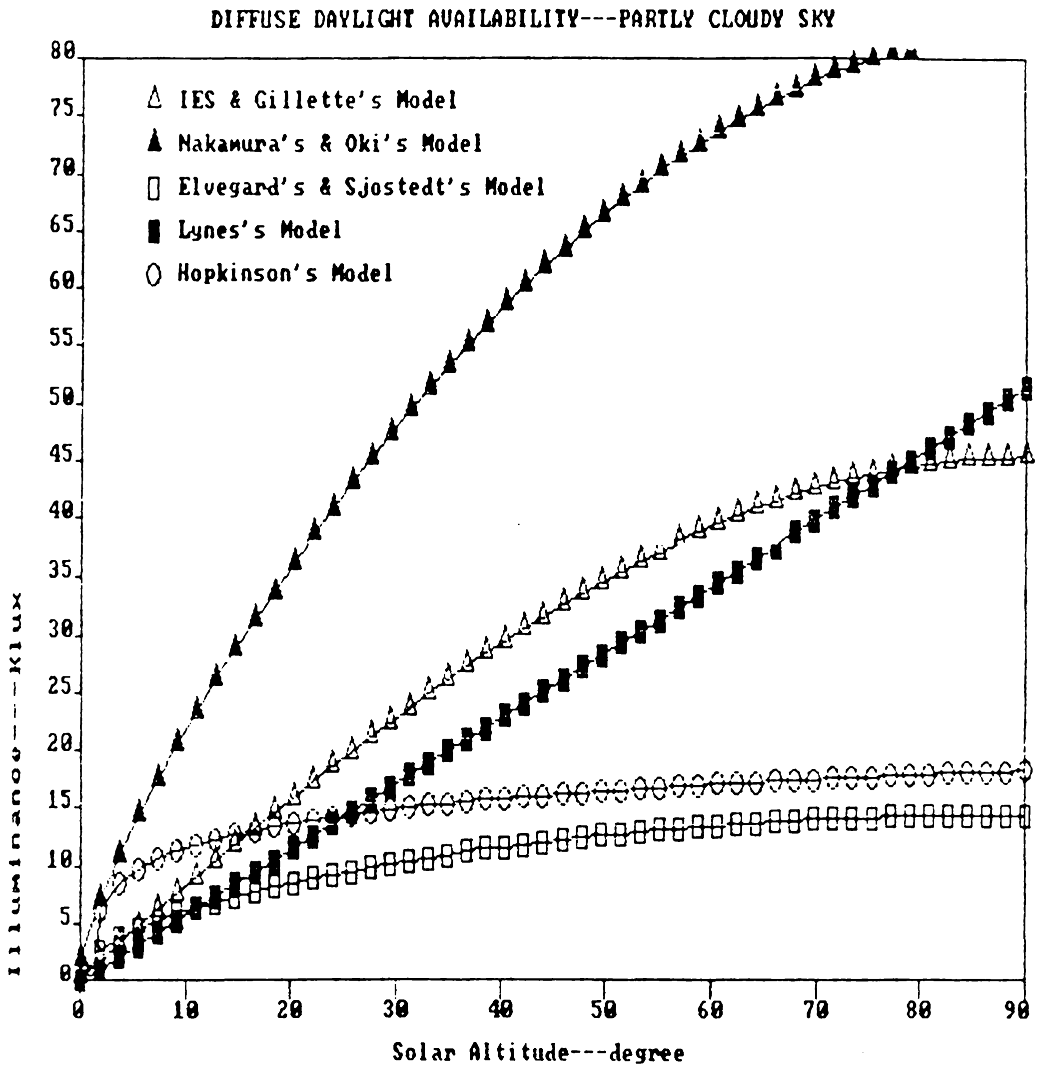

Figure 2. Comparison of Diffuse Daylight Availability Models Under Partly Cloudy sky Condition

A cloudy sky is defined as a cloud ratio greater than 0.8; the presence of clouds which almost cover the complete sky and cause the sky to be less stable. Factors such as cloud density, water vapor, cloud height, and air pressure difference are continuing changing and effect the predictability of daylight availability. *Kittler*[30] in his paper shows that cloud type and snow cover alone could vary the overcast horizontal illuminance by as much as 300 percent. Several researchers proposed equations to predict cloudy sky condition. Figure 3 on page 18 is the comparison of these equations. Absolute overcast sky models are given by:

Kittler[14]

$$E_{dovr} = 9.75 \; x \; (1 + \sin A_t) \; \sin A_t \quad (inKLux); \qquad [2.2.4]$$

Hopkinson[24]

$$E_{dovr} = 0.215 \; x \; A_t \quad (inKLux); \qquad [2.2.5]$$

Feitsma[31]

$$E_{dovr} = 0.467 \; x \; A_t \quad (inKLux); \qquad [2.2.6]$$

Nakamura and Oki[26]

$$E_{dovr} = 0.5 + 42.5 \; x \; \sin A_t \quad (inKLux); \qquad [2.2.7]$$

Elvegard and Sjostzdt[27]

$$E_{dovr} = 0.26 \; x \; (123.2 \; \sin A_t) \; (\frac{10^{-0.1}}{\sin A_t}) + 0.54 (16.25 \; \sin^{0.5} A_t) \quad (inKLux); \qquad [2.2.8]$$

Pierpoint[6]

$$E_{dovr} = 0.2 + 0.31 \times A_t + 10.3 \times (1 - \cos A_t) \quad (inKLux); \qquad [2.2.9]$$

Krochmann[32]

$$E_{dovr} = 0.3 + 21 \times \sin A_t \quad (inKlux); \qquad [2.2.10]$$

where

A_t = solar altitude.

Equations 2.2.4, 2.2.5, 2.2.6, and 2.2.8 give $E_{dovr} = 0$ for solar altitude (A_t) equal to zero. Equation 2.2.8 is not acceptable for the case when A_t =0. The factor 0.467 in equation 2.2.6 seems to be too large. In equations 2.2.5 and [2.2.6 E_{dovr} is given as a linear function of solar altitude, which is not likely a good idea to predict cloudy sky illuminance. However, Figure 3 on page 18is evident that some of these expressions plot the diffuse illuminance in approximately the same way, and given the scatter in the data, imply the sufficiency of the more simple forms. Especially the Krochmann's equation 2.2.10, which is generated from a large data base since 1923 to 1962[32] (not a continuous data base), probably the best fit to the instability of the cloudy sky condition, is also among the simplest. Furthermore, the values used in the IES Reference Volume (shown) demonstrate that this equation is in general agreement with the IES reference data as well.

2.3 Daylighting Calculations

There are many recognized methods for calculating the illuminance level inside a *room*[33] as mentioned in chapter I. Most were developed in Europe, where cloudy skies prevail, and few are well suited to United States, where the clear sky prevails. Most of these calcu-

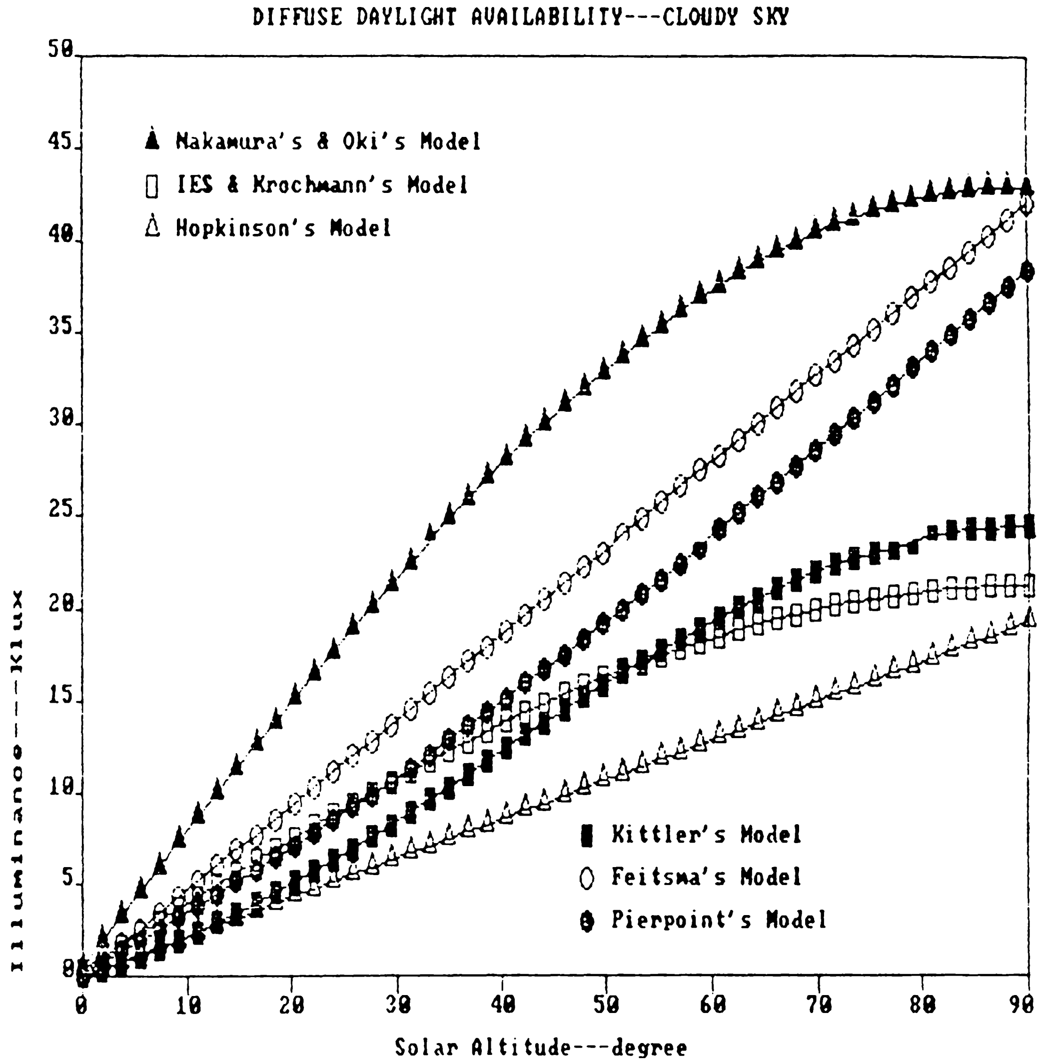

Figure 3. Comparison of Diffuse Daylight Availability Models Under Cloudy Sky Condition

lation methods can be divided into two groups: the lumen method and the daylight factor method.

The lumen *method*,[34] of daylighting based on the extensive empirical data from building measurements as well as model studies under an artificial sky, was developed by J.W. Griffith at Southern Methodist University and adopted by *IES*.[35] This method, which can consider both clear and overcast sky conditions, was developed originally for Libbey-Owens-Ford *Company*[36] and is widely used in the United States. It allows comparison of various window wall schemes and their economic tradeoffs with HVAC and electrical lighting value. Factors such as ground and wall reflectances, diffusing shades, glass transmittances, sky conditions, and direct solar radiation are included in the method.

The lumen method is limited to schemes of maximum coefficient of utilization of daylight, and it predicts illuminance levels on a center line from the windows at five feet from the back of the room, five feet from the front, and at the center point. The method was designed to evaluate schemes of different window management, as well as fixed controls, to obtain the total benefits of daylight utilization, rather than meeting a minimum requirement. The method is applicable to a limited range of window configurations and accurate only for points situated along the center line from the window; it is also limited to vertical glazing.

The daylight factor *method*,[37] is used in Europe, particularly in Britain where design aids such as protractors, nomographs, tables and graphs have been developed by A.F. *Dufton*[38] and J. *Longmore*[39] for easy determination of daylight factors at various stages of the design process. Unlike the lumen method, the daylight factor method can predict daylight at any point in the room and can be used for a wide range of window configurations, but without sun incident on the window. The daylight factor is described as the ratio of interior illuminance at a given point to the available illuminance from an unobstructed sky, received at a reference point.

The daylight factor method allows non-uniform sky luminance distribution and is sensitive to the position of a window in a wall. There is no limit to room size or shape, and it accommodates nonvertical glazing. Its capacity to respond to shading devices and clear sky condition is limited. Direct sun is excluded. The daylight factor method, however, does provide a relative measure of all daylight, not only directly from the sky, but also from visible exterior surfaces and from light inter-reflected between the room's interior surfaces.

2.4 Scale Model Studies and Photometry

Of all the methods used for studying a proposed building while it is still at the design stage, the use of scale models is probably the most reliable daylighting evaluation tool. *Evans*[40] points out difficulties in the technique of model studies such as lack of detail in the model building as compared to the full-scale building, the determination of the sky condition for model simulation, and the spectral difference between instrument response and the visual range of the human eye. Although these technical problems do exist, model studies provide information to assist designers in daylighting analysis. The advantages of the physical model studies in daylighting are:

1. A crude model can provide an approximate illuminance level.

2. Single-element design comparisons can be made easily and quickly.

3. Physical scale model studies are common in professional offices and, with slight modifications, can result in a sensitive design tool for daylighting analysis in addition to continuing to be an effective communication device.

4. Physical scale models provide opportunities for quantitative and qualitative study through visual observation and/or photography.

5. Model studies can provide quick evaluations with a minimum time, cost, and effort.

A full-scale model of the interior of a building or a room is a true subjective simulation of the lighting conditions and permits a precise evaluation to be made of the illuminance in its photometric aspects. The scale of the model and the amount of detailing are dependent upon the use to which the model will be put. Photometric studies alone do not require the simulation of visual appearance detail, but the model should be true to scale and the main internal surfaces must have reflectances corresponding to those of the room being simulated. Where a surface in the full-scale room consists of a number of small surfaces or objects, this can often be matched in the photometric model by a uniform surface of the same average reflectance. However, careful simulation of the window details is essential for a precise prediction.

In theory, the scale of a model intended for photometric measurements is of no significance. In practice, scale is limited by the size of the photocell which is to be used for measurements. This determines the size of the physical model, because if the photocell is too large relative to the model, only a broad generalization of the daylight distribution can be obtained, and because if the photocell is too small, the sensitivity of illuminance is not approximate for measuring. Hopkinson, Petherbridge, and *Longmore*[41] suggest that a scale of 1 in. to 1 ft. for models of interiors with ceiling heights of the order on 10 ft. is approximate for general practice. Larger interiors can conveniently be modelled to a scale of $\frac{1}{2}$ in. to 1 ft. *Evans*[40] finds that a scale of $\frac{3}{4}$ in. to 1 ft. produces a convenient size model for studying a room. For larger buildings, a scale of $\frac{1}{2}$ or $\frac{3}{8}$ in. to 1 ft. may be used if care is exercised in model construction. *Egan*[42] also suggests model scales in the range of $\frac{3}{2}$ in. to 1 ft. to $\frac{3}{8}$ in. to 1 ft. Usually, the larger the scale, the easier it will be to duplicate complex shapes.

The most difficult problem in studying daylight with the use of models is simulating the sky. Sometimes the natural sky is used, but then work is limited to those days in which the sky luminance distribution is that desired. However, it is with this method that the greatest chance of errors exists, because of the changing character of the sky. This problem can be overcome by making daylight measurements of the ratio of interior to exterior illumination rather than in interior illumination only. Two *factors*,[41] the daylight factor and the window factor, should be employed in measurements made under the natural sky.

Most model studies are made with the model under an artificial *sky*.[2,3] This has the great advantage that the required luminance distribution can be controlled for as long as many be desired. Two kinds of artificial sky, the hemispherical sky and the rectilinear *sky*,[40,45,46] are used for the detailed photometric study of daylighting in scale model interiors. There are three requirements for the artificial sky: first, a luminous surface of known and controlled luminance distribution to represent the sky; second, a surface of known reflectance to represent the ground; and third, a horizon which is correctly placed in relation to the models to be used in the artificial sky.

The *advantage*[41] of the hemispherical artificial sky is that it is readily appreciated by the layman for what it represents, and is therefore particularly suitable for demonstration. The disadvantages of such a sky are two. First, the models must be of small scale in relation to the diameter of the sky dome. Secondly, the luminous surface of the artificial sky should not extend below the window head in the model, because otherwise light will reach the ceiling in the model from below the horizontal.

The rectilinear type of artificial sky, used for teaching and general research purposes, can be easily constructed. The disadvantages of such a sky is that it is difficult to control the illumination level that is suitable for a specific condition.

Scale model photometry is an empirical method for predicting daylighting. Ideally, the quantity of illuminance measured inside a scale model is equal to the quantity of illuminance in a full-scale room or building. This is because the ratio between the wavelength of the visible light and the size of a scale model is relatively small. Besides, radiative light is addable, which supports testing under different light sources and measuring separately and ensures that the total quantity of luminance can be obtained by adding.

Measurements of illuminance in scale model are made with photocells. Hopkinson and *Kay*[47] suggest that the measurements should not be undertaken by the inexperienced because the process poses all the regular problems of the measurement of illumination together with two additional aggravations: first the need to measure simultaneously two levels of illumination, outdoors and indoors, differing by 100 to 1 or more, and second the need to measure light which reaches the sensors at near glancing incidence. Simultaneous measurement of outdoor and indoor illumination is necessary to obtain daylight factors. With appropriate interface system between photocells and a microcomputer, the difficulty of simultaneous measurement is resolved. The second of these difficulties is met by a photometer which incorporates a degree of "obliquity error" correction not normally used in the photometry of interior lighting.

There are four requirements of the photometer for daylight measurements. First, the photometer must be color corrected, which makes it sensitive only to the visible portions of the sunlight spectrum. Second, it must be cosine corrected, which makes the photocell sensitive to the incidental light coming between the horizontal and 90° from the vertical. Third, the size of the photocells must not be too large in relation to the dimensions of the scale model. Fourth, the linearity of the photometer must correlate with the expected range of measured quantities. The photometer should be capable of measuring from 1 to 12,000 *footcandles.*[40] regular calibration is required.

Evans[40] suggests that 9 measuring points in rectangular rooms are suitable in model studies. The positioning of the photocells within the model can be chosen based on the designer's need for the particular conditions of his design.

With the greatly improved computer technology in the past decade, the data acquisition method of model studies in daylighting can be interfaced with microcomputers which enables the multiple photometric sensors to be recorded simultaneously. Two interfacing systems have been developed to execute data acquisition in daylighting experiments. One is the *SAM*[48] (Serial Analog Module) with the EPSON portable microcomputer. The data acquisition of SAM scans up to 32 photocells maximum and uses a 12-bit analog-to-digital converter to do the data translation which enables a conversion rate as high as 15 per second and accurate to one-tenth of a footcandle. Another is the RELAY Interface Model 4874[49] with the Hewlett-Packard 85A microcomputer, which enables the data acquisition unit to scan up to 12 photometric sensors and provides the measurement of the lighting level to the nearest one-hundredth of a footcandle. It is very possible to enlarge the abilities of these computer interface systems in the near future to include activities such as 3-dimensional graphic presentation, simple statistical analysis, and the automation of data acquisition in certain periods of time.

2.5 Computer-Aided Daylighting Analysis

As mentioned in chapter 1, a number of computer programs have been developed for energy analysis. Most concentrate on thermal issues and deal with illuminance by using standardized operating profiles for installed lighting. Only a few deal with daylight. Large programs are relatively complex and expensive, and are therefore of limited usefulness for the design profession. Small programs are too simplified to predict and analyze the daylight distribution.

In 1969, both the Architectural Science *Review*[50] and the Ministry of Public Buildings and *Works*[51] published bibliographies and reports on computer-aided architectural design and related areas. Both contain only a few references to lighting. A recent search, which involved abstracts in architecture, engineering, and scientific fields, confirmed that publications dealing with the application of computers or microcomputers to lighting are very thinly spread over the whole field of lighting. In spite of this, it has become apparent from the information gathered by the *IES*[52] that there is considerable interest and as yet much unpublished experience in the use of computers in lighting.

For most beneficial use of the computer, it is important to recognize those functions which are best done by man and those which are best performed by computer. This issue has been discussed by *Singleton*[53] and by the Design Research Laboratory at *UMIST*[54] (University of Manchester, Institute of Science and Technology). A set of principles has been established to assist the development of computer-aided design in lighting. The following is a brief review of the relative roles of lighting and computers in some well know public domain programs.

Barthes, Burrus, and *Richard*[55] have developed an on-line program for use in interior lighting design. The first of these starts with the specification of room dimensions, required working plane illuminance, reflectances and a desired luminance ratio. The program considers all cases using a given range of fitting types and prints out acceptable solutions with details of fitting types, wall and ceiling luminances, and the total installed flux. A subroutine program can then be used to apply further restrictions on the installations layout or the fitting type.

A different approach has been used by *Phillips.*[56] The surfaces of a rectangular room are divided up into a total of 30 elements. A set of 30 equations may be written for the inter-reflection behavior within the room. The initial data consist of the room dimensions from which the form factors and the reflectances of each of the elements may be calculated. Any of the elements may be specified as a window with a given sky luminance. The program then calculates the direct, indirect and total illuminances for each of 30 elements. Comparisons have been made between measured and computed values and good agreement has been claimed. Dwyer, Franta, and the *ENSAR*[49] Group have developed a design tool using a micro processor for the analysis of daylighting schemes in both physical models and full-size buildings. This tool has the ability to produce instant two dimensional CRT (cathode ray tube) graphic image, print the graphic hard copy, and allow the measuring instrument to be used as an iterative design tool. The complete system consists of the LI-COR photometric sensors, a RELAY interface model 4874 to transfer the signals to digital reading, an integrating multi-slope converter which enables the user to trade reading speed for resolution, and an HP-85 microcomputer to provide a CRT display and print a hard copy. The ENSAR Group also provides a software package to communicate with the data acquisition unit and the HP-85 for the daylight analysis program.

The ENSAR Group assumes that physical model studies are the best way to evaluate the quantitative and qualitative design elements of daylighting schemes; therefore, they have developed the ENSAR daylight analysis program which consists of a computer and a data acquisition system for modeling the distribution of natural lighting in buildings based on the experiments. The systems primary use is with scale models; in other words, the LI-COR photometers provide the input data to support the daylighting analysis. It can provide quick feedback for designers on daylighting design under different daylight conditions.

Davis and *Bernecker*[57] have described certain consideration which seem to be important in developing computer models for lighting and have reported on an experiment which examines the validity of using these models to predict the visual environment function of lighting systems. Results from their study show that these models do indeed have great potential for allowing the designers to predict the effect their design will have on human impressions of the visual environment. They also suggest that the changes in people's responses between lighting conditions were so closely matched by the computer model responses that perhaps the best use of these computer images at the present time is in comparing alternative lighting systems.

Bryan, Clear, Rosen, and *Selkowitz*[58] have developed the Quicklite 1 computer program to predict daylight illuminance at any point within a room. The CIE sky luminance distribution function for predicting the daylight availability under *overcast*[33] and *clear*[59] skies are used for calculating in Quicklite 1. Two components are considered when executing the calculation of any interior reference point. One is the sky component which uses a source area formula to calculate. Another is the reflected component which uses the split flux approach to calculate. This program has been designed to be relatively accurate, simple, and quick in predicting. The computation of the total daylight factor is limited by one reference point for each calculation. For repeated predictions, it is necessary to re-enter part of the input data. Because the reflected component is calculated as an average value throughout the room, the simulation will generally result in an overestimate of daylight illuminance in the rear part of the room.

Gillette and Kusuda have developed the DALITE and *RMLITE*[60] computer programs which are designed to study the dynamic energy performance of buildings that employ daylighting. Unlike other programs in daylighting simulation, this program is intended for inclusion as a subroutine into larger energy programs such as *DOE − 2*,[61] *BLAST*,[62] *andNBSLD*.[63] It provides a method to simulate the daylighting conditions simultaneously with the thermal calculations hour by hour. Both the DALITE and RMLITE programs can simulate a continuous range of partly cloudy sky conditions, the reflected light from exterior surfaces such as surrounding buildings and reflected ground light, and the interior inter-reflected light. Direct sunlight is excluded. The results of simulation compared to the data of field measurements show a correlation in most cases within 30 percent of real condition.

Milne[64] and others in UCLA have developed a program to simulate daylighting for assisting architects and architecture students at the very beginning of the design process, which is written in Fortran IV and run on a Tektronix storage tube graphics terminal. It uses the Kusuda and *Lynes*[65] equations to predict the daylight availability for the input of the luminance source. The sun's altitude and bearing angles are calculated based on the equation contained in the ASHRAE *Handbook*.[66] The lumen method, based on experimental work done originally by Griffith and others in the early 1950's, was employed to do the algorithm work for calculation the daylight distribution in a room. As the lumen method, this program has the ability to predict the illuminance at any one of three spots along the center-line of the room, to consider various sky conditions for any window orientation and latitude, to accommodate the different ground reflectance and the different glazing transmittances, and to draw a 2-dimensional section with a plot of the illuminance in footcandles.

Another computer-aided simplified daylighting design tool called MICROLITE-1 was reported by Bryan and *Krinkel*[67] in 1982. It is an outgrowth of the British daylight factor method originally developed by Hopkinson, but which normally applies only to overcast skies. Bryan earlier *reported*[68] using the CIE clear sky luminance distribution equation to develop a Waldram diagram for clear skies. This program has interactive input, with the output available in three different forms: Daylight factors printed on a plan, a section overlaid with a plot of the daylight factors, and a plot the the room with daylight factors appearing as 3-dimensional lines. It illustrates one of the main strengths of the daylight factor approach, that it can calculate a value for any point in the room and for a wide range of window sizes and shades. The disadvantage is that it cannot handle direct sunlight on the window and overhangs, and the clear sky methodology has not yet been validated experimentally. Nor does it give illuminance data directly in footcandles, the units of measure most familiar to designers in the United States.

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CHAPTER 3 MATHEMATICAL MODEL OF DIRECT SUNLIGHT

3.1 Analysis of Daylighting

The only and the original source of daylight is the sun. Diffuse skylight supplies the major component of interior daylighting in the temperate, overcast climates. Direct and diffuse daylight supply areas with other climate types, especially in the middle latitude areas where there is no adequate diffuse daylight to light interior space.

The relative contributions of direct daylight and of diffuse daylight in interior lighting depend on, the latitude and longitude of the place, and on the local climate with respect to the distributed sky. These two natural factors determine the building tradition in relation to windows and fenestration design in architecture. Hence, the theoretical model can be divided into three parts. One is the relationship between the sun's rhythm and the geometry of a rectangular room. The second is the relationship between direct sunlight and the distribution of interior illuminance. The third is the relationship between diffuse daylight and the distribution of interior illuminance. These three sections of the theoretical model then be combined for calculating the total quantity of daylighting distribution in a rectangular room. It is the purpose of this study to deal with the quantity of interior daylighting distribution only.

3.2 Choosing a Daylight Availability Model

Introduction: As mentioned in section 2.2, daylight availability can be defined in terms of the amount of light at a specific location, time, day, and sky *condition*.[1] In the process of developing the mathematical model for calculating daylight distribution in a rectangular room, it is necessary to know how much exterior daylight can be expected from the unobstructed sky. One of the problems in predetermining the role of daylight distribution in buildings is the need for reliable models of daylight availability. There have been several approaches to defining and predicting daylight availability using different reference models.

Existing references suggest many approaches which can be divided into three types. Type one is the meteorological model which is based on continuous measurements of global and diffuse illuminance on an unobstructed horizontal plane. Type two comprises the models which are usually employed in illumination engineering research and assume some conditions to typify the daylight climate. Type three includes the theoretical or synthetic models which attempt to characterize prevailing, average daylight availabilities for definite locations or climatic zones and time periods according to practical requirements.

Choosing a Theoretical Model: The meteorological models are limited by location with no general case or formula to predict daylight availability in any arbitrary area. Theoretical or synthetic models are not suitable for comparing daylight designs since they attempts to quantify the energy effects of daylighting.

In daylight design, the usual concern is with the minimum daylight availability conditions which will meet the design criteria. Thus, the usual approach is to predict approximate intensity of illuminance of the standard clear sky, partly cloudy sky, and cloudy sky(overcast). To meet the minimum daylight distribution requirements, these standard sky conditions can be very helpful for designers when they use daylight factors in building design. *Gillette*,[1] found that these approaches can be used in North America with a fair amount of confidence because the predictions from use of the type two approach was found to be similar to actual measurements recently made in the United States. Thus reasonably accurate comparisons can be made of daylighting design alternatives without further information of the local sky luminance data. This means that daylight availability can be calculated for different standard sky conditions with such variables as optical air mass, atmospheric extinction coefficient, cloud ratios, time, and season. The following are the daylight availability models which were chosen and used in this study for the theoretical model of daylighting distribution in a rectangular room.

Direct Solar Illuminance:

Solar Illumination Constant

$$E_{sc} = K_m \int G_\lambda \; V_\lambda \; d_\lambda \qquad [3.2.1]$$

where

E_{sc} = solar illumination constant

K_m = international standard maximum spectral luminous efficacy, 683 lumens/*watt*[2]

G_λ = solar spectral irradiance at wavelength lambda

V_λ = CIE standard photo-spectral eye *response*[2]

λ = wavelength in nanometers (380-780 nanometers)

Solar illumination constant = 127.5 K Lux = 11,850*fc*.[3]

Extraterrestrial Solar Illuminance: To obtain the extraterrestrial solar illuminance on any day of the year, it is necessary to adjust the formula to compensate for the relative uneven movement relation between sun and earth.

$$E_{xt} = E_{sc}\{1 + 0.034\cos[\frac{2\pi}{365}(J - 2)]\} \qquad [3.2.2]$$

where

E_{xt} = extraterrestrial solar illuminance

J = Julian date ($1 \leq J \leq 365$).

Direct Normal Solar Illuminance: To obtain the quantity of direct normal solar illuminance inside the atmosphere when sunlight reaches the ground at any time of any day of a year, the optical air mass and the atmospheric extinction coefficient factors should be *considered.*[4] The amount of direct normal solar illuminance (see Figure 4 on page 36 , and Figure 5 on page 37) that passes through the atmosphere can be expressed by,

$$E_{dn} = E_{xt}e(-cm) \qquad [3.2.3]$$

where

E_{dn} = direct normal solar illuminance

c = atmospheric extinction *coefficient*[2]

where

c = 0.21 for clear sky condition

c = 0.80 for partly cloudy sky condition

c = 0.00 for cloudy sky condition (no direct sun $E_{dn} = 0$)

m = optical air mass

e = 2.7183

The air mass(m) also can be expressed *by,*[5]

$$m = \frac{1}{\sin A_t} \quad [3.2.4]$$

where

A_t = solar altitude.

Direct Horizontal Solar Illuminance

$$E_{dh} = E_{dn} \sin A_t \quad [3.2.5]$$

where

E_{dh} = direct horizontal solar illuminance (Figure 4 on page 36).

Direct Vertical Solar Illuminance

$$E_{dv} = E_{dn} \cos A_i \quad [3.2.6]$$

where

E_{dv} = direct vertical solar illuminance

A_i = incident angle between sun's ray and the normal line to vertical surface.

The direct daylight on a vertical elevation is expressed in the above equation and Figure 6 on page 38. It is not practical to use the incident angle in the real physical environment. Hence, the concepts of trigonometry and vector geometry were employed here to represent equation [3.2.6] in the following forms (Figure 6 on page 38).

$$\cos A_i = \cos A_t \cos A_z \quad [3.2.7]$$

$$E_{dv} = E_{dn} \cos A_t \cos A_z \quad [3.2.8]$$

where

A_z = solar-elevation azimuth.

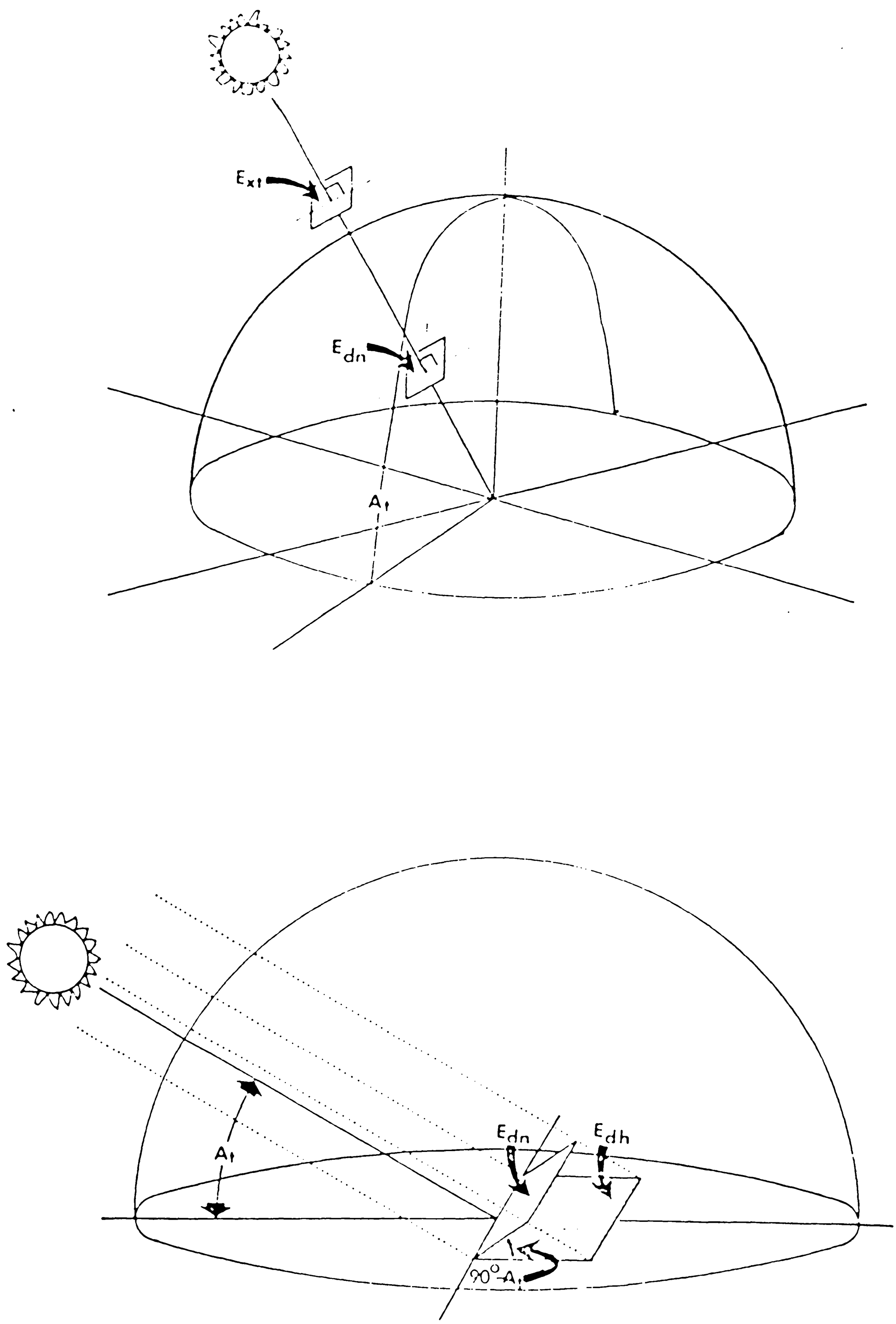

Figure 4. The Relationship Between Extraterrestrial Solar Illuminance and Direct Normal Solar Illuminance

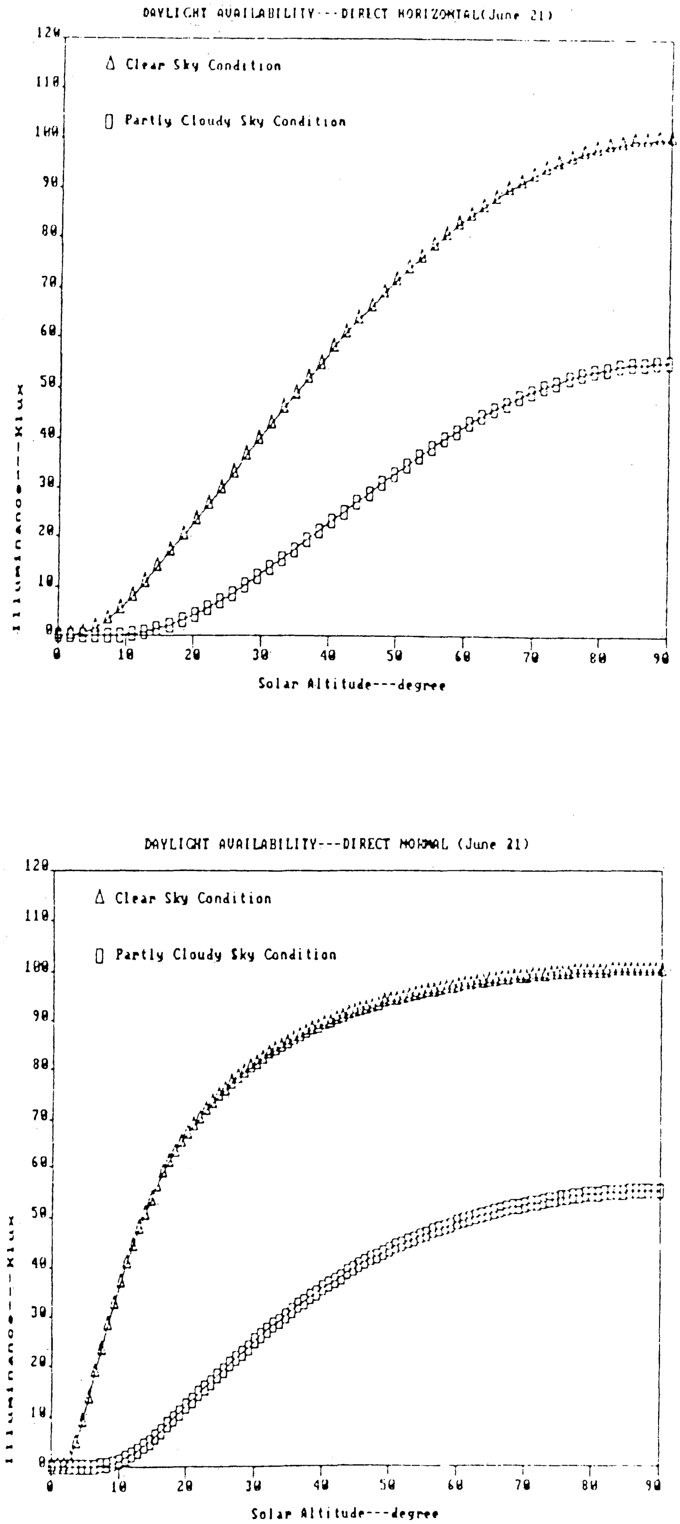

Figure 5. An Example of Direct Normal/Horizontal Solar Illuminance on June 21

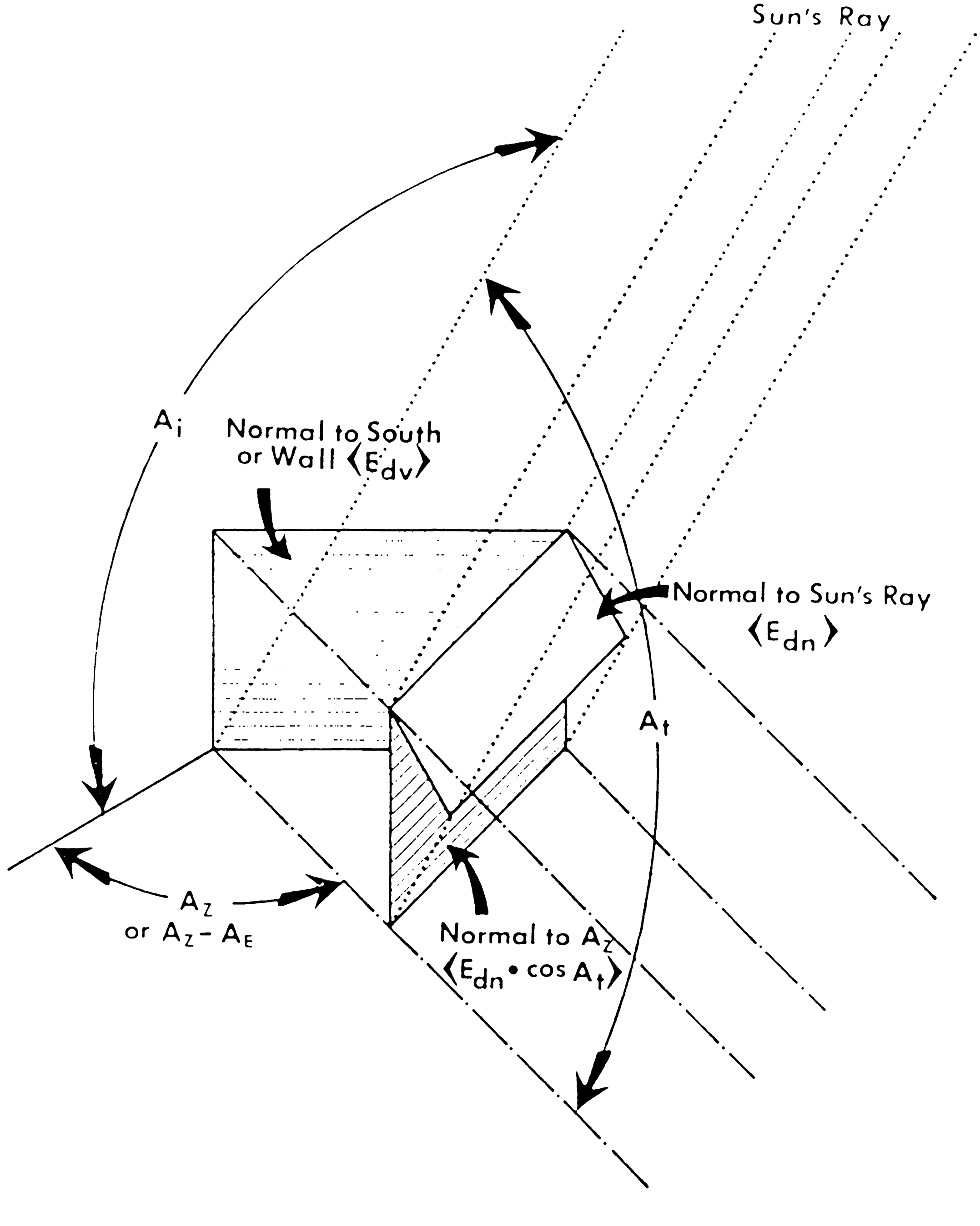

Figure 6. The Relationship Among Solar Alititude, Solar Incident, and Solar Azimuth Angles

Consistency of Direct Solar Illuminance: For the purpose of consistency and convenience in later study of theoretical development, it is necessary to unify the equations of direct normal solar illuminance (E_{dn}), and direct horizontal solar illuminance (E_{dv}).

From equation [3.2.2], [3.2.3], and [3.2.4]

$$E_{dn} = 127.5KLux\{1 + 0.034\cos[0.9863014(J-2)]\}\ 2.7183(-\frac{c}{\sin A_t}) \qquad [3.2.9]$$

From equation [3.2.5], and [3.2.9]

$$E_{dh} = 127.5\,KLux\{1 + 0.034\cos[0.9863014(J-2)]\}\,2.7183(-\frac{c}{\sin A_t})\ \sin A_t \quad [3.2.10]$$

From equation [3.2.8], and [3.2.9]

$$E_{dv} = 127.5KLux\{1 + 0.034\cos[0.9863014(J-2)]\}2.7183(\frac{-c}{\sin A_t})\cos A_t \cos(A_z - A_e) \quad [3.2.11]$$

3.3 Sun Angles on Buildings

A major obstacle to daylighting design is a continuing lack of simple and accurate design analysis methods to obtain solar altitude, solar azimuth, and profile angles for any given time of day or day of the year To deal with the difference in sun angles according to day and season without sun-earth relationship from the viewpoint of astrometry is an incomplete and logically inconstant approach. The literature search revealed no methods now to determine with absolute accuracy of the solar altitude, the hour angle, the solar azimuth, and the profile angles. Thus, this section presents a method to obtain exact angles between sun and buildings.

3.3.1 Celestial Coordinates: To understand the sun-earth relationship a knowledge of the celestial *sphere*[6] is essential. The celestial sphere is an imaginary sphere constructed with an arbitrary radius with its center at the observer's point on the surface of the earth. The basic lines and points of location of a celestial body, in this case the sun, are indicated on its surface. Figure 7 on page 41 shows the construction of a celestial with coordinates sphere. Let us briefly review our imaginary position with respect to the visible sky. The sky appear to us as an infinitely large hollow sphere.

Let the point in the northern sky as the north celestial pole about which the celestial sphere seems rotate be designated. The celestial equator can then be defined as an invisible but nevertheless real reference coordinate which divides the celestial sphere into two hemispheres. Then, the latitude circles on the celestial sphere can be established. Figure 7 on page 41 shows the latitude and longitude of a given point P with reference to the prime meridian on the earth's surface. (0° longitude). The prime meridian according to international agreement passes through Greenwich, *England*[7].

Terminology and Explanation

1. **Elevation Azimuth (A_e) :** For the purpose of calculating daylight on a vertical surface from a plan view of the building. The angle of elevation azimuth is measured clockwise with respect to true south. (Figure 8 on page 42)

2. **Standard Meridian for Time Zone (SM) :** The standard time zones in the United States (not including Alaska and Hawaii) are Eastern Standard Time (EST), Central Standard Time (CST), Mountain Standard Time (MST), and Pacific Standard Time (PST), which respectively keep the mean time of the meridians at 75, 90, 105, and 120 degrees of west *longitude*.[7]

3. **Julian Calendar (J) :** The *calendar*[8] was to be based on the tropical year, whose length had at that time been determined to be 365.25 days. Of course, one-fourth of a day could not be tacked on to the end of the calendar year. Therefore, common years were to con-

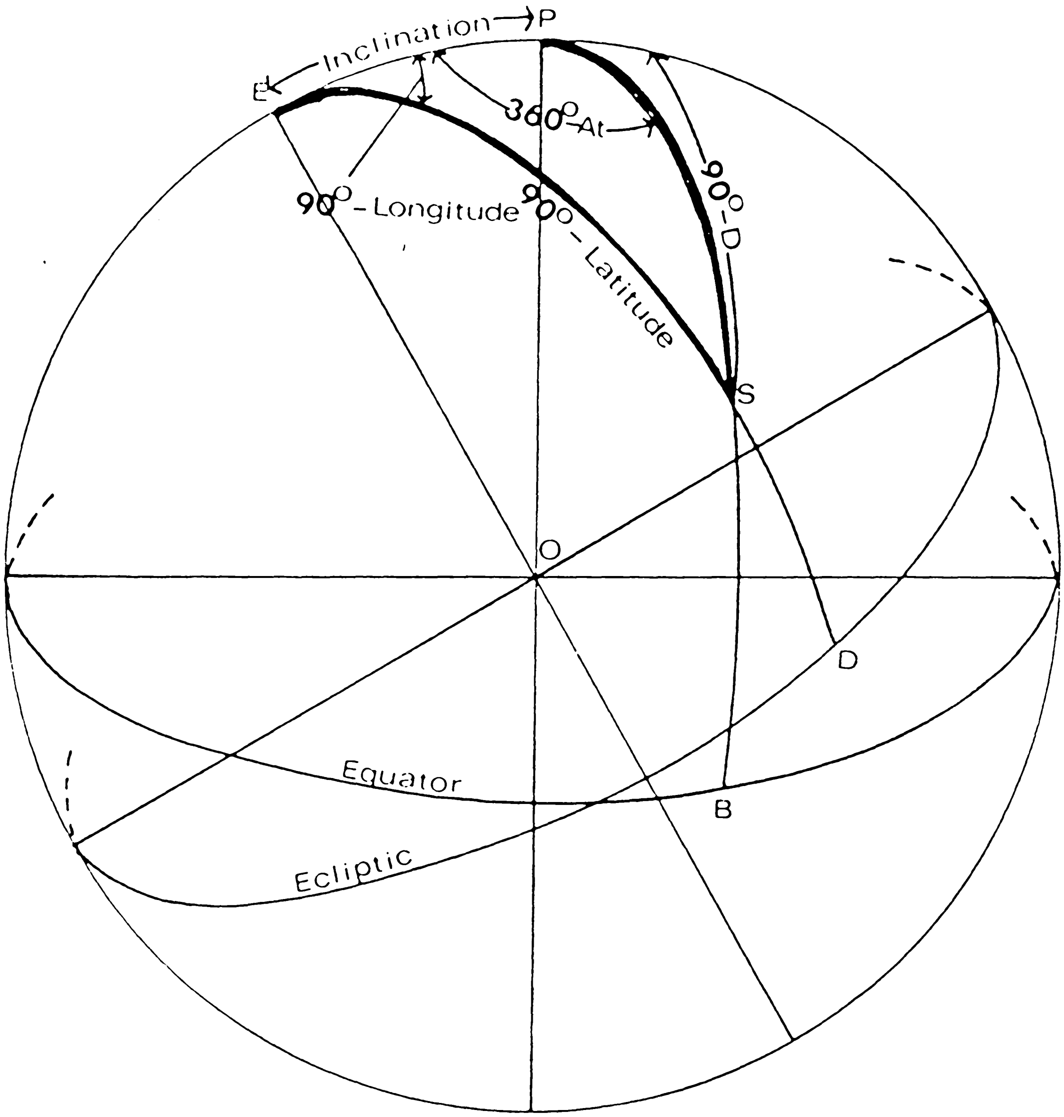

Figure 7. Celestial Sphere Coordinate System

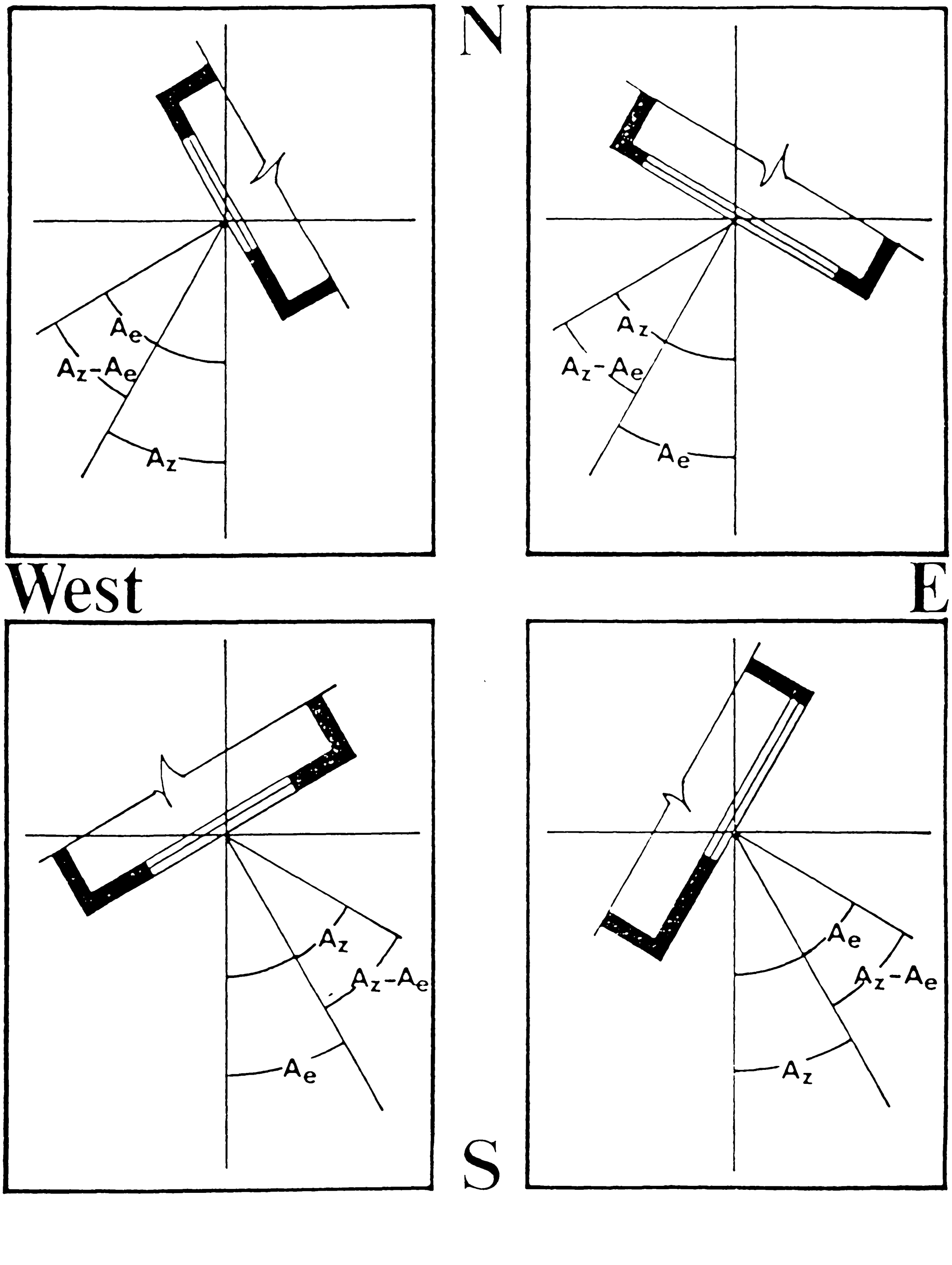

Figure 8. Relationships Between Azimuth Angle and Elevation Azimuth Angle

tain only 365 days, This study takes the integral part of the Julian calendar of each individual year.

4. **Hour Angle (HA) :** The **angle**[9] measured westward along the celestial equator from the local meridian to the hour circle passing through an object. Time is reckoned by the angular distance around the sky that the reference object has moved since it last crossed the meridian. The motion of that point around the sky is like the motion of the hour hand on a 24-hour clock. The angle measured to the west along the celestial equator from the local meridian to the hour circle passing through sun is the sun's hour angle. Because of the relation between hour angle and time, it is often convenient to measure angles in time units. In this notation, 24 hours corresponds to a full circle of 360° , 1 hour equals 15° , and 1° is four minutes of time.

5. **Apparent Solar Time (T) :** The hour angle of the sun's center plus 12 hours, so apparent solar time is determined by the hour angle of the sun. At midday, apparent solar time, the sun is on the meridian. The positive hour angle of the sun is the time past midday. The negative hour angle of the sun is the time before midday. It is convenient to start the day not at noon, but at midnight. Therefore the elapsed apparent solar time since midnight day is the hour angle of the Sun plus 12 *hours*[10] .

6. **Mean Solar Time (T_m) :** Mean solar time is defined as the hour angle of the mean sun plus 12 hours, where the mean sun is a fictitious point in the sky that moves uniformly to the east along the celestial equator, with the same average eastern rate as the true sun. In other words, mean solar time is just apparent solar time averaged uniformly. The irregular rate of apparent solar time causes it to run alternately ahead of and behind mean solar time. The difference between the two kinds of time can accumulate to about 17 *minutes*[10] . (Figure 9 on page 44)

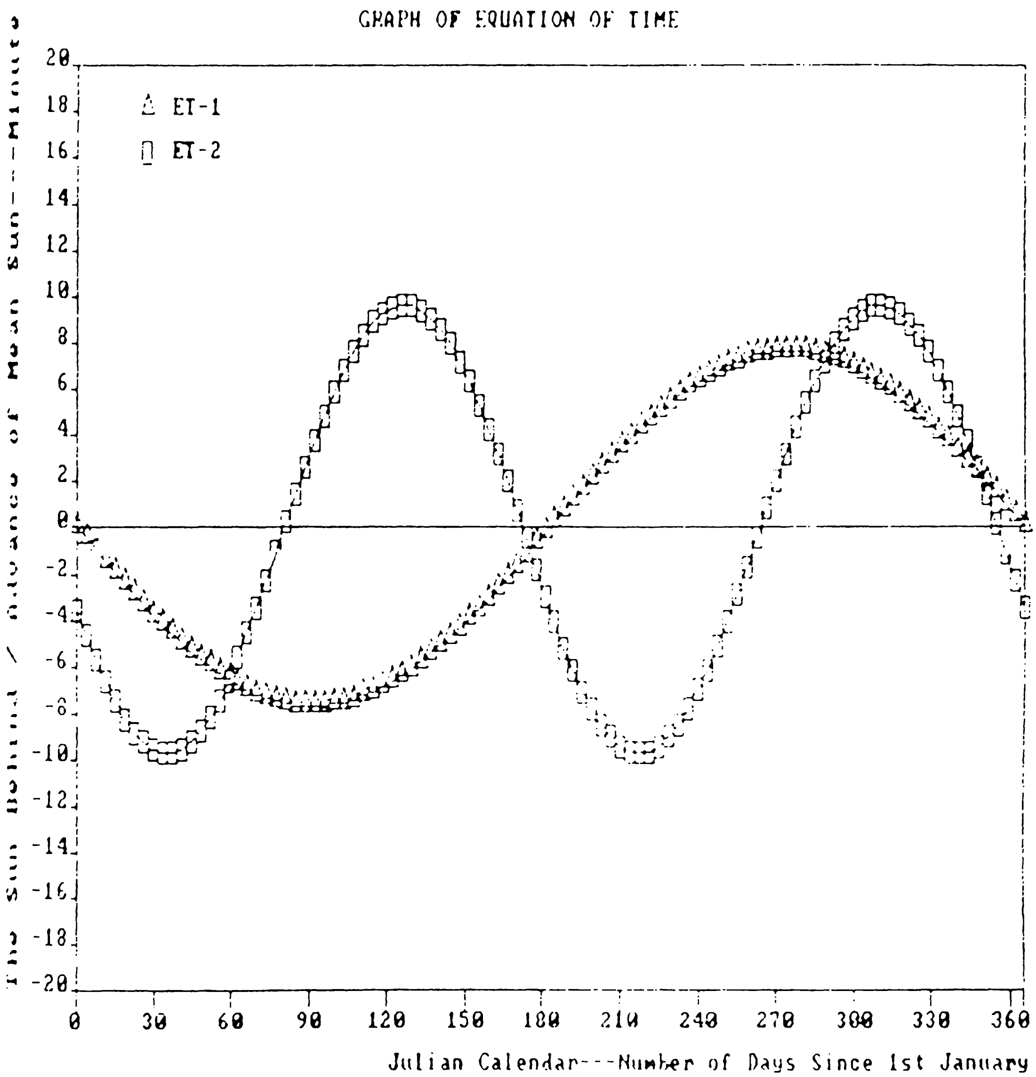

Figure 9. Graph of Equation of Time

7. **Equation of time (ET) :** The equation of time is the quantity which must be added algebraically to the apparent time to produce the mean solar time, in other words, the difference between apparent and mean solar 2:48 *a.m.*[9] (Figure 9 on page 44)

8. **Local Time (T_s) :** The measure of time defined by the standard meridian for time zone.

9. **Solar Declination (D) :** The angular distance from the celestial equator to the point in question measured along the hour circle through the point. It is reckoned positive north (negative south) of the celestial equator. The north polar distance is sometimes *used.*[10] (Figure 7 on page 41)

10. **Solar Azimuth (A_z) :** The azimuth is the number of degrees along the horizon to the vertical circle of the sun from some reference point on the horizon. In astronomical tradition, azimuth formerly was measured clockwise from the south point on the observer's horizon, but in this study, the true bearing of azimuth of the sun is the angle between the plane of the observer's meridian and the plane of the great circle passing through the zenith and the sun, measured clockwise (positive) from the observer's meridian with respect to true south (Figure 8 on page 42 and Figure 10 on page 46).

11. **Normal Incident Angle (A_{in}) :** The angle between the normal to the wall and the rays of the sunlight. (Figure 10 on page 46)

12. **Parallel Incident angle (A_{ip}) :** The angle between a plane parallel to the wall and the rays of the sunlight. (Figure 10 on page 46)

13. **Normal Profile Angle (A_{np}) :** The angle between the apparent altitude of the sun in the vertical plane and the normal to the wall. (Figure 10 on page 46)

14. **Parallel Profile Angle (A_{pp}) :** The angle between the plane parallel to the window and the rays of the sun perpendicular to the window plane. (Figure 10 on page 46)

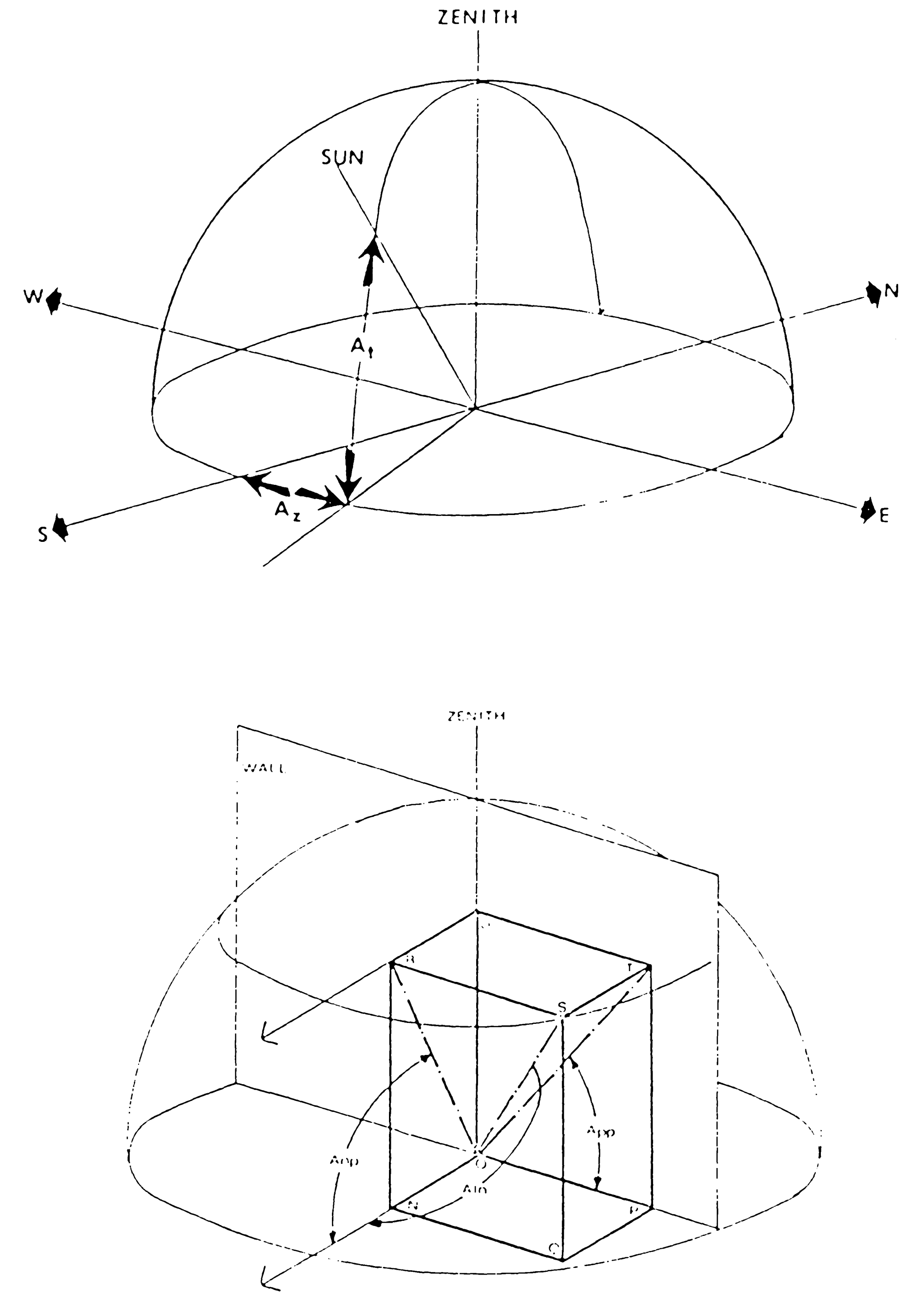

Figure 10. Solar Altitude, Azimuth, and Profile Angles

3.4 Mathematical Approach

Equation of Time: *Mills*[11] suggests five mathematical models to calculate the equation of time. For easily understanding and calculation, in this study has combined two of them to obtain the equation of time. These two models are

$$ET = ET_1 + ET_2 \quad \text{min} \qquad [3.4.1]$$

$$ET_1 = -7.64 \times \sin(L + 78) \; min$$

$$ET_2 = 9.683 \times \sin(2 \times L) \quad \text{min}$$

$$L = (J - 80.5) \times \frac{360}{365.25}$$

where

ET = Equation of times (see Figure 9 on page 44)

ET_1 = component from the eccentricity of the Earth's orbit

ET_2 = component from the inclination of the ecliptic (23.44°)

L = sun's longitude

$$ET_1 = -7.64 \times sin\left(\frac{360}{365.25} \times J\right) \quad \text{min} \qquad [3.4.2]$$

where •

J = Number of days since January 1st

Equation [3.4.1] can be expand as:

$$ET = -7.64 \times \sin(0.9856263 \times J) + 9.683\sin[1.9712526 \times (J - 80.5)] \text{ min} \qquad [3.4.3]$$

Solar Declination: The solar declination can be calculated precisely by the ecliptic longitude E_{lo}, and ecliptic latitude E_{la}, use the following formula:

$$D = \sin sup -1 \{\sin(E_{la}) \times \cos(D_{max}) + \cos(E_{la}) \times \sin(D_{max}) \times \sin(E_{lo})\} \qquad [3.4.4]$$

where the D_{max} is the obliquity of the ecliptic (23.44°), E_{la} = 0° (since the Earth's orbital radius is taken to be unity), E_{lo} is in the range from 0° to 360° , it is depend upon the numbers of days since January 1st. Hence, equation [3.4.4] can be expressed as:

$$D = \sin^{-1}[\sin(23.44) \times \sin(J - 81 \times \frac{360}{364})] \qquad [3.4.5]$$

where

D = Solar declination

Mean Solar Time

$$T_m = T_s + (L_{ozt} - L_{ol}) \times \frac{4}{60} \text{ hour} \qquad [3.4.6]$$

where

T sub m = Mean solar time

T_s = Local time in decimal hour

T_{ozt} = Longitude of Zone Time area

T_{ol} = Longitude of location

Apparent Solar Time: Based on definitions which were expressed in the last section, the difference between mean solar time and apparent solar time is the Equation of Time. Therefore, combine [3.4.3] and [3.4.6] to create equation [3.4.7] and to convert the local time to apparent solar time.

$$T = T_m + \frac{ET}{60} \ hour$$

$$T = T_s + (L_{ozt} - L_{ol}) \times 0.25 + (-0.12733) sin (0.9856263 \times J) + (0.16138) sin (1.9712526 \times J - 156) \ hour \qquad [3.4.7]$$

Hour Angle: According to the definition of hour angle and equation [3.4.7], use the following equations to convert the apparent solar time into solar hour angle.

$$HA = (T - 12) \times 15 \ ^\circ \qquad [3.4.8]$$

Solar Altitude

$$A_t = \sin^{-1}[\ \sin(D) \times \sin(L_a) + \cos(D) \times \cos(L_a) \times \cos(HA)\ ] \qquad [3.4.9]$$

Solar Azimuth

$$A_z = \cos^{-1} \frac{\sin(D) - \sin(L_a) \times \sin(A_t)}{\cos(L_a) \times \cos(A_t)} \qquad [3.4.10]$$

Because this study measures the solar azimuth as positive (or negative) clockwise (or counterclockwise) from the observer's meridian with respect to true south (Figure 8 on page 42 , Figure 10 on page 46), and the calculators or computers can only return inverse trigonometrical function correctly over half the range from 0° to 360° . It is necessary to correct the cosine function mathematically to suit the need of this study. Equation [3.4.10] is not the true solar azimuth needed in this study. Hence, whenever the inverse function of cosine is taken an ambiguity arises which has to be cleared up by the following method. If the "sin (HA)" is positive then the true azimuth is "180 - A_z" degrees. If the "sin (HA)" is negative then the true azimuth is "A_z - 180" degrees.

Normal and Parallel Incident Angle

$$A_{in} = \cos^{-1} (\cos A_t \times \cos (A_z - A_e)) \qquad [3.4.11]$$

$$A_{ip} = \cos^{-1} (\cos A_t \times \cos (90 - A_z + A_e)) \qquad [3.4.12]$$

Normal and Parallel Profile Angle

$$A_{np} = \tan^{-1} (\frac{\sin A_t}{\cos A_{in}}) \qquad [3.4.13]$$

$$A_{pp} = \tan^{-1} (\frac{\sin A_t}{\cos A_{ip}}) \qquad [3.4.14]$$

Based on the above mathematical equations, the calculation for obtaining solar altitude, solar azimuth, and profile angles is available and accurate. A computer program will be built to calculate these angles for any year and to make simulations for predicting direct and diffuse daylight distribution and to do validation.

3.5 Mathematical Model for Dealing with Direct Daylight

3-D Rectangular Coordinate System

A three-dimension rectangular coordinate system is defined and set for the purposes of convenience and consistency in the study of direct daylight distribution, and with the projection of windows by the direct daylight. Any coordinate system is based on one-, two-, or three axes depend upon the dimensions. Hence, any rectangular room can be defined as a 3-D rectangular coordinate system. In Figure 11 on page 52 , origin point is set as the lower-left deep corner of a rectangular room, and the interior walls including floor and ceiling can be defined as the following:

1. **Left Wall** $(0 \le x \le d, y = 0, 0 \le z \le h)$

2. **Back Wall** $(x = 0, 0 \le y \le w, 0 \le z \le h)$

3. **Right Wall** $(0 \le x \le d, y = w, 0 \le z \le h)$

4. **Window Wall** $(x = 0, 0 \le y \le w, 0 \le z \le h)$

5. **Floor** $(0 \le x \le d, 0 \le y \le w, z = 0)$

6. **Ceiling** $(0 \le x \le d, 0 \le y \le w, z = h)$

where

h = room's height

w = room's width

d = room's depth

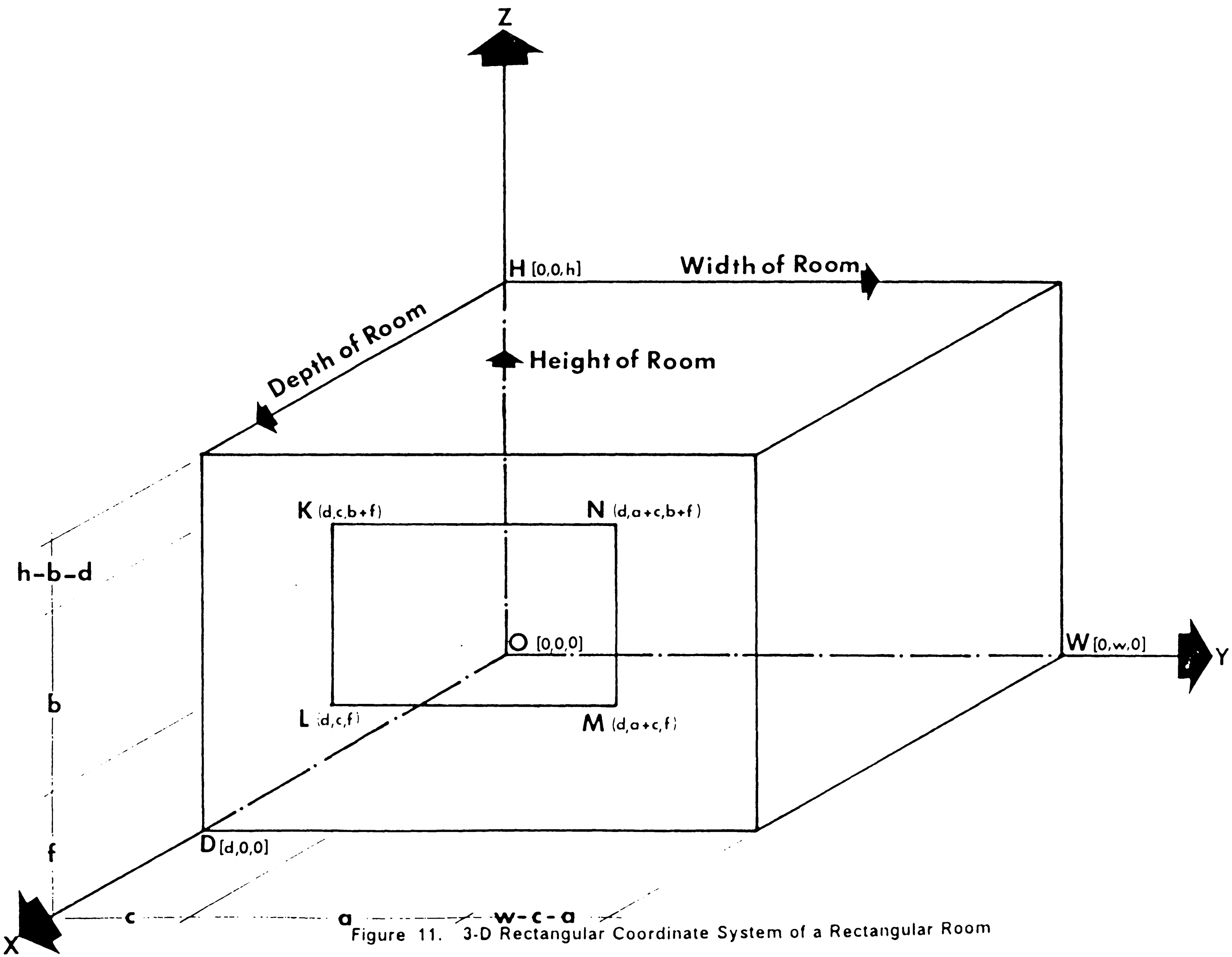

Figure 11. 3-D Rectangular Coordinate System of a Rectangular Room

Base on above definitions of a 3-D rectangular coordinate system, any sizes and positions of a rectangular window can be expressed by this coordinate system.

If the width of window is **a** , the height of window is **b** , the distance of left edge lines between window and room is c , and the distance between bottom edge line of window and floor is **f** as the Figure 11 on page 52 shown, then the four corners' coordinates are:

1. **K---Upper Left Corner** ($x_k = d, y_k = c, z_k = b + f$)

2. **L---Lower Left Corner** ($x_l = d, y_l = c, z_l = f$)

3. **M---Lower Right Corner** ($x_m = d, y_m = a + c, z_m = f$)

4. **N---Upper Right Corner** ($x_n = d, y_n = a + c, z_n = b + f$)

Therefore, any rectangular room with rectangular windows can be defined and expressed as above coordinates. The variables in this coordinate system are the sizes of room, the sizes of window, and the positions of window in window wall, and these variables' value are known in the study of developing the theoretical model for predicting direct and diffuse daylight distribution.

Sun's Ray---The Direct Angle and Direct Cosine

For defining a directed line in a 3-D rectangular coordinate system, it is necessary to know the direct cosine and direct angle of this directed line (see Appendix A). If the solar altitude (A_t), solar azimuth (A_z), and elevation azimuth (A_e) are known, then the Sun's ray can be defined with the assumption that all the sun's rays are parallel. In Figure 12 on page 54 , the direct angle α is angle AOC , the direct angle β is angle AOD, and the direct angle γ is angle AOE. If the direct cosine α , β and γ are known, then the sun's rays can be defined with the following formula.

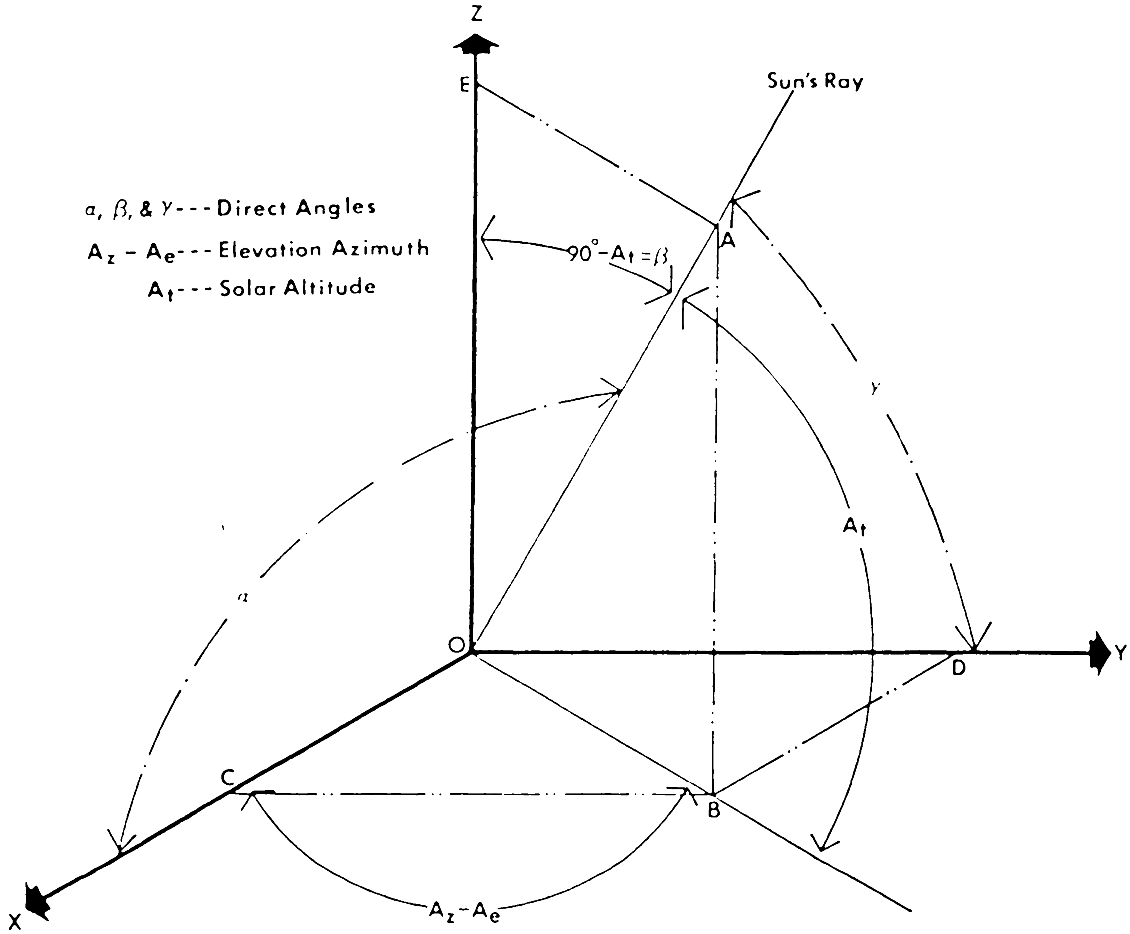

Figure 12. Direct Cosine and Direct Angle in 3-D Coordinate System

$$\frac{x - x_1}{\cos\alpha} = \frac{y - y_1}{\cos\beta} = \frac{z - z_1}{\cos\gamma} \qquad [3.5.1]$$

where

(x_1, y_1, z_1) are the coordinates of any possible point which was passed through by the sun's rays

In Figure 12 on page 54 , the angle AOB is the solar altitude, the angle BOC is the angle of ($A_z - A_e$). The relationships among angles of A_t, A_z, A_e , $\alpha, \beta, and \gamma$ can be found by the trignometry transformation.

Angle AOB $= A_t$

Angle BOC $= A_z - A_e$

Angle BOD $= 90^\circ - (A_z - A_e)$

From the definition of direct cosine and direct angle in the 3-D coordinate system, the direct cosine of the sun's rays are:

$$\cos\alpha = \cos AOC = \frac{OC}{AO} = \frac{OB}{AO} x \frac{OC}{OB} = \cos A_t x \cos(A_z - A_z) \qquad [3.5.2]$$

$$\cos\beta = \cos AOD = \frac{OD}{AO} = \frac{OB}{AO} x \frac{OD}{OB} = \frac{\cos A_t}{\cos}(90^\circ - A_z + A_e) \qquad [3.5.3]$$

$$\cos\gamma = \cos AOE = \cos(90^\circ - A_t) \qquad [3.5.4]$$

Once the direct angles of the sun's rays $\alpha, \beta, and \gamma$ can be expressed by the known factors $A_t, A_z, and A_e$ in a certain time and place, the equation of any single sun's rays passing through any point (P_{x1} , P_{y1} , P_{z1}) can be expressed as:

$$\frac{x - P_{x1}}{\cos\alpha} = \frac{y - P_{y1}}{\cos\beta} = \frac{z - P_{z1}}{\cos\gamma} \qquad [3.5.5]$$

Projection of Window

Theoretically, the direct daylight will not be incident to the ceiling and window wall itself, therefore, only four interior surfaces (left wall, back wall, right wall, and floor) are possible to be lighted by direct daylight. The direction of the sun's rays is required to determine the projection of any rectangular window in a rectangular room.

From the definitions and concepts of 3-D analytic geometry, it is known that there is one, and only one, intersected point between a directed line (sun's rays passing through one of the window's four corners) and a plane (four possible interior surfaces) which are not parallel. Hence, it is possible that the projections or images of the window by the sun's rays exist in plane x = 0 (back wall), plane y = 0 (left wall), plane z = 0 (floor), and plane y = w (right wall). But whether or not the projections or images are insides the range of the room's coordinates is not confirmed at this moment. Therefore, to locate the four projections or images of the window's in these four planes is the first step; to check these four window's projections or images are in the coordinates' range of 4 possible interior surfaces is the second step; and to decide the actual window's projection on interior surfaces is the third step. The following are the processes to obtain the interior lighting area by direct daylight penetrating through the window.

Left Wall ($0 \le x \le d, y = 0, 0 \le z \le h$ **)**

The window's projection or image does exist in plane y = 0 and the four corners of this projection or image are assigned (x_{lk} , 0 , z_{lk}), (x_{ll} , 0 , z_{ll}), (x_{lm} , 0 , z_{lm}), and (x_{ln} , 0 , z_{ln}). From this definition of a line in section 3.6.2 , the sun's rays which pass through the window's corners (x_k, y_k, z_k), (x_l, y_l, z_l), (x_m, y_m, z_m), and (x_n, y_n, z_n) can be obtained as the following four equations (see Figure 13 on page 57):

$$\frac{x_{lk} - x_k}{\cos\alpha} = \frac{0 - y_k}{\cos\beta} = \frac{z_{lk} - z_k}{\cos\gamma} \qquad [3.5.6]$$

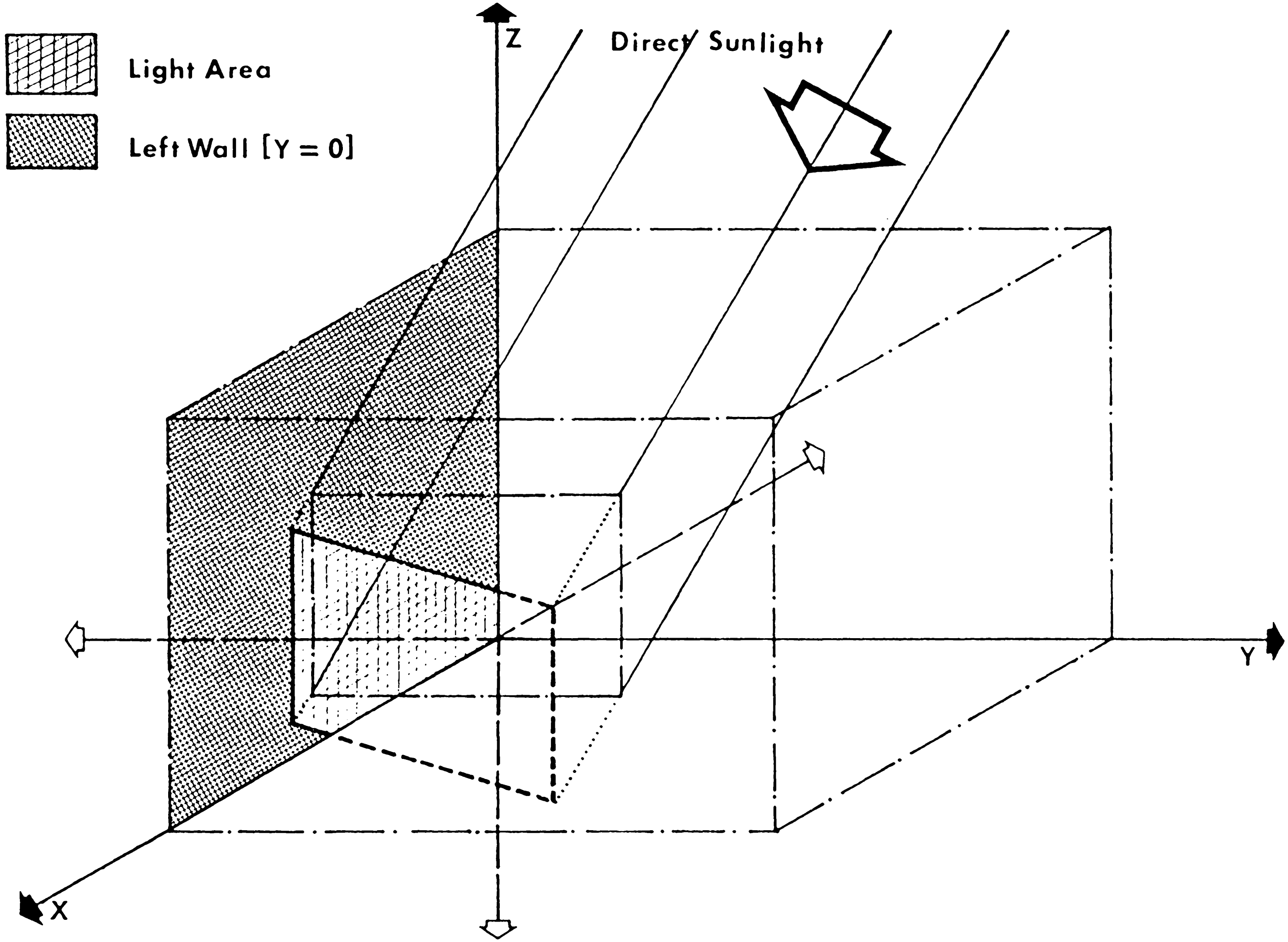

Figure 13. Window's Projection on Plane y = 0

$$\frac{x_{ll} - x_l}{\cos\alpha} = \frac{0 - y_l}{\cos\beta} = \frac{z_{ll} - z_l}{\cos\gamma} \qquad [3.5.7]$$

$$\frac{x_{lm} - x_m}{\cos\alpha} = \frac{0 - y_m}{\cos\beta} = \frac{z_{lm} - z_m}{\cos\gamma} \qquad [3.5.8]$$

$$\frac{x_{ln} - x_n}{\cos\alpha} = \frac{0 - y_n}{\cos\beta} = \frac{z_{ln} - z_n}{\cos\gamma} \qquad [3.5.9]$$

From equation [3.5.6]

$$\frac{x_{lk} - x_k}{\cos\alpha} = \frac{0 - y_k}{\cos\beta}$$

$$\cos\beta \; (x_{lk} - x_k) = \cos\alpha \; (-y_k)$$

$$x_{lk} - x_k = \frac{\cos\alpha}{\cos\beta} \; (-y_k)$$

$$x_{lk} = \frac{\cos\alpha}{\cos\beta} \; (-y_k) + x_k \qquad [3.5.10]$$

From equation [3.5.6]

$$\frac{0 - y_k}{\cos\beta} = \frac{z_{lk} - z_k}{\cos\gamma}$$

$$\cos\beta \; (z_{lk} - z_k) = \cos\gamma \; (-y_k)$$

$$z_{lk} - z_k = \frac{\cos\gamma}{\cos\beta} \; (-y_k)$$

$$z_{lk} = \frac{\cos\gamma}{\cos\beta} \; (-y_k) + z_k \qquad [3.5.11]$$

From equation [3.5.7]

$$x_{ll} = \frac{\cos\alpha}{\cos\beta}(-y_l) + x_l \qquad [3.5.12]$$

$$z_{ll} = \frac{\cos\gamma}{\cos\beta}(-y_l) + z_l \qquad [3.5.13]$$

From equation [3.5.8]

$$x_{lm} = \frac{\cos\alpha}{\cos\beta}(-y_m) + x_m \qquad [3.5.14]$$

$$z_{lm} = \frac{\cos\gamma}{\cos\beta}(-y_m) + z_m \qquad [3.5.15]$$

From equation [3.5.9]

$$x_{ln} = \frac{\cos\alpha}{\cos\beta}(-y_n) + x_n \qquad [3.5.16]$$

$$z_{ln} = \frac{\cos\gamma}{\cos\beta}(-y_n) + z_n \qquad [3.5.17]$$

The projection of window in plane y=0 is the area connecting these four intersected points (x_{lk} , 0, z_{lk}), (x_{ll} , 0, z_{ll}), (x_{lm} , 0, z_{lm}), and (x_{ln} , 0, z_{ln}). Determining whether this projection is in the left wall area or not is based on the definitions of left wall ($0 \le x \le d$, y=0, $0 \le z \le h$).

Hence,

if $0 \le x_{lk} \le d$ *and* $0 \le z_{lk} \le h$

Then the projection of point K (the upper-left corner of window) is in the left wall area, and located at point (x_{lk} , 0, z_{lk}); otherwise, the projection of point K is not in left the wall. Apply the above procedure to the other three intersected points to judge whether these three points (x_{ll} , 0 , z_{ll}) , (x_{lm} , 0 , z_{lm}) , and (x_{ln} , 0 , z_{ln}) are in the left wall or not (see Figure 13 on page 57). If any of these four points are not all the range of the left wall, then there must be another one or two surfaces on which the direct daylight falls. If these four points are all in the left wall, then the projection in plane y=0 is the actual projection of the window in a rectangular room (see Figure 15 on page 62 type 4). In other words, this projection is the area where the direct daylight passes through the complete window area and strikes inside to the left wall of a rectangular room.

Unfortunately, it does not often happen as in the above case. The projections of a window on the interior surfaces have 19 possible types which are illustrated in Figure 14 on page 61 , Figure 15 on page 62 , Figure 16 on page 63 , Figure 17 on page 64 , and Figure 18 on page 65 ; therefore, it is necessary to determine which type of projection one has to deal with. To determine the type of window projection, two sets of coordinates are needed: one is the actual projection points of the window corners, another is the intersected points of direct daylight passing through the window frame (line K-L, line L-M, line M-N, and line K-N) and incident to the line O-H, line O-D, line O-W, line W-Q, and line W-R. For example, if the actual projections of point L (the lower-left corner of window) and point M (the lower-right corner of window) were in the floor, and point N (the upper-right corner of window) and point K (the upper-left corner of window) were in the back wall, it is very clear that the window projection is type 3 in Figure 14 on page 61. It is still uncertain how to connect these four known projection points of the window's corners; thus, the coordinates of KL_y and MN_y are required to find out how to connect these six projection points in the back wall and floor of type 3 (KL_y is the intersected point where the direct daylight passes through the window's left frame K-L and is incident to the line O-W; MN_y is the intersected point of the direct daylight passing through the window's right frame M-N and incident to the line O-W).

Intersection Points at Axes

Window's Top Frame and Z-axis: line K-N ($x_{kn} = d,\ c \leq y_{kn} \leq c + a,\ z_{kn} = b + f$)

line O-H ($x_{uoh} = 0,\ y_{uoh} = 0,\ 0 \leq z_{uoh} \leq h$)

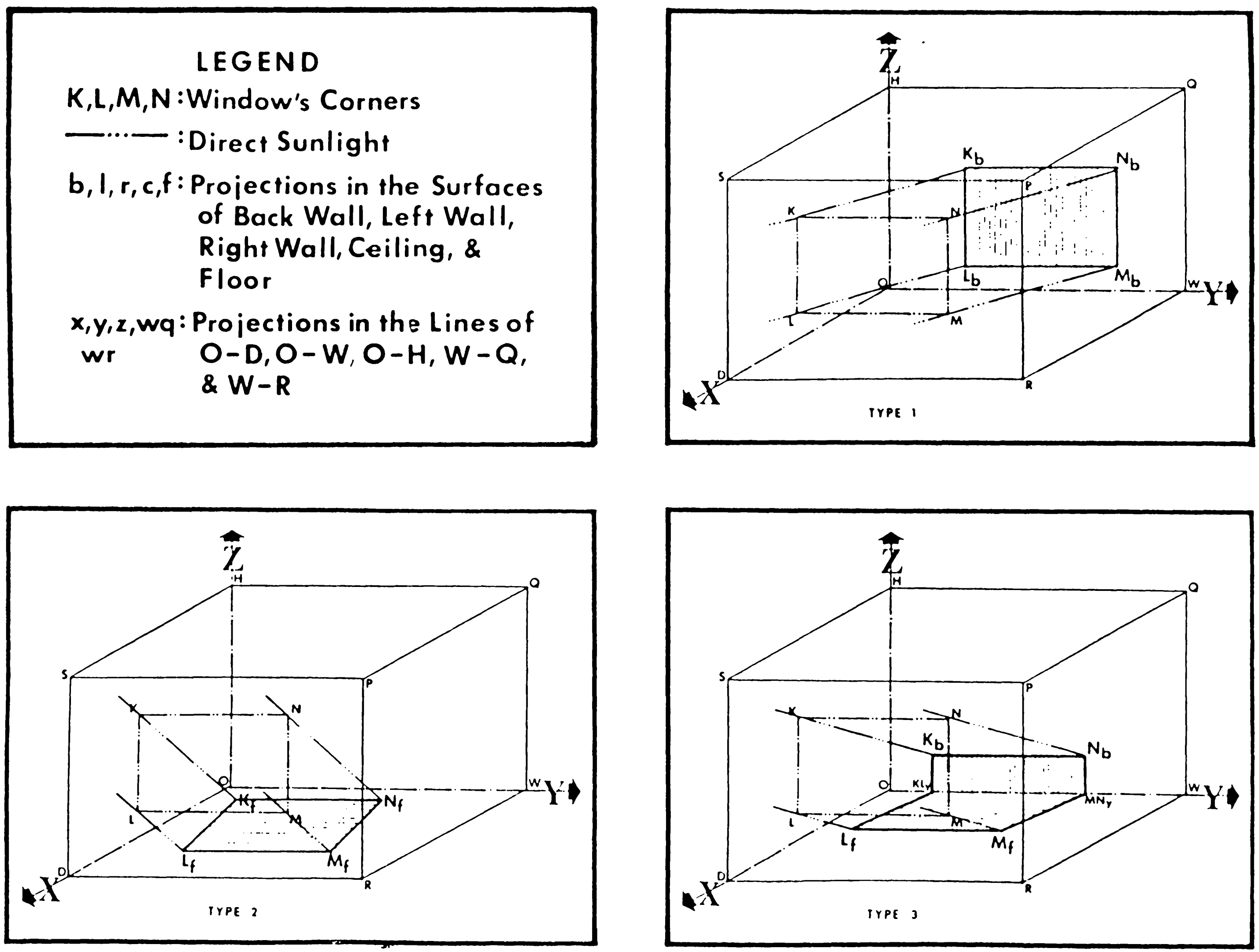

Figure 14. Window's Projection Type 1 - 3

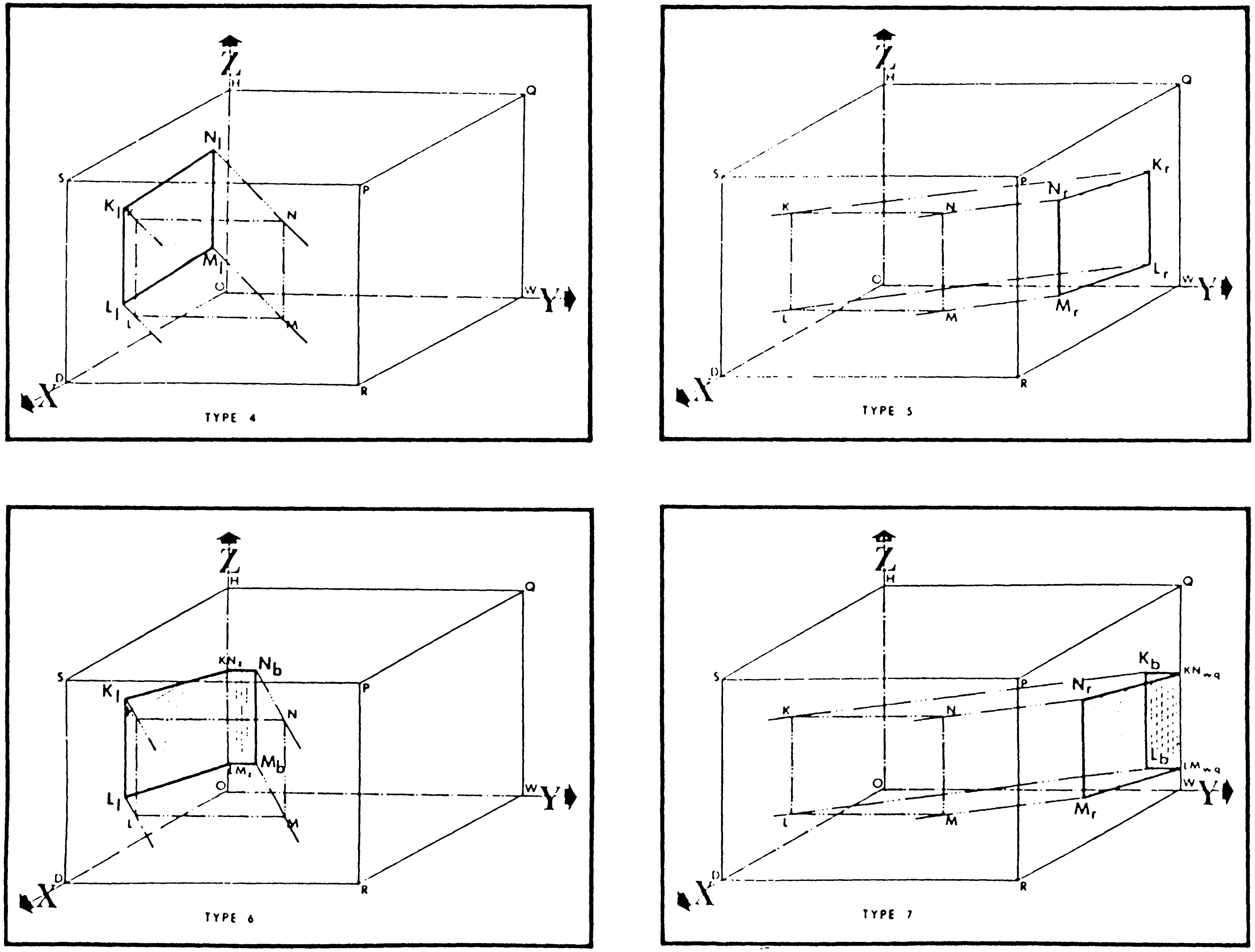

Figure 15. Window's Projection Type 4 - 7

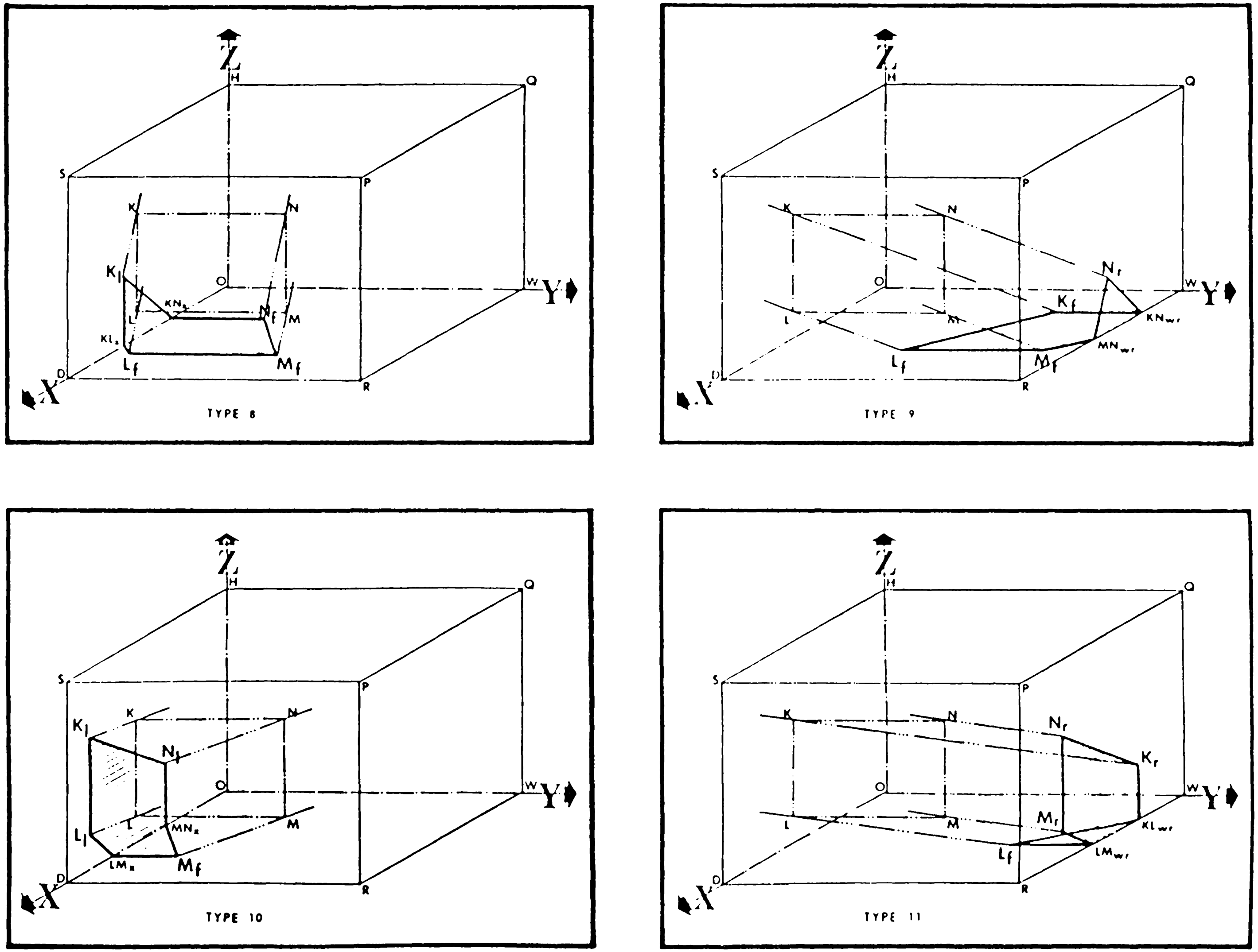

Figure 16. Window's Projection Type 8 - 11

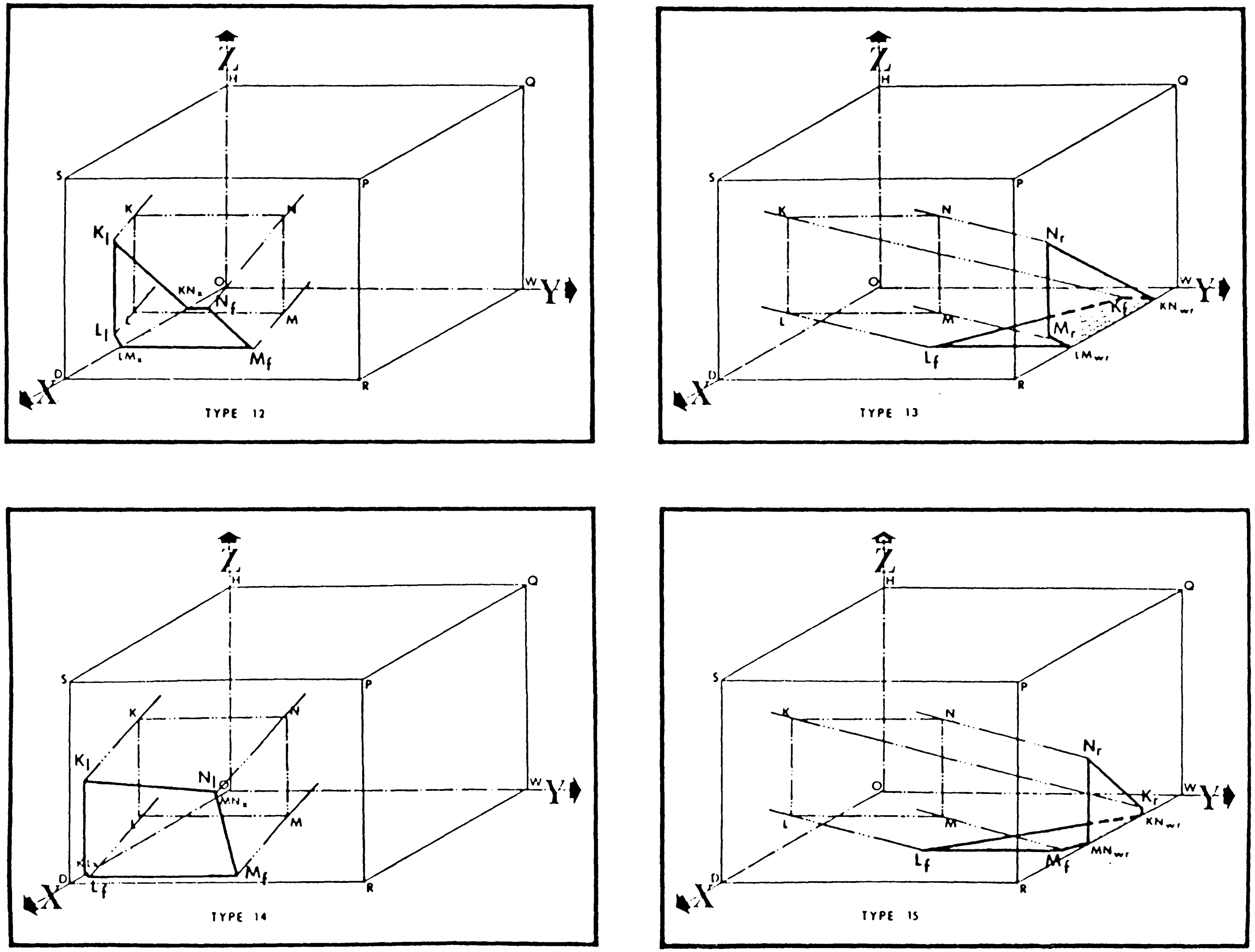

Figure 17. Window's Projection Type 12 - 15

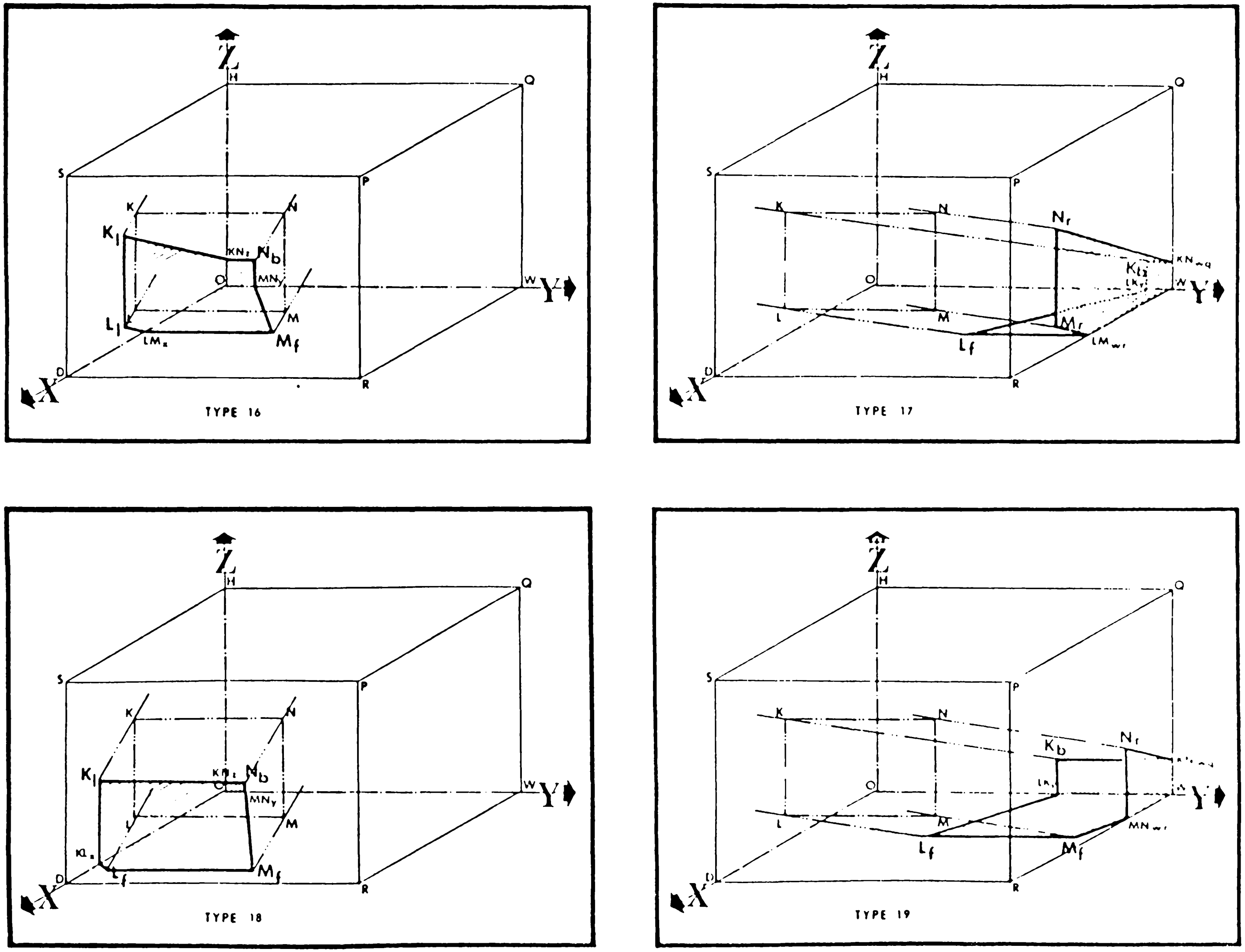

Figure 18. Window's Projection Type 16 - 19

$$\frac{d - 0}{\cos\alpha} = \frac{y_{kn} - 0}{\cos\beta} = \frac{b + f - z_{uoh}}{\cos\gamma} \qquad [3.5.18]$$

From equation [3.5.18]

$$\frac{d - 0}{\cos\alpha} = \frac{y_{kn} - 0}{\cos\beta}$$

$$y_{kn} \cos\alpha = \cos\beta \; d$$

$$y_{kn} = \frac{\cos\beta}{\cos\alpha} d \qquad [3.5.19]$$

From equation [3.5.18]

$$\frac{d - 0}{\cos\alpha} = \frac{b + f - z_{uoh}}{\cos\gamma}$$

$$(b + f - z_{uoh}) \cos\alpha = \cos\gamma\,(d)$$

$$b + f - z_{uoh} = \frac{\cos\gamma}{\cos\alpha} d$$

$$z_{uoh} = b + f - (\frac{\cos\gamma}{\cos\alpha} d) \qquad [3.5.20]$$

If $c \le y_{kn} \le c + a$ *and* $0 \le z_{uoh} \le h$, then the point (0, 0, z_{uoh}) in the z-axis is the intersection point between the sun's rays passing through the point (d, y_{kn} , b+d) in the top frame of the window and the line O-H. In other words, the projection of the window is at least on the two surface-wall (left wall and back wall). Repeating the process of equation [3.6.54], [3.6.55], and [3.6.56], the actual intersection points for direct daylight passing through the window frame into axes or lines (line O-H, line O-D, line O-W, line W-Q, and line W-R) can be calculated and checked. The following are the results of processing.

Window's Top Frame and X-axis: line K-N ($x_{kn} = d,\ c \le y_{kn} \le c + a,\ z_{kn} = b + f$)

line O-D ($0 \le x_{uod} \le d,\ y_{uod} = 0,\ z_{uod} = 0$)

$$\frac{d - x_{uod}}{\cos\alpha} = \frac{y_{kn} - 0}{\cos\beta} = \frac{b + f - 0}{\cos\gamma} \qquad [3.5.21]$$

From equation [3.5.21]

$$d - x_{uod} \ \cos\gamma = (b + f - 0)\ x\ \cos\alpha$$

$$(b + f)\ \cos\alpha = \cos\gamma\ (d - x_{uod})$$

$$x_{uod} = d - \frac{\cos\alpha}{\cos\gamma}\ (b + f) \qquad [3.5.22]$$

From equation [3.5.21]

$$\frac{b + f - 0}{\cos\gamma} = \frac{y_{kn} - 0}{\cos\beta}$$

$$(b + f)\ \cos\beta = \cos\gamma\ y_{kn}$$

$$y_{kn} = (b + f)\ (\frac{\cos\beta}{\cos\gamma}) \qquad [3.5.23]$$

If $c \le y_{kn} \le c + a$ *and* $0 \le x_{uod} \le d$, then the point (x_{uod} , 0, 0) in the x-axis is the intersection point between the sun's rays passing through the point (d, y_{kn} , b+d) in the top frame of the window and the line O-D. In other words, the projection of the window is at least on the two surfaces (left wall and floor). Repeating the process between equation [3.5.18] and equation [3.5.23], the actual intersection points for direct daylight passing through the window's top frame into line W-Q, and line W-R can be calculated and checked. The following are the results of processing.

Window's Top Frame and Line W-Q: line K-N ($x_{kn} = d,\ c \le y_{kn} \le c + a,\ z_{kn} = b + f$)

line W-Q ($x_{uwq} = 0,\ y_{uwq} = w,\ 0 \le z_{uwq} \le h$)

$$\frac{d - 0}{\cos\alpha} = \frac{y_{kn} - w}{\cos\beta} = \frac{b + f - z_{uwq}}{\cos\gamma} \qquad [3.5.24]$$

$$z_{uwq} = b + f - \frac{\cos\gamma}{\cos\alpha}(d) \qquad [3.5.25]$$

$$y_{kn} \doteq w + \left(\frac{\cos\beta}{\cos\alpha}\right)(d) \qquad [3.5.26]$$

Window's Top Frame and Line W-R: line K-N ($x_{kn} = d,\ c \le y_{kn} \le c + a,\ z_{kn} = b + f$)

line W-R ($0 \le x_{uwr} \le d,\ y_{uwr} = w,\ z_{uwq} = 0$)

$$\frac{d - x_{uwr}}{\cos\alpha} = \frac{y_{kn} - w}{\cos\beta} = \frac{b + f - 0}{\cos\gamma} \qquad [3.5.27]$$

$$x_{uwr} = d - \frac{\cos\alpha}{\cos\gamma}(b + f) \qquad [3.5.28]$$

$$y_{kn} = w + \left(\frac{\cos\beta}{\cos\gamma}\right)(b + f) \qquad [3.5.29]$$

If $c \le y_{kn} \le c + a$ *and* $0 \le z_{uwq} \le h$, then the point (0, w, z_{uwq}) in the line W-Q is the intersection point between sun's rays passing through the point (d, y_{kn} , b+d) in the top frame the of window and the line W-Q. In other words, the projection of the window is at least on the two surfaces (right wall and back wall). Again, if $c \le y_{kn} \le c + a$ *and* $0 \le x_{uwr} \le d$, then the point (x_{uwr}, w, 0) in the line W-R is the intersection point between the sun's rays passing through the point (d, y_{kn} , b+d) in the top frame of window and the line W-R. In other words, the projection of the window is at least on the two surfaces (right wall and floor). Repeating the process between equation [3.5.18] and equation [3.5.29], the actual intersection points for direct daylight passing through the window's lower frame into axes or lines (line O-H, line O-D, line W-Q, and line W-R) can be calculated and checked (appendix C).

Type 16 ---Figure 19 on page 70 and Figure 20 on page 71

$$O\ (x_o = 0,\ y_o = 0,\ z_o = 0)$$

$$K_l\ (x_{lk},\ y_{lk} = 0,\ z_{lk})$$

$$L_l\ (x_{ll},\ y_{ll} = 0,\ z_{ll})$$

$$M_f\ (x_{fm},\ y_{fm},\ z_{fm} = 0)$$

$$N_b\ (x_{bn},\ y_{bn} = 0,\ z_{bn})$$

$$LM_x\ (x_{dod},\ y_{dod} = 0,\ z_{dod} = 0)$$

$$L_{lx}\ (x_{lx} = x_{ll},\ y_{lx} = 0,\ z_{lx} = 0)$$

$$MN_y\ (x_{row} = 0,\ y_{row},\ z_{row} = 0)$$

$$KN_z\ (x_{uoh} = 0,\ y_{uoh} = 0,\ z_{uoh})$$

The values of z_{uoh} , x_{dod} , and y_{row} can be obtained from equation [3.5.20], [C.3], and [C.18].From Figure 20 on page 71 , the lighting areas can be divided into three portions to analyze ---lighting area in the left wall, back wall, and floor. Apply the procedures in appendix D to calculate the intensity of illuminance in the interior surfaces which were influenced by the lighting areas of type 16. The following are the processes and results to obtain the intensity of illuminance which were affecting by the inter-reflective diffuse daylight on all the six interior surfaces. This inter-reflective diffuse daylight influenced by the direct sunlight of type 16.

Type 16-I

From equation [D.2]

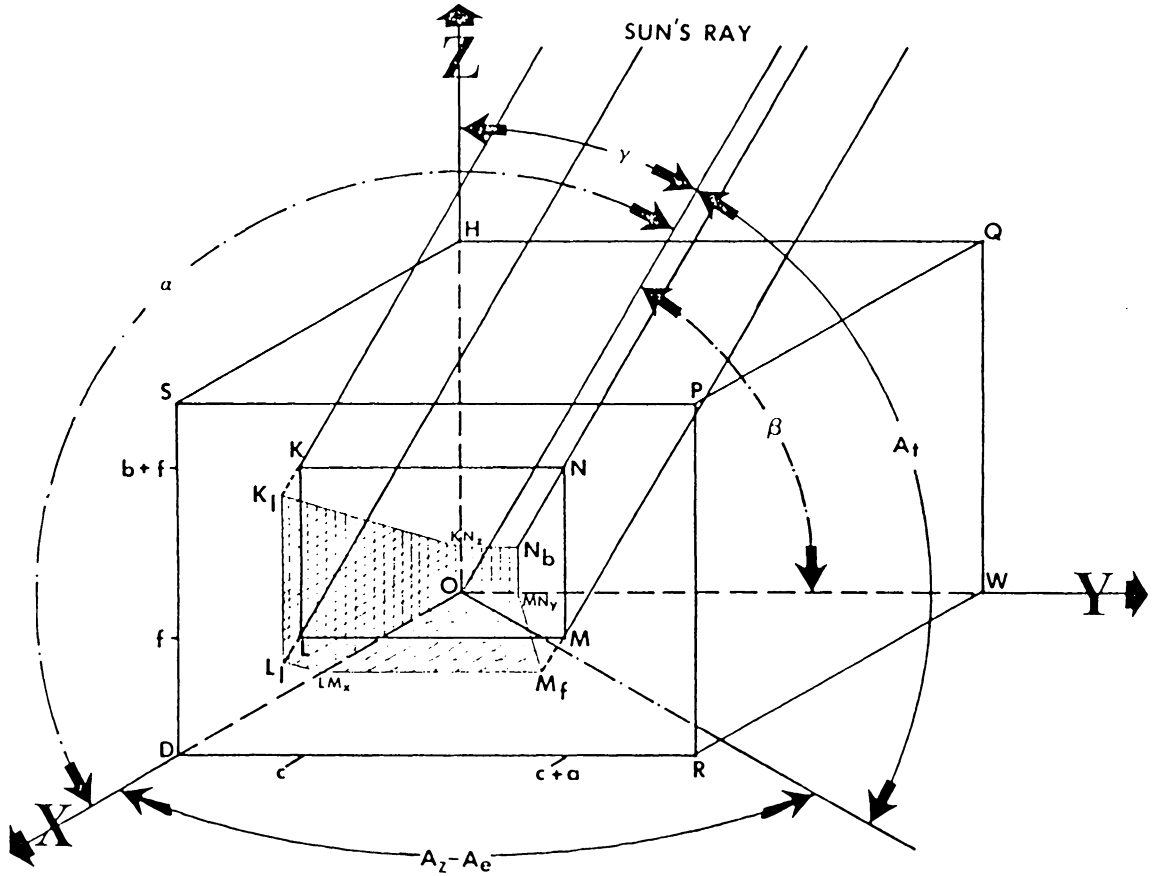

Figure 19. Relative Angles of Direct Sunlight Transfer---Type 16

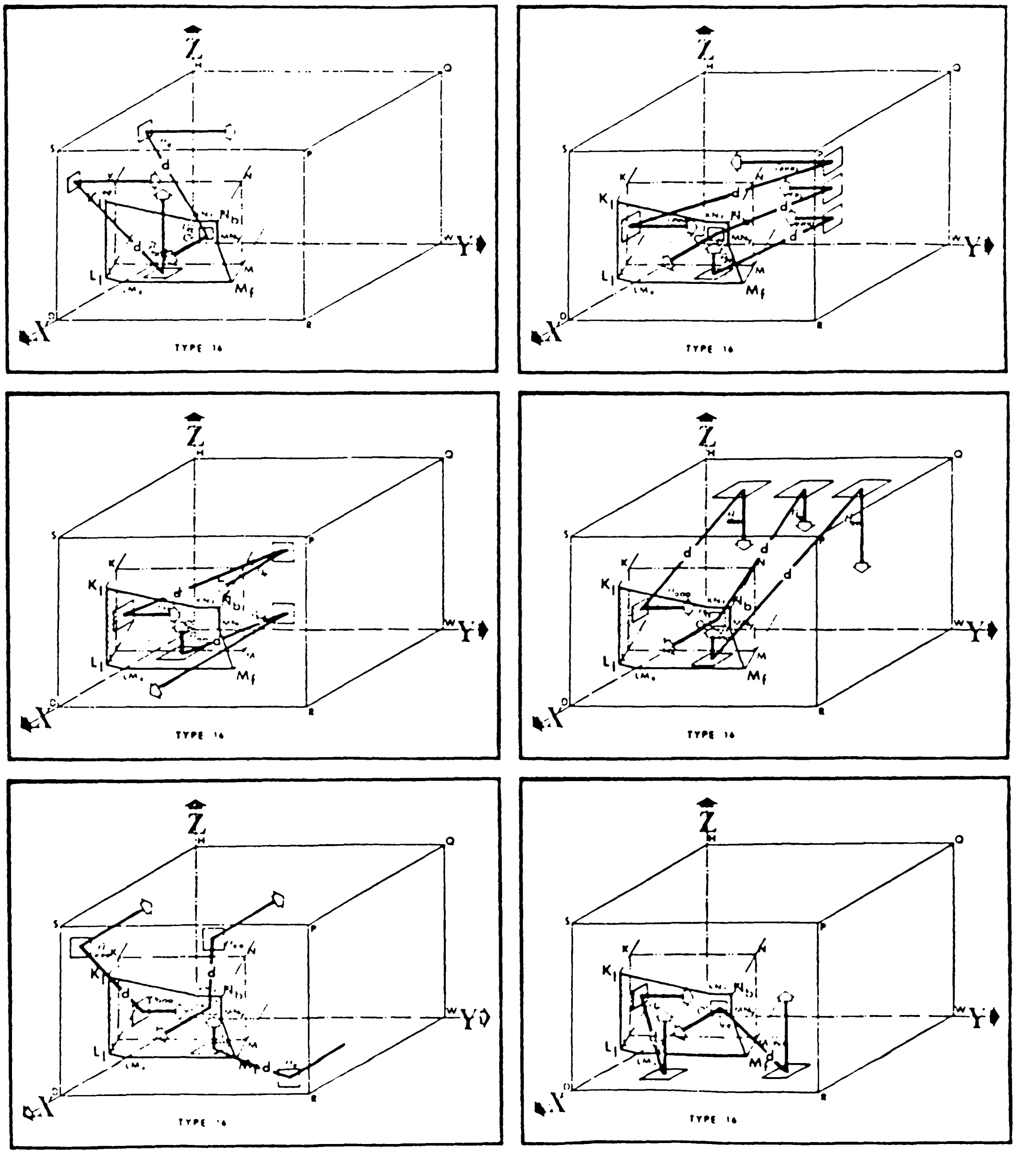

Figure 20. Direct Sunlight Transfer---Type 16

$$E_{lb} = \int_{f(z)}^{g(z)} \int_{y_o}^{y_{row}} \frac{E_{dvb}\, T_g\, R_b\, y_b\, x_l}{r_{lb}^4\, \pi}\, dy\, dz \qquad [3.5.30]$$

From equation [D.7]

$$E_{lf} = \int_{f(y)}^{g(y)} \int_{x_o}^{x_{dod}} \frac{E_{dh}\, T_g\, R_f\, z_l\, y_f}{r_{lf}^4\, \pi}\, dx\, dy \qquad [3.5.31]$$

where

$f(z)$ = Line $O - MN_y = z_o + (y_b - y_o)\dfrac{z_{row} - z_o}{y_{row} - y_o} = 0$

$g(z)$ = Line $KN_z - N_b = z_{uoh} + (y_b - y_{uoh})\dfrac{z_{bn} - z_{uoh}}{y_{bn} - y_{uoh}} = z_{uoh}$

$f(y)$ = Line $O - LM_x = y_o + (x_f - x_o)\dfrac{y_{dod} - y_o}{x_{dod} - x_o} = 0$

$g(y)$ = Line $MN_y - M_f = y_{row} + (x_f - x_{row})\dfrac{y_{fm} - y_{row}}{x_{fm} - x_{row}}$

form equation [3.5.6]

$r_{lb} = \sqrt{(x_l - x_b)^2 + (y_l - y_b)^2 + (z_l - z_b)^2}$

r_{lb} is the distance between any possible point in left wall and any possible point in the lighting portion of back wall.

$r_{lf} = \sqrt{(x_l - x_f)^2 + (y_l - y_f)^2 + (z_l - z_f)^2}$

r_{lf} is the distance between any possible point in left wall and any possible point in the lighting portion of the floor.

where

$0 \le x_l \le d,\ y_l = 0,\ 0 \le z_l \le h$

$x_b = 0,\ 0 \le y_b \le y_{row} = y_{bn},\ 0 \le z_b \le z_{uoh} = z_{bn}$

$0 \le x_f \le x_{fm} = x_{dod},\ 0 \le y_f \le y_{fm},\ z_f = 0$

Combine equation [3.5.30] and [3.5.31]

$$E_l = E_{lb} + E_{lf} \qquad [3.5.32]$$

Equation [3.5.32] gives a method to calculate the intensity of illuminance of any point or small area in the left wall which was influenced by the lighting area of type 16. E_l is the intensity of illuminance of left wall.

Type 16-b

From equation [D.14]

$$E_{bl} = \int_{f(z1)}^{g(z1)} \int_{x_o}^{x_{lx}} \frac{E_{dvl}\, T_g\, R_l\, y_b\, x_{l1}}{r_{bl1}^4\, \pi}\, dx\, dz$$

$$- \int_{f(z2)}^{g(z2)} \int_{x_{dod}}^{x_{lx}} \frac{E_{dvl}\, T_g\, R_l\, y_b\, x_{l2}}{r_{bl2}^4\, \pi}\, dx\, dz \qquad [3.5.33]$$

From equation [D.12]

$$E_{bf} = \int_{f(y)}^{g(y)} \int_{x_o}^{x_{dod}} \frac{E_{dh}\, T_g\, R_f\, z_b\, x_f}{r_{bf}^4\, \pi}\, dx\, dy \qquad [3.5.34]$$

where

$$f(z1) = \text{Line } O - L_{lx} = z_o + (x_{l1} - 0)\frac{z_{lx} - z_o}{x_{lx} - x_o} = 0$$

$$g(z1) = \text{Line } KN_z - K_l = z_{uoh} + (x_{l1} - x_{uoh})\frac{z_{lk} - z_{uoh}}{x_{lk} - x_{uoh}}$$

$$f(z2) = \text{Line } LM_x - L_{lx} = z_{dod} + (x_{l2} - x_{dod})\frac{z_{lx} - z_{dod}}{x_{lx} - x_{dod}} = 0$$

$$g(z2) = \text{Line } LM_x - L_l = z_{dod} + (x_{l2} - x_{dod})\frac{z_{ll} - z_{dod}}{x_{ll} - x_{dod}}$$

$$f(y) = \text{Line } O - LM_x = y_o + (x_f - x_o)\frac{y_{dod} - y_o}{x_{dod} - x_o} = 0$$

$$g(y) = \text{Line } MN_y - M_f = y_{row} + (x_f - x_{row})\frac{y_{fm} - y_{row}}{x_{fm} - x_{row}}$$

form equation [3.5.6]

$$r_{bl1} = \sqrt{(x_b - x_{l1})^2 + (y_b - y_{l1})^2 + (z_b - z_{l1})^2}$$

r_{bl1} is the distance between any possible point in back wall and any possible point inside the quadrilateral $O - KN_z - K_l - L_{lx}$ in left wall.

$$r_{bl2} = \sqrt{(x_b - x_{l2})^2 + (y_b - y_{l2})^2 + (z_b - z_{l2})^2}$$

r_{bl2} is the distance between any possible point inside the triangle of $L_l - LM_x - L_{lx}$ in left wall and any possible point in back wall.

$$r_{bf} = \sqrt{(x_b - x_f)^2 + (y_b - y_f)^2 + (z_b - z_f)^2}$$

r_{bf} is the distance between any possible point in back wall and any possible point in the lighting portion of floor.

where

$$0 \le x_{l1} \le x_{ll} = x_{lk}, y_{l1} = 0, 0 \le z_{l1} \le z_{lk}$$

$$x_{dod} \le x_{l2} \le x_{ll} = x_{lk}, y_{l2} = 0, 0 \le z_{l2} \le z_{ll}$$

$$x_b = 0, 0 \le y_b \le w, 0 \le z_b \le h$$

$$0 \le x_f \le x_{fm} = x_{dod}, 0 \le y_f \le y_{fm}, z_f = 0$$

Combine equation [3.5.33] and [3.5.34]

$$E_b = E_{bl} + E_{bf} \qquad [3.5.35]$$

Equation [3.5.35] gives a method to calculate the intensity of illuminance of any point or small area in back wall which were influenced by the lighting area of type 16. E_b is the intensity of illuminance of the back wall.

Type 16-w

From equation [D.3]

$$E_{wb} = \int_{f(z)}^{g(z)} \int_{y_O}^{y_{row}} \frac{E_{dvb}\, T_g\, R_b\, x_w\, x_w}{r_{wb}^4\, \pi}\, dy\, dz \qquad [3.5.36]$$

From equation [D.15]

$$E_{wl} = \int_{f(z1)}^{g(z1)} \int_{x_O}^{x_{lx}} \frac{E_{dvl}\, T_g\, R_l\, y_w\, (x_w - x_{l1})}{r_{wl1}^4\, \pi}\, dx\, dz$$

$$- \int_{f(z2)}^{g(z2)} \int_{x_{dod}}^{x_{lx}} \frac{E_{dvl}\, T_g\, R_l\, y_w\, (x_w - x_{l2})}{r_{wl2}^4\, \pi}\, dx\, dz \qquad [3.5.37]$$

From equation [D.9]

$$E_{wf} = \int_{f(y)}^{g(y)} \int_{x_O}^{x_{dod}} \frac{E_{dh}\, T_g\, R_f\, z_w\, (x_w - x_f)}{r_{wf}^4\, \pi}\, dx\, dy \qquad [3.5.38]$$

where

$$f(z) = \text{Line } O - MN_x = z_o + (y_b - y_o)\,\frac{z_{row} - z_o}{y_{row} - y_o} = 0$$

$$g(z) = \text{Line } KN_z - N_b = z_{uoh} + (y_b - y_{uoh})\,\frac{z_{bn} - z_{uoh}}{y_{bn} - y_{uoh}}$$

$$f(z1) = \text{Line } O - L_{lx} = z_o + (x_{l1} - 0)\,\frac{z_{lx} - z_o}{x_{lx} - x_o} = 0$$

$$g(z1) = \text{Line } KN_z - K_l = z_{uoh} + (x_{l1} - x_{uoh})\,\frac{z_{lk} - z_{uoh}}{x_{lk} - x_{uoh}}$$

$$f(z2) = \text{Line } LM_x - L_{lx} = z_{dod} + (x_{l2} - x_{dod}) \frac{z_{lx} - z_{dod}}{x_{lx} - x_{dod}} = 0$$

$$g(z2) = \text{Line } LM_x - L_l = z_{dod} + (x_{l2} - x_{dod}) \frac{z_{ll} - z_{dod}}{x_{ll} - x_{dod}}$$

$$f(y) = \text{Line } O - LM_x = y_o + (x_f - x_o) \frac{y_{dod} - y_o}{x_{dod} - x_o} = 0$$

$$g(y) = \text{Line } MN_y - M_f = y_{row} + (x_f - x_{row}) \frac{y_{fm} - y_{row}}{x_{fm} - x_{row}}$$

form equation [3.5.6]

$$r_{wb} = \sqrt{(x_w - x_b)^2 + (y_w - y_b)^2 + (z_w - z_b)^2}$$

r_{wb} is the distance between any possible point in window wall and any possible point in the lighting portion of back wall.

$$r_{wl1} = \sqrt{(x_w - x_{l1})^2 + (y_w - y_{l1})^2 + (z_w - z_{l1})^2}$$

r_{wl1} is the distance between any possible point in window wall and any possible point inside the quadrilateral $O - KN_z - K_l - L_{lx}$ in left wall.

$$r_{wl2} = \sqrt{(x_w - x_{l2})^2 + (y_w - y_{l2})^2 + (z_w - z_{l2})^2}$$

r_{wl2} is the distance between any possible point inside the triangle of $L_l - LM_x - L_{lx}$ in left wall and any possible point in window wall.

$$r_{wf} = \sqrt{(x_w - x_f)^2 + (y_w - y_f)^2 + (z_w - z_f)^2}$$

r_{wf} is the distance between any possible point in window wall and any possible point in the lighting portion of floor.

where

$0 \le x_{l1} \le x_{ll} = x_{lk}, y_{l1} = 0, 0 \le z_{l1} \le z_{lk}$

$x_{dod} \le x_{l2} \le x_{ll} = x_{lk}, y_{l2} = 0, 0 \le z_{l2} \le z_{ll}$

$x_b = 0, 0 \le y_b \le y_{row} = y_{bn}, 0 \le z_b \le z_{uoh} = z_{bn}$

$0 \le x_f \le x_{fm} = x_{dod}, 0 \le y_f \le y_{fm}, z_f = 0$

$x_w = d, 0 \le y_w \le w, 0 \le z_w \le h$

Combine equation [3.5.36], [3.5.37] and [3.5.38]

$$E_w = E_{wb} + E_{wl} + E_{wf} \qquad [3.5.39]$$

Equation [3.5.39] gives a method to calculate the intensity of illuminance of any point or small area in window wall which was influenced by the lighting area of type 16. E_w is the intensity of illuminance of the window wall.

Type 16-r

From equation [D.4]

$$E_{rb} = \int_{f(z)}^{g(z)} \int_{y_o}^{y_{row}} \frac{E_{dvb}\, T_g\, R_b\, x_r\,(y_r - y_b)}{r_{rb}^4\, \pi}\, dy\, dz \tag{3.5.40}$$

From equation [D.16]

$$E_{rl} = \int_{f(z1)}^{g(z1)} \int_{x_o}^{x_{lx}} \frac{E_{dvl}\, T_g\, R_l\, y_r\, y_r}{r_{rl1}^4\, \pi}\, dx\, dz - \int_{f(z2)}^{g(z2)} \int_{x_{dod}}^{x_{lx}} \frac{E_{dvl}\, T_g\, R_l\, y_r\, y_r}{r_{rl2}^4\, \pi}\, dx\, dz \tag{3.5.41}$$

From equation [D.10]

$$E_{rf} = \int_{f(y)}^{g(y)} \int_{x_o}^{x_{dod}} \frac{E_{dh}\, T_g\, R_f\, z_r\,(y_r - y_f)}{r_{rf}^4\, \pi}\, dx\, dy \tag{3.5.42}$$

where

$$f(z) = \text{Line } O - MN_x = z_o + (y_b - y_o)\,\frac{z_{row} - z_o}{y_{row} - y_o} = 0$$

$$g(z) = \text{Line } KN_z - N_b = z_{uoh} + (y_b - y_{uoh})\,\frac{z_{bn} - z_{uoh}}{y_{bn} - y_{uoh}}$$

$$f(z1) = \text{Line } O - L_{lx} = z_o + (x_{l1} - 0)\,\frac{z_{lx} - z_o}{x_{lx} - x_o} = 0$$

$$g(z1) = \text{Line } KN_z - K_l = z_{uoh} + (x_{l1} - x_{uoh})\,\frac{z_{lk} - z_{uoh}}{x_{lk} - x_{uoh}}$$

$$f(z2) = \text{Line } LM_x - L_{lx} = z_{dod} + (x_{l2} - x_{dod})\,\frac{z_{lx} - z_{dod}}{x_{lx} - x_{dod}} = 0$$

$$g(z2) = \text{Line } LM_x - L_l = z_{dod} + (x_{l2} - x_{dod})\,\frac{z_{ll} - z_{dod}}{x_{ll} - x_{dod}}$$

$$f(y) = \text{Line } O - LM_x = y_o + (x_f - x_o)\,\frac{y_{dod} - y_o}{x_{dod} - x_o} = 0$$

$$g(y) = \text{Line } MN_y - M_f = y_{row} + (x_f - x_{row})\,\frac{y_{fm} - y_{row}}{x_{fm} - x_{row}}$$

form equation [3.4.6]

$$r_{rb} = \sqrt{(x_r - x_b)^2 + (y_r - y_b)^2 + (z_r - z_b)^2}$$

r_{rb} is the distance between any possible point in right wall and any possible point in the lighting portion of back wall.

$r_{rl1} = \sqrt{(x_r - x_{l1})^2 + (y_r - y_{l1})^2 + (z_r - z_{l1})^2}$

r_{rl1} is the distance between any possible point in right wall and any possible point inside the quadrilateral $O - KN_z - K_l - L_{lx}$ in left wall.

$r_{rl2} = \sqrt{(x_r - x_{l2})^2 + (y_r - y_{l2})^2 + (z_r - z_{l2})^2}$

r_{rl2} is the distance between any possible point inside the triangle of $L_l - LM_x - L_{lx}$ in left wall and any possible point in right wall.

$r_{rf} = \sqrt{(x_r - x_f)^2 + (y_r - y_f)^2 + (z_r - z_f)^2}$

r_{rf} is the distance between any possible point in right wall and any possible point in the lighting portion of floor.

where

$0 \le x_{l1} \le x_{ll} = x_{lk}, y_{l1} = 0, 0 \le z_{l1} \le z_{lk}$

$x_{dod} \le x_{l2} \le x_{ll} = x_{lk}, y_{l2} = 0, 0 \le z_{l2} \le z_{ll}$

$x_b = 0, 0 \le y_b \le y_{row} = y_{bn}, 0 \le z_b \le z_{uoh} = z_{bn}$

$0 \le x_f \le x_{fm} = x_{dod}, 0 \le y_f \le y_{fm}, z_f = 0$

$0 \le x_r \le d, y_r = w, 0 \le z_r \le h$

Combine equation [3.5.40], [3.5.41] and [3.5.42]

$$E_r = E_{rb} + E_{rl} + E_{rf} \qquad [3.5.43]$$

Equation [3.5.43] gives a method to calculate the intensity of illuminance of any point or small area in right wall which was influenced by the lighting area of type 16. E_r is the intensity of illuminance of the window wall.

Type 16-c

From equation [D.5]

$$E_{cb} = \int_{f(z)}^{g(z)} \int_{y_o}^{y_{row}} \frac{E_{dvb}\, T_g\, R_b\, x_c\, (z_c - z_b)}{r_{cb}^4\, \pi}\, dy\, dz \qquad [3.5.44]$$

From equation [D.17]

$$E_{cl} = \int_{f(z1)}^{g(z1)} \int_{x_o}^{x_{lx}} \frac{E_{dvl}\, T_g\, R_l\, y_c\, (z_c - z_{l1})}{z_{cl1}^4\, \pi}\, dx\, dz$$

$$- \int_{f(z2)}^{g(z2)} \int_{x_{dod}}^{x_{lx}} \frac{E_{dvl}\, T_g\, R_l\, y_c\, (z_c - z_{l2})}{r_{cl2}^4\, \pi}\, dx\, dz \qquad [3.5.45]$$

From equation [D.11]

$$E_{cf} = \int_{f(y)}^{g(y)} \int_{x_o}^{x_{dod}} \frac{E_{dh}\, T_g\, R_f\, z_c\, z_c}{r_{cf}^4\, \pi}\, dx\, dy \qquad [3.5.46]$$

where

$f(z) = \text{Line } O - MN_x = z_o + (y_b - y_o)\, \frac{z_{row} - z_o}{y_{row} - y_o} = 0$

$g(z) = \text{Line } KN_z - N_b = z_{uoh} + (y_b - y_{uoh})\, \frac{z_{bn} - z_{uoh}}{y_{bn} - y_{uoh}}$

$f(z1) = \text{Line } O - L_{lx} = z_o + (x_{l1} - 0)\, \frac{z_{lx} - z_o}{x_{lx} - x_o} = 0$

$g(z1) = \text{Line } KN_z - K_l = z_{uoh} + (x_{l1} - x_{uoh})\, \frac{z_{lk} - z_{uoh}}{x_{lk} - x_{uoh}}$

$f(z2) = \text{Line } LM_x - L_{lx} = z_{dod} + (x_{l2} - x_{dod})\, \frac{z_{lx} - z_{dod}}{x_{lx} - x_{dod}} = 0$

$g(z2) = \text{Line } LM_x - L_l = z_{dod} + (x_{l2} - x_{dod})\, \frac{z_{ll} - z_{dod}}{x_{ll} - x_{dod}}$

$f(y) = \text{Line } O - LM_x = y_o + (x_f - x_o)\, \frac{y_{dod} - y_o}{x_{dod} - x_o} = 0$

$g(y) = \text{Line } MN_y - M_f = y_{row} + (x_f - x_{row})\, \frac{y_{fm} - y_{row}}{x_{fm} - x_{row}}$

form equation [3.4.6]

$r_{cb} = \sqrt{(x_c - x_b)^2 + (y_c - y_b)^2 + (z_c - z_b)^2}$

r_{cb} is the distance between any possible point in ceiling and any possible point in the lighting portion of back wall.

$r_{cl1} = \sqrt{(x_c - x_{l1})^2 + (y_c - y_{l1})^2 + (z_c - z_{l1})^2}$

r_{cl1} is the distance between any possible point in ceiling and any possible point inside the quadrilateral $O - KN_z - K_l - L_{lx}$ in left wall.

$r_{cl2} = \sqrt{(x_c - x_{l2})^2 + (y_c - y_{l2})^2 + (z_c - z_{l2})^2}$

r_{cl2} is the distance between any possible point inside the triangle of $L_l - LM_x - L_{lx}$ in left wall and any possible point in ceiling.

$r_{cf} = \sqrt{(x_c - x_f)^2 + (y_c - y_f)^2 + (z_c - z_f)^2}$

r_{cf} is the distance between any possible point in ceiling and any possible point in the lighting portion of floor.

where

$0 \leq x_{l1} \leq x_{ll} = x_{lk}, y_{l1} = 0, 0 \leq z_{l1} \leq z_{lk}$

$x_{dod} \leq x_{l2} \leq x_{ll} = x_{lk}, y_{l2} = 0, 0 \leq z_{l2} \leq z_{ll}$

$x_b = 0, 0 \leq y_b \leq y_{row} = y_{bn}, 0 \leq z_b \leq z_{uoh} = z_{bn}$

$0 \leq x_f \leq x_{fm} = x_{dod}, 0 \leq y_f \leq y_{fm}, z_f = 0$

$0 \leq x_c \leq d, 0 \leq y_c \leq w, z_c = h$

Combine equation [3.5.44], [3.5.45] and [3.5.46]

$$E_c = E_{cb} + E_{cl} + E_{cf} \qquad [3.5.47]$$

Equation [3.5.47] gives a method to calculate the intensity of illuminance of any point or small area in ceiling which was influenced by the lighting area of type 16. E_c is the intensity of illuminance of the window wall.

Type 16-f

From equation [D.6]

$$E_{fb} = \int_{f(z)}^{g(z)} \int_{y_o}^{y_{row}} \frac{E_{dvb}\, T_g\, R_b\, x_f\, z_b}{r_{fb}^4\, \pi}\, dy\, dz \qquad [3.5.48]$$

From equation [D.18]

$$E_{fl} = \int_{f(z1)}^{g(z1)} \int_{x_o}^{x_{lx}} \frac{E_{dvl}\, T_g\, R_l\, y_f\, z_{l1}}{z_{fl1}^4\, \pi}\, dx\, dz - \int_{f(z2)}^{g(z2)} \int_{x_{dod}}^{x_{lx}} \frac{E_{dvl}\, T_g\, R_l\, y_f\, z_{l2}}{r_{fl2}^4\, \pi}\, dx\, dz \qquad [3.5.49]$$

where

$f(z) = \text{Line } O - MN_x = z_o + (y_b - y_o)\,\frac{z_{row} - z_o}{y_{row} - y_o} = 0$

$g(z) = \text{Line } KN_z - N_b = z_{uoh} + (y_b - y_{uoh})\,\frac{z_{bn} - z_{uoh}}{y_{bn} - y_{uoh}}$

$f(z1) = \text{Line } O - L_{lx} = z_o + (x_{l1} - 0)\,\frac{z_{lx} - z_o}{x_{lx} - x_o} = 0$

$$g(z1) = \text{Line } KN_z - K_l = z_{uoh} + (x_{l1} - x_{uoh}) \frac{z_{lk} - z_{uoh}}{x_{lk} - x_{uoh}}$$

$$f(z2) = \text{Line } LM_x - L_{lx} = z_{dod} + (x_{l2} - x_{dod}) \frac{z_{lx} - z_{dod}}{x_{lx} - x_{dod}} = 0$$

$$g(z2) = \text{Line } LM_x - L_l = z_{dod} + (x_{l2} - x_{dod}) \frac{z_{ll} - z_{dod}}{x_{ll} - x_{dod}}$$

form equation [3.4.6]

$$r_{fb} = \sqrt{(x_f - x_b)^2 + (y_f - y_b)^2 + (z_f - z_b)^2}$$

r_{fb} is the distance between any possible point in floor and any possible point in the lighting portion of back wall.

$$r_{fl1} = \sqrt{(x_f - x_{l1})^2 + (y_f - y_{l1})^2 + (z_f - z_{l1})^2}$$

r_{fl1} is the distance between any possible point in floor and any possible point inside the quadrilateral $O - KN_z - K_l - L_{lx}$ in left wall.

$$r_{fl2} = \sqrt{(x_f - x_{l2})^2 + (y_f - y_{l2})^2 + (z_f - z_{l2})^2}$$

r_{fl2} is the distance between any possible point inside the triangle of $L_l - LM_x - L_{lx}$ in left wall and any possible point in floor.

where

$$0 \le x_{l1} \le x_{ll} = x_{lk}, y_{l1} = 0, 0 \le z_{l1} \le z_{lk}$$

$$x_{dod} \le x_{l2} \le x_{ll} = x_{lk}, y_{l2} = 0, 0 \le z_{l2} \le z_{ll}$$

$$x_b = 0, 0 \le y_b \le y_{row} = y_{bn}, 0 \le z_b \le z_{uoh} = z_{bn}$$

$$0 \le x_f \le d, 0 \le y_f \le w, z_f = 0$$

Combine equation [3.5.48] and [3.5.49]

$$E_f = E_{fb} + E_{fl} \qquad [3.5.50]$$

Equation [3.5.50] gives a method to calculate the intensity of illuminance of any point or small area in floor which was influenced by the lighting area of type 16. I_f is the intensity of illuminance of the window wall.

Illuminance of Reference Plane

Reference Plane

Definition

To define the plane at which work is usually done, and on which the visual function lies, the illumination is specified and measured. Unless otherwise indicated, this plane is assumed to be horizontal and 30 inches or 2.5 feet above the floor plane.

According to the above definition, the reference plane in a rectangular room can be defined as follows (plane z = r) :

Reference Plane (x_r , y_r , z_r)

where

$0 \le x_r \le d$

$0 \le y_r \le w$

z_r = r = 30-inch = 2.5 feet

The intensity of illuminance in the reference plane affected by direct daylight under clear sky and partly cloudy sky conditions was one of the targets in this study. Three situations needed to be considered for calculating the intensity of illuminance in the reference plane. First was the illuminance in the reference plane affected by direct sunlight penetrating through the window and directly incident to the measurement point (E_1) . Second was the lighted area higher than the reference plane on vertical surfaces (left wall, back wall, and right wall), lighted by the direct daylight penetrating through the window and directly incident to the vertical surfaces, which diffuse daylight to the reference plane (E_2) . Third is the lighted area of the window projection which diffuse daylight to every point of every interior surface; the interior surfaces will diffuse and inter-reflect diffuse light to each other until the illuminance at every point of any surface is stabilized; these stabilized interior surfaces which are higher than the reference plane diffuse daylight to the reference plane (E_3) . All three situations of light received in the reference plane must be combined E_1 , E_2 , *and* E_3 will give a total intensity of illuminance E_{dir} in the reference plane. This is the prediction of this mathematical model for the direct daylight condition only.

Situation One (E_1)

To assign the coordinates of the four corners of the window projection in the reference plane z=r are (x_{rk} , y_{rk} , z_{rk}) , (x_{rl} , y_{rl} , z_{rl}) , (x_{rm} , y_{rm} , z_{rm}) , and (x_{rn} , y_{rn} , z_{rn}) . Then the intersected area of the direct daylight penetrating through the window and incident to the reference plane can be calculated using the equations from [A.25] to [A.36]. From the definition of line in section 3.2 , the following equations can be obtained(see Figure 21 on page 83).

From equation [3.4.8]

$$\frac{x_{rk} - x_k}{\cos \alpha} = \frac{y_{rk} - y_k}{\cos \beta} = \frac{2.5 - z_k}{\cos \gamma} \quad [3.5.51]$$

$$\frac{x_{rl} - x_l}{\cos \alpha} = \frac{y_{rl} - y_l}{\cos \beta} = \frac{2.5 - z_l}{\cos \gamma} \quad [3.5.52]$$

$$\frac{x_{rm} - x_m}{\cos \alpha} = \frac{y_{rm} - y_m}{\cos \beta} = \frac{2.5 - z_m}{\cos \gamma} \quad [3.5.53]$$

$$\frac{x_{rn} - x_n}{\cos \alpha} = \frac{y_{rn} - y_n}{\cos \beta} = \frac{2.5 - z_n}{\cos \gamma} \quad [3.5.54]$$

From equation [3.5.51]

$$\frac{x_{rk} - x_k}{\cos \alpha} = \frac{2.5 - z_k}{\cos \gamma}$$

$$(x_{rk} - x_k) \cos \gamma = \cos \alpha (2.5 - z_k)$$

$$x_{rk} - x_k = \frac{\cos \alpha}{\cos \gamma} (2.5 - z_k)$$

$$x_{rk} = x_k + \frac{\cos \alpha}{\cos \gamma} (2.5 - z_k) \quad [3.5.55]$$

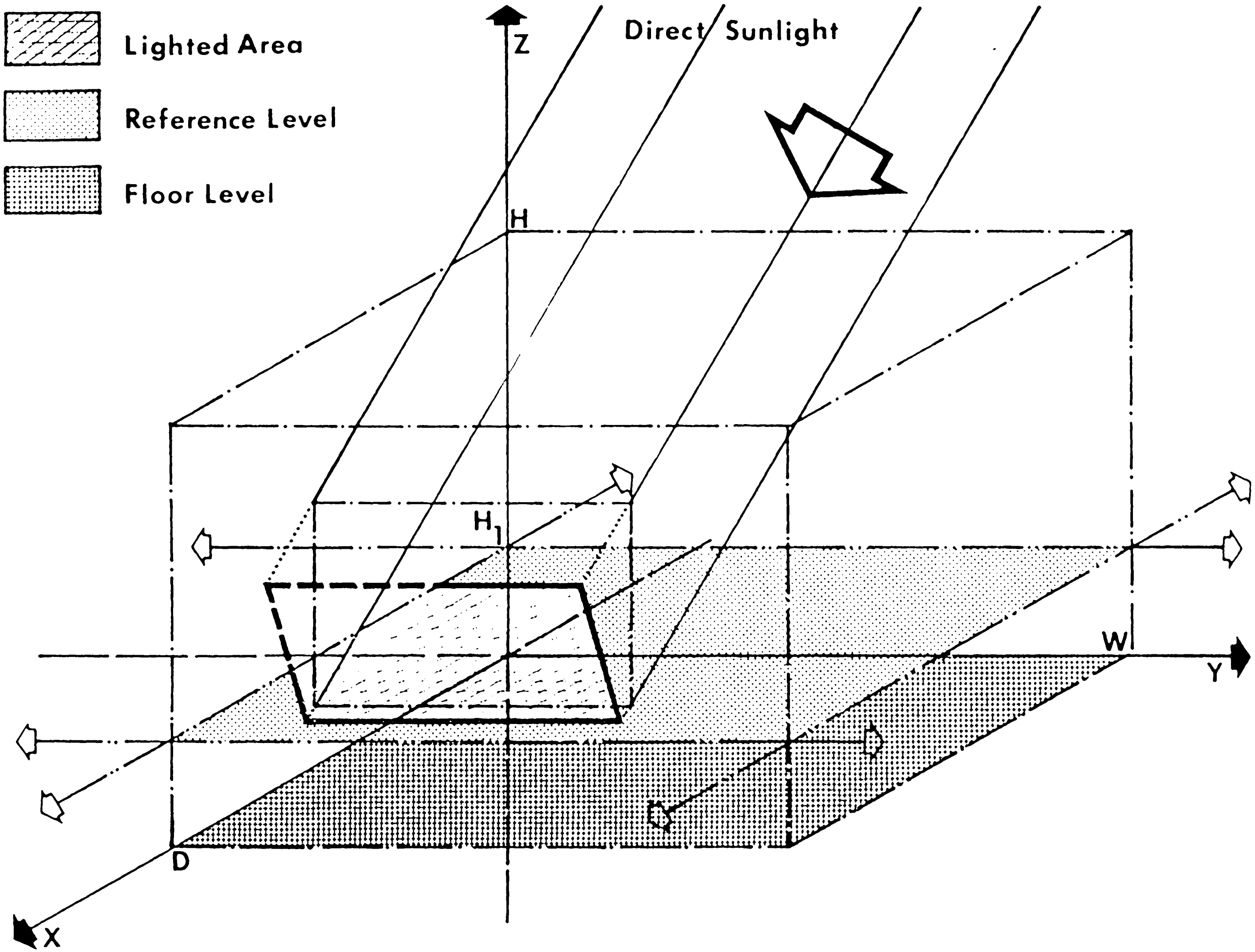

Figure 21. Window's Projection in the Reference Plane

$$\frac{y_{rk} - y_k}{\cos\beta} = \frac{2.5 - z_k}{\cos\gamma}$$

$$(y_{rk} - y_k)\ \cos\gamma = \cos\beta\ (2.5 - z_k)$$

$$y_{rk} - y_k = \frac{\cos\beta}{\cos\gamma}\ (2.5 - z_k)$$

$$y_{rk} = y_k + \frac{\cos\beta}{\cos\gamma}\ (2.5 - z_k) \qquad [3.5.56]$$

From equation [3.5.52]

$$x_{rl} = x_l + \frac{\cos\alpha}{\cos\gamma}\ (2.5 - z_l) \qquad [3.5.57]$$

$$y_{rl} = y_l + \frac{\cos\beta}{\cos\gamma}\ (2.5 - z_l) \qquad [3.5.58]$$

From equation [3.5.53]

$$x_{rm} = x_m + \frac{\cos\alpha}{\cos\gamma}\ (2.5 - z_m) \qquad [3.5.59]$$

$$y_{rm} = y_m + \frac{\cos\beta}{\cos\gamma}\ (2.5 - z_m) \qquad [3.5.60]$$

From equation [3.5.54]

$$x_{rn} = x_n + \frac{\cos\alpha}{\cos\gamma}\ (2.5 - z_n) \qquad [3.5.61]$$

$$y_{rn} = y_n + \frac{\cos\beta}{\cos\gamma}\ (2.5 - z_n) \qquad [3.5.62]$$

The projection of the window in the reference plane (z = r = 2.5 feet) is the area connecting these four intersected points (x_{rk}, y_{rk}, z_{rk}) , (x_{rl}, y_{rl}, z_{rl}) , $(x_{rm}, y_{rm}, zsurrm)$, and (x_{rn}, y_{rn}, z_{rn}) . Determining whether this projection is in the reference plane or not is based on the definition of the reference plane ($0 \le x_r \le d$, $0 \le y_r \le w$, $z = 2.5$). Hence, if $0 \le x_{rk} \le d$ and $0 \le y_{rk} \le w$, then the projection of point K (the upper-left corner of window) is in the reference plane. Apply the above procedure to the other three intersected points to judge whether points (x_{rl} , y_{rl} , 2.5) , (x_{rm} , y_{rm} , 2.5) , and (x_{rn} , y_{rn} , 2.5) are in reference plane or not, and decide which intersected point at axes needs to be further calculated and checked. If all the four intersected points are in the reference plane, then the projection of the window is type 2 (see Figure 14 on page 61 and appendix A). Otherwise, the intersected points between the window frame and the following lines need to be further checked.

Line $H_1 - H$ ($x_{H1H} = 0, y_{H1H} = 0, 2.5 \le z_{H1H} \le h$)

Line $H_1 - H_3$ ($0 \le x_{H1H3} \le d, y_{H1H3} = 0, z_{H1H3} = 2.5$)

Line $H_1 - H_2$ ($x_{H1H2} = 0, 0 \le y_{H1H2} \le w, z_{H1H2} = 2.5$)

Line $H_2 - Q$ ($x_{H2Q} = 0, y_{H2Q} = w, 2.5 \le z_{H2Q} \le h$)

Line $H_2 - H_4$ ($0 \le x_{H2H4} \le d, y_{H2H4} = w, z_{H2H4} = 2.5$)

The processes of calculating intersected points of the sun rays passing through the window frame and incident to the above line are similar to section 3.5.4 . It is unnecessary to re-process here; therefore, the following are the results of processing.

Window's Upper Frame K-N ($x_{kn} = d, c \le y_{kn} \le c + a, z_{kn} = b + f$)

From equation [3.5.18], the intersected point between Line K-N and Line $H_1 - H$ are

$$y_{kn} = \frac{\cos\beta}{\cos\alpha} d$$

$$z_{uH1H} = b + f - \frac{\cos\gamma}{\cos\alpha} d$$

if $c \le (y_{kn} = \frac{\cos\beta}{\cos\alpha} d) \le (c + a)$, and $2.5 \le (z_{uH1H} = b + f - \frac{\cos\gamma}{\cos\alpha} d) \le h$, there is a one and only one sun's ray passing through the (d, $\frac{\cos\beta}{\cos\alpha} d$, b + f) which is in the upper frame of window and incident to the point (0, 0, $b + f - \frac{\cos\gamma}{\cos\alpha} d$) which is in the line $H_1 - H$. The above method determines which type of window projection there will be, and the boundary of the lighted area (window projection) caused by direct daylight. Every combination of window frame and edges of a rectangular room with a reference plane needed to be checked to determine the boundaries and type of window projection.

From equation [3.5.21], the intersected point between Line K-N and Line $H_1 - H_3$ is

$$y_{kn} = \frac{\cos\beta}{\cos\gamma}(b + f - 2.5)$$

$$x_{uH1H3} = d - \frac{\cos\alpha}{\cos\gamma}(b + f - 2.5)$$

Checking Condition : $0 \le x_{uH1H3} \le d$

From equation [3.5.24], the intersected point between Line K-N and Line $H_2 - Q$ is

$$y_{kn} = w + \frac{\cos\beta}{\cos\alpha} d$$

$$z_{uH2Q} = b + f - \frac{\cos\gamma}{\cos\alpha} d$$

Checking Condition : $2.5 \le z_{uH2Q} \le h$

From equation [3.5.27], the intersected point between Line K-N and Line $H_2 - H_4$ is

$$y_{kn} = w + \frac{\cos\beta}{\cos\gamma}(b + f - 2.5)$$

$$x_{uH2H4} = d - \frac{\cos\alpha}{\cos\gamma}(b + f - 2.5)$$

Checking Condition : $0 \le x_{uH2H4} \le d$

Window's Lower Frame L-M $(x_{lm} = d, c \le y_{lm} \le c + a, z_{lm} = f)$

From equation [C.1], the intersected point between Line L-M and Line $H_1 - H$ is

$$y_{lm} = \frac{\cos\beta}{\cos\alpha} d$$

$$z_{dH1H} = f - \frac{\cos\gamma}{\cos\alpha} d$$

Checking Condition : $2.5 \leq z_{dH1H} \leq h$

From equation [C.3], the intersected point between Line L-M and Line $H_1 - H_3$ is

$$y_{lm} = \frac{\cos\beta}{\cos\gamma} (f - 2.5)$$

$$x_{dH1H3} = d - \frac{\cos\alpha}{\cos\gamma} (f - 2.5)$$

Checking Condition : $0 \leq x_{dH1H3} \leq d$

From equation [C.5], the intersected point between Line L-M and Line $H_2 - Q$ is

$$y_{lm} = w + \frac{\cos\beta}{\cos\alpha} d$$

$$z_{dH2Q} = f - \frac{\cos\gamma}{\cos\alpha} d$$

Checking Condition : $2.5 \leq z_{dH2Q} \leq h$

From equation [C.7], the intersected point between Line L-M and Line $H_2 - H_4$ is

$$y_{lm} = w + \frac{\cos\beta}{\cos\gamma} (f - 2.5)$$

$$x_{dH2H4} = d - \frac{\cos\alpha}{\cos\gamma} (f - 2.5)$$

Checking Condition : $0 \leq x_{dH2H4} \leq d$

Window's Left Frame K-L $(x_{kl} = d , y_{kl} = c , f \leq z_{kl} \leq b + f)$

From equation [C.12], the intersected point between Line K-L and Line $H_1 - H_3$ is

$$z_{kl} = \frac{\cos\gamma}{\cos\beta} c$$

$$x_{lH1H3} = d - \frac{\cos\alpha}{\cos\beta} c$$

Checking Condition : $0 \le x_{lH1H3} \le d$ and $f \le z_{kl} \le b + f$

From equation [C.16], the intersected point between Line K-L and Line $H_2 - H_4$ is

$$z_{kl} = 2.5 + \frac{\cos\gamma}{\cos\beta} (c - w)$$

$$x_{lH2H4} = d - \frac{\cos\alpha}{\cos\beta} (c - w)$$

Checking Condition : $0 \le x_{dH2H4} \le d$

From equation [C.9], the intersected point between Line K-L and Line $H_1 - H_2$ is

$$z_{kl} = \frac{\cos\gamma}{\cos\alpha} d$$

$$y_{lH1H2} = c - \frac{\cos\beta}{\cos\alpha} d$$

Checking Condition : $0 \le y_{lH2H4} \le w$

Window's Left Right M-N ($x_{mn} = d, y_{mn} = c + a, f \le z_{mn} \le b + f$)

From equation [C.23], the intersected point between Line M-N and Line $H_1 - H_3$ is

$$z_{mn} = \frac{\cos\gamma}{\cos\beta} (c + a) + 2.5$$

$$x_{rH1H3} = d - \frac{\cos\alpha}{\cos\beta}(c + a)$$

Checking Condition : $0 \leq x_{rH1H3} \leq d$ and $f \leq z_{kl} \leq b + f$

From equation [C.25], the intersected point between Line M-N and Line $H_2 - H_4$ is

$$z_{mn} = 2.5 + \frac{\cos\gamma}{\cos\beta}(c + a - w)$$

$$x_{rH2H4} = d - \frac{\cos\alpha}{\cos\beta}(c + a - w)$$

Checking Condition : $0 \leq x_{rH2H4} \leq d$

From equation [C.21], the intersected point between Line M-N and Line $H_1 - H_2$ is

$$z_{mn} = \frac{\cos\gamma}{\cos\alpha} d + 2.5$$

$$y_{rH1H2} = c + a - \frac{\cos\beta}{\cos\alpha} d$$

Checking Condition : $0 \leq y_{rH2H4} \leq w$

Based on the above calculations and checking procedures, it is clear that the type of window projection in the reference plane can be decided. From equation [3.2.10] the intensity of illuminance in the lighted area of reference plane caused by direct daylight then can be expressed as

$$E_1 = 127.5\{1 + 0.034\cos[0.9863014(J - 2)]\}\, 2.7183^{\frac{-c}{\sin A_t}} \sin A_t T_g \quad KLux \qquad [3.5.63]$$

E_1 is the illuminance of direct daylight penetrate through window and incident to the measuring point in the reference plane. If the measuring point is not in the lighted area of the reference plane, then the E_1 = 0 lux.

Situation Two E_2

There are two more situations affecting the illuminance, under the condition of direct daylight penetrating through a window, which need to be calculated. One is where the window projection is not in the floor or part of the projection in not in the floor area. In other words, at least a certain portion of the window projection is in a vertical surface (left wall, back wall, and right wall). The lighted area in the vertical surface, which is higher than the reference plane ($\geq$ 2.5 feet), will diffuse daylight to the reference plane. Hence, any point in the reference plane will be illuminated. This illuminance of any point in reference plane, which was affected by the potion of lighted area on the vertical surface, can be expressed as the following equations.

Lighted Portion in Left Wall

From equation [D.18]

$$E_{2L} = \int_{f(z)}^{g(z)} \int_{x_{ln}}^{x_{lk}} \frac{E_{dvl} T_g R_l y_r (z_l - 2.5)}{r_{RL}^4 \pi} dx\, dz \qquad [3.5.64]$$

where

E_{dvl} = direct vertical solar illuminance of left wall from equation [3.2.11].

$E_{dvl} = E_{dn} \cos_{At} \sin(A_z - A_e)$

T_g = Transmission factor of glass (0.85)

R_l = Reflectance factor of left wall

$f_{(z)}$ *and* $g_{(z)}$ depend on the type of window projection. The details for calculating f(z) and g(z) are in section 3.5.5 .

r_{RL} = The distance between any point in the reference plane and any point in the lighted area in the left wall which is higher than 2.5 feet. $r_{RL} = \sqrt{(x_r - x_l)^2 + (y_r - y_l)^2 + (z_r - z_l)^2}$

If there is no lighted area in the left wall which is higher than 2.5 feet, then the $E_{2L} = 0$. In other words, no light will diffuse from the left wall to the reference plane.

Lighted Portion in Back Wall

From equation [D.6]

$$E_{2B} = \int_{f(z)}^{g(z)} \int_{y_{bl}}^{y_{bm}} \frac{E_{dvb}\, T_g\, R_b\, x_r\,(\, z_b - 2.5\,)}{r_{R-B}^4\ \pi}\, dy\ dz \qquad [3.5.65]$$

Lighted Portion in Right Wall

$$E_{2R} = \int_{f(z)}^{g(z)} \int_{x_{rl}}^{x_{rm}} \frac{E_{dvr}\, T_g\, R_r\,(\, w - y_r\,)\,(\, z_r - 2.5\,)}{r_{RR}^4\ \pi}\, dx\ dz \qquad [3.5.66]$$

Combine equation [3.5.64], [3.5.65], and [3.5.66], the E_2 then can be found as:

$$E_2 = E_{2L} + E_{2B} + E_{2R} \qquad [3.5.67]$$

Normally, neither E_{2L} nor E_{2R} will be equal to zero, because it is impossible for the window projection to fall in the left wall and the right wall simultaneously. Equation [3.5.67] is a general form to express light transfer diffusely from vertical lighting area, which is caused by the direct daylight penetrating through the window and incident to the vertical surface which is higher than the reference plane, to the reference plane.

Once the direct daylight come into the interior space, no matter what types of window projection there is, all the interior surfaces will receive light from the window projection and inter-reflect with each other. No matter how many of inter-reflections occur among these six interior surfaces, they finally will reach a steady state because the inter-reflection phenomenon is a mathematical convergence. This inter-reflective phenomenon is the third situation to affect the illuminance under the condition of direct sunlight penetrating through the window and will be discussed in below.

One of the chief mathematical complexities in treating light transfer among interior surfaces is accounting for the geometric relations involved in how the surfaces view each other.

These effects result mathematically in integrations of the light inter-reflecting over the finite areas involved in the inter-reflective processes.

In this section, a method of accounting for the perfect diffuse surfaces condition is employed to calculate the quantity of reflected light from interior surfaces to the measuring points in the reference plane. In section 3.6.5 , the intensity of light at any point on each interior surface can be calculated. For example, if the window projection is type 16, then the intensity of light for any point in the back wall can be expressed as the equation [3.5.35]. The equation [3.5.35] only presents the illuminance which was affected by the lighted area of type 16. Actually, the illuminance in the back wall is also affected by the inter-reflective phenomenon of light transfer from other surfaces. Therefore, the following equation presents further calculation of the illuminance in the back wall which take the results of inter-reflection into consideration.

Illuminance in back wall

$$E_B = E_b + E_{BL} + E_{BW} + E_{BR} + E_{BC} + E_{BF} \qquad [3.5.68]$$

where E_b is exactly the same with equation [3.5.35]. E_{BW} , E_{BW} , E_{BR} , E_{BC} , and E_{BF} are the illuminance reflected from the left wall, window wall, right wall, ceiling, and floor and was received on the back wall. The following are the mathematical formulas to calculate the above illuminance increased by the inter-reflection phenomenon.

Illuminance transfer from left wall to back wall

$$E_{BL} = \int_0^h \int_0^d \frac{E_l\, R_l\, y_b\, x_l}{r_{BL}^4\, \pi}\, dx\, dz \qquad [3.5.69]$$

where E_l can be obtained from equations [3.5.30] to [3.5.32], R_l is the reflective factor of the left wall, y_b is the y-axis coordinate of any possible measuring point in the back wall, x_l is the x-axis coordinate of any possible point in the left wall, and r_{BL} is the distance of any possible combination points between the back wall and the left wall. Repeating the above processes, the following formulas can be obtained to calculate the illuminance which diffuse from the other four surfaces and was received in back wall.

$$E_{BW} = \int_0^h \int_0^w \frac{E_w R_w x_w x_w}{r_{BW}^4 \pi} dy\, dz \qquad [3.5.70]$$

where E_w can be obtained from equation [3.5.36] to [3.5.39].

$$E_{BR} = \int_0^h \int_0^d \frac{E_r R_r x_r (y_r - y_b)}{r_{BR}^4 \pi} dx\, dz \qquad [3.5.71]$$

where E_r can be obtained from equation [3.5.40] to [3.5.43].

$$E_{BC} = \int_0^w \int_0^d \frac{E_c R_c x_c (z_c - z_b)}{r_{BC}^4 \pi} dx\, dy \qquad [3.5.72]$$

where E_c can be obtained from equation [3.5.44] to [3.5.47].

$$E_{BF} = \int_0^w \int_0^d \frac{E_f R_f x_f z_b}{r_{BF}^4 \pi} dx\, dy \qquad [3.5.73]$$

where E_f can be obtained from equation [3.5.48] to [3.5.50].

Equation [3.5.69] to [3.5.71] gives a explanation of equation [3.5.56]. Repeating the above processes from equation [3.5.568] to [3.5.61] and applying them to the other surfaces, the following equations will be produced to calculate the illuminance, which includes the illuminance coming from the lighted area of the window projection and from the phenomenon of inter-reflection among the other five interior surfaces.

Illuminance in left wall

$$E_L = E_l + E_{LW} + E_{LR} + E_{L-B} + E_{LC} + E_{LF} \qquad [3.5.74]$$

$$E_W = E_w + E_{WL} + E_{WR} + E_{WB} + E_{WC} + E_{WF} \qquad [3.5.75]$$

$$E_R = E_r + E_{RL} + E_{RW} + E_{R-B} + E_{RC} + E_{RF} \qquad [3.5.76]$$

$$E_C = E_c + E_{CL} + E_{CW} + E_{CR} + E_{CB} + E_{CF} \qquad [3.5.77]$$

$$E_F = E_f + E_{FL} + E_{FW} + E_{FR} + E_{FB} + E_{FC} \qquad [3.5.78]$$

The intensities of light on all six interior surfaces are known at this stage. The next step will calculate the illuminance which is diffused from these six interior surfaces and incident to the measuring points in the reference plane. The concept employed here is the same as the phenomenon of the inter-reflection among surfaces. The only difference is to treat light transfer between the measuring point and the surfaces as the geometric relations involved in how the measuring point views these six surfaces. As a matter of fact, the light of the floor area and the vertical surfaces which are below the reference plane ($z \leq 2.5 feet$) will not influence the intensity of light in any point of the reference plane. This is because the reference plane only receives light from the surfaces above and not from any light sources from below. Hence, the following calculation only process the reflective light from the surfaces which are higher than the reference plane. In other words, the range of the integration involved in the z-axis will start from 2.5 feet and end at h (the height of room).

Light transfer from left wall to the points in the reference plane

$$E_{3L} = \int_{2.5}^{h} \int_{0}^{d} \frac{E_L R_l y_r (z_l - 2.5)}{r_{RL}^4 \pi} dx \, dz \qquad [3.5.79]$$

where

E_L can be obtained from equation [3.5.74]

R_l is the reflective factor of the left wall

y_r is the y-axis coordinate of the reference point

z_l is the z-axis coordinate of the left wall

r_{RL} is the distance of any possible combination of points between the reference plane and the left wall

Light transfer from window wall to the points in the reference plane

$$E_{3W} = \int_{2.5}^{h} \int_{0}^{h} \frac{E_W R_w (z_w - 2.5) (d - x_r)}{r_{RW}^4 \pi} dy\ dz \qquad [3.5.80]$$

where E_L can be obtained from equation [3.5.75]

Light transfer from right wall to the points in the reference plane

$$E_{3R} = \int_{2.5}^{h} \int_{0}^{d} \frac{E_R R_r (z_r - 2.5) (w - y_r)}{r_{RR}^4 \pi} dx\ dz \qquad [3.5.81]$$

where E_R can be obtained from equation [3.5.76]

Light transfer from back wall to the points in the reference plane

$$E_{3B} = \int_{2.5}^{h} \int_{0}^{w} \frac{E_B R_b (z_b - 2.5) x_r}{r_{R-B}^4 \pi} dy\ dz \qquad [3.5.82]$$

where E_B can be obtained from equation [3.5.68]

Light transfer from ceiling to the points in the reference plane

$$E_{3C} = \int_{0}^{w} \int_{0}^{d} \frac{E_C R_v (h - z_r) (h - z_r)}{r_{RC}^4} dx\ dy \qquad [3.5.83]$$

where E_C can be obtained from equation [3.5.77]

From equation [3.5.79] to [3.5.83], each equation expresses the quantity of light transfer from each surface to the measuring point in the reference plane. Therefore, the total received illuminance of the measuring point in the reference plane is the gross of the above equations.

$$E_3 = E_{3L} + E_{3W} + E_{3R} + E_{3B} + E_{3C} \qquad [3.5.84]$$

Considering the direct daylight coming from the exterior and incident to the measuring points(E_1 from equation [3.5.83]), the illuminance emitted from the lighted area which caused by direct daylight and diffuse to the measuring points(E_2 from equation [3.5.75]), and the illuminance gained by the phenomenon of inter-reflection(E_3 from equation [3.5.84), the total illuminance for any measuring points in the reference plane can be obtained by combining the equations [3.5.71], [3.5.75], and [3.5.84].

$$E_{direct} = E_1 + E_2 + E_3 \qquad [3.5.85]$$

E_{direct} stands for the total illuminance which was affected by the direct daylight in this analytical model under the clear sky or partly cloudy sky condition.

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CHAPTER 4 MATHEMATICAL MODEL OF DIFFUSE DAYLIGHT

4.1 Introduction, and Definition

This section begins the discussion of diffuse daylight exchange among interior surfaces in a rectangular room and is concerned with the special situation in which all the room surfaces diffuse daylight perfectly. These surfaces reflect in a perfectly diffuse fashion, such that the light leaving a surface is independent of the direction of emission. This simplifies the computation of how much of this light will reach another surface.

The window is the only opening to let daylight come in and to light the interior space. It is the basic assumption that no window means no daylight available in the room. This does not mean that the larger opening will produce a higher quality of daylighting, but it does mean a higher quantity of daylight available. In this part of the study, the major concern is the diffuse daylight coming from the sky vault and the exterior ground; other factors, such as diffuse daylight reflected from external obstructing buildings will be discussed in a later chapter.

Basically, the diffuse daylight received via the window at any measuring points can be divided into two parts: light directly from sky vault, and light indirectly and reflectively from the exterior ground. Both kinds of diffuse daylight coming from exterior to interior can be termed the first order of diffuse daylight. This first order of diffuse daylight must transit through the window to the interior reference points or surfaces. Once the surfaces receive the diffuse daylight from the exterior, a certain amount of diffuse light will be reflected to the other surfaces or reference points which depend on the reflectance of the surfaces. Therefore, this illuminance passing through the window is the key point for discussing the distribution of diffuse daylight in a room. In other words, the window is the only source of diffuse daylight for interior space as the sky vault is the only source of diffuse daylight for the earth. Hence, the intensity of illuminance for an interior point depends on solid angle, the source of diffuse daylight outside the window, and how the diffuse daylight is transferred among surfaces and between surfaces and reference points inside a room.

DEFINITION : SOLID ANGLE

the area intercepted on the surface of a unit sphere by a conical angle originating at the sphere *center*.[1] Figure 22 on page 99 shows that the solid angle $d\omega$ is related to the projected area of dA_1 and to the distance between the differential elements.

4.2 Solid Angles in A Rectangular Coordinate System

The solid angle can be obtained from the following *formula*.[2]

$$d\omega = \frac{dA \ \cos\theta}{R^2} \qquad [4.1]$$

where dA is a very small area of the source (here is window) of diffuse daylight, R is the *distance*[3] from an interior point to dA, θ_1 ,and θ_2 are the angles between the normal line of point T (see Figure 23 on page 100) and the distance line of R.

$$R = \sqrt{(x_{dA} - x_t)^2 + (y_{dA} - y_t)^2 + (z_{dA} - z_t)^2} \qquad [4.2]$$

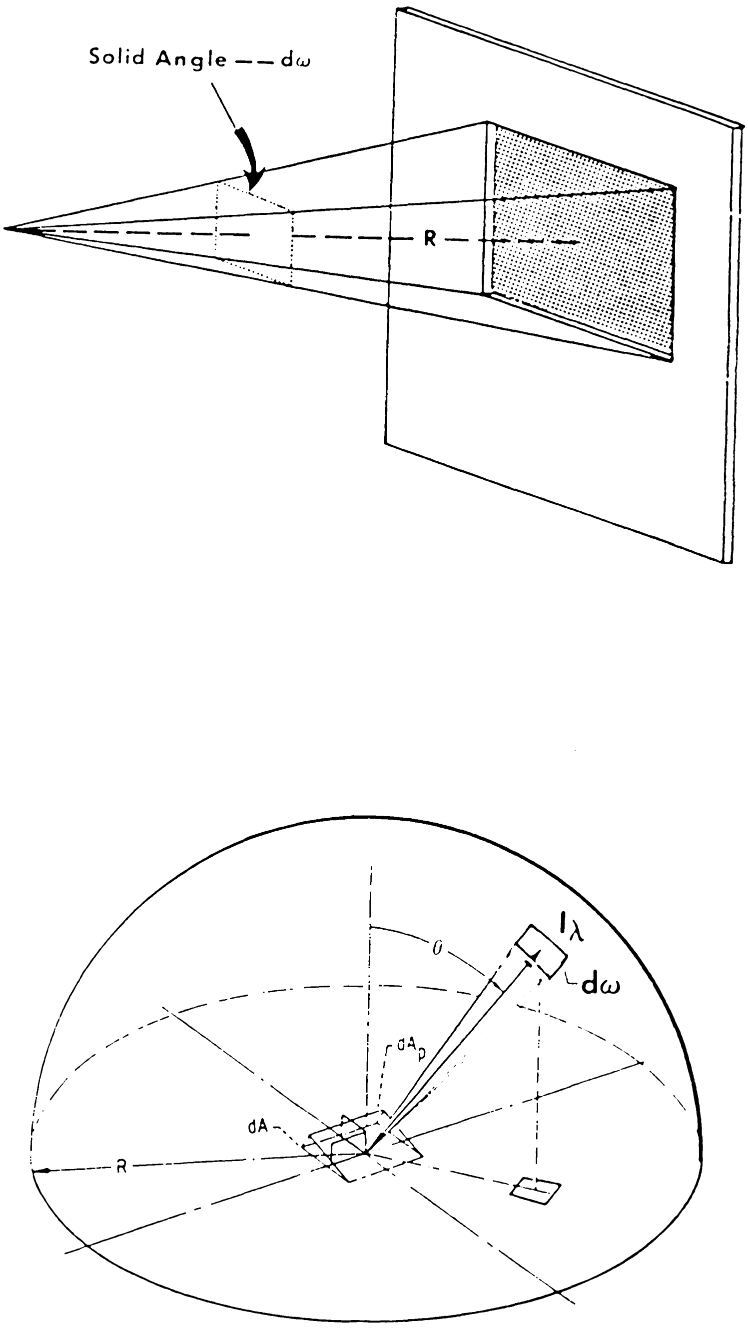

Figure 22. An Example of a Solid Angle in 3-Dimension

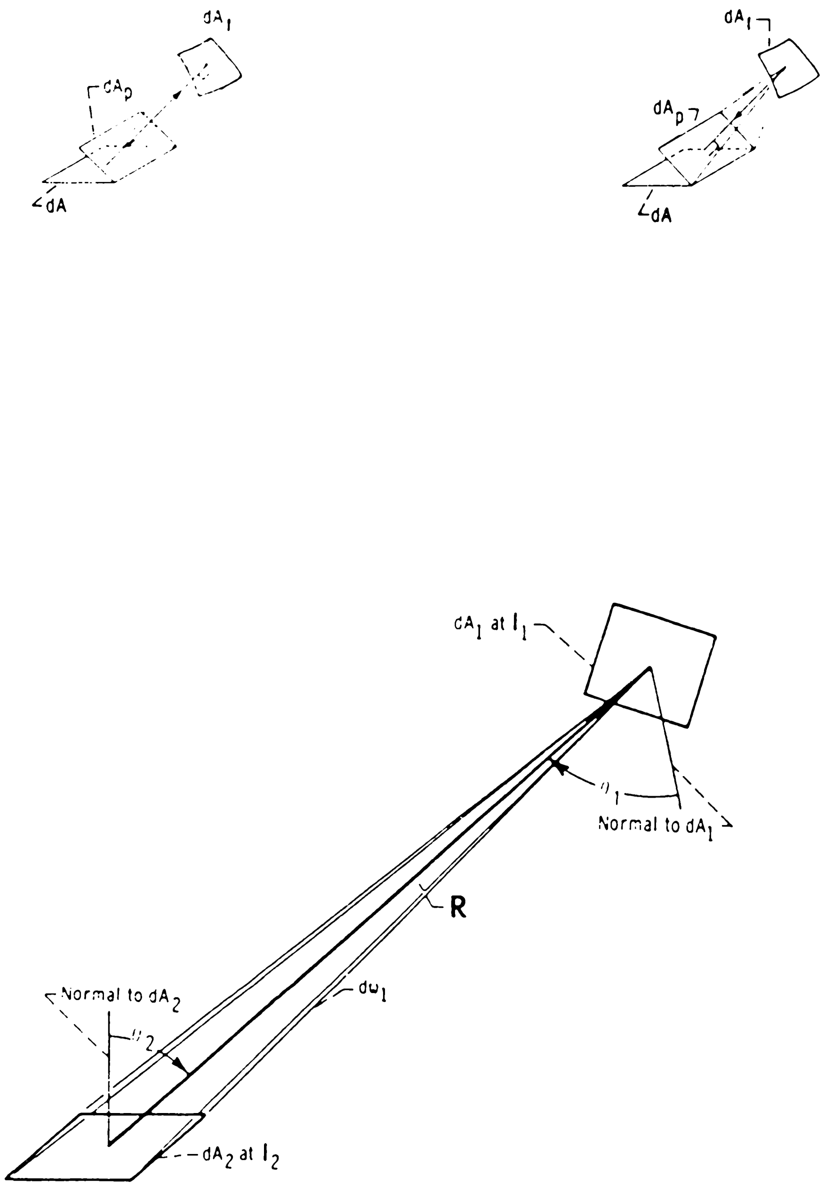

Figure 23. Diffuse Light Interchange Between Two Differential Areas

$$\cos\theta = | \cos\alpha_1 \cos\alpha_2 + \cos\beta_1 \cos\beta_2 + \cos\gamma_1 \cos\beta_2 | \quad [4.3]$$

where

$\cos\alpha_1 = \frac{x_{dA} - x_t}{R}$, $\cos\beta_1 = \frac{y_{dA} - y_t}{R}$, $\cos\gamma_1 = z_{dA} - z_t$, $\cos\alpha_2 = 0$,

$\cos\beta_2 = 1$, and $\cos\gamma_2 = 0$

$\alpha_1, \beta_1, \gamma_1, \alpha_2, \beta_2$, *and* γ are the direct angles of line R and normal of point T.

To obtain a point's solid angle toward a rectangular window, the integration was employed to integrate the whole window area. The following is the general formula to calculate an interior point's solid angle when viewing the window.

$$\omega = \int_{z_{\text{lower edge}}}^{z_{\text{upper edge}}} \int_{y_{\text{left edge}}}^{y_{\text{right edge}}} \frac{\cos\theta}{R^2} \, dA \quad [4.4]$$

For example, if the dimensions of a window are 12 feet by 6 feet and the point P is in the left wall, then the solid angle for point T is view of the window.

$$\omega = \int_{z_l = 3}^{z_k = 9} \int_{y_l = 5}^{y_m = 17} \frac{\cos\theta}{R^2} \, dA \quad [4.5]$$

4.3 Sources of Exterior Diffuse Daylight

Based on the above assumptions and definition, it is understandable that a solid angle does exist for every interior point viewing the exterior throught the window. Two points having equal solid angles does not mean that these two points will receive equal quantities of diffuse daylight from the the exterior. Because two possible exterior sources of diffuse daylight, the sky vault and the ground, have different illuminance and luminance. Therefore, three types of solid angles for any interior point can be determined in this study according to three types of these angles can be used to calculate the intensity of illuminance received from the exterior sources. The first is the solid angle toward the sky vault only; in other words, the areas or points in surfaces or space below the lower edge of the window. The second is the solid angle toward the exterior ground only; in other words, the areas or points in surfaces or space above the upper edge of the window. The third is the solid angle toward the sky vault and the ground both, in other words, the areas or points in the surfaces or space within the range of the window's height.

4.4 Diffuse Daylight Transfer Between Two Surfaces

The fraction of the light leaving one surface that reaches another surface is defined as the geometric configuration factor between the two surfaces, because it depends on the geometric orientation of the surfaces with respect to each other (Figure 23 on page 100). The geometric dependence is discussed here for perfectly diffuse interior surfaces, but the results have a wider applicability as they will apply for any uniform diffuse light leaving a surface such as the sky vault or the ground. This geometric dependence leads to some algebraic relations between the factors, and these relations are demonstrated in this section for a rectangular room under a uniform diffuse sky condition.

After the relation for exchange between two surfaces has been developed, the relation can be applied to any number of surfaces arranged to form a rectangular room of six surfaces, each at a different intensity and reflectance.

In the following section, the general set of equations governing the exchange within such a rectangular room is developed, and some illustrative examples are provided. The relations describing diffuse daylight transfer between differential areas are considered first, as they will be used in the succeeding sections to derive the relations for diffuse daylight transfer from the window to the interior surfaces or reference plane and the inter-reflective relations among the interior surfaces. Consider two differential areas as shown in Figure 24 on page 104 The area dA_w (a very small area in the window with the coordinates of x_w , y_w , *and* z_w) and dA_f (a very small area in the floor with the coordinates of x_f , y_f , *and* z_f) are isochromtaic at intensities of

E_w *and* E_f , respectively, are arbitrarily oriented, and have their normals at angles θ_w *and* θ_f to the line of length R joining them.

The total luminance per unit time leaving dA_w and incident upon dA_f is :

$$dE_{Aw-Af} = E_{Aw} \cos\theta_w \cos\theta_f \, d\omega_f \qquad [4.6]$$

where $d\omega_f$ is the solid angle subtended by dA_w when viewed from dA_f . Equation [4.6] follows directly from the definition of E_{Aw} , the light intensity of the window, as the light emitted by window(Aw) per unit time, per unit of area dA_w is projected normal to R (the distance between dA_w *and* dA_f), and per unit of solid angle.

The solid angle dw_f is related to the projected area of dA_w and the distance between the differential areas by the relation of equation [4.6].

$$d\omega_f = \frac{\textbf{projected area of } dA_w}{R^2} = \frac{dA_w \cos\theta_w}{R^2} \qquad [4.7]$$

Substituting this relation into equation [4.6] gives the following for the total light leaving dA_w that is incident upon dA_f :

$$dE_{Aw-Af} = \frac{E_{Aw} \cos\theta_w \, dA_f \cos\theta_f}{R^2} \qquad [4.8]$$

The total quantities of light at dA_f from the window area are then found by integrating the over all area of the window as in the following formula.

$$E_{Aw-Af} = \int_e^{e+g} \int_d^{d+f} \frac{E_{Aw} \cos\theta w \cos\theta f}{R^2 \pi} dy \, dz \qquad [4.9]$$

where

E_{Aw-Af} = The total diffuse daylight leaving the window and incident to the area dA_f

$E_{Aw} = E_d \, T_g$ *or* $E_G \, . \, T_g$

E_d = Horizontal illuminance (section 3.5)

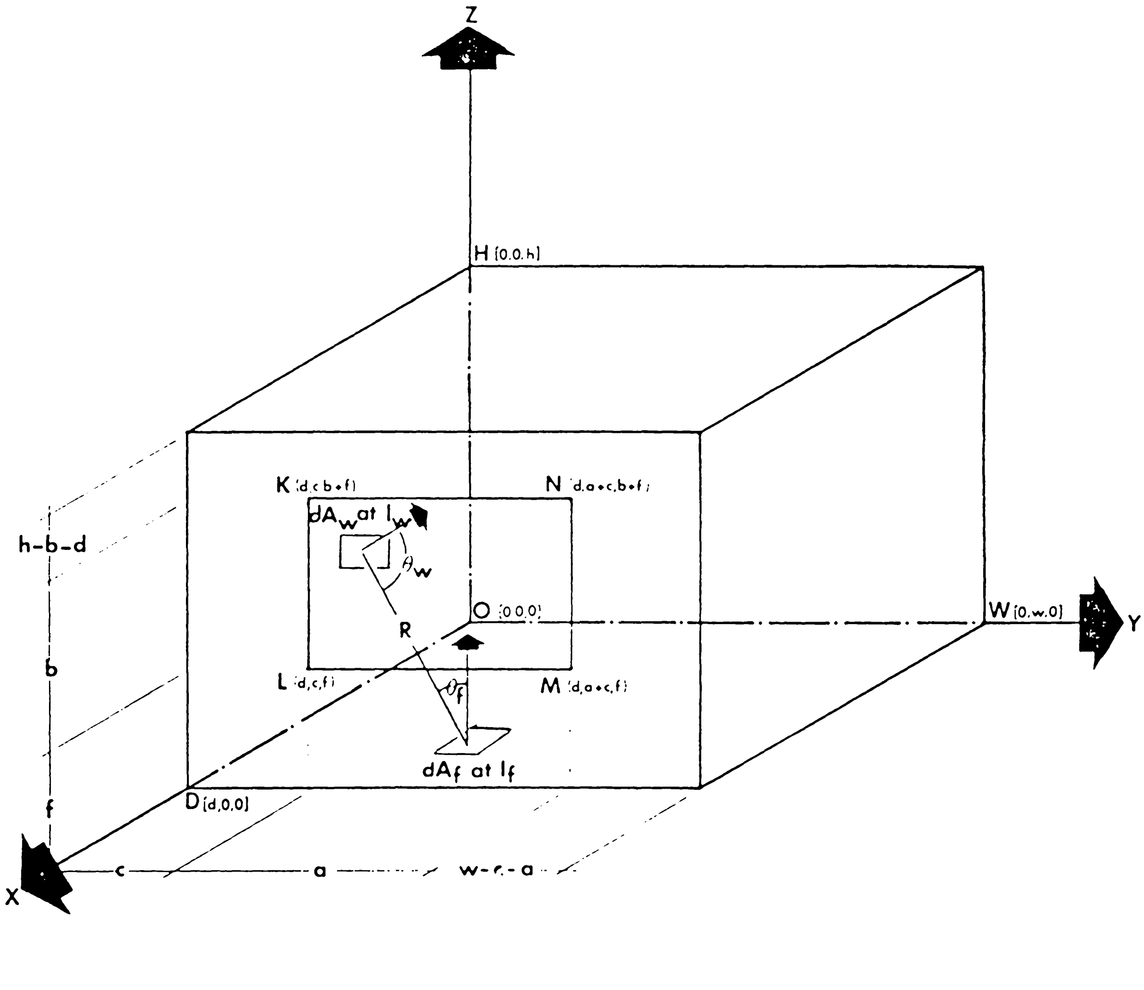

Figure 24. Diffuse Daylight Transfer from Window to Floor

T_g = Transmission factor of glass (0.85)

$E_G = E_d \ R_{ground}$

E_G = Ground luminance

R_{ground} = Reflectance of ground

θ_w = Angle between normal to dA_w and the line of length R

θ_f = Angle between normal to dA_f and the line of length R

R = The distance between dA_w and dA_f

In this case, point T is in the floor which is below the lower edge of the window; therefore, the exterior source of diffuse daylight for point T is the sky vault only. In other words, the intensity of illuminance for the secondary source (window) here is $E_{AW} = E_d \ T_g$.

4.5 Diffuse Daylight Directly From the Exterior

From section 4.3, a standard was developed to divide three types of solid angle into the interior areas or points which receive the different sources of diffuse daylight directly from the exterior, and from section 4.4, processes were developed to calculate the illuminance of any interior points. This section is based on the above two sections to calculate the illuminance received in the interior surfaces and reference plane (z = 2.5 feet). The diffuse daylight availability model used in this study are listed in the following which are accepted by *IES – CPC*[5] in 1984 as mentioned in section 2.2.

ClearSky[6] $E_{dclr} = 0.8 + 15.5 \ (\sin A_t)^{0.5}$ (*in Klux*)

PartlyCloudySky[6] $E_{dpc} = 0.3 + 45.0 \ \sin A_t$ (*inKlux*)

CloudySky[7] $E_{dovr} = 0.3 + 21.0 \ \sin A_t$ (*inKlux*)

Left Wall $(0 \le x_l \le d , y_l = 0 , 0 \le z_l \le h)$

Window Area $(x_w = d , c \le y_w \le a + c , f \le z_w \le b + f)$

From section 4.3 and Figure 25 on page 107 , the solid angle for any points in the left wall can be divided into three parts to discuss. They are:

(1) Points above the upper edge of the window $(0 \le x_l \le d , y_l = 0 , b + f \le z_l \le h)$

From equation [4.9]

$$E_{LG} = \int_f^{b+f} \int_c^{a+c} \frac{E_G \, T_w \cos \theta_w \cos \theta l}{R_{LW}^2 \, \pi} \, dy \, dz \qquad [4.10]$$

(2) Points below the lower edge of the window $(0 \le x_l \le d , y_l = 0 , 0 \le z_l \le f)$

From equation [4.9]

$$E_{LS} = \int_f^{b+f} \int_c^{a+c} \frac{E_H \, T_w \cos \theta_w \cos \theta l}{R_{LW}^2 \, \pi} \, dy \, dz \qquad [4.11]$$

(3) Points having the same height as the window $(0 \le x_l \le d , y_l = 0 , f \le z_l \le b + f)$

From equation [4.9]

$$E_{LGS} = \int_{z_l}^{b+f} \int_c^{a+c} \frac{E_G \, T_w \cos \theta_w \cos \theta l}{R_{LW}^2 \, \pi} \, dy \, dz + \int_f^{z_l} \int_c^{a+c} \frac{E_H \, T_w \cos \theta_w \cos \theta_l}{R_{LW}^2 \, \pi} \, dy \, dz \qquad [4.12]$$

where

E_{LG} = The illuminance of any point in the left wall which is higher than the upper edge of the window

E_{LS} = The illuminance of any point in the left wall which is below the lower edge of the window

E_{LGS} = The illuminance of any point in the left wall which has the same height with the window

E_G = The luminance of the exterior ground

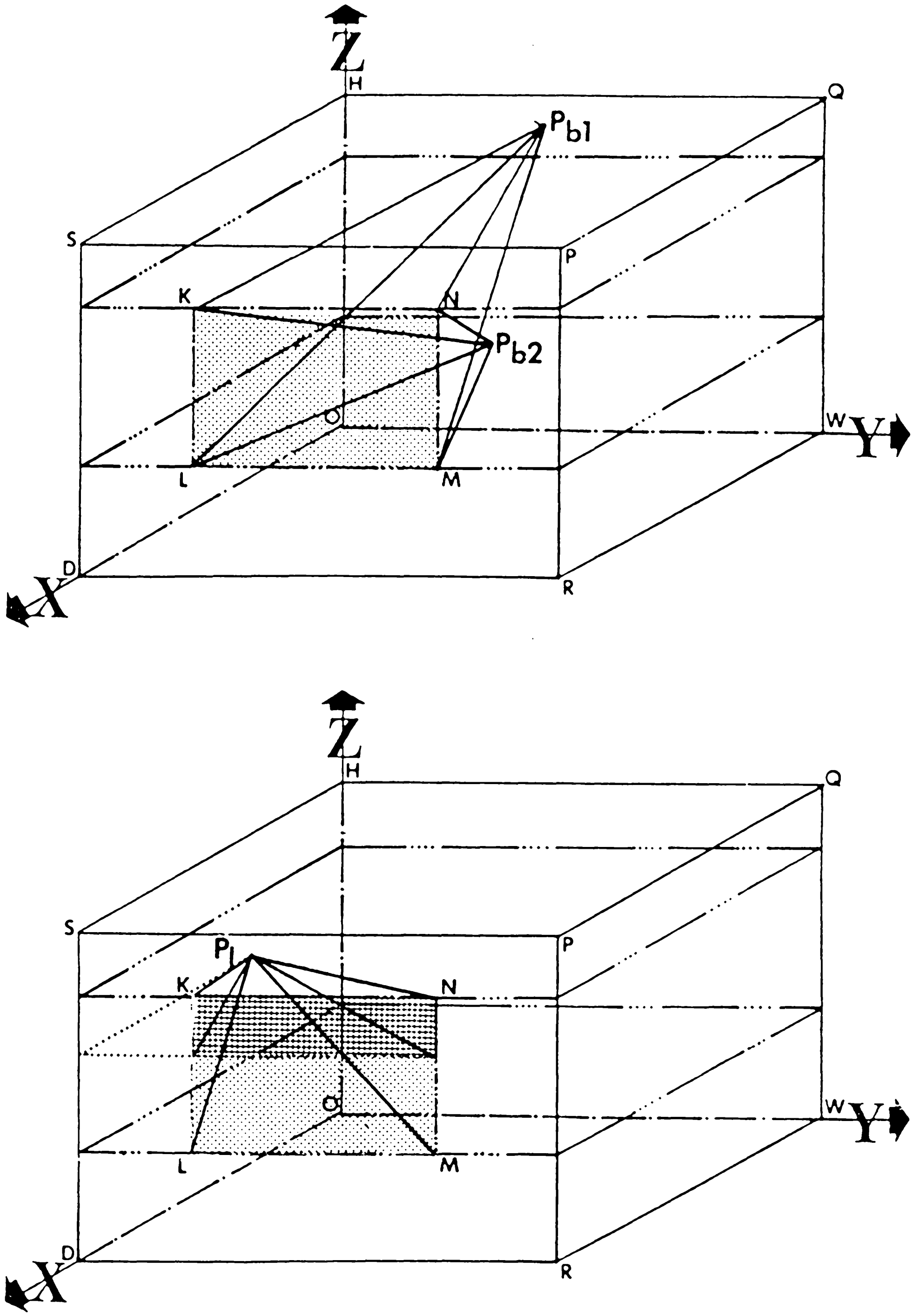

Figure 25. Diffuse Daylight Directly Received in Left Wall and Back Wall

E_H = The luminance of the sky vault (assume a uniform diffuse sky condition)

T_w = Transmission factor of window (normally assume $T_g = 0.85$)

R_{LW} = The length of line R connecting the any point in the left wall and the any small area in the window

θ_w = The angle between the normal to the and small area in the window and the line of length R_{LW}

θ_l = The angle between the normal to the any point in the left wall and the line of length R_{LW}

$$R_{LW} = \sqrt{(d - x_l)^2 + (y_w - 0)^2 + (z_w - z_l)^2} \qquad [4.13]$$

$$\cos\theta_w = |\cos\alpha_{LW}\cos\alpha_w + \cos\beta_{LW}\cos\beta_w + \cos\gamma_{LW}\cos\gamma_w| \qquad [4.14]$$

$$\cos\theta_l = |\cos\alpha_{LW}\cos\alpha_l + \cos\beta_{LW}\cos\beta_l + \cos\gamma_{LW}\cos\gamma_l| \qquad [4.15]$$

where

α_{LW}, β_{LW}, $and \gamma_{LW}$ are the direction angles of the line of length R_{LW} (section 3.5), α_w, β_w, and γ_w are the direction angles of the normal to the window, α_l, β_l, and γ_l are the direction angles of the normal to the left wall.

$$\cos\alpha_w = -1, \ \cos\beta_w = 0, \ and \cos\gamma_w = 0$$

$$\cos\alpha_l = 0, \ \cos\beta_l = 1, \ and \cos\gamma_l = 0$$

$$\cos\alpha_{LW} = \frac{x_w - x_l}{R_{LW}} = \frac{d - x_l}{R_{LW}}$$

$$\cos\beta_{LW} = \frac{y_w - y_l}{R_{LW}} = \frac{y_w - 0}{R_{LW}}$$

$$\cos\gamma_{LW} = \frac{z_w - z_l}{R_{LW}}$$

Reduce [4.14] and [4.15]

$$\cos\theta_w = |\cos\alpha_{LW}\cos\alpha_w| = \left|\frac{d - x_l}{R_{LW}}\right| \qquad [4.16]$$

$$\cos\theta_l = |\cos\beta_{LW}\cos\beta_l| = \left|\frac{y_w}{R_{LW}}\right| \qquad [4.17]$$

Equation [4.10], or [4.11], or [4.12] expresses that the diffuse daylight, either from the sky vault or ground, penetrates through the window and is incident to the left wall. Based on these equations, the illuminance for every point or small area in the left wall can be obtained. This illuminance in the left wall is directly affected by the exterior sources of diffuse daylight. The illuminance of the inter-reflection of diffuse daylight among the interior surfaces then will be calculated base on this direct illuminance from the exterior and will be discussed later. Repeating the processes from equation [4.10] to [4.17], the formula for calculating the illuminance of other surfaces can be obtained, which is shown in the appendix E.

Reference Plane $(0 \leq x_{ref} \leq d , o \leq y_{ref} \leq w , z_{ref} = 2.5)$

The illuminance which comes from the exterior and is incident to the reference plane depends upon the window's position and size. Therefore, it is necessary to analyze the relationship between the height of the window and the height of the reference plane for determining the effective opening of the window and the sources of diffuse daylight. It is clear that the height of opening which is lower than the height of the reference plane will not emit any diffuse daylight into the reference plane. In other words, the reference plane only receives illuminance from space, surfaces, and opening above it. If the height of the window's upper edge is lower than 2.5 feet (height of the reference plane), no diffuse daylight will pass through the window and be incident to the reference plane directly. If the height of the window's upper edge is higher than 2.5 feet and the height of window's lower edge is below 2.5 feet, then the reference plane will only receive the diffuse daylight which directly penetrates through the portion of the window with the height higher than 2.5 feet. If the height of window's lower edge is higher than 2.5 feet, then all the rays of diffuse daylight passing through the window are effective to the reference plane. The following are based on the above conditions to analyze the luminance received in the reference plane.

Window Area $(x_w = d . 0 \leq y_w \leq w , f \leq z_w \leq b + f)$

$f \leq 2.5 feet$ (window's lower edge higher than the height of the reference plane)

$$E_{ref-ext} = \int_{f}^{b+f} \int_{c}^{a+c} \frac{E_H \, T_g \cos \theta_w \cos \theta_{ref}}{R^2_{Ref-W} \, \pi} \, dy \, dz \qquad [4.18]$$

$f \leq 2.5 feet \leq b + f$ (window's lower edge lower than the height of the reference plane and window's upper edge higher than the height of the reference plane)

$$E_{ref-ext} = \int_{2.5}^{b+f} \int_{c}^{a+c} \frac{E_H \, T_g \cos \theta_w \cos \theta_{ref}}{R^2_{Ref-W} \, \pi} \, dy \, dz \qquad [4.19]$$

$(b + f) \leq 2.5 feet$ (window's upper edge lower than the height of the reference plane)

$$E_{ref-ext} = 0 \qquad [4.20]$$

where

$$R_{Ref\text{-}W} = \sqrt{(d - x_{ref})^2 + (y_w - y_{ref})^2 + (z_w - 2.5)^2}$$

$$\cos \theta_w = \left| \frac{d - x_{ref}}{R_{Ref-W}} \right|$$

$$\cos \theta_{ref} = \left| \frac{z_w - 2.5}{R_{Ref-W}} \right|$$

4.6 Diffuse Daylight Exchanges Among Surfaces

In section 4.5, the situations of illuminance incident from exterior diffuse sources into interior surfaces and the reference plane have been introduced. Once the diffuse daylight strikes the surface, the surface itself also has the ability to reflect light to space. Thus, all the interior surfaces will reflect the light to each other, depending on the reflectance factor of each surface. A method will be developed to analyze the inter-reflective phenomenon of diffuse daylight transfer among interior surfaces in this section.

For the purpose of convenience in predicting the result of the inter-reflective phenomenon, it is necessary to assume that there is a surface which is the first surface receiving the reflective light from the other five surfaces in a rectangular room; even through the actual phenomenon of inter-reflection among interior surfaces occurs instantaneously and continuously. This section is based on the same idea which has been introduced in section 3.6.5 to process the results of inter-reflective light transfer among interior surfaces. In section 4.5, no illuminance comes from the exterior to the window wall directly; therefore, the first surface which will be processed to calculate the result of inter-reflective light transfer among surfaces is the window wall, then the other five surfaces.

Window Wall : $(x_w = d , 0 \leq y_w \leq w , 0 \leq z_w \leq h)$

The illuminance which comes from the exterior and is incident to the interior surfaces will give these surfaces the ability to reflect light into the interior space. The luminance of these surfaces depends on the reflectance factor of each surface. The illuminance of the interior surfaces can be obtained from equation [4.10] to [4.17] in section 4.5. Therefore, to obtain the luminance of any small area or any point in each surface, simply multiply the reflectance factor with the illuminance of that area or point.

$$L_{luminance} = E_{illuminance} \ R_{reflectancefactor}$$

Light Transfer From Left Wall to The Window Wall

$$E_{Wl} = \int_0^h \int_0^d \frac{E_{LL} R_l \cos \theta_w \cos \theta_l}{R_{WL}^2 \pi} dx\, dz \qquad [4.21]$$

where

E_{WL} = The luminance received for a small area or a point in the window wall diffused from the left wall

E_{LL} = The luminance of a point or a small area in the left wall which is caused by exterior sources of diffuse daylight (equation [4.10] to 4.12]), $E_{LL} = E_{LG}$, or $E_{LL} = E_{LS}$, or $I_{LL} = E_{LGS}$

R_l = The reflectance factor of the left wall

R_{WL} = The distance between the calculated point in the window wall and the any possible point or small area in left wall

θ_w = Angle between the normal to the calculated point or small area in the left wall and the line of length R_{WL}

θ_l = Angle between the normal to the calculated point or small area in the left wall and the line of length R_{WL}

To obtain the total diffuse daylight affected by the illuminance of interior surfaces for a calculated point in a specific surface, the formulas to calculate the light transfer from surfaces to the calculated point must be developed. Repeat the processes of obtaining the light coming from the left wall to the calculated point in the window wall; the following formulas will be obtained.

Light Transfer From Right Wall to The Window Wall

$$E_{Wr} = \int_0^h \int_0^d \frac{E_{RR} R_r \cos \theta_w \cos \theta_r}{R_{WR}^2 \pi} dx\, dz \qquad [4.22]$$

where

$E_{RR} = E_{RG}$ (from equation [E.1]), or

E_{RS} (from equation [E.2]), or

E_{RGS} (from equation [E.3])

Light Transfer From Back Wall to The Window Wall

$$E_{Wb} = \int_0^h \int_0^w \frac{E_{BB} R_b \cos\theta_w \cos\theta_b}{R_{WB}^2 \pi} dy\ dz \qquad [4.23]$$

where

$E_{BB} = E_{BG}$ (from equation [E.7]), or

E_{BS} (from equation [E.8]), or

E_{BGS} (from equation [E.9])

Light Transfer From Ceiling to The Window Wall

$$E_{Wc} = \int_0^w \int_0^d \frac{E_{CC} R_c \cos\theta_w \cos\theta_c}{R_{WC}^2 \pi} dx\ dy \qquad [4.24]$$

where

$E_{CC} = E_{CG}$ (from equation [E.13])

Light Transfer From Floor to The Window Wall

$$E_{Wf} = \int_0^w \int_0^d \frac{E_{FF} R_f \cos\theta_w \cos\theta_f}{R_{WF}^2 \pi} dx\ dy \qquad [4.25]$$

where

$E_{FF} = E_{FS}$ (from equation [E.17])

From equation [4.21] to [4.25], the quantity of illuminance from the interior surfaces (except the window wall itself) to the calculated point in the window wall has been derived. Therefore, the illuminance for any point of the window wall can be expressed in the following form.

$$E_{WI} = E_{Wl} + E_{Wr} + E_{Wb} + I_{Wc} + E_{Wf} \qquad [4.26]$$

In section 4.5, the illuminance coming from the exterior to the interior surfaces has already been calculated. Equation [4.26] only explains the illuminance for a calculated point in the window wall, which come from the interior surfaces and is received in the window wall. Combine E_{wi} and the illuminance coming from the exterior to the window wall directly; the diffuse daylight in the window wall can be obtained as E_{wi} here. Because no diffuse daylight will directly come from outside and strike to the inside of the window wall. Equation [4.26] stands for the intensity of light in the window wall and will be used later to calculate the light transfer from the window wall to the other five surfaces and the reference plane.

Only the illuminance of the window wall which was affected by the inter-reflective phenomenon among interior surfaces has been developed at this stage. Repeat the processes from equation [4.21] to [4.26], the illuminance of other five surfaces caused by the phenomenon of inter-reflection can be obtained which is shown in the appendix E.

In this section, the inter-reflection among interior surfaces has been analyzed. In the nature of light, the inter-reflection among surfaces is continuous. In other words, the light transfer among surfaces is continuous until every surface reaches a temporary stable condition unless the intensity of the original sources is changed. The processes in this section only deal with the first inter-reflective phenomenon among interior surfaces. The reason for only calculating light exchange among surfaces once is that the difference of illuminance between primary and secondary inter-reflection is too small to be significant.

4.7 Illuminance in the Reference Plane

The analyses of diffuse daylight transfer from exterior to interior and diffuse daylight exchange by inter-reflection among interior surfaces are discussed in section 4.5 and 4.6. The illuminance for every point or small area on each interior surface can be obtained via the equation in the last two sections. This section will use the results of the last two sections to calculate the illuminance in the reference plane.

The illuminance of the reference plane, which defined as y=2.5 feet, depends upon the intensity of light sources and their reflectances. The possible light sources for the reference plane can be divided into two parts. One is the diffuse daylight coming from the exterior and incident directly to the reference plane, which has already been developed and can be calculated with the equations of [4.18], [4.19], and [4.20]. The other is the diffuse daylight coming from the interior surfaces which is the major topic in this section.

In section 4.3, the model for light leaving one surface and that reaching another surface has already been introduced. Based on this model, once the intensities of illuminance and luminance for a source surface (interior surfaces) are known, then the intensity of illuminance for the target surface (reference plane) can be calculated.

Since the reference plane is defined as z=2.5 feet (2.5 feet higher than the floor level), the surface which is lower than 2.5 feet will not diffuse daylight to the reference plane. In other words, no matter how high the intensity of luminance in the surfaces lower than 2.5 feet, there is no change of illuminance in the reference plane. Therefore, Only the opening and the interior surfaces higher than the reference plane ($z \geq 2.5 feet$) will affect the illuminance of the reference plane directly. The following are the processes to obtain the illuminance coming from different surface and incident to a point in the reference plane.

Reference Plane : ($0 \leq x_{ref} \leq d$, $0 \leq y_{ref} \leq w$, $z_{ref} = 2.5$)

Light Transfer From Left Wall to Reference Plane

Effective Area of Left Wall : ($0 \leq x_l \leq d$, $y_l = 0$, $2.5 \leq z_l \leq h$)

$$E_{Ref-L} = \int_{2.5}^{h} \int_{0}^{d} \frac{E_L R_l \cos\theta_{ref} \cos\theta_l}{R_{Ref-L}^2 \pi} dx\, dz \qquad [4.27]$$

Light Transfer From Window Wall to Reference Plane

Effective Area of Window Wall : $(x_w = d , 0 \leq y_w \leq w , 2.5 \leq z_w \leq h)$

$$E_{Ref\text{-}W} = \int_{2.5}^{h} \int_{0}^{w} \frac{E_W\, R_w \cos \theta_{ref} \cos \theta_w}{R^2_{Ref\text{-}W}\, \pi}\, dy\, dz \qquad [4.28]$$

Light Transfer From Right Wall to Reference Plane

Effective Area of Right Wall $(0 \leq x_w \leq d , y_w = w , 2.5 \leq z_r \leq h)$

$$E_{Ref\text{-}R} = \int_{2.5}^{h} \int_{0}^{d} \frac{E_R\, R_r \cos \theta_{ref} \cos \theta_r}{R^2_{Ref\text{-}R}\, \pi}\, dx\, dz \qquad [4.29]$$

Light Transfer From Back Wall to Reference Plane

Effective Area of Back Wall : $(x_b \leq 0 , 0 \leq y_b \leq w , 2.5 \leq z_b \leq h)$

$$E_{Ref-B} = \int_{2.5}^{h} \int_{0}^{w} \frac{E_B\, R_b \cos \theta_{ref} \cos \theta_b}{R^2_{Ref-B}\, \pi}\, dy\, dz \qquad [4.30]$$

Light Transfer From Ceiling to Reference Plane

Effective Area of Ceiling : $(0 \leq x_c \leq d , 0 \leq y_c \leq w , 2.5 \leq z_c \leq h)$

$$E_{Ref-C} = \int_{0}^{d} \int_{0}^{w} \frac{E_C\, R_c \cos \theta_{ref} \cos \theta_c}{R^2_{Ref-C}\, \pi}\, dx\, dy \qquad [4.31]$$

From equation [4.27] to [4.31], each equation expresses the quantity of light transferred from each interior surface is higher than the reference plane, to the calculated point in the reference plane. these equations can be combined to obtain the illuminance of the calculated point in the reference plane affected by the inter-reflective phenomenon.

$$E_{Ref-Inter-reflection} = E_{Ref-L} + E_{Ref-W} + E_{Ref-R} + E_{Ref-B} + E_{Ref-C} \qquad [4.32]$$

Equation [4.32] expresses the light coming from interior surfaces and incident to the reference plane. To obtain the total illuminance for the reference plane, which includes not only the illuminance from the inter-reflection but also the illuminance directly from the exterior diffuse daylight source (sky vault and ground), the equation [4.18], or [4.19], or [4.20] must be combined with equation [4.32]. Determining which equation should be combined with equation [4.32] is based on the effective opening, discussed in section 4.5. Equation [4.33] is the formula to calculate the total diffuse daylight received in the reference plane, which include diffuse daylight transferred from exterior to interior, and diffuse daylight exchanged among interior surfaces (inter-reflection).

$$E_{Reference} = E_{Ref-Inter-reflection} + I_{Ref-Ext} \qquad [4.33]$$

The mathematical model for predicting the illuminance distribution of direct sunlight and diffuse daylight in a rectangular room has been well developed in this chapter. The illuminance of any point in the reference plane can be obtained with equations [3.6.165] and [4.33]. The illuminance can be predicted either in direct sunlight or diffuse daylight, or both. The following chapter will present the experimental study and statistical analysis to validate this mathematical model of daylighting.

4.8 Computer Simulation

A computer program using a high level language, the Advanced BASIC (Beginners All-purpose Symbolic Instruction Code), under IBM PC's DOS version 2.1 has been written for simulation and prediction of the diffuse daylight distribution in a rectangular room. All calculation methods in this program are based on the mathematical model previously stated.

Naturally, this program was written for the IBM PC, XT, and AT system. It permits the user to use one or two disk drives for the master program diskette and the storage diskettes. The initialized disk may be used as a storage disk. As a result, more than one design case may be calculated during any period of time and orientation, and more than one storage diskette may be used for different options. This program allows the prediction of illuminance at any point in the interior with any combination of rectangular fenestration and reflective surfaces under different sky conditions. A program list is in appendix F and a brief description of each stage of the program is explained in the following.

Organization of Input Data

Two groups of information are required for the input of this program. One is the weather data. Another is the basic geometry information of a room. The following are the required input data for weather information.

1. The location of the room which includes the longitude, latitude, time zone, and the orientation of the window facing.

2. The time of the daylighting need to be analyzed which includes the time of the day and the date of the year.

3. The desired sky condition which includes the clear sky, the partly cloudy sky, and the cloudy sky.

With the weather data input, the program will calculate the daylight availability based on the IES accepted equations which have been discussed previously. The solar altitude, solar azimuth, and profile angles will be calculated also. The input of the desired sky conditions are an optional function which depends upon the user's need. In other words, this program has the ability to predict different sky conditions simultaneously.

The minimum information of a room required to run this program is normally available at the schematic design stage. Once a designer has sketched a building shape, he needs only the following information to use this program for daylighting prediction.

1. The size of a room, which included the depth (x-axis), the width (y-axis), and the clear ceiling height (z-axis) of a room.

2. The location and the size of windows, which include the distances between the left wall and the left edge of the windows, the right wall and the right edge of the windows, the floor and the lower edge of the windows, and the ceiling and upper edge of the windows.

3. The reflectances of each interior surface. If the reflectances have not been decided and input, the program itself has the ability to default to the *IES*[8] suggested reflectances for each interior surface.

4. The transmission factor of the glass. If no factor is entered, it defaults to 0.85.[9]

5. The correction factor of maintenance of the glass. If no factor is entered, it defaults to 0.85 which means the program will not put this factor in prediction.

6. The correction factor of window framing and window bars. This factor is determined by dividing the actual glass area by the area of window aperture. If no factor is entered, it defaults to 0.75.[10]

7. The height of the reference plane. If no value is entered, It defaults to 2.5 *feet*.[11] The calculation process needs this value to decide the effective window area of diffuse daylight.

Algorithms

Two numerical analysis methods were employed to execute the calculations in this program for daylighting prediction. One is the well-known Simpson's second *rule*,[12] probably the most frequently used of all the integration formulas. Simpson's second rule, which is based on odd intervals with an even number of base points, is applied to calculate the double integrations in the mathematical model. This numerical method promises that the error of calculating will be insignificant in this study.

Another method is the zoning method, which was originally *designed*[13] for calculating the radiant heat exchange in a gas-filled enclosure. Hottel and *Sarofim*[14] develop this method at some length for computer solution in calculating the iterative phenomenon of radiative transfer. This method can compute light exchange in a rectangular space containing known reflectances of surfaces, which for calculation are divided into finite areas, while the medium is divided into finite volumes. The areas and volumes are assumed to be individually uniform, and luminance and illuminance exchange among all areas and volumes is then calculated. In this program, each interior surface is divided into 81 small areas for calculating the quantity of illuminance caused by inter-reflection phenomenon. The more areas into which each surface has been divided, the better precision in prediction will be obtained. This method allows the calculation of inter-reflective phenomena to be made individually; thus, the analysis of reflectances for each surface is accessible. Other calculation procedures in this program are the same as the mathematical model.

Organization of Output Data

Two kinds of output data are provided in this computer simulation. One is the quantity of predicted illuminance for 11 by 9 points in the reference plane, which provides the following information.

1. All the given input data.
2. The position of each point being calculated in the reference plane.
3. The illuminance of each point due to direct incident daylight.
4. The illuminance of each point due to inter-reflective phenomena.
5. The total illuminance of each point.
6. The predicted daylight factor for each point.

Another kind of output data is the quantity of predicted illuminance for each of the 81 points on each interior surface, which provides the same information as the former output did. With this output data, designers can analyse the illuminance affected due to direct incident daylight via openings and due to inter-reflective phenomena via surfaces separately or together. This analysis can assist designers to adjust their schematic designs or reflective surface as needed.

Graphic Representation

Figure 26 on page 123 shows three kinds of graphic representation to explain the results of daylighting distribution in this program. First is the typical floor plan showing footcandles or daylight factors for 25 points, which provides a quantitative overview of the entire room. Second is the typical section showing curve change in footcandles or daylight factors, which provides the relative brightness from the window wall to the back wall. This is useful in evaluating potential glare problems. Third is the 3-dimension graphic contour, which provides complete information of daylighting distribution in a rectangular room. The Bicubic *Spline*[15] method is employed to execute the calculation of curve fitting and surface fitting.

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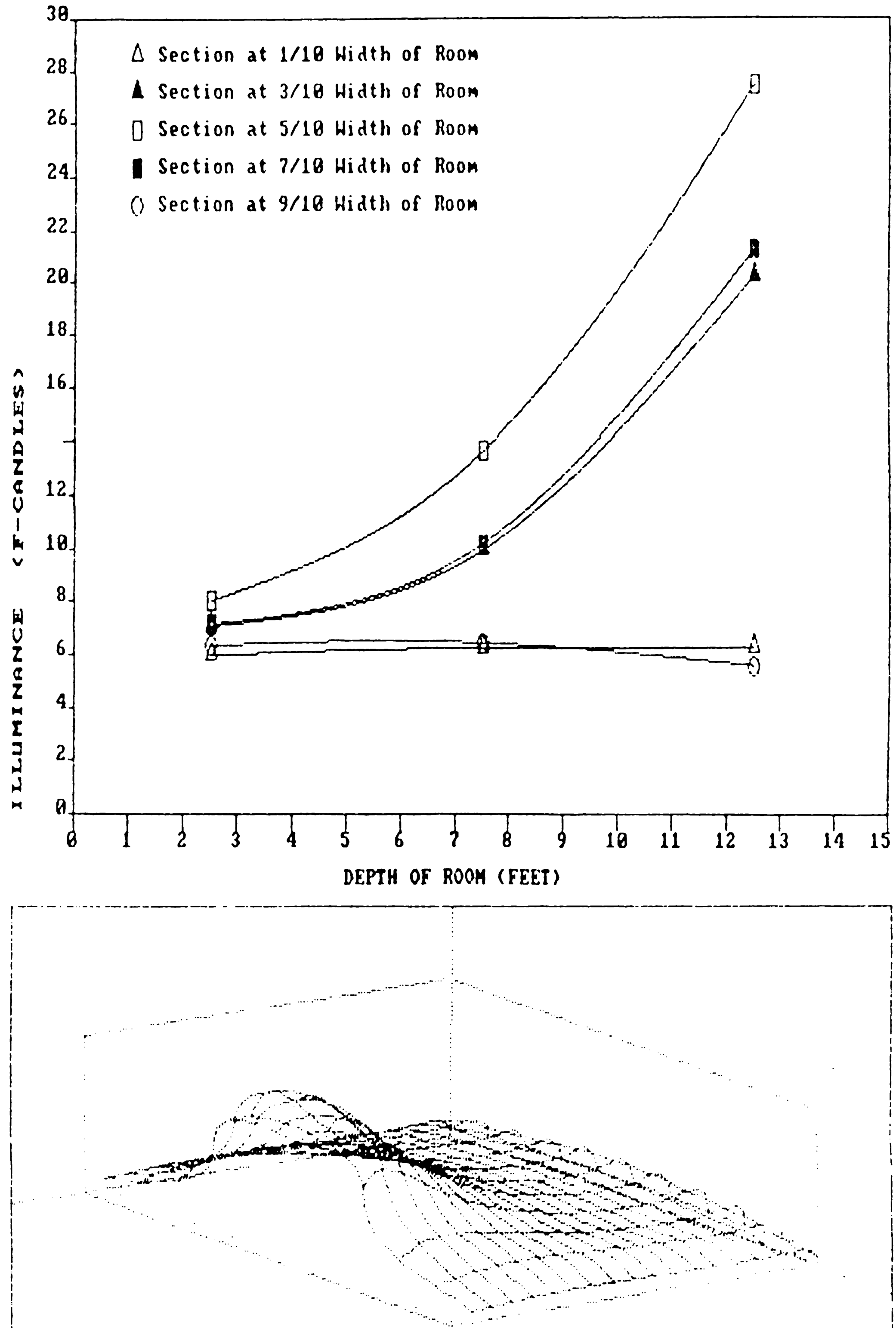


Figure 26. Graphic Representation of Computer Simulation

CHAPTER 5 SCALE MODEL STUDIES AND VALIDATION

5.1 Instrumentation and Calibration

Several instruments have been employed in validation of the mathematical model developed here. These include a *photometer*,[1] a glossmeter and *reflectometer*,[2] an analog-signal to digital-code interface board, and a set of 16 quick response photocells. The latter two instruments were specially designed and constructed for this study.

Photometer: A Tektronix J-16 photometer/radiometer with a J-6511 photometric probe was used as a standard with which to calibrate the Clairex *CL*909*L*[3] photocells. The J-16 has been calibrated by the manufacturer with a 3100 degree K tungsten-halogen light source traceable to NBS standards. The J-16 with J-6511 provides stability within 2% per year, linearity within 2% over the entire range, integration time within 100 ms which is similar to the human eye, cosine correction for a 180 degree field-of-view, and wavelength response which insures a close match to the CIE photopic curve.

Reflectometer: A Gardner portable glossmeter and reflectometer was used to measure the reflectance of materials used in the model study.

Analog/Digital (A/D) Converter Card: An analog-signal to digital-code converter card for signal transfer was developed and constructed. It can be programmed from the IBM PC's interpreted or compiled Advanced Basic language to perform analog-signal to digital-code conversions. An A/D converter changes the analog voltage(the output of a photocell) into a digital-code of 0's and 1's which is intelligible to the computer. The hardware includes a 16 channel multiplexer(AD 7507) followed by an instrumentation amplifier(714), a sample and hold(AD 582), and a twelve bit A/D converter (*AD*574*ak*).[4]

This A/D card provides a resolution of one in 4096 which is required if illumination is to be read to a tenth of a foot candle in the 400 footcandles range. The data acquisition time is 25us; in other words, it only take a half second to collect 30 readings for each channel. The hardware schematic described above, the calibration procedure of this A/D card, and the software to communicate between the A/D card and the IBM PC are in Appendix G.

The linearity error refers to the deviation of each individual code from a line drawn from "zero" through "full scale". The point used as "zero" is 1.22 mV for a 10 volt span before the first code(0) transition. Full scale is defined as 3.67 mV for a 10 volt span beyond the last code(4095) transition. The AD 574ak grades are guaranteed for maximum nonlinearity of 1.22 mV. For this grade, this means that an analog value which falls exactly in the center of a given code width will result in the correct digital output code. Values nearer the upper or lower transition of the code width may produce the next upper or lower digital output code. The calibration procedure for this A/D card is in Appendix G.

Photocells: In a physical model study of daylighting, the simultaneity of data collection has always been an important criteria for predicting illuminance distribution coincidentally. Many photometers are available for measuring the illuminance in models. Usually, these photometers involve the application·of electronic devices for translatting the output voltage of photocells into illuminance units.

However, none of the existing photometers can support the simultaneous measurement of illuminance (in less than half a second) for 16 positions. The simultaneity of data collected in the Skydome Daylight Simulator is important because the unstable voltage situation for the light source inside the Skydome causes fast changes in illuminance. This also applies to measurements made in the fast changing of the real physical environment. Hence, it was necessary to improve the factor of simultaneity in data collection for the this study and the validation of the analytical model.

16-Channel Photocell Set: The photocells selected for this study were produced by Clairex Electronics Co. (Mount Vernon, New York 10550). The index number of these photocells is CL909L. The CL909L's have the following characteristics to suit the requirements of physical model experiments in the Skydome Daylight Simulator:

1. The peak spectral response is 5500 Angstroms which closely matches that of the human eye.

2. Its stability, high speed, and low temperature coefficient allow use in the real physical environment and Skydome Daylight Simulator.

3. There is no more than a 6% difference in accuracy from -25 degrees to +75 degrees Celsius.

4. The maximum measurement voltage is 10V, which matches the A/D card need.

5. Response time is less than 0.005 seconds at 1.0 footcandles, 0.002 seconds at 10 footcandles, and 0.001 seconds at 100 footcandles.

6. The variation of conductance with temperature and light is less than 2.5%.

7. The sensitivity versus angstroms curve sufficient for simulation of illuminance in the physical environment.

The CL909L photocells do not have cosine correction, thus, it was necessary to accomodate for cosine correction in the computer program. The 16-channel set of photocells and the A/D converter card allow the simultaneous measurement of model illuminances and were used to validate the mathematical model for use by designers for the prediction of interior daylighting distribution.

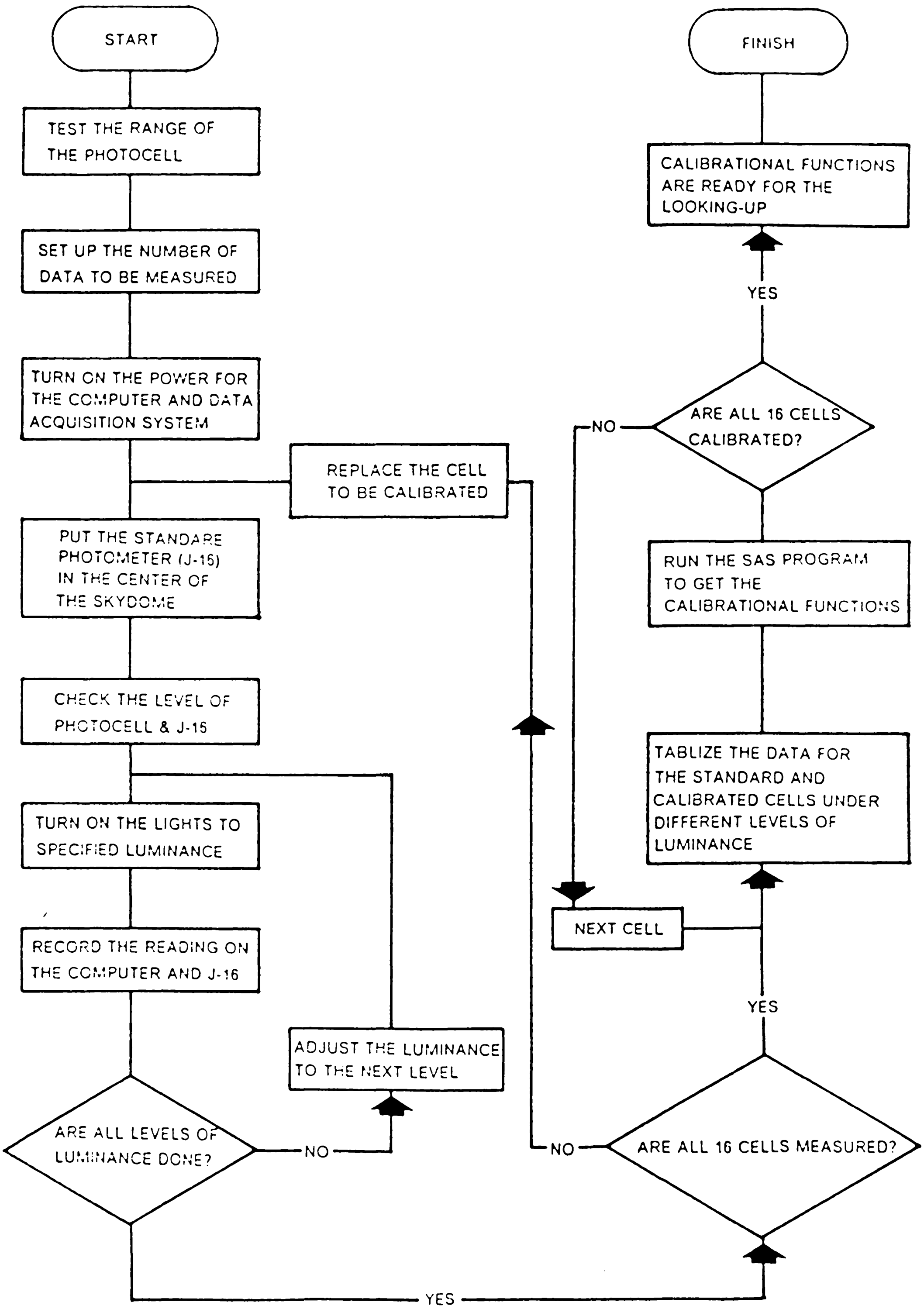
The spectral response, the details of photocell, the color temperature response, the variation of conductance with temperature and light, the response time versus light, and the electronic circuit design of CL909L are listed Appendix G.

Calibration of Photocells: The CL909L photocells were calibrated using the J-16 photometer as a reference. Based on a range from 0 footcandles to 118.8 footcandles of illuminance in the Skydome, each photocell was calibrated via 19 observations. Table 1 on page 128 shows the steps in the calibration procedure. The calibration procedure and program to communicate between photocells and the IBM PC are listed in Appendix G.

The statistical Analysis System (SAS) package was employed to find the General Linear Model (GLM) for each photocell to predict the illuminance as the J-16 did. According to the R-Square of these 16 GLM created by SAS, the CL909L's prediction ability of illuminance is dependable and stable. Table 2 on page 130 shows the GLM and R-Square for each channel.

Even through the R-Square of each photocell provide a minimum value of 0.99 for the correlation coefficients between J-16 and CL909L photocells, the intercepts of some GLMs are too high to predict a low illuminance level. Hence, it is necessary to divide the observations into three parts to find the GLM for each range of illuminance which permits the lower illuminance prediction precisely. Table 3 on page 131 , Table 4 on page 132 , and Table 5 on page 133 show the GLM and R-Square for each photocells. Figure 27 on page 134 expresses the linear characteristic for the prediction in different ranges of illuminance. All the

Table 1. Flow Chart of Photocell Calibration



interceptions for every GLM at low illuminance levels are small enough to execute the prediction.

5.2 Scale Model Studies and Data Acquisition

Forty-eight sequential diffuse daylighting model studies were done for the validation of this study under the Skydome in the PFRC at VPI&SU. Four scale model floor plans were built for the 48 case studies. The models were all at the same scale of 3/4″ = 1′. The models were treated to simulate as realistically as possible the assumptions made in this study, such as the perfectly diffusing ground and room surfaces, and the luminance in the Skydome (homogeneous and isotropic). Dimensions of the four plans are shown below:

1. 12 feet deep by 18 feet wide

2. 12 feet deep by 24 feet wide

3. 14 feet deep by 19 feet wide

4. 15 feet deep by 26 feet wide.

The range variables chosen for the scale model studies are as follows:

1. Ceiling height --- 10 feet, 11 feet, and 12 feet

2. Sill height --- 2 feet, 2.5 feet, 3 feet, and 3.5 feet

3. Ceiling reflectance --- .06, .51, .76, and .81

4. Wall reflectance --- .06, .31, .51, .76

Table 2. The Correlation Coefficient Function for CL909L (range: 0 to 118.8 footcandles)

CL909L	R-SQUARE	PARAMETER	ESTIMATE	T FOR H0: PARAMETER=0	PR > |T|
		INTERCEPT	4.22663514	2.70	0.0151
1	0.997104	P	-0.03776282	-5.75	0.0001
		P*P	0.00014129	23.98	0.0001
		INTERCEPT	6.53043228	2.30	0.0343
2	0.991461	P	-0.04274789	-5.24	0.0001
		P*P	0.0000788	15.56	0.0001
		INTERCEPT	1.01258003	2.49	0.0232
3	0.999701	P	0.02572579	10.47	0.0001
		P*P	0.00014666	49.26	0.0001
		INTERCEPT	3.90399009	2.71	0.0150
4	0.997458	P	-0.03228407	-5.43	0.0001
		P*P	0.00012946	24.93	0.0001
		INTERCEPT	2.57671076	2.80	0.0124
5	0.998829	P	-0.01667462	-3.67	0.0019
		P*P	0.00015351	32.85	0.0001
		INTERCEPT	5.38276496	2.47	0.0245
6	0.994608	P	-0.03516351	-5.35	0.0001
		P*P	0.0000783	18.49	0.0001
		INTERCEPT	4.16597794	2.61	0.0184
7	0.996748	P	-0.02834615	-4.85	0.0002
		P*P	0.0000990	22.01	0.0001
		INTERCEPT	5.71873371	2.43	0.0265
8	0.993800	P	-0.04032526	-5.33	0.0001
		P*P	0.0000914	17.54	0.0001
		INTERCEPT	5.35246745	2.45	0.0253
9	0.994430	P	-0.03439060	-5.07	0.0001
		P*P	0.0000803	17.97	0.0001
		INTERCEPT	4.95244503	2.56	0.0205
10	0.995655	P	-0.03342135	-5.43	0.0001
		P*P	0.0000839	20.14	0.0001
		INTERCEPT	5.54071587	2.45	0.0252
11	0.994185	P	-0.03499634	-5.25	0.0001
		P*P	0.0000751	17.86	0.0001
		INTERCEPT	4.07956637	2.77	0.0131
12	0.997427	P	-0.03112351	-5.87	0.0001
		P*P	0.00010293	25.24	0.0001
		INTERCEPT	4.68187746	2.52	0.0222
13	0.995825	P	-0.03262170	-5.06	0.0001
		P*P	0.0000951	20.09	0.0001
		INTERCEPT	3.94840953	2.32	0.0328
14	0.995698	P	-0.01472081	-2.89	0.0102
		P*P	0.0000553	17.74	0.0001
		INTERCEPT	4.56885388	2.54	0.0213
15	0.996102	P	-0.03307660	-5.10	0.0001
		P*P	0.00010220	20.66	0.0001
		INTERCEPT	0.13942532	0.60	0.5539
16	0.999865	P	0.23417147	58.42	0.0001
		P*P	0.00049677	37.03	0.0001

Table 3. The Correlation Coefficient Function for CL909L (range: 0 to 10.9 footcandles)

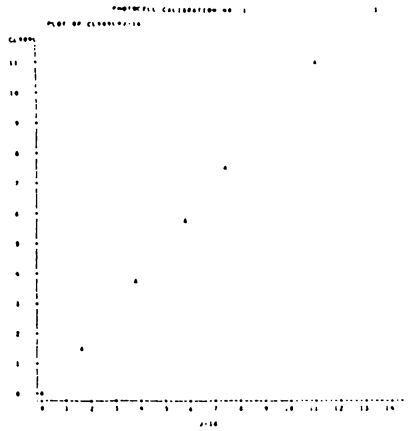
CL909L	R-SQUARE	PARAMETER	ESTIMATE	T FOR H0: PARAMETER=0	PR > |T|
		INTERCEPT	0.00958946	0.28	0.7983
1	0.999951	P	0.00839214	19.93	0.0003
		P*P	0.0000624	54.56	0.0001
		INTERCEPT	0.01028910	0.21	0.8496
2	0.999900	P	0.00356873	9.37	0.0026
		P*P	0.0000279	42.71	0.0001
		INTERCEPT	0.00956556	0.80	0.4835
3	0.999993	P	0.04195117	136.26	0.0001
		P*P	0.00010608	63.76	0.0001
		INTERCEPT	0.00624326	0.26	0.8124
4	0.999976	P	0.00936370	31.61	0.0001
		P*P	0.0000597	74.24	0.0001
		INTERCEPT	-0.01266599	-0.48	0.6669
5	0.999970	P	0.01723783	39.97	0.0001
		P*P	0.0000836	54.82	0.0001
		INTERCEPT	-0.00891133	-0.25	0.8182
6	0.999948	P	0.00548825	18.39	0.0004
		P*P	0.0000306	54.62	0.0001
		INTERCEPT	-0.00496879	-0.17	0.8775
7	0.999963	P	0.01057084	32.10	0.0001
		P*P	0.0000428	53.41	0.0001
		INTERCEPT	0.00036915	0.01	0.9918
8	0.999955	P	0.00550724	18.70	0.0003
		P*P	0.0000344	59.12	0.0001
		INTERCEPT	-0.02577031	-0.49	0.6586
9	0.999886	P	0.00688165	14.87	0.0007
		P*P	0.0000312	34.42	0.0001
		INTERCEPT	-0.01877994	-0.39	0.7212
10	0.999906	P	0.00627079	14.57	0.0007
		P*P	0.0000344	39.79	0.0001
		INTERCEPT	-0.02378986	-0.49	0.6564
11	0.999905	P	0.00590585	14.90	0.0007
		P*P	0.0000284	39.06	0.0001
		INTERCEPT	-0.00877306	-0.21	0.8496
12	0.999926	P	0.00731909	16.40	0.0005
		P*P	0.0000465	44.49	0.0001
		INTERCEPT	-0.01310101	-0.33	0.7658
13	0.999933	P	0.00829301	20.42	0.0003
		P*P	0.0000396	43.59	0.0001
		INTERCEPT	-0.06293237	-0.72	0.5238
14	0.999662	P	0.01528041	17.33	0.0004
		P*P	0.0000217	11.35	0.0015
		INTERCEPT	-0.02703111	-0.46	0.6793
15	0.999856	P	0.00845886	13.65	0.0009
		P*P	0.0000436	30.17	0.0001
		INTERCEPT	0.28993800	1.31	0.2815
16	0.997056	P	0.24835530	9.87	0.0022
		P*P	-0.00010639	-0.19	0.8633

Table 4. The Correlation Coefficient Function for CL909L (range: 7.3 to 58.0 footcandles)

CL909L	R-SQUARE	PARAMETER	ESTIMATE	T FOR H0: PARAMETER=0	PR > |T|
		INTERCEPT	8.85654288	7.46	0.0003
1	0.999778	P	-0.04325979	-9.20	0.0001
		P*P	0.00013630	31.20	0.0001
		INTERCEPT	14.70741085	6.93	0.0004
2	0.999475	P	-0.04961430	-9.02	0.0001
		P*P	0.0000751	22.28	0.0001
		INTERCEPT	0.40945781	0.70	0.5116
3	0.999826	P	0.03613131	9.53	0.0001
		P*P	0.00012634	22.97	0.0001
		INTERCEPT	7.52156230	6.21	0.0008
4	0.999745	P	-0.03439832	-7.26	0.0003
		P*P	0.00012235	28.24	0.0001
		INTERCEPT	3.89053791	5.13	0.0022
5	0.999858	P	-0.01308137	-3.55	0.0120
		P*P	0.00014125	34.16	0.0001
		INTERCEPT	11.03004883	7.57	0.0003
6	0.999694	P	-0.03859124	-9.54	0.0001
		P*P	0.0000737	27.87	0.0001
		INTERCEPT	7.36449194	5.97	0.0010
7	0.999699	P	-0.02745641	-6.43	0.0007
		P*P	0.0000907	26.33	0.0001
		INTERCEPT	11.98123563	7.25	0.0003
8	0.999625	P	-0.04469338	-9.19	0.0001
		P*P	0.0000860	25.53	0.0001
		INTERCEPT	10.09931406	7.08	0.0004
9	0.999671	P	-0.03500462	-8.56	0.0001
		P*P	0.0000735	26.72	0.0001
		INTERCEPT	10.02724048	8.03	0.0002
10	0.999760	P	-0.03663809	-9.94	0.0001
		P*P	0.0000792	31.00	0.0001
		INTERCEPT	11.70603635	7.28	0.0003
11	0.999616	P	-0.03945949	-9.03	0.0001
		P*P	0.0000713	25.50	0.0001
		INTERCEPT	8.85724010	7.53	0.0003
12	0.999779	P	-0.03695544	-9.22	0.0001
		P*P	0.00010044	31.34	0.0001
		INTERCEPT	8.52470445	7.42	0.0003
13	0.999772	P	-0.03250121	-8.73	0.0001
		P*P	0.0000873	30.91	0.0001
		INTERCEPT	4.66156101	4.66	0.0035
14	0.999668	P	-0.00591958	-2.05	0.0864
		P*P	0.0000447	23.39	0.0001
		INTERCEPT	8.51802930	8.56	0.0001
15	0.999829	P	-0.03396838	-10.11	0.0001
		P*P	0.0000949	35.73	0.0001
		INTERCEPT	0.00857413	0.01	0.9898
16	0.999571	P	0.23248452	16.56	0.0001
		P*P	0.00050533	7.63	0.0003

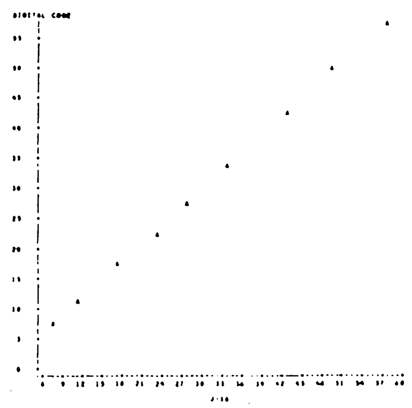
Table 5. The Correlation Coefficient Function for CL909L (range: 49.8 to 118.8 footcandles)

CL909L	R-SQUARE	PARAMETER	ESTIMATE	T FOR H0: PARAMETER=0	PR > |T|
		INTERCEPT	62.21160861	11.53	0.0001
1	0.999956	P	-0.19263292	-15.60	0.0001
		P*P	0.00024064	34.33	0.0001
		INTERCEPT	170.46404934	9.32	0.0001
2	0.999738	P	-0.33360043	-11.57	0.0001
		P*P	0.00020450	18.10	0.0001
		INTERCEPT	12.93260402	80.72	0.0001
3	0.999936	P	-0.01860516	-37.46	0.0001
		P*P	0.00018516	488.68	0.0001
		INTERCEPT	54.58618601	9.19	0.0001
4	0.999941	P	-0.16533200	-12.48	0.0001
		P*P	0.00021304	29.10	0.0001
		INTERCEPT	34.99829351	7.84	0.0002
5	0.999948	P	-0.11641456	-9.92	0.0001
		P*P	0.00022667	29.74	0.0001
		INTERCEPT	117.40288284	20.37	0.0001
6	0.999964	P	-0.24314048	-25.73	0.0001
		P*P	0.00017198	44.74	0.0001
		INTERCEPT	77.43981409	19.62	0.0001
7	0.999975	P	-0.19194635	-24.89	0.0001
		P*P	0.00018719	50.12	0.0001
		INTERCEPT	122.62840467	9.79	0.0001
8	0.999843	P	-0.27348403	-12.48	0.0001
		P*P	0.00020415	21.45	0.0001
		INTERCEPT	110.08570114	6.90	0.0005
9	0.999702	P	-0.23505934	-8.81	0.0001
		P*P	0.00017332	15.65	0.0001
		INTERCEPT	90.86737783	12.02	0.0001
10	0.999928	P	-0.20361117	-15.63	0.0001
		P*P	0.00016529	29.67	0.0001
		INTERCEPT	135.55077274	28.13	0.0001
11	0.999975	P	-0.26785384	-34.69	0.0001
		P*P	0.00017662	57.51	0.0001
		INTERCEPT	36.49087578	2.13	0.0773
12	0.999508	P	-0.11178562	-3.33	0.0159
		P*P	0.00014981	9.16	0.0001
		INTERCEPT	93.96988761	7.12	0.0004
13	0.999760	P	-0.22267303	-9.04	0.0001
		P*P	0.00019296	16.92	0.0001
		INTERCEPT	116.04708009	6.91	0.0005
14	0.999486	P	-0.20531207	-7.95	0.0002
		P*P	0.00013397	13.62	0.0001
		INTERCEPT	99.47989791	12.13	0.0001
15	0.999904	P	-0.24051610	-15.09	0.0001
		P*P	0.00021216	27.64	0.0001
		INTERCEPT	-7.40699368	-2.27	0.0639
16	0.999786	P	0.30499171	10.63	0.0001
		P*P	0.00033964	5.55	0.0014

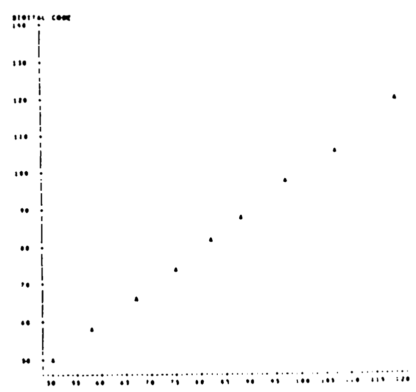


PHOTOCELL CALIBRATION NO. 1

OBS	CL909L	SD	J-16
1	0.000	0.00000	0.0000
2	102.900	0.59722	1.5445
3	185.533	1.23108	3.7431
4	246.433	1.40673	5.8534
5	282.967	1.97456	7.3315
6	357.167	2.14605	10.9858



1	282.967	1.97456	7.3315
2	357.167	2.14605	10.9858
3	449.733	2.85112	17.0885
4	517.267	3.86379	22.8767
5	563.100	3.25935	28.1013
6	614.733	3.82913	33.4359
7	681.833	3.96723	42.4028
8	730.033	4.46828	49.8548
9	778.233	4.33346	58.0164



1	730.03	4.46828	49.855
2	778.23	4.33346	58.016
3	823.13	5.14285	66.696
4	859.90	4.64292	74.508
5	893.27	5.17000	82.142
6	919.53	5.34623	88.435
7	952.53	5.46341	96.972
8	988.47	4.66714	107.280
9	1029.83	6.25611	118.860

Figure 27. GLM Model for Channel No. 1

5. Floor reflectance --- .06, .23, and .31

6. Exterior ground reflectance --- .06 and .31

7. Opening to Wall ratio --- from 23% to 49%

8. Available diffuse daylight on the horizontal --- from 31 footcandles to 118 footcandles.

These variables in the model studies were designed to be interchangeable to further increase the number of possible combinations. To make comparisons between scale models and the mathematical model, variables such as glass transmission, maintenance factor, and the correction factor of window framing were not considered in these studies.

Figure 28 on page 136 shows the 15 measuring points in the floor plan; photocells 1 to 15 are put inside the model for measuring the diffuse daylight distribution in each case. Photocell 16 is put outside the model for measuring the available horizontal illuminance of the Skydome. All the photocells were mounted on the floor and the upper surface of each photocell was at a height of 30 scale inches.

As mentioned in the previous section, the data acquisition procedure employs a computer interface system to collect data simultaneously from the 16 photocells. Fifty observations were collected and recorded for each photocell in each case. The analog signals from photocells are transferred via AD574ak into digital-codes and saved temporarily in the RAM of an IBM PC. These digital-codes then were translated via the correlation coefficient functions, which were established in the calibration procedures under the Statistical Analysis System computer package, into illuminance. Figures 29-32 graphically present the collected data in 4 cases. All data from the 4 cases, including the digital-codes and footcandles, are shown in Appendix H.

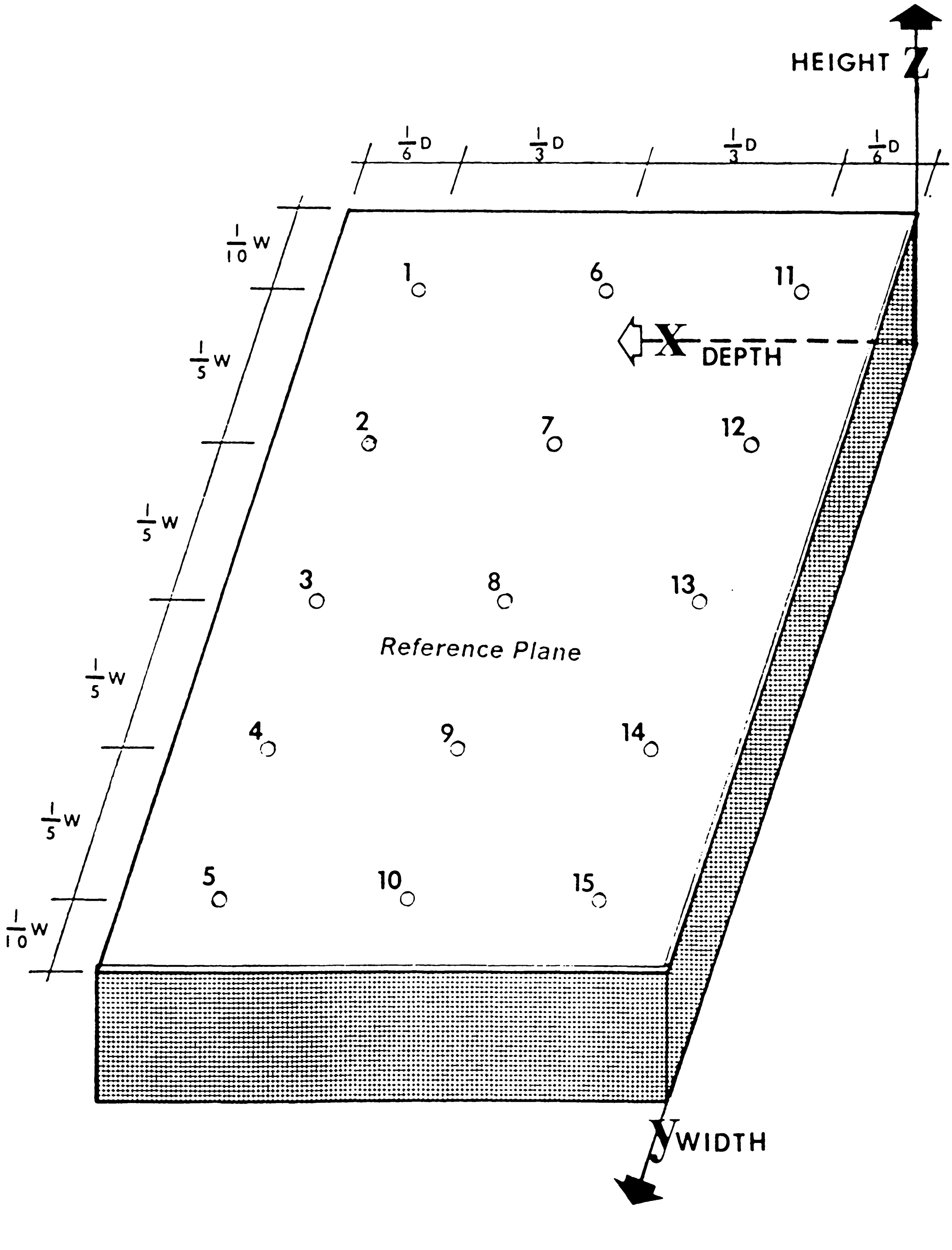


Figure 28. The Measuring Points in the Floor Plan

TEST CONDITION

DIFFUSE DAYLIGHT AVAILABLE IN SKYDOME ---------------- 105.9381 FOODCANDLES
DIMENSION OF ROOM -------------------------- 15 (D) x 26 (W) x 12 (H) FEET
DISTANCE BETWEEN WINDOW LEFT EDGE AND LEFT WALL -------------------- 7 FEET
DISTANCE BETWEEN WINDOW RIGHT EDGE AND RIGHT WALL ------------------ 7 FEET
DISTANCE BETWEEN WINDOW UPPER EDGE AND CEILING --------------------- 2 FEET
DISTANCE BETWEEN WINDOW LOWER EDGE AND FLOOR ---------------------- 4 FEET
TRANSMISSION FACTOR OF WINDOW --- 1.0 REFLECTANCE OF EXTERIOR GROUND -- .31
REFLECTANCE FACTORS LEFT WALL--- .51 BACK WALL--- .51 RIGHT WALL----- .51
CEILING----- .76 FLOOR------- .06 WINDOW WALL --- .51

CASE 1 --- SCALE MODEL STUDIES S: 3/4" = 1'

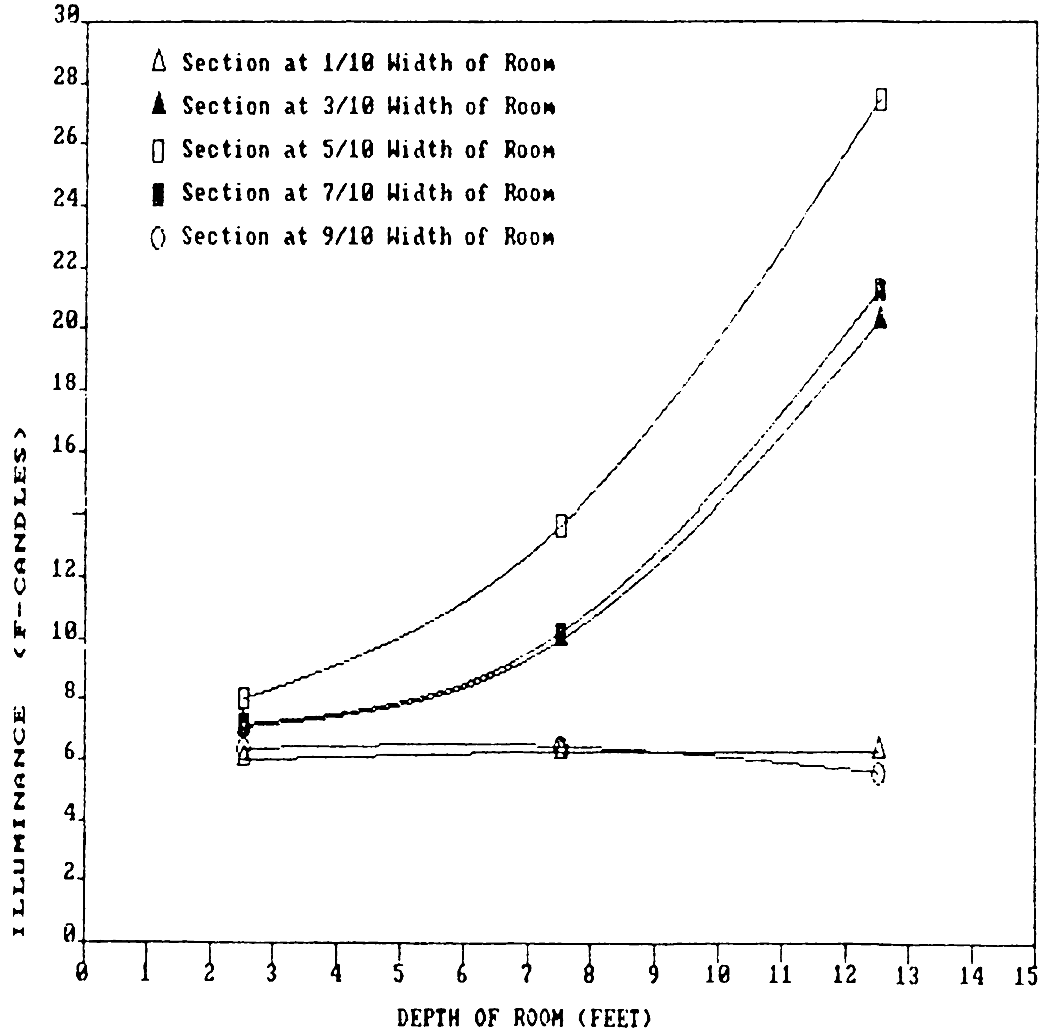


Figure 29. Scale Model Studies --- Case 1

TEST CONDITION

DIFFUSE DAYLIGHT AVAILABLE IN SKYDOME ---------------- 105.1735 FOODCANDLES
DIMENSION OF ROOM ------------------------- 15 (D) x 26 (W) x 12 (H) FEET
DISTANCE BETWEEN WINDOW LEFT EDGE AND LEFT WALL ------------------ 7 FEET
DISTANCE BETWEEN WINDOW RIGHT EDGE AND RIGHT WALL ----------------- 7 FEET
DISTANCE BETWEEN WINDOW UPPER EDGE AND CEILING ------------------- 2 FEET
DISTANCE BETWEEN WINDOW LOWER EDGE AND FLOOR -------------------- 4 FEET
TRANSMISSION FACTOR OF WINDOW --- 1.0 REFLECTANCE OF EXTERIOR GROUND -- .31
REFLECTANCE FACTORS LEFT WALL--- .76 BACK WALL--- .76 RIGHT WALL----- .76
CEILING----- .76 FLOOR------- .06 WINDOW WALL --- .76

CASE 2 --- SCALE MODEL STUDIES S: 3/4" = 1'

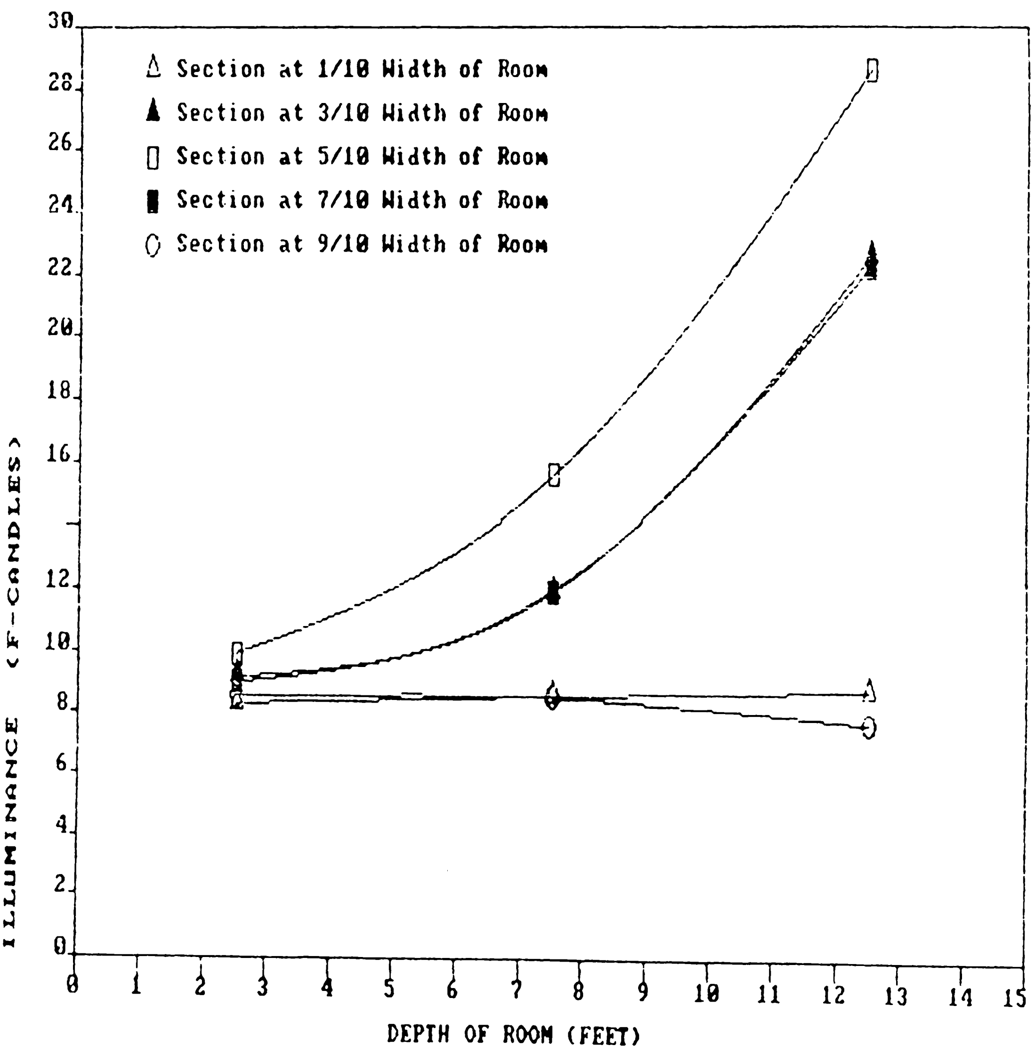


Figure 30. Scale Model Studies --- Case 2

TEST CONDITION

DIFFUSE DAYLIGHT AVAILABLE IN SKYDOME ----------------- 111.9105 FOODCANDLES
DIMENSION OF ROOM -------------------------- 12 (D) x 13 (W) x 10 (H) FEET
DISTANCE BETWEEN WINDOW LEFT EDGE AND LEFT WALL ------------------- 5 FEET
DISTANCE BETWEEN WINDOW RIGHT EDGE AND RIGHT WALL ----------------- 5 FEET
DISTANCE BETWEEN WINDOW UPPER EDGE AND CEILING -------------------- 2.5 FEET
DISTANCE BETWEEN WINDOW LOWER EDGE AND FLOOR ---------------------- 3.5 FEET
TRANSMISSION FACTOR OF WINDOW --- 1.0 REFLECTANCE OF EXTERIOR GROUND -- .31
REFLECTANCE FACTORS LEFT WALL--- .51 BACK WALL--- .51 RIGHT WALL----- .51
CEILING----- .84 FLOOR------- .06 WINDOW WALL --- .51

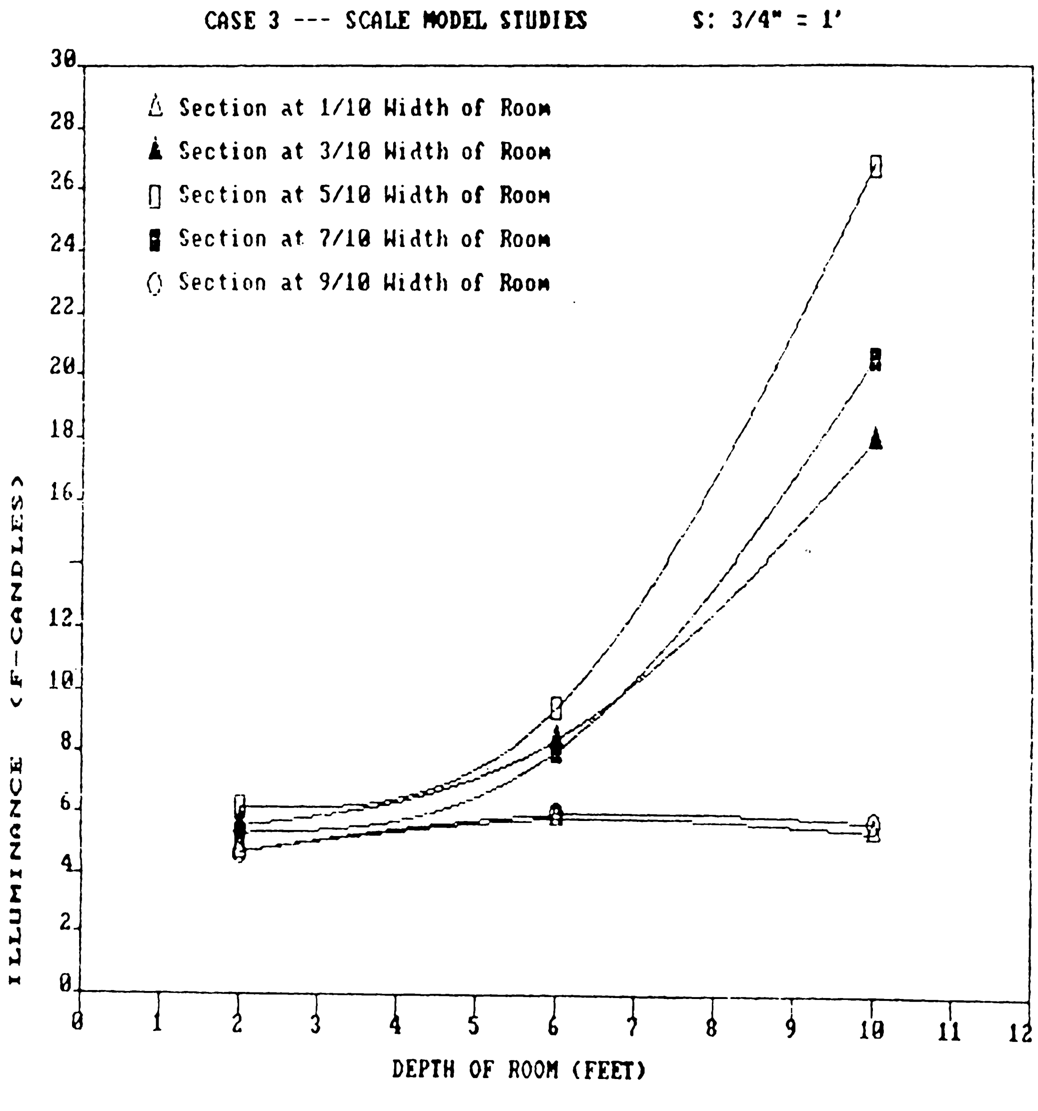


Figure 31. Scale Model Studies --- Case 3

TEST CONDITION

DIFFUSE DAYLIGHT AVAILABLE IN SKYDOME ---------------- 112.0621 FOODCANDLES
DIMENSION OF ROOM ------------------------- 14 (D) x 19 (W) x 12 (H) FEET
DISTANCE BETWEEN WINDOW LEFT EDGE AND LEFT WALL ------------------- 5 FEET
DISTANCE BETWEEN WINDOW RIGHT EDGE AND RIGHT WALL ----------------- 2 FEET
DISTANCE BETWEEN WINDOW UPPER EDGE AND CEILING -------------------- 2 FEET
DISTANCE BETWEEN WINDOW LOWER EDGE AND FLOOR ---------------------- 3 FEET
TRANSMISSION FACTOR OF WINDOW --- 1.0 REFLECTANCE OF EXTERIOR GROUND -- .31
REFLECTANCE FACTORS LEFT WALL--- .06 BACK WALL--- .06 RIGHT WALL----- .06
CEILING----- .06 FLOOR------- .06 WINDOW WALL --- .06

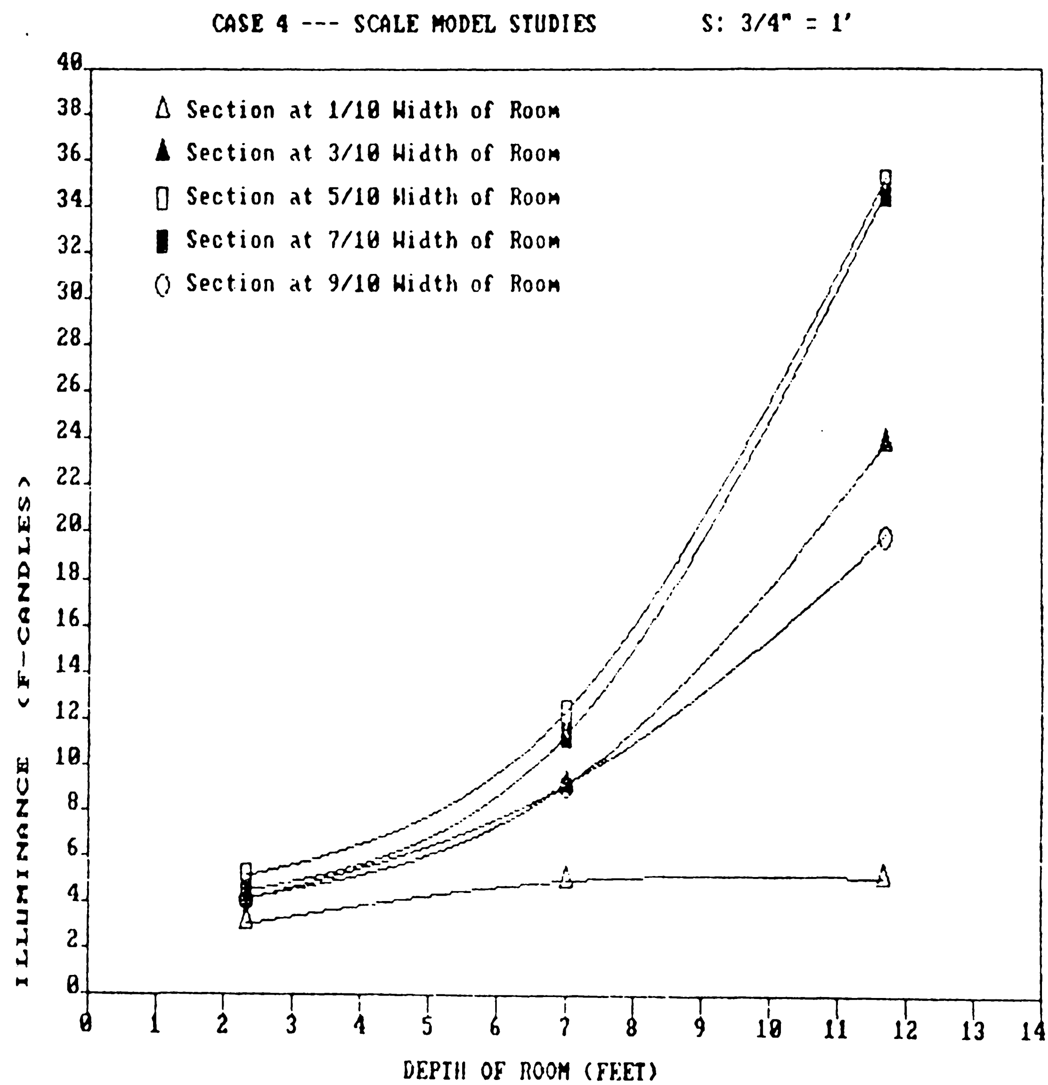


Figure 32. Scale Model Studies --- Case 4

5.3 Comparison of Experimental and Theoretical Results

The mathematical model for predicting daylight distribution has been validated by the scale model studies. The scale model study was selected because it represents the simplest, most acceptable, and most reliable technique for simulating daylighting distribution, as mentioned in Chapter 2.

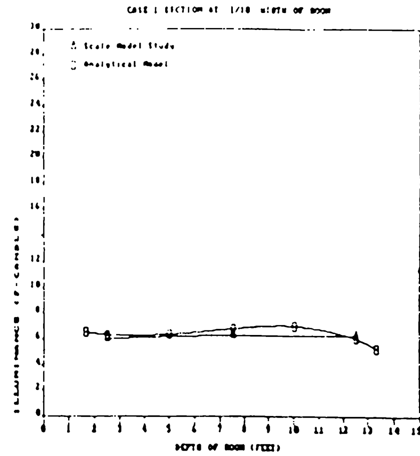
To validate the daylighting predictability of the proposed mathematical model, measurements were made in models in Skydome. The major concern in validation of the mathematical model was how accurately the daylighting distribution might be predicted as compared to the model studies.

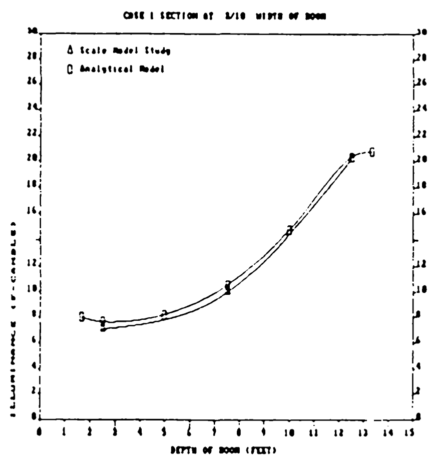
Forty-eight cases were studied and in most of them the agreements were quite good, considering the unavoidable uncertainties in generating both instrumentation and scale model construction. Four cases are presented in Figures 33-36, which plot measured illuminance in the scale model studies and the corresponding computed values generated by the mathematical model. The completed data lists of these 4 cases, both collected from experiments and generated from computer simulations, are listed in Appendix H.

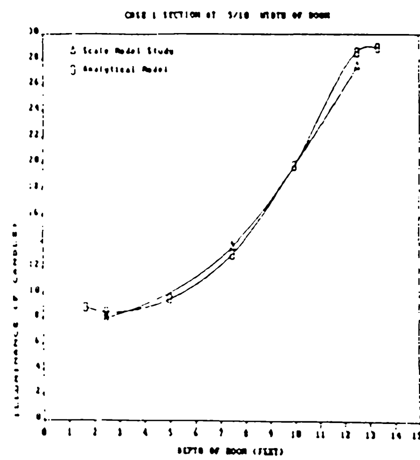
The difference in the data of these 4 cases between the scale model studies and the mathematical model were computed and all presented in Tables 6-9. It can be observed from these 4 tables that the greatest difference between the mathematical model results and the scale model results in 14 percent, which occurs in 3 out of 3,000 observations at channel 5 in case 1. It should be noted that the greatest portion of this difference occurred at the very lowest illuminance levels, which can be explained by the fact that photometers have lower linearity at low illuminance situation as mentioned in section 5.1. The differences are less than 10 percent in most other observations of each channel for each case. The standard deviations for the scale model data are less than 5 percent compare to the mean values respectively. These results suggest a satisfactory correlation between the scale model studies and the mathematical model.

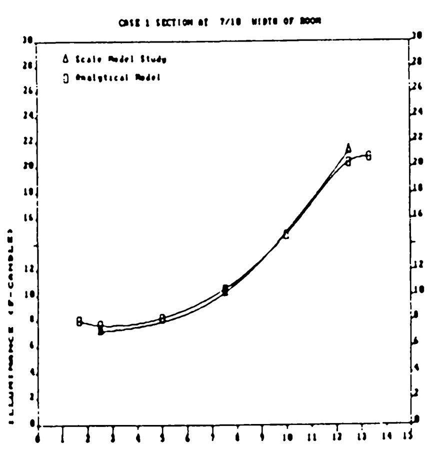
TEST CONDITION

ILLUMINANCE ---- 105.9381 FOOTCANDLES
ROOM DIMENSION 15(D) 26(W) 12(H) FEET
DISTANCE BETWEEN WINDOW FRAME AND
LEFT WALL ------------ 7 FEET
RIGHT WALL ----------- 7 FEET
CEILEING ------------- 2 FEET
FLOOR ---------------- 4 FEET
WINDOW TRANSMISSION ------------- 1.0
REFLECTANCE FACTORS:
EXTERIOR GROUND ---------------- .31
LEFT WALL -- .51 RIGHT WALL -- .51
BACK WALL -- .51 WINDOW WALL - .51
CEILING ---- .76 FLOOR ------- .06









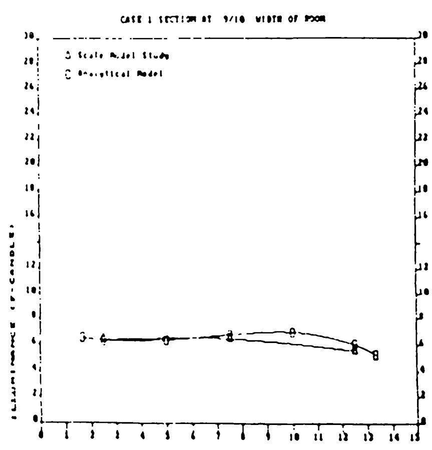
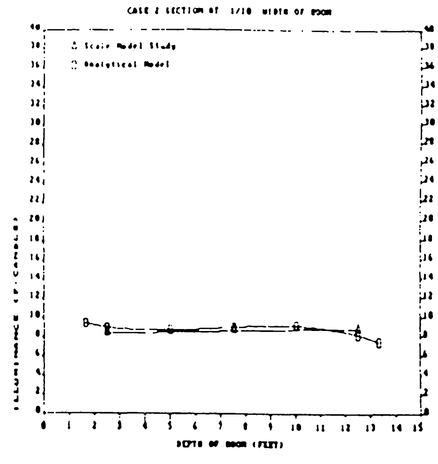


Figure 33. Comparison of Experimental and Theoretical Results --- Case 1

TEST CONDITION

ILLUMINANCE ---- 105.1735 FOOTCANDLES
ROOM DIMENSION 15(D) 26(W) 12(H) FEET
DISTANCE BETWEEN WINDOW FRAME AND
LEFT WALL ------------ 7 FEET
RIGHT WALL ----------- 7 FEET
CEILEING ------------- 2 FEET
FLOOR ---------------- 4 FEET
WINDOW TRANSMISSION ------------ 1.0
REFLECTANCE FACTORS:
EXTERIOR GROUND ---------------- .31
LEFT WALL -- .76   RIGHT WALL -- .76
BACK WALL -- .76   WINDOW WALL - .76
CEILING ---- .76   FLOOR ------- .76



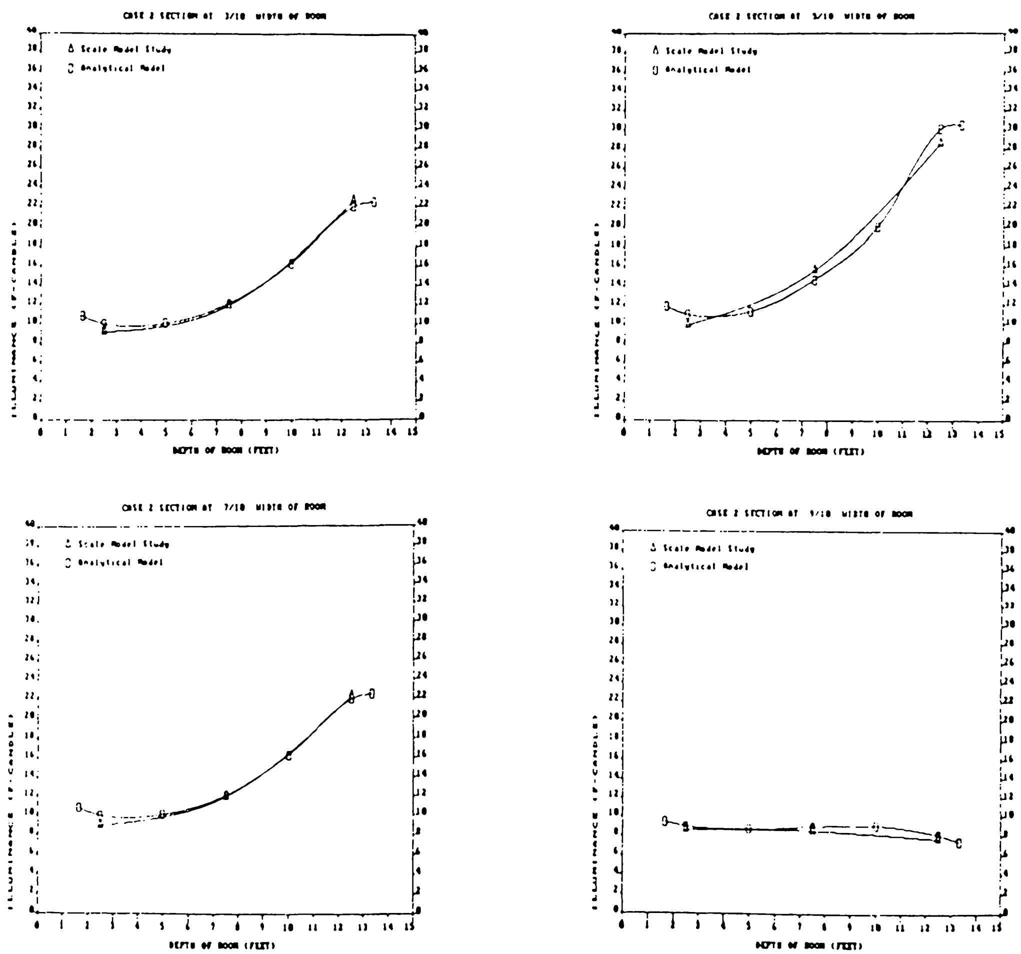
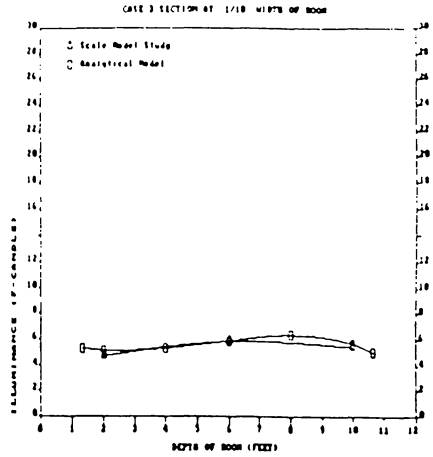
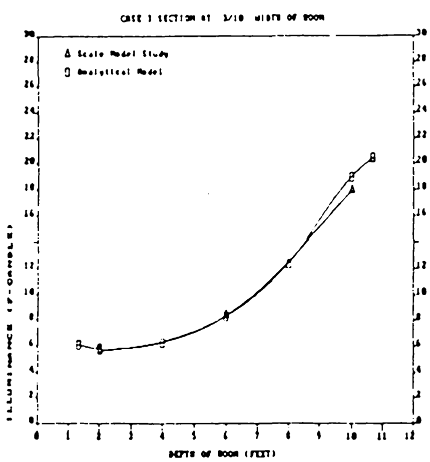


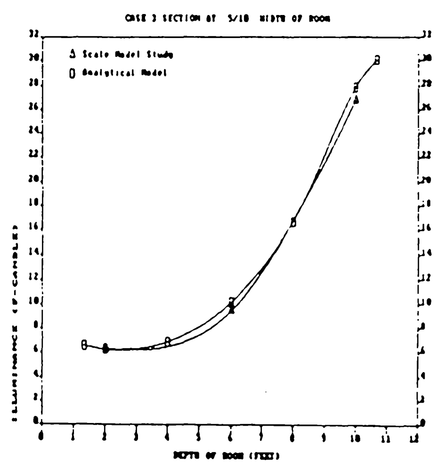
Figure 34. Comparison of Experimental and Theoretical Results --- Case 2

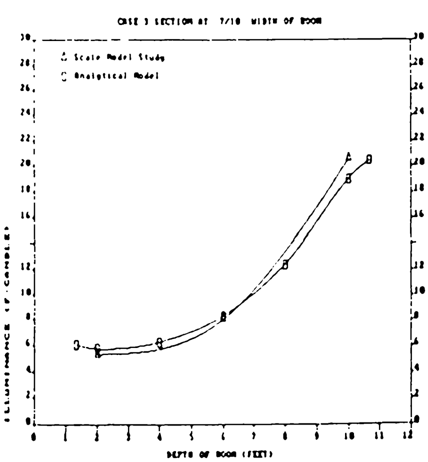
TEST CONDITION

ILLUMINANCE ---- 111.9105 FOOTCANDLES
ROOM DIMENSION 12(D) 15(W) 10(H) FEET
DISTANCE BETWEEN WINDOW FRAME AND
  LEFT WALL ----------- 5 FEET
  RIGHT WALL ---------- 5 FEET
  CEILEING ------------ 2.5 FEET
  FLOOR --------------- 3.5 FEET
WINDOW TRANSMISSION ------------- 1.0
REFLECTANCE FACTORS:
 EXTERIOR GROUND ---------------- .31
 LEFT WALL -- .51   RIGHT WALL -- .51
 BACK WALL -- .51   WINDOW WALL - .51
 CEILING ---- .84   FLOOR ------- .06









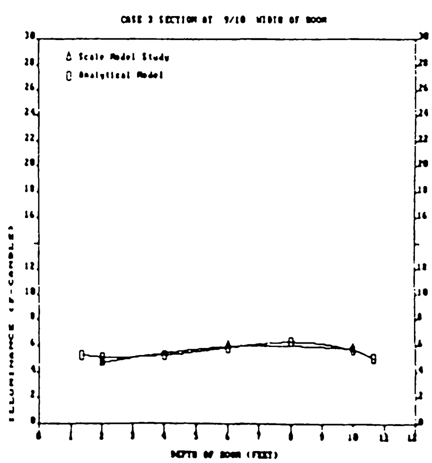
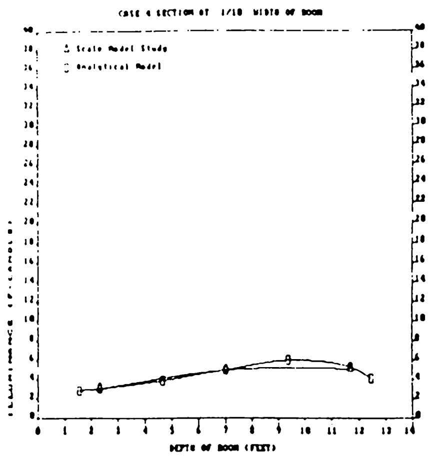
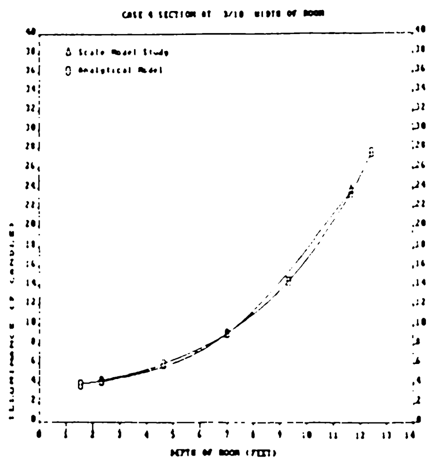


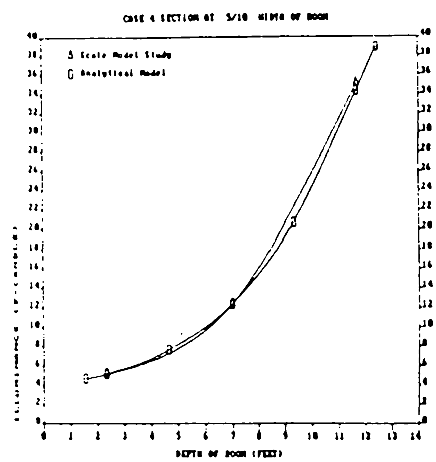
Figure 35. Comparison of Experimental and Theoretical Results --- Case 3

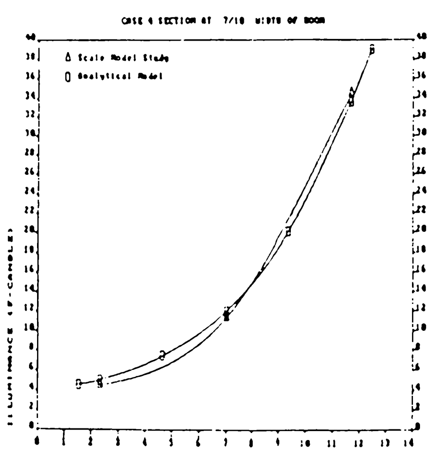
TEST CONDITION

ILLUMINANCE ---- 112.0621 FOOTCANDLES
ROOM DIMENSION 14(D) 19(W) 12(H) FEET
DISTANCE BETWEEN WINDOW FRAME AND
LEFT WALL ------------ 5 FEET
RIGHT WALL ----------- 2 FEET
CEILEING ------------- 2 FEET
FLOOR ---------------- 3 FEET
WINDOW TRANSMISSION ------------ 1.0
REFLECTANCE FACTORS:
EXTERIOR GROUND ---------------- .31
LEFT WALL -- .06   RIGHT WALL -- .06
BACK WALL -- .06   WINDOW WALL - .06
CEILING ---- .06   FLOOR ------- .06









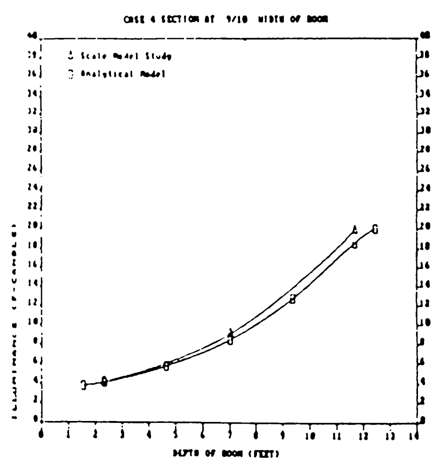


Figure 36. Comparison of Experimental and Theoretical Results --- Case 4

Table 6. Difference Analysis of Experimental and Theoretical Results --- Case 1

Case 1

DIFFERENCE ANALYSIS BETWEEN MODEL STUDY AND COMPUTER SIMULATION

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	0.01	0.01	0.04	0.06	0.11	0.08	0.04	0.03	0.04	0.04	0.05	0.08	0.06	0.06	0.01
2	0.03	0.02	0.05	0.05	0.09	0.09	0.03	0.03	0.03	0.05	0.05	0.07	0.05	0.07	0.00
3	0.03	0.01	0.01	0.03	0.12	0.07	0.05	0.03	0.03	0.05	0.05	0.07	0.09	0.07	0.03
4	0.00	0.02	0.03	0.06	0.10	0.08	0.05	0.05	0.03	0.05	0.07	0.09	0.06	0.07	0.05
5	0.04	0.01	0.06	0.05	0.08	0.09	0.06	0.04	0.03	0.05	0.05	0.10	0.06	0.07	0.05
6	0.03	0.00	0.05	0.02	0.08	0.08	0.05	0.03	0.03	0.01	0.05	0.06	0.05	0.08	0.00
7	0.09	0.01	0.02	0.04	0.11	0.09	0.04	0.04	0.04	0.05	0.05	0.06	0.05	0.07	0.01
8	0.05	0.01	0.03	0.08	0.09	0.08	0.04	0.04	0.03	0.07	0.05	0.06	0.04	0.04	0.01
9	0.03	0.02	0.05	0.06	0.09	0.09	0.05	0.05	0.03	0.06	0.06	0.09	0.06	0.06	0.00
10	0.05	0.00	0.05	0.02	0.06	0.06	0.06	0.04	0.03	0.05	0.04	0.06	0.05	0.07	0.00
11	0.03	0.02	0.02	0.04	0.07	0.08	0.05	0.04	0.04	0.05	0.05	0.07	0.05	0.05	0.00
12	0.03	0.01	0.04	0.06	0.07	0.08	0.03	0.04	0.03	0.04	0.05	0.06	0.05	0.05	0.01
13	0.03	0.02	0.06	0.05	0.07	0.06	0.06	0.06	0.04	0.05	0.05	0.07	0.04	0.04	0.04
14	0.04	0.02	0.05	0.06	0.05	0.09	0.06	0.06	0.03	0.05	0.05	0.07	0.05	0.05	0.01
15	0.03	0.02	0.05	0.06	0.07	0.07	0.05	0.04	0.03	0.06	0.06	0.07	0.05	0.05	0.05
16	0.05	0.01	0.06	0.06	0.10	0.07	0.05	0.06	0.03	0.05	0.07	0.09	0.07	0.07	0.01
17	0.03	0.00	0.03	0.01	0.07	0.08	0.06	0.03	0.03	0.05	0.04	0.07	0.05	0.05	0.01
18	0.06	0.02	0.05	0.05	0.01	0.09	0.07	0.04	0.03	0.05	0.05	0.08	0.08	0.07	0.03
19	0.03	0.00	0.03	0.01	0.07	0.07	0.07	0.03	0.04	0.04	0.05	0.09	0.05	0.07	0.01
20	0.04	0.01	0.02	0.04	0.07	0.06	0.05	0.03	0.04	0.05	0.05	0.07	0.05	0.06	0.01
21	0.00	0.02	0.05	0.05	0.07	0.08	0.06	0.06	0.03	0.05	0.07	0.10	0.08	0.07	0.02
22	0.01	0.00	0.04	0.03	0.07	0.08	0.08	0.03	0.03	0.02	0.05	0.06	0.09	0.05	0.01
23	0.09	0.01	0.04	0.05	0.11	0.07	0.05	0.04	0.03	0.05	0.06	0.09	0.07	0.07	0.03
24	0.03	0.00	0.04	0.02	0.07	0.08	0.06	0.03	0.03	0.05	0.05	0.07	0.05	0.07	0.01
25	0.03	0.00	0.03	0.01	0.07	0.08	0.06	0.03	0.02	0.05	0.05	0.07	0.05	0.07	0.00
26	0.00	0.01	0.01	0.05	0.08	0.07	0.04	0.05	0.03	0.05	0.05	0.07	0.05	0.05	0.00
27	0.03	0.00	0.07	0.05	0.09	0.08	0.06	0.06	0.04	0.01	0.05	0.10	0.07	0.07	0.03
28	0.03	0.01	0.03	0.04	0.08	0.07	0.03	0.04	0.04	0.05	0.04	0.06	0.05	0.06	0.01
29	0.06	0.02	0.06	0.06	0.01	0.07	0.05	0.06	0.03	0.05	0.06	0.10	0.07	0.07	0.01
30	0.03	0.00	0.07	0.04	0.07	0.08	0.07	0.04	0.01	0.05	0.05	0.08	0.07	0.07	0.02
31	0.01	0.01	0.01	0.02	0.09	0.07	0.04	0.04	0.03	0.05	0.06	0.09	0.04	0.05	0.01
32	0.03	0.00	0.06	0.04	0.01	0.07	0.06	0.03	0.01	0.01	0.05	0.07	0.09	0.08	0.01
33	0.03	0.01	0.05	0.03	0.04	0.07	0.07	0.04	0.03	0.01	0.05	0.07	0.08	0.08	0.01
34	0.03	0.00	0.02	0.03	0.07	0.06	0.06	0.03	0.03	0.05	0.04	0.07	0.05	0.05	0.02
35	0.03	0.02	0.06	0.05	0.07	0.09	0.07	0.05	0.03	0.05	0.05	0.10	0.06	0.08	0.01
36	0.03	0.00	0.05	0.02	0.07	0.06	0.06	0.04	0.02	0.01	0.05	0.07	0.07	0.08	0.01
37	0.01	0.00	0.03	0.03	0.07	0.05	0.06	0.03	0.03	0.05	0.04	0.07	0.05	0.06	0.03
38	0.03	0.03	0.05	0.04	0.08	0.10	0.06	0.05	0.01	0.04	0.06	0.08	0.09	0.07	0.00
39	0.03	0.01	0.02	0.02	0.07	0.06	0.05	0.03	0.04	0.05	0.05	0.06	0.05	0.06	0.00
40	0.04	0.01	0.05	0.05	0.14	0.06	0.06	0.05	0.02	0.05	0.05	0.08	0.09	0.07	0.01
41	0.00	0.00	0.02	0.02	0.14	0.06	0.04	0.04	0.04	0.05	0.05	0.07	0.05	0.05	0.04
42	0.03	0.01	0.02	0.04	0.14	0.06	0.04	0.05	0.04	0.05	0.07	0.07	0.05	0.05	0.03
43	0.03	0.03	0.05	0.06	0.07	0.09	0.06	0.06	0.03	0.05	0.07	0.09	0.07	0.08	0.01
44	0.02	0.00	0.03	0.01	0.09	0.07	0.05	0.04	0.04	0.05	0.05	0.06	0.06	0.05	0.01
45	0.05	0.02	0.06	0.06	0.07	0.08	0.05	0.04	0.03	0.05	0.06	0.09	0.09	0.07	0.00
46	0.03	0.00	0.05	0.02	0.03	0.07	0.06	0.04	0.03	0.04	0.05	0.09	0.06	0.08	0.03
47	0.03	0.00	0.03	0.04	0.07	0.06	0.04	0.03	0.04	0.05	0.05	0.07	0.06	0.05	0.04
48	0.07	0.01	0.05	0.06	0.04	0.08	0.07	0.05	0.03	0.05	0.07	0.07	0.07	0.07	0.01
49	0.03	0.01	0.05	0.02	0.07	0.07	0.06	0.03	0.03	0.04	0.05	0.08	0.06	0.07	0.05
50	0.05	0.02	0.03	0.05	0.01	0.08	0.05	0.06	0.02	0.05	0.05	0.09	0.05	0.07	0.05

Table 7. Difference Analysis of Experimental and Theoretical Results --- Case 2

Case 2

DIFFERENCE ANALYSIS BETWEEN MODEL STUDY AND COMPUTER SIMULATION

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	0.07	0.02	0.05	0.02	0.04	0.05	0.00	0.06	0.00	0.02	0.07	0.08	0.10	0.11	0.04
2	0.11	0.03	0.07	0.02	0.04	0.04	0.04	0.07	0.01	0.05	0.07	0.08	0.10	0.10	0.03
3	0.12	0.04	0.07	0.03	0.02	0.07	0.03	0.07	0.00	0.05	0.07	0.08	0.09	0.10	0.04
4	0.07	0.01	0.04	0.03	0.08	0.05	0.02	0.08	0.02	0.05	0.07	0.09	0.10	0.10	0.04
5	0.08	0.04	0.06	0.00	0.00	0.03	0.03	0.07	0.00	0.05	0.07	0.08	0.09	0.11	0.04
6	0.08	0.01	0.02	0.04	0.09	0.05	0.00	0.08	0.02	0.05	0.08	0.10	0.09	0.11	0.02
7	0.09	0.05	0.06	0.00	0.06	0.04	0.03	0.07	0.01	0.07	0.08	0.09	0.10	0.11	0.02
8	0.07	0.03	0.07	0.00	0.05	0.04	0.03	0.07	0.00	0.05	0.08	0.09	0.10	0.10	0.06
9	0.07	0.04	0.06	0.00	0.06	0.04	0.03	0.06	0.00	0.05	0.07	0.08	0.10	0.13	0.07
10	0.08	0.03	0.03	0.01	0.08	0.04	0.00	0.07	0.02	0.05	0.06	0.08	0.09	0.11	0.05
11	0.04	0.03	0.07	0.04	0.05	0.06	0.02	0.07	0.02	0.05	0.08	0.09	0.11	0.11	0.06
12	0.07	0.03	0.06	0.01	0.06	0.05	0.04	0.06	0.00	0.05	0.08	0.09	0.12	0.11	0.03
13	0.09	0.04	0.05	0.01	0.07	0.03	0.02	0.04	0.02	0.01	0.06	0.08	0.10	0.11	0.08
14	0.07	0.03	0.01	0.01	0.12	0.03	0.00	0.07	0.02	0.05	0.07	0.08	0.10	0.10	0.07
15	0.10	0.02	0.07	0.01	0.02	0.04	0.02	0.08	0.00	0.05	0.09	0.08	0.10	0.10	0.02
16	0.05	0.05	0.05	0.00	0.03	0.04	0.03	0.05	0.03	0.05	0.06	0.08	0.10	0.11	0.07
17	0.08	0.03	0.03	0.04	0.05	0.04	0.00	0.05	0.03	0.05	0.07	0.08	0.09	0.10	0.03
18	0.08	0.02	0.06	0.02	0.07	0.04	0.03	0.07	0.00	0.06	0.09	0.10	0.11	0.11	0.03
19	0.12	0.01	0.08	0.03	0.05	0.04	0.02	0.07	0.02	0.05	0.09	0.08	0.10	0.11	0.07
20	0.12	0.04	0.07	0.01	0.04	0.05	0.02	0.07	0.02	0.05	0.07	0.08	0.09	0.10	0.06
21	0.12	0.01	0.05	0.02	0.08	0.07	0.02	0.07	0.01	0.05	0.08	0.09	0.10	0.10	0.03
22	0.10	0.04	0.03	0.00	0.00	0.04	0.02	0.05	0.02	0.05	0.08	0.08	0.09	0.11	0.06
23	0.05	0.02	0.03	0.04	0.07	0.04	0.00	0.07	0.02	0.05	0.06	0.08	0.09	0.10	0.05
24	0.04	0.03	0.03	0.01	0.08	0.03	0.00	0.08	0.02	0.05	0.07	0.08	0.09	0.10	0.03
25	0.10	0.03	0.07	0.03	0.06	0.05	0.04	0.07	0.00	0.05	0.07	0.10	0.10	0.11	0.02
26	0.08	0.03	0.02	0.01	0.08	0.04	0.00	0.07	0.02	0.05	0.06	0.08	0.09	0.10	0.02
27	0.09	0.03	0.07	0.03	0.05	0.05	0.03	0.07	0.00	0.03	0.07	0.09	0.11	0.12	0.07
28	0.04	0.03	0.03	0.02	0.07	0.04	0.00	0.07	0.02	0.05	0.07	0.08	0.10	0.10	0.04
29	0.12	0.02	0.06	0.04	0.06	0.04	0.00	0.07	0.02	0.05	0.08	0.10	0.11	0.11	0.07
30	0.07	0.03	0.05	0.00	0.05	0.03	0.03	0.05	0.01	0.05	0.07	0.08	0.11	0.11	0.07
31	0.03	0.02	0.05	0.03	0.08	0.05	0.01	0.07	0.01	0.06	0.09	0.09	0.10	0.12	0.05
32	0.03	0.04	0.04	0.00	0.05	0.06	0.04	0.07	0.02	0.05	0.07	0.09	0.11	0.12	0.08
33	0.04	0.02	0.04	0.01	0.05	0.03	0.00	0.06	0.03	0.05	0.08	0.09	0.10	0.11	0.04
34	0.06	0.03	0.07	0.00	0.01	0.04	0.03	0.07	0.02	0.05	0.09	0.09	0.11	0.11	0.07
35	0.07	0.02	0.08	0.00	0.06	0.06	0.03	0.06	0.01	0.05	0.08	0.10	0.11	0.12	0.07
36	0.07	0.03	0.04	0.01	0.08	0.04	0.03	0.04	0.03	0.05	0.06	0.08	0.10	0.11	0.08
37	0.08	0.02	0.03	0.01	0.07	0.04	0.01	0.07	0.04	0.05	0.08	0.09	0.09	0.10	0.04
38	0.09	0.02	0.07	0.00	0.04	0.06	0.04	0.07	0.00	0.07	0.07	0.09	0.10	0.10	0.03
39	0.08	0.04	0.06	0.00	0.03	0.04	0.03	0.05	0.02	0.03	0.06	0.09	0.10	0.11	0.07
40	0.03	0.02	0.03	0.04	0.08	0.04	0.00	0.07	0.02	0.05	0.09	0.09	0.09	0.11	0.00
41	0.08	0.02	0.06	0.02	0.08	0.06	0.03	0.07	0.00	0.05	0.07	0.10	0.10	0.11	0.03
42	0.07	0.02	0.06	0.01	0.07	0.04	0.02	0.06	0.01	0.04	0.07	0.09	0.10	0.12	0.07
43	0.10	0.02	0.03	0.02	0.08	0.04	0.01	0.07	0.02	0.05	0.09	0.10	0.10	0.12	0.06
44	0.04	0.05	0.03	0.01	0.06	0.04	0.01	0.05	0.03	0.05	0.08	0.08	0.10	0.10	0.00
45	0.07	0.01	0.07	0.04	0.08	0.04	0.01	0.07	0.03	0.05	0.08	0.09	0.10	0.11	0.03
46	0.09	0.02	0.07	0.01	0.04	0.04	0.04	0.06	0.00	0.04	0.07	0.09	0.11	0.10	0.07
47	0.07	0.03	0.03	0.01	0.05	0.03	0.02	0.05	0.03	0.05	0.06	0.06	0.09	0.12	0.03
48	0.08	0.02	0.03	0.02	0.07	0.07	0.02	0.07	0.01	0.05	0.08	0.08	0.11	0.12	0.03
49	0.07	0.04	0.03	0.00	0.03	0.04	0.01	0.06	0.03	0.05	0.07	0.08	0.09	0.09	0.04
50	0.07	0.03	0.07	0.01	0.07	0.04	0.02	0.07	0.00	0.05	0.09	0.08	0.10	0.10	0.06

Table 8. Difference Analysis of Experimental and Theoretical Results --- Case 3

Case 3

DIFFERENCE ANALYSIS BETWEEN MODEL STUDY AND COMPUTER SIMULATION

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	0.08	0.04	0.04	0.09	0.00	0.01	0.01	0.07	0.02	0.01	0.07	0.00	0.01	0.06	0.08
2	0.00	0.04	0.05	0.08	0.05	0.00	0.01	0.08	0.04	0.01	0.07	0.04	0.01	0.07	0.07
3	0.06	0.06	0.05	0.10	0.00	0.01	0.03	0.07	0.03	0.01	0.09	0.02	0.01	0.07	0.08
4	0.08	0.06	0.06	0.11	0.02	0.03	0.01	0.07	0.02	0.00	0.07	0.03	0.02	0.09	0.13
5	0.05	0.09	0.02	0.08	0.01	0.01	0.01	0.07	0.04	0.02	0.11	0.03	0.00	0.09	0.08
6	0.06	0.07	0.02	0.07	0.03	0.01	0.03	0.07	0.05	0.01	0.07	0.02	0.02	0.06	0.10
7	0.00	0.07	0.06	0.10	0.03	0.02	0.01	0.08	0.04	0.00	0.11	0.06	0.01	0.07	0.08
8	0.06	0.07	0.05	0.10	0.00	0.03	0.00	0.07	0.03	0.02	0.10	0.02	0.01	0.08	0.08
9	0.07	0.07	0.02	0.05	0.02	0.01	0.01	0.09	0.05	0.02	0.07	0.03	0.02	0.07	0.08
10	0.08	0.07	0.02	0.09	0.00	0.01	0.03	0.08	0.06	0.01	0.07	0.02	0.00	0.06	0.06
11	0.03	0.06	0.05	0.09	0.05	0.01	0.00	0.07	0.04	0.02	0.10	0.06	0.01	0.07	0.08
12	0.06	0.04	0.06	0.10	0.03	0.01	0.00	0.08	0.05	0.02	0.10	0.06	0.00	0.06	0.08
13	0.03	0.06	0.05	0.07	0.01	0.01	0.00	0.08	0.04	0.01	0.07	0.06	0.02	0.08	0.13
14	0.06	0.05	0.05	0.07	0.03	0.01	0.00	0.07	0.04	0.03	0.10	0.03	0.01	0.09	0.09
15	0.05	0.05	0.04	0.06	0.05	0.00	0.03	0.09	0.04	0.01	0.07	0.02	0.02	0.07	0.08
16	0.08	0.06	0.03	0.08	0.00	0.01	0.02	0.07	0.05	0.01	0.10	0.04	0.02	0.07	0.06
17	0.05	0.04	0.05	0.07	0.02	0.01	0.00	0.08	0.04	0.03	0.09	0.02	0.01	0.09	0.10
18	0.06	0.06	0.02	0.07	0.02	0.03	0.01	0.07	0.04	0.01	0.10	0.04	0.00	0.08	0.08
19	0.05	0.08	0.05	0.10	0.02	0.02	0.01	0.08	0.04	0.01	0.10	0.04	0.02	0.07	0.08
20	0.01	0.06	0.05	0.06	0.02	0.01	0.00	0.07	0.04	0.02	0.07	0.03	0.02	0.08	0.09
21	0.05	0.06	0.02	0.06	0.01	0.01	0.00	0.07	0.03	0.01	0.07	0.02	0.01	0.07	0.13
22	0.10	0.05	0.02	0.06	0.00	0.00	0.02	0.07	0.05	0.01	0.10	0.03	0.01	0.07	0.08
23	0.07	0.06	0.06	0.08	0.00	0.03	0.00	0.07	0.03	0.05	0.07	0.04	0.01	0.10	0.09
24	0.08	0.04	0.05	0.10	0.04	0.02	0.01	0.07	0.04	0.01	0.07	0.04	0.01	0.08	0.08
25	0.05	0.05	0.00	0.07	0.01	0.01	0.01	0.07	0.04	0.01	0.07	0.04	0.01	0.08	0.09
26	0.06	0.06	0.03	0.08	0.03	0.02	0.02	0.07	0.04	0.01	0.10	0.04	0.02	0.09	0.08
27	0.05	0.06	0.07	0.06	0.01	0.03	0.01	0.08	0.04	0.01	0.07	0.06	0.03	0.11	0.10
28	0.08	0.06	0.02	0.06	0.00	0.00	0.02	0.07	0.04	0.02	0.07	0.03	0.00	0.07	0.09
29	0.06	0.07	0.07	0.12	0.00	0.03	0.00	0.07	0.03	0.01	0.11	0.06	0.02	0.09	0.08
30	0.06	0.06	0.02	0.06	0.00	0.01	0.00	0.09	0.05	0.01	0.07	0.03	0.01	0.09	0.10
31	0.07	0.06	0.02	0.08	0.05	0.01	0.05	0.07	0.06	0.00	0.10	0.04	0.00	0.07	0.08
32	0.07	0.05	0.07	0.08	0.05	0.01	0.01	0.09	0.04	0.01	0.10	0.04	0.01	0.08	0.09
33	0.05	0.05	0.03	0.08	0.02	0.01	0.02	0.07	0.06	0.01	0.07	0.01	0.01	0.07	0.08
34	0.03	0.07	0.05	0.10	0.03	0.01	0.02	0.08	0.06	0.00	0.11	0.06	0.00	0.07	0.13
35	0.02	0.04	0.06	0.09	0.02	0.03	0.01	0.08	0.03	0.03	0.07	0.04	0.00	0.07	0.09
36	0.06	0.05	0.07	0.06	0.00	0.03	0.01	0.08	0.04	0.02	0.07	0.02	0.01	0.08	0.07
37	0.06	0.06	0.03	0.11	0.01	0.01	0.02	0.08	0.03	0.01	0.10	0.04	0.00	0.07	0.08
38	0.01	0.06	0.04	0.09	0.04	0.01	0.01	0.08	0.04	0.02	0.07	0.02	0.01	0.08	0.09
39	0.06	0.05	0.02	0.08	0.02	0.00	0.00	0.07	0.04	0.02	0.07	0.04	0.01	0.08	0.08
40	0.06	0.06	0.02	0.08	0.00	0.01	0.02	0.08	0.06	0.01	0.07	0.02	0.01	0.07	0.05
41	0.05	0.04	0.01	0.06	0.01	0.01	0.00	0.07	0.02	0.03	0.07	0.06	0.00	0.08	0.08
42	0.06	0.06	0.02	0.08	0.02	0.00	0.00	0.07	0.04	0.02	0.07	0.04	0.01	0.08	0.09
43	0.00	0.06	0.01	0.08	0.02	0.01	0.03	0.08	0.05	0.01	0.09	0.02	0.00	0.07	0.08
44	0.00	0.06	0.05	0.10	0.00	0.05	0.01	0.08	0.04	0.02	0.10	0.03	0.02	0.08	0.08
45	0.03	0.04	0.05	0.05	0.00	0.01	0.02	0.07	0.05	0.02	0.09	0.03	0.00	0.07	0.08
46	0.00	0.06	0.05	0.10	0.00	0.01	0.00	0.08	0.03	0.01	0.11	0.06	0.00	0.08	0.09
47	0.08	0.05	0.05	0.07	0.03	0.00	0.00	0.08	0.04	0.03	0.07	0.03	0.02	0.07	0.08
48	0.06	0.04	0.03	0.07	0.05	0.01	0.00	0.09	0.05	0.02	0.07	0.04	0.03	0.09	0.11
49	0.05	0.04	0.06	0.08	0.00	0.02	0.01	0.07	0.04	0.02	0.09	0.02	0.02	0.08	0.10
50	0.04	0.06	0.01	0.07	0.00	0.01	0.02	0.08	0.22	0.00	0.10	0.05	0.01	0.07	0.07

Table 9. Difference Analysis of Experimental and Theoretical Results --- Case 4

Case 4

DIFFERENCE ANALYSIS BETWEEN MODEL STUDY AND COMPUTER SIMULATION

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	0.04	0.03	0.01	0.01	0.07	0.01	0.03	0.01	0.05	0.08	0.02	0.02	0.02	0.12	0.03
2	0.06	0.00	0.04	0.04	0.06	0.02	0.00	0.02	0.07	0.07	0.00	0.03	0.01	0.11	0.02
3	0.05	0.00	0.03	0.04	0.05	0.00	0.01	0.00	0.06	0.06	0.04	0.02	0.01	0.13	0.01
4	0.07	0.00	0.01	0.04	0.06	0.02	0.02	0.00	0.06	0.07	0.01	0.02	0.02	0.11	0.02
5	0.02	0.00	0.01	0.03	0.05	0.02	0.01	0.01	0.06	0.06	0.00	0.02	0.01	0.11	0.03
6	0.02	0.00	0.02	0.04	0.06	0.01	0.01	0.00	0.06	0.07	0.01	0.02	0.00	0.08	0.02
7	0.03	0.00	0.05	0.03	0.05	0.00	0.01	0.01	0.07	0.06	0.00	0.01	0.00	0.10	0.00
8	0.06	0.00	0.02	0.04	0.07	0.04	0.01	0.01	0.05	0.07	0.01	0.05	0.01	0.12	0.01
9	0.03	0.02	0.02	0.02	0.09	0.01	0.02	0.01	0.05	0.08	0.01	0.01	0.01	0.12	0.00
10	0.03	0.00	0.05	0.04	0.04	0.02	0.01	0.01	0.06	0.07	0.01	0.02	0.01	0.09	0.04
11	0.06	0.00	0.01	0.03	0.08	0.02	0.00	0.00	0.05	0.07	0.01	0.02	0.01	0.09	0.02
12	0.04	0.00	0.00	0.02	0.07	0.02	0.02	0.00	0.06	0.07	0.01	0.03	0.02	0.12	0.02
13	0.07	0.02	0.05	0.00	0.06	0.00	0.02	0.00	0.06	0.07	0.00	0.08	0.01	0.12	0.02
14	0.05	0.00	0.04	0.00	0.05	0.01	0.02	0.01	0.07	0.07	0.00	0.02	0.00	0.12	0.02
15	0.06	0.00	0.02	0.02	0.06	0.00	0.02	0.00	0.07	0.07	0.01	0.02	0.01	0.10	0.03
16	0.03	0.00	0.05	0.04	0.06	0.01	0.00	0.01	0.06	0.08	0.02	0.01	0.01	0.12	0.01
17	0.04	0.01	0.02	0.04	0.06	0.01	0.00	0.01	0.06	0.06	0.00	0.01	0.01	0.09	0.01
18	0.02	0.01	0.01	0.02	0.10	0.01	0.02	0.01	0.06	0.06	0.00	0.03	0.01	0.11	0.01
19	0.06	0.02	0.01	0.01	0.09	0.01	0.02	0.00	0.04	0.09	0.01	0.03	0.01	0.12	0.00
20	0.04	0.02	0.03	0.02	0.05	0.02	0.00	0.00	0.05	0.08	0.01	0.02	0.01	0.09	0.02
21	0.01	0.00	0.03	0.04	0.06	0.01	0.00	0.01	0.06	0.05	0.01	0.03	0.01	0.11	0.01
22	0.01	0.02	0.01	0.01	0.08	0.01	0.02	0.02	0.05	0.07	0.00	0.03	0.01	0.12	0.02
23	0.03	0.02	0.05	0.00	0.07	0.00	0.00	0.01	0.07	0.06	0.01	0.01	0.01	0.08	0.02
24	0.02	0.00	0.01	0.04	0.10	0.02	0.02	0.00	0.07	0.06	0.04	0.02	0.01	0.08	0.02
25	0.04	0.01	0.01	0.04	0.07	0.02	0.02	0.00	0.06	0.07	0.02	0.03	0.00	0.10	0.02
26	0.01	0.03	0.02	0.03	0.09	0.01	0.03	0.00	0.05	0.08	0.01	0.02	0.01	0.12	0.00
27	0.05	0.02	0.05	0.03	0.05	0.00	0.01	0.01	0.06	0.06	0.00	0.01	0.00	0.08	0.02
28	0.04	0.01	0.01	0.04	0.04	0.01	0.02	0.00	0.05	0.08	0.00	0.04	0.02	0.13	0.01
29	0.01	0.02	0.04	0.02	0.06	0.01	0.01	0.01	0.07	0.07	0.00	0.03	0.01	0.12	0.02
30	0.06	0.00	0.05	0.03	0.04	0.01	0.00	0.01	0.06	0.06	0.01	0.02	0.01	0.12	0.01
31	0.02	0.03	0.01	0.01	0.08	0.01	0.02	0.00	0.05	0.09	0.00	0.04	0.01	0.12	0.02
32	0.04	0.02	0.04	0.03	0.05	0.00	0.00	0.01	0.06	0.06	0.04	0.01	0.00	0.10	0.03
33	0.00	0.00	0.01	0.04	0.05	0.01	0.01	0.01	0.05	0.08	0.01	0.02	0.01	0.13	0.01
34	0.05	0.01	0.05	0.02	0.08	0.01	0.01	0.01	0.06	0.07	0.04	0.02	0.00	0.09	0.01
35	0.04	0.03	0.00	0.02	0.09	0.02	0.02	0.01	0.04	0.07	0.00	0.03	0.01	0.08	0.00
36	0.01	0.02	0.01	0.03	0.07	0.02	0.03	0.00	0.05	0.08	0.02	0.03	0.01	0.12	0.01
37	0.05	0.03	0.05	0.01	0.08	0.01	0.01	0.00	0.06	0.07	0.00	0.02	0.02	0.12	0.02
38	0.00	0.00	0.02	0.03	0.08	0.02	0.00	0.00	0.05	0.06	0.02	0.04	0.02	0.12	0.02
39	0.01	0.00	0.01	0.01	0.03	0.01	0.03	0.01	0.05	0.09	0.02	0.03	0.01	0.13	0.01
40	0.08	0.01	0.02	0.00	0.01	0.02	0.02	0.01	0.07	0.05	0.04	0.04	0.01	0.12	0.00
41	0.01	0.01	0.00	0.01	0.06	0.02	0.01	0.00	0.06	0.06	0.02	0.02	0.01	0.12	0.04
42	0.01	0.02	0.00	0.03	0.07	0.01	0.04	0.01	0.05	0.09	0.01	0.04	0.03	0.13	0.02
43	0.08	0.01	0.04	0.01	0.06	0.01	0.00	0.01	0.06	0.08	0.04	0.03	0.00	0.11	0.03
44	0.01	0.00	0.00	0.04	0.05	0.01	0.00	0.01	0.06	0.07	0.01	0.02	0.00	0.09	0.02
45	0.03	0.02	0.02	0.04	0.07	0.01	0.01	0.00	0.05	0.08	0.02	0.04	0.00	0.12	0.01
46	0.06	0.02	0.02	0.00	0.06	0.01	0.02	0.00	0.05	0.09	0.02	0.02	0.01	0.11	0.02
47	0.03	0.00	0.03	0.01	0.06	0.01	0.02	0.01	0.06	0.09	0.01	0.01	0.02	0.11	0.01
48	0.06	0.00	0.03	0.03	0.05	0.03	0.01	0.00	0.06	0.07	0.04	0.03	0.01	0.10	0.01
49	0.06	0.02	0.02	0.01	0.09	0.02	0.02	0.00	0.05	0.07	0.02	0.05	0.00	0.12	0.04
50	0.03	0.03	0.02	0.02	0.10	0.01	0.03	0.02	0.06	0.09	0.01	0.02	0.02	0.12	0.01

5.4 Validation

As mentioned in the previous section, 48 combined scale model studies have been conducted for validation. The results of these model studies show that there were no significant differences between the computer simulations and those of the experimental work for 47 of 48 scale models. Only in a very low available diffuse daylight situation (about 30 footcandles available on the horizontal in the Skydome) was there a significant difference (21% difference maximum) between experimental and theoretical predictions. This means the CL909L photocell does not have good sensitivity when low illuminance is encountered. Fortunately, the daylight available in the real physical environment normally does not have luminance less than 500 footcandles; therefore, this unmatched predictions does not have significance in the validation process.

The curves shown in Figures 33 through 36 compare the predictions of the mathematical model to those of the scale model studies for each of the 4 cases with a separate curve for each measured section. The variations of curves among the 5 sections shown in each case indicate that the 4 scale model studies presented demonstrated no significant difference between predictions of the mathematical model and actual value of scale model studies, further validating the mathematical model. In addition, although finding no significant differences (Table 6-9) between means is normally a weak conclusion from the statistical viewpoint, the curves show that in each section, the predicted curves of the mathematical model have general agreements that the predicted curves of scale model studies. These results confirm the assumptions made in this study are acceptable and the mathematical procedures are reliable. The consistency between the scale model studies and the mathematical model confirm the validity of the computer simulations based on the mathematical model for predicting diffuse daylight distribution in a room.

Reference

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3. Clairex Electrics, **Optoelectronics Designers Handbook,** Mount Vernon, New York, 1985
4. **Analog Devices 1984 Databook,** Vol. 1, Norwood, MA., pp. 10-61, 1984
5. Microsoft Corp., **IBM-PC Technical Reference**

Chapter 6 DISCUSSION

6.1 Introduction

Most designers predict daylight distribution using methods such as the lumen *method*,[2] the daylight factor *method*,[3] and charts and tables in the IES *Handbook*.[1] Others use scale model studies under a daylight simulator and real sky. Still others use sophisticated computer programs based on correlation coefficient functions generated mainly via scale model studies. While these methods are claimed to be relatively reliable and accurate, most of them are limited by the number of points to be predicted and tend to be time-consuming. This time requirement discourages designers for considering daylight in their designs, who must also deal with such variables as reflectances, glass transmission factors, and reference plane heights, several candidate design schemes determining the optimal combination for a given condition.

The mathematical model proposed in this study with the associated microcomputer program is intended to provide a more convenient design method for designers and to encourage them to consider daylight in their designs. This chapter discusses the scale model studies and validation presented in the previous chapter, the literature review presented in Chapter 2, and comparisons with other design methods.

6.2 The Proposed Mathematical Model

A mathematical approach leads to a reliable method of predicting daylight distribution that can give rapid calculation of distribution under different sky luminance patterns. First, the angles between sun and buildings can be calculated and stored in the microcomputer. Second, daylight availabilities under different sky condition can be calculated from the functions which were reported in section 2.2 and 3.2, and can be stored as data in the diskette. Third, the daylight factors and the illuminance of direct daylight passing through the windows and incident to the 209 points in the reference plane are calculated from the geometry and characteristics of the rooms. Fourth, the daylight factors and the illuminance affected by the inter-reflection of the 209 points in the reference plane are calculated based on the reflectances of each surface. The zoning *method*[4]was employed here, which divides each surface into 81 small areas, for calculating in the computer simulation instead of calculation in the mathematical model. The computation of inter-reflection is the most complex part in this study. As mentioned in section 3.5 and 4.6, the inter-reflection computation is carried out one time in estimation. The daylight factor increase in the reference plane caused by an individual interior surface, for instance the left wall, can be calculated and stored in the microcomputer separately. The increased daylight factor described above allows the reflectance analysis of different surfaces possible. Then, for each interior surface, the exchange daylight factor affected by the inter-reflection among surfaces is summed. Fifth, the total daylight factor of each estimated point is summed based on the luminance passing through the windows and the luminance diffusing from surfaces. Sixth, the daylight factors or illuminance received at the considered 209 points in the reference plane are represented in graphic display to assist designers in their daylight design.

6.3 The Dilemma of Comparisons

Comparing the proposed mathematical model with other available daylight design methods in predicting daylight distribution in an interior forces four difficulties.

First, as in all measurement, there is no real value of illuminance for a point under a specific situation which is independent of the measuring system. All the daylight design methods give only a reference value for estimating the daylight factor and illuminance received at a specific point at a specific time and place. Hence, the significance of comparisons between the proposed model and other design methods can only express relative relationships. No conclusion about the improvement of accuracy with the mathematical model can be drawn via these kinds of comparisons.

Second, the best procedure for estimating the illuminance at an interior point is would have been a study under perfect diffuse sky conditions in a real room. However, many difficulties exist when make thistype of comparison: the real sky condition changes very quickly and is not in the experimental control; appropriate rooms for testing are hard to find; suitable photometry is not available to provide sensitive responses to the changing sky. Additionally, the assumptions made in the proposed model, such as the homogeneous and isotropic sky and the perfect diffuse character of the exterior ground and interior surfaces, do not allow use of the real sky method for comparison.

Third, the difficulty in comparing computer methods is that most other computer programs concentrate on thermal design and energy related daylight performance and only a few of them provide the ability to estimate daylight distribution based on some simple correlation coefficient functions. They are relatively expensive and poorly documented; therefore, no available programs at VPI&SU allow the comparison to be made at the state-of-the-art. Additionally, these computer-aided daylighting analysis programs are written for different computer systems with different languages; these programs cannot be run without the appropriate computer facilities and not all are available at VPI&SU.

Fourth, most manual daylight design methods are based on extensive empirical data from scale model studies. Most computer programs are based on public domain methods, such as the lumen method and the daylight factor method, and these also were initially obtained from scale model studies. Scale model studies under a skydome or a real sky costitute the original data base for most manual and computer-oriented daylight design methods. As mentioned in section 2.4, scale model studies are probably the most reliable daylighting evaluation tool, though there are some associated technical problems. Therefore, direct comparison with scale model studies provides the best answer.

For validation, a method to be compared to the proposed mathematical model should provide a reliable prediction of daylight distribution and an opportunity to obtain the same test conditions between this method and the proposed mathematical model. The scale model study is the method which best meets these requirements.

6.4 The Proposed Mathematical Model

A major limitation of this mathematical model is its inability to predict the daylight distribution in a room with complex geometry and windows. This mathematical model is only at the beginning stage to develop a prediction method for direct and diffuse daylight distribution in a room from a scientific viewpoint. Certainly, prediction of daylight distribution in a room is subject to a compromise between precision and numerical complexity. The diffuse daylight computer simulation presented in this study can calculate 209 points in the reference level. The predictions of these 209 points provides an abundant information for building designers in their iterative design work.

Compared with the conventional renderings and model studies, which are not always appropriate because of the labor and time cost, computer simulations are economical, convenient, and practical. They are available to provide graphic presentations for realistic views of daylighting distribution in an architectural space. While scale model studies are still applicable in some specific design features, computer graphics are becoming a vital tool in the architectural professions and the clients need to visualize potential designs to check them for aesthetic acceptability. Some discussions based on the proposed mathematical model and its implications are listed below.

Better Precision in Prediction

As mentioned in section 5.1, the data acquisition method in the scale model studies employed the computer interface of the data acquisition system to enable simultaneous measurements and high resolution in illuminance. Thus, the scale model experiments conducted in this study are reliable enough to represent the reference values for comparison between the proposed mathematical model and the scale model studies. In general, the proposed model results compared quite well to scale model studies. Almost all values predicted by computer simulation are within 10% of the 35,000 observations in scale model studies. Part of the difference analysis were showed in tables 6-9. There was thus no significant difference between the proposed mathematical model and the scale model studies; the proposed model predicted as well as the scale model did.

One of the advantages of this proposed computer program is that the maximum points, 209 points in the reference plane, can be estimated simultaneously, unlike other design methods or computer programs which are limited by the number of points for each estimating. For examples, the lumen method is limited to predict illuminance levels on a center line from the windows at intervals of five feet from the back of the room; Though the daylight factor method can predict any point in the room, it cannot estimate different points simultaneously; the scale model study method is practically (but not in principle) limited to representing 16 points maximum with the computer interface system; the Quicklite 1 and the *Protractor*[7] programs can estimate 9 points; and the *MICROLITE*[6] program can predict 15 points simultaneously. Some of the methods or programs claim that they have the ability to estimate daylight at any point in the room by the linear interpolation method, or the high order polynomial function method, or the spline interpolation, based on the concept that a precise interpolation depends on a sufficiently small interpolation step. In other words, the more known points, the better precision of estimation when interpolation methods apply. Again, the proposed program's ability to predict 209 points simultaneously allow better precision in prediction.

Ability to Analyze Direct Sunlight

Though many methods are available to provide knowledge for daylight design, no methods have offered the ability to analyze direct sunlight. In temperate and northern latitudes area, the admission of sunlight to a room is generally regarded as an amenity. On the other hand there are areas, such as tropics and subtropics, in which sunlight must be carefully excluded from a room or some parts of it. A compromise is necessary, direct sunlight being admitted to a limited extent, either at certain seasons of the year or certain periods of the day, and excluded at other times.

A knowledge of diffuse daylight alone is not enough for the daylight design process because the diffuse sky condition is not the only sky condition in the physical environment. Thus, a knowledge of direct sunlight related to building design is important, either to let the direct sunlight penetrate through the windows or to keep the direct sunlight away from a room.

The proposed study has the ability to analyze the direct sunlight situation as well as the diffuse daylight sunlight condition reported so far. This study took a large number of design parameters into consideration such as relative angles between sun and buildings, aperture size and location, glass transmittance, building orientation, room geometry, room reflectances, and other design features which influence direct sunlight distribution in space. A mathematical model has been developed for estimating the influence of direct sunlight in a room. The proposed model not only has the ability to predict the direct sunlight distribution but also to analyze the light exchange among surfaces inside a room.

While the proposed mathematical model has been validated for diffuse daylight experimentally; it has not been validated for direct daylight distribution. The major difficulty for validation is that there is no available and reliable parallel light source except the sun itself. Thus a real sky is the best situation for validating direct sunlight. But the inability to distinguish between direct sunlight and diffuse daylight made the validation impossible.

Comparison Capabilities for Daylight Design Performance

In the early stages of design, the designers need to sense the lighting performance in their design and decide which lighting distribution may be appropriate. With computer simulation and 3-D graphic presentation, it is possible to compare the daylight performance in different design schematics. The 3-D contour graphically presents the complete information which enables the designer to be aware of the place of worst situation in daylight performance and decide where he or she needs to integrate the daylighting with the electric lighting system. This can assist the designer to narrow down the options in detailed considerations.

Additionally, the proposed computer program can provide the average daylight factors which allow designers to examine the daylight performance in their design. With the knowledge of average daylight factors and the worst situation, designers may alter their layout of interior space and to analyze the control strategies for different zones.

Ability to Analyze Reflectance of Different Materials

This mathematical model has the ability to provide three types of illuminance data for every considered point. First is the illuminance coming from the exterior and directly incident at the considered point. Second is the illuminance caused by the inter-reflection among interior surfaces and received at the considered point. Third is the total illuminance, which is the summation of the first and second, receive at the considered point. With these three types of data, designers can have a better idea how the openings and reflectance factors will affect the daylight distribution in their design separately. This gives designers detailed information to assist them not only in their schematic design but also in choosing the interior materials finishing for their design.

Ability to Compare Aiming Angles

Graphic presentations can allow designers to look at the lighting distribution produced by a range of aiming angles in order to pinpoint the appropriate angle before the positions and sizes of openings are decided.

Graphic Presentation of Daylighting Distribution

The proposed computer program offers three different graphic representations of results. First is the plan drawing showing the grid of considered points and their illuminance. This display provides a quantitative overview of the entire plane. Second is the sectional view of the illuminance and/or daylight factors. This sectional display clearly shows the relative brightness from the window wall to the back wall. Overlays can then be used to compare the distributions through different sections of a room. Third is the 3-dimensional contour showing the complete daylight distribution in a room. This 3-D display is more significant than the absolute values of the illuminance or daylight factors in interpreting data. This is because of the ability of the human eye to adapt to varying overall interior illuminance levels while easily perceiving differences in illuminance within the space at a given situation. With the three types of graphic display, designers can present the distribution with less explanation and with more rapid communication with clients.

User-Friendly Interface

In general, most of the computer programs available to date are accessible only to users sophisticated in the use of programmable hand calculators (Quicklite 1) or large batch-loaded programs (DOE-2). This means they are limited to the few design professionals who has such expertise. A user-friendly interface is therefore an important feature for computer-aided daylight design.

The proposed computer program was written for the widely distributed IBM microcomputer system which may be the most accessible and affordable system in architectural offices and schools. The structure of the proposed program is designed to be self-instructional, enabling the user with no knowledge of programming to operate the functions of daylight distribution analysis easily. The program is menu-driven to make the input and output easy for the users.

Self-Training Potential

The computer simulation with graphics can give designers an idea of how their designs will perform in daylighting, and provide them a better opportunity through self-training to develop intuitive understanding of daylight situations. The designer can test the different schematics under many conditions rapidly, and every time a schematic is run, the designer gains experience in the possibilities of daylighting. Once the designer has experienced the computer simulation, the proposed model could be a part of the designer's decision-making process.

Simulation Speed

Unlike other design methods and computer programs, the method in this proposed study treats daylight transfer based on the physical characteristics of light via mathematical calculations. Thus, the prediction of daylight distribution in a room is subject to a compromise between accuracy and numerical complexity. As mentioned in section 4-8, the zoning method was employed in computer calculation, which divided each interior surface into 81 small areas for calculating the daylight exchange. The more areas divided, the better precision in prediction obtained and the longer time required. The proposed computer simulation requires 21 minutes to simulate a specific situation use the IBM AT microcomputer. If with the IBM PC system, 80 minutes are required. Other programs such as Energy *Nomographs*[8] need about 30 minutes to analyze daylight distribution, and the program developed at *UCLA*,[9] which based on the *IES/LOF*[10]method, only needs 30 seconds to estimate 3 points for drawing a section with no curve fitting function. The LOF approach is computationally very simple, but becomes cumbersome because of the large number of tables of data required and because it is not readily extendable to design conditions other than those listed in the tables. However, due to the limitations of the LOF method in room size, ceiling height, reflectances, and the number of points available for calculation, its usefulness for evaluating daylight distributions in limited.

In comparison with other programs, the proposed program is not fast. Two main reasons can explain the difference in speed. One is the difference of the computer system facilities. The microcomputer, the main frame system , and the minicomputer system work at different speed. Second is the difference of approach methods between the proposed program and others. The complex mathematical calculations of the proposed method take longer than the oversimplified correlation coefficient functions from an empirical data base in other methods. Therefore, the compromise of the number of points available for calculation and the precision of prediction are the critical factors affecting the speed of the proposed program.

To encourage designers to take the time for daylight function consideration, the proposed program provides three options in the number of points available for calculation, and hence the time required. First is 15 points which needs about 5 minutes to run in IBM AT system. Second is 77 points which needs about 10 minutes to simulate the daylight distribution. Third is 209 points which need about 21 minutes to obtain the complete estimation.

The number of points to be estimated is based on the designers' needs. In other words, quick estimation of different schematics could be a major factor in the early design stage. But in the final design stage, designers might need a complete daylight distribution to present the daylight distribution in their design. Thus, the option of determining the number of points to be estimated in program simulation is necessary.

The development of hardware technology promises that microcomputer systems will have more power of computation in the future. With the capabilities of the microprocessor, the speed of simulation in microcomputers will improve rapidly. Therefore, the disadvantage of long run time in the proposed program will not be a factor in the near future.

The proposed mathematical model with its associated computer program have certain advantages in the field of daylighting. The methods shows considerable saving of time and labor in comparison with scale model studies and relative accuracy compared with other computer programs. This proposed method should free the design professional and lighting engineer from irksome lengthy calculations, thus so allowing them to consider a wider range of possible solutions. With the development of BASICA---a high level programming language and microcomputer system, it is hoped that more designers will be encouraged to take advantage of the method documented in this study.

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Chapter 7 SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

7.1 Summary

A mathematical method is presented for calculating expected interior distribution of both direct and diffuse daylight, and a microcomputer program is developed for simulating diffuse daylight. The mathematical approach presented is based on astrometry for calculating of the required angles between sun and building; and on three dimensional and solid geometry to examine the spatial relation among the openings, room, and reference plane; and on the physics of light to determine the daylight transfer from exterior to interior and exchange among interior surfaces. The microcomputer program, based on the mathematical approach, uses the BASICA high level language, and has been written for simulation of the diffuse daylight distribution in a rectangular room. This program has the ability to calculate the illuminance at and daylight factor for any interior point, to account for the effect of different reflectances, and to represent the diffuse daylight distribution in graphic display.

This study includes a discussion and analysis of certain aspects which seem to be critical in developing a mathematical model for evaluating daylight performance and has compared the results of this mathematical model with scale model measurements as a method for establishing the validity of the mathematical model. Results of this study indicate that this approach does indeed have the potential for allowing designers to predict the effect of daylight performance in the schematic design stage. Because the analysis has verified that there is no significant variation between scale model and computer simulation, this mathematical model with its computer program does provide a method for effectively determining direct and diffuse daylight distribution during the building design process.

7.2 Conclusions

The mathematical model presented in this study should be viewed as a starting point for a more complete computational method of predicting daylight distribution in a room. Computer-aided daylight design can benefit from further exploration of microcomputer technology and further development of programming techniques. On the basis of this study, the following conclusions are derived:

1. Unlike other daylighting design methods and computer packages, this study presents a mathematical method for predicting the daylight distribution in a rectangular room. Base on the results of comparisons between computer simulation and scale model measurements, the proposed mathematical model could be used to evaluate daylighting designs without the need for conventional methods and scale model studies within the limitations of geometry specified.

2. The mathematical model developed here allows not only calculation of illuminance received in a room and daylight factor for any specific interior point, but also the average and the minimum daylight factors. These two factors provide the criteria for assessing daylight performance within an enclosure.

3. The computer-based mathematical daylight simulation program developed herein provides both 2- and 3-dimensional graphic images which are preferable to the tabular graphics. Usually presented by other computer-aided daylight design programs.

4. The mathematical model developed here can be used to analyze direct sunlight distribution and light exchange among surfaces inside a room. No other daylight simulation techniques are capable of dealing with direct sun.

5. The mathematical model presented here is limited to specified geometric room scheme. For more complex building configurations, the use of scale models is still the prefered method of analysis.

This study presumably has contributed to the body of knowledge in microcomputer-aided daylighting design, and has provide a useful tool for building designers. It is hoped that this mathematical approach with its computer simulation program will result in an increased use of daylighting.

7.3 Recommendations for Future Study

This study presents the initial work done in the development of the mathematical model for estimation of direct and diffuse daylight distribution, and light exchange among interior surfaces in a room. Further development and implementation of this model remains to be done. Four related areas that should be investigated are presented in the following paragraphs.

First, more appropriate daylight availability models are needed. The daylight availability model most widely used in the United States involves the charts, tables, and graphs shown in the IES *Handbook*[1] and is based on empirical data collected by Kimball and *Hand*[2] during the 1920s in Washington D.C. The IES model does not allow for variations in atmospheric conditions based on geographic location. The needed daylight availability model should have not only the capability of providing predicted illuminance on the horizontal and vertical surfaces at a specific time, day, and location, but should also provide the following data:

1. the maximum and minimum illuminance conditions,

2. illuminance of different sky conditions,

3. average hourly illuminance for critical months or seasons,

4. statistical probability of occurrence of different illuminance range.

Second, the mathematical model and attendant computer program developed here for assessing daylight distribution is only applicable to relatively simple window and room geometry. The model is incapable of dealing with complicated geometries, complex design details, and non-perfectly diffusing reflection properties. Thus, continued investigation is made for development of a more rigorous mathematical model that can simulate complex building and window geometries, and non-perfectly diffusive surfaces.

Third, the present model is designed to estimate direct and diffuse daylight distribution in a room. No effort has been made to analyze the annual energy and economic savings for a specific design. Thus, a study of possibility of converting quantitative illuminance or daylight factors for different sky conditions into direct and indirect energy and economic savings would be valuable. Such a study might be in two directions.

1. Development of a model for evaluation of energy savings based on a daylighting analysis performed on this model.

2. Development of a subroutine to interface with other energy analysis programs. In other words, the output data of the daylight analysis model can be used as input data for energy analysis programs.

Fourth, external obstructions have not been considered in the development of this mathematical model. This is hardly realistic. Thus, a subroutine is needed to put external obstructions factors into diffuse daylight estimation.

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Appendix A. Fundamental of Plane and Solid Analytic Geometry

The Coordinate System: This section is a brief presentation of the basic concepts of plane and solid analytic geometry, including planes, lines, and points.

There are a number of useful coordinate systems which may be used to describe points, lines, and planes in three dimensions, and before the study of theoretical model, it is necessary to build and confine a rectangular coordinate system. This system is defined by drawing three mutually perpendicular directed lines through a common point O called the origin, and assign directions on these lines as indicated in Figure 37 on page 174 . These lines are called coordinate axes, and each pair of them determines a coordinate plane. These three coordinate axes are traditionally called the x axis, the y axis, and the z axis. The coordinate planes are referred to as the xy plane, the xz plane, and the yz plane. The position of a point P is described by its three directed distances (x,y,z) from each of the coordinate planes as shown in Figure 37 on page 174.

Basic Formulas of Distances and Directions: If P is a point whose coordinates are (x,y,z), then the line OP is the diagonal of a rectangular paralleled whose edges are OA = x, OB = y, OC

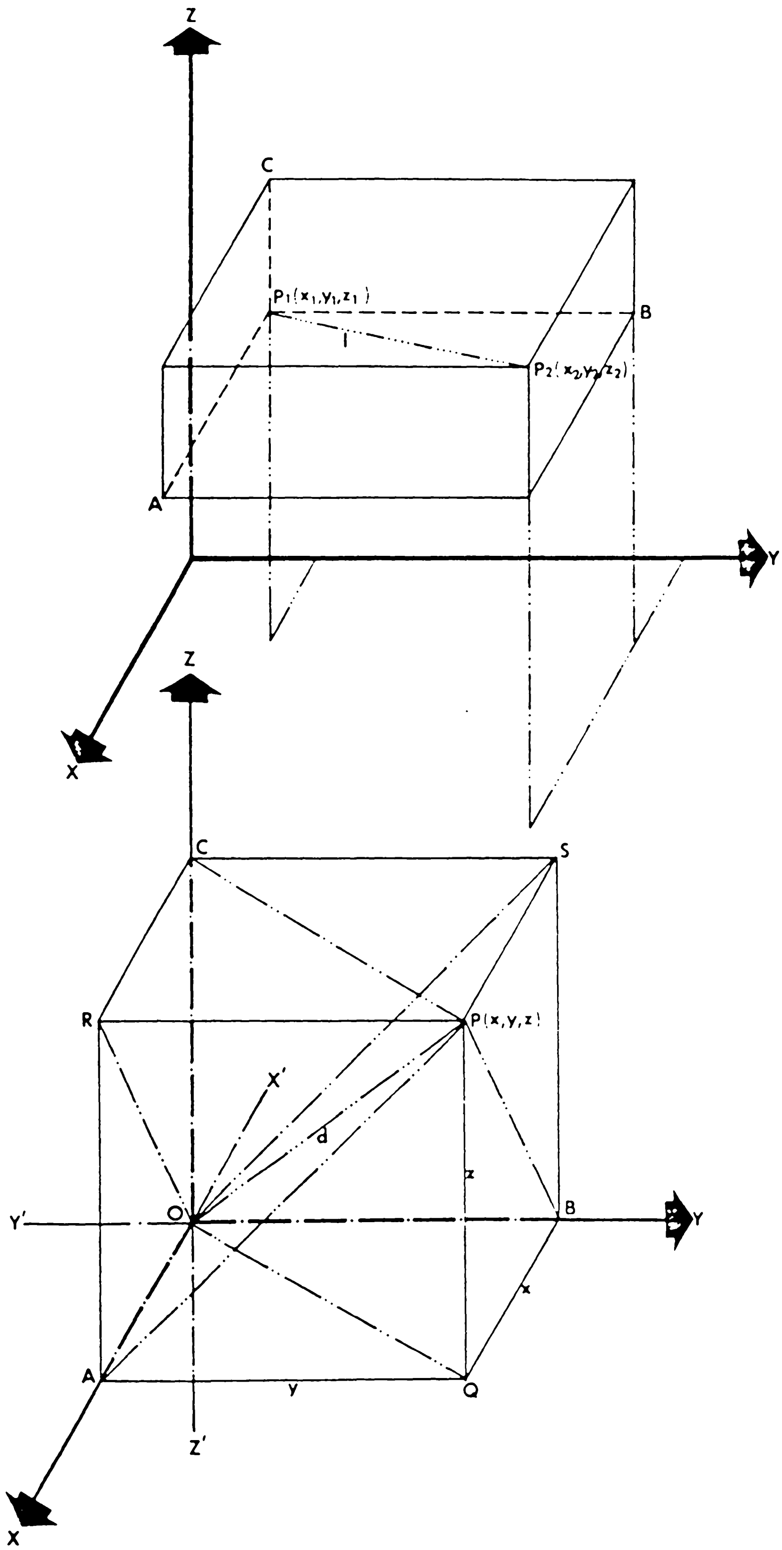

Figure 37. Rectangular Coordinates in Three Dimensions and the Distance Between Two Points

= z (see Figure 37 on page 174). The following formulas are evidently true for any position of the point *P*.[1,2,3,4]

x = perpendicular distance from the yz-plane.

y = perpendicular distance from the zx-plane.

z = perpendicular distance from the xy-plane.

$\sqrt{y^2 + z^2}$ = perpendicular distance from the x-axis.

$\sqrt{z^2 + x^2}$ = perpendicular distance from the y-axis.

$\sqrt{x^2 + y^2}$ = perpendicular distance from the z-axis.

$\sqrt{x^2 + y^2 + z^2}$ = distance from the origin.

In solid geometry, as in plane geometry, the angle between two directed lines in the angle between their positive directions. The angle between two lines which do not intersect is defined as the angle between two intersecting lines which are parallel, respectively, to the given lines.

The **direction angles** of a directed line are the angles between the line and the three coordinate axes. The direction angles are usually denoted by α , β , γ . That is, α is the angle between a line and the x-axis, β the angle between the line and the y-axis, and γ the angle between the line and the z-axis.

In Figure 37 on page 174 , angle AOP = α , angle BOP = β , angle COP = γ .

The **direction cosines** of a line are the cosines of its direction angles. Since the angle between two directed lines cannot exceed 180° , the angle is acute if its cosine is positive and obtuse if its cosine is negative.

In Figure 37 on page 174 we have $OP^2 = OQ^2 + QP^2 = OA^2 + OB^2 + OC^2$. Hence if OP = d, then

$$d^2 = x^2 + y^2 + z^2 \qquad [A.1]$$

Let the angles between OP and OX, OY, and OZ be, respectively, α, β, *and*γ. The triangle OAP is a right triangle, for OA is perpendicular to AP. Also, angle XOP = α . Hence OA = OP cos α , or x = d cos α . Similar values for y and z are found from the right triangles OBP and OCP.

Hence

$$x = d\cos\alpha, y = \cos\beta, z = \cos\gamma. \qquad [A.2]$$

Squaring these equations, adding them, using [A.1], and dividing by d^2 , an important relation can be obtained

$$\cos^2\alpha + \cos^2\beta + \cos^2\gamma = 1 \qquad [A.3]$$

Hence the sum of the squares of the direction cosines of a line is unity. Equation [A.2] may be written as a set of equal ratios, namely,

$$\frac{\cos\alpha}{x} = \frac{\cos\beta}{y} = \frac{\cos\gamma}{z} = \frac{1}{d} \qquad [A.4]$$

Solving [A.2] for $\cos\alpha$, $\cos\beta$, $\cos\gamma$, and using the value of d from [A.1], we obtain

$$\cos\alpha = \frac{x}{\sqrt{x^2 + y^2 + z^2}}, \cos\beta = \frac{y}{\sqrt{x^2 + y^2 + z^2}}, \cos\gamma = \frac{z}{\sqrt{x^2 + y^2 + z^2}} \qquad [A.5]$$

Thus, define the length l of the line P_1P_2 joining two points $P_1(x_1,y_1,z_1) and P_2(x_2,y_2,z_2)$, and the direction cosines of the line P_1P_2 in Figure 37 on page 174 The length l of the line joining any two points $P_1 and P_2$ is given *by*[5,6]

$$l = \sqrt{(x_1 - x_2)^2 + (y_1 - y_2)^2 + (z_1 - z_2)^2} \qquad [A.6]$$

Let α , β , and γ be the direction angles of the line from P_1 to P_2 . Then, from the Figure 37 on page 174 , angle $AP_1P_2 = \alpha$, and $P_1A = l\cos\alpha$. Similarly, $P_1B = l\cos\beta, P_1C = l\cos\gamma$.

Hence, the following relation will be obtained

$$x_2 - x_1 = l\cos\alpha, y_2 - y_1 = l\cos\beta, z_2 - z_1 = l\cos\gamma \qquad [A.7]$$

From equations [A.7] the values of the direction cosines may be found. Equation [A.7] can be reduced as the following formula:

From equation [A.7]

$$l = \frac{x_2 - x_1}{\cos\alpha} = \frac{y_2 - y_1}{\cos\beta} = \frac{z_2 - z_1}{\cos\gamma}$$

Therefore, a line which pass through any point P(x_1, y_1, z_1) in this coordinate system can be defined as:

$$\frac{x - x_1}{\cos\alpha} = \frac{y - y_1}{\cos\beta} = \frac{z - z_1}{\cos\gamma} \qquad [A.8]$$

Appendix B. The Calculation of The Window Projection

Back Wall Back Wall (0, $0 \le y \le w, 0 \le z \le h$ **):** Define the coordinates of window's projection or image in plane x = 0 are (0, y_{bk}, z_{bk}), (0, y_{bl}, z_{bl}), (0, y_{bm}, z_{bm}), and (0, y_{bn}, z_{bn}), and repeat the processes from equation [3.5.6] to [3.6.17] to obtain the values of these coordinates which just defined.

From section 3.5, the sun's rays which just passed through window's corners can be obtained as the following equations (see Figure 38 on page 179).

$$\frac{0 - x_k}{\cos \alpha} = \frac{y_{bk} - y_k}{\cos \beta} = \frac{z_{bk} - z_k}{\cos \gamma}. \qquad [B.1]$$

$$\frac{0 - x_l}{\cos \alpha} = \frac{y_{bl} - y_l}{\cos \beta} = \frac{z_{bl} - z_l}{\cos \gamma} \qquad [B.2]$$

$$\frac{0 - x_m}{\cos \alpha} = \frac{y_{bm} - y_m}{\cos \beta} = \frac{z_{bm} - z_m}{\cos \gamma} \qquad [B.3]$$

$$\frac{0 - x_n}{\cos \alpha} = \frac{y_{bn} - y_n}{\cos \beta} = \frac{z_{bn} - z_n}{\cos \gamma} \qquad [B.4]$$

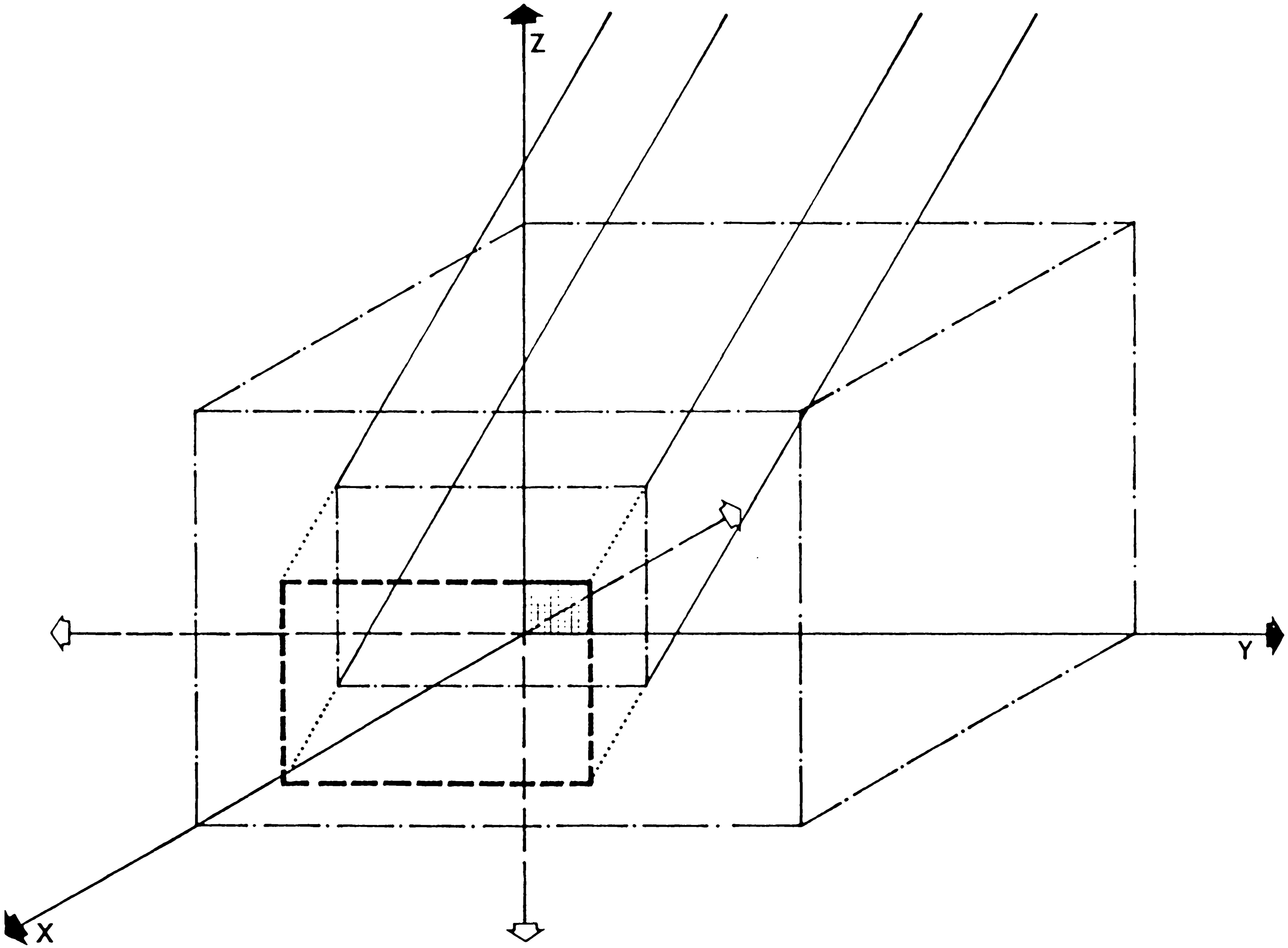

Figure 38. Window's Projection on Plane x = 0

From equation [B.1]

$$\frac{y_{bk} - y_k}{\cos\beta} = \frac{0 - x_k}{\cos\alpha}$$

$$\cos\alpha x(y_{bk} - y_k) = \cos\beta \ (- x_k)$$

$$y_{bk} - y_k = \frac{\cos\beta}{\cos\alpha} \ (- x_k)$$

$$y_{bk} = \frac{\cos\beta}{\cos\alpha} \ (- x_k) + y_k \qquad [B.5]$$

From equation [B.1]

$$\frac{0 - x_k}{\cos\alpha} = \frac{z_{bk} - z_k}{\cos\gamma}$$

$$\cos\alpha \ (z_{bk} - z_k) = \cos\gamma \ (- x_k)$$

$$z_{bk} - z_k = \frac{\cos\gamma}{\cos\alpha} \ (- x_k)$$

$$z_{bk} = \frac{\cos\gamma}{\cos\alpha} \ (- x_k) + z_k \qquad [B.6]$$

From equation [B.2]

$$y_{bl} = \frac{\cos\beta}{\cos\alpha} \ (- x_l) + y_l \qquad [B.7]$$

$$z_{bl} = \frac{\cos\gamma}{\cos\alpha} \ (- x_l) + z_l \qquad [B.8]$$

From equation [B.3]

$$y_{bm} = \frac{\cos\beta}{\cos\alpha} \ (- x_m) + y_m \qquad [B.9]$$

$$z_{bm} = \frac{\cos \gamma}{\cos \alpha} \ (- x_m) + z_m \qquad [B.10]$$

From equation [B.4]

$$y_{bn} = \frac{\cos \beta}{\cos \alpha} \ (- x_n) + y_n \qquad [B.11]$$

$$z_{bn} = \frac{\cos \gamma}{\cos \alpha} \ (- x_n) + z_n \qquad [B.12]$$

Right Wall Right Wall ($0 \le x \le d, y = w, 0 \le z \le h$ **)** :Repeating the process in the section of the left wall, the coordinates of window projection or image in the plan y%%=%%w are (x_{rk}, w, z_{rk}), (x_{rl}, w, z_{rl}), (x_{rl}, w, z_{rm}), and (x_{rn}, w, z_{rn}). The line equations of sun's rays passing through the window corners are (see Figure 39 on page 182):

$$\frac{x_{rk} - x_k}{\cos \alpha} = \frac{w - y_k}{\cos \beta} = \frac{z_{rk} - z_k}{\cos \gamma} \qquad [B.13]$$

$$\frac{x_{rl} - x_l}{\cos \alpha} = \frac{w - y_l}{\cos \beta} = \frac{z_{rl} - z_l}{\cos \gamma} \qquad [B.14]$$

$$\frac{x_{rm} - x_m}{\cos \alpha} = \frac{w - y_m}{\cos \beta} = \frac{z_{rm} - z_m}{\cos \gamma} \qquad [B.15]$$

$$\frac{x_{rn} - x_n}{\cos \alpha} = \frac{w - y_n}{\cos \beta} = \frac{z_{rn} - z_n}{\cos \gamma} \qquad [B.16]$$

From equation [B.13]

$$\frac{x_{rk} - x_k}{\cos \alpha} = \frac{w - y_k}{\cos \beta}$$

$$\cos \beta \ (x_{rk} - x_k) = \cos \alpha \ (w - y_k)$$

$$x_{rk} - x_k = \frac{\cos \alpha}{\cos \beta} \ (w - y_k)$$

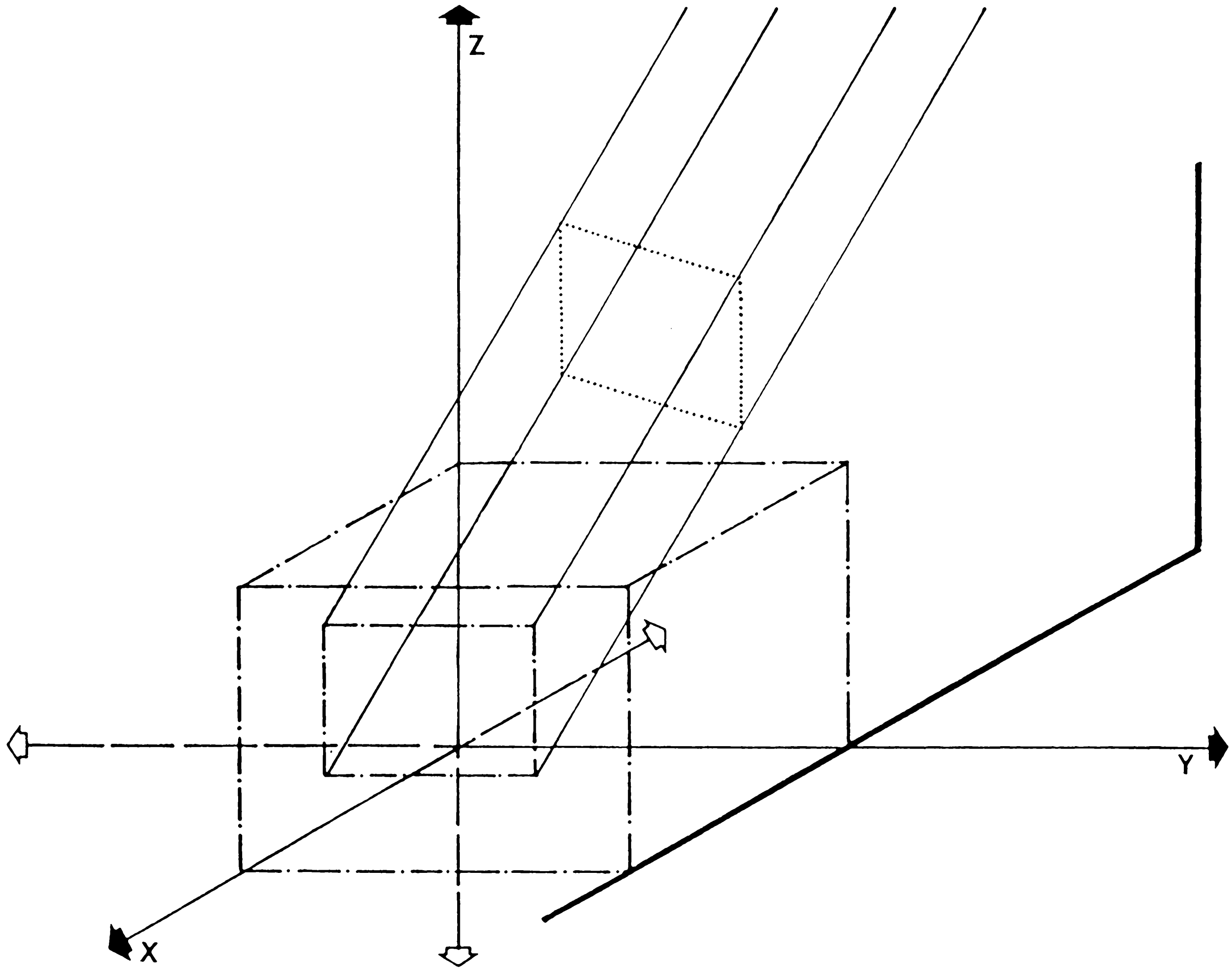

Figure 39. Window's Projection on Plane y = w

$$x_{rk} = \frac{\cos\alpha}{\cos\beta}\ (w - y_k) + x_k \qquad [B.17]$$

From equation [B.13]

$$\frac{w - y_k}{\cos\beta} = \frac{z_{rk} - z_k}{\cos\gamma}$$

$$\cos\beta\ (z_{rk} - z_k) = \cos\gamma\ (w - y_k)$$

$$z_{rk} - z_k = \frac{\cos\gamma}{\cos\beta}\ (w - y_k)$$

$$z_{rk} = \frac{\cos\gamma}{\cos\beta}\ (w - y_k) + z_k \qquad [B.18]$$

From equation [B.31]

$$x_{rl} = \frac{\cos\alpha}{\cos\beta}\ (w - y_l) + x_l \qquad [B.19]$$

$$z_{rl} = \frac{\cos\gamma}{\cos\beta}\ (w - y_l) + z_l \qquad [B.20]$$

From equation [B.15]

$$x_{rm} = \frac{\cos\alpha}{\cos\beta}\ (w - y_m) + x_m \qquad [B.21]$$

$$z_{rm} = \frac{\cos\gamma}{\cos\beta}\ (w - y_m) + z_m \qquad [B.22]$$

From equation [B.16]

$$x_{rn} = \frac{\cos\alpha}{\cos\beta}\ (w - y_n) + x_n \qquad [B.23]$$

$$z_{rn} = \frac{\cos \gamma}{\cos \beta} (w - y_n) + z_n \qquad [B.24]$$

Floor Floor ($0 \le x \le d, 0 \le y \le w, 0$ **)** :: Repeating the process in the section of the left wall, the coordinates of window projection or image in the plan z%%=%%0 are ($x_{fk}, y_{fk}, 0$), ($x_{fl}, y_{fl}, 0$), ($x_{fm}, y_{fm}, 0$), and ($x_{fn}, y_{bn}, 0$). The line equations of sun's rays passing through the window's corners are (see Figure 40 on page 185):

$$\frac{x_{fk} - x_k}{\cos \alpha} = \frac{y_{fk} - y_k}{\cos \beta} = \frac{0 - z_k}{\cos \gamma} \qquad [B.25]$$

$$\frac{x_{fl} - x_l}{\cos \alpha} = \frac{y_{fl} - y_l}{\cos \beta} = \frac{0 - z_l}{\cos \gamma} \qquad [B.26]$$

$$\frac{x_{fm} - x_m}{\cos \alpha} = \frac{y_{fm} - y_m}{\cos \beta} = \frac{0 - z_m}{\cos \gamma} \qquad [B.27]$$

$$\frac{x_{fn} - x_n}{\cos \alpha} = \frac{y_{fn} - y_n}{\cos \beta} = \frac{0 - z_n}{\cos \gamma} \qquad [B.28]$$

From equation [B.25]

$$\frac{x_{fk} - x_k}{\cos \alpha} = \frac{0 - z_k}{\cos \gamma}$$

$$\cos \gamma \; (x_{fk} - x_k) = \cos \alpha \; (- z_k)$$

$$x_{fk} - x_k = \frac{\cos \alpha}{\cos \gamma} (- z_k)$$

$$x_{fk} = \frac{\cos \alpha}{\cos \gamma} (- z_k) + x_k \qquad [B.29]$$

From equation [B.25]

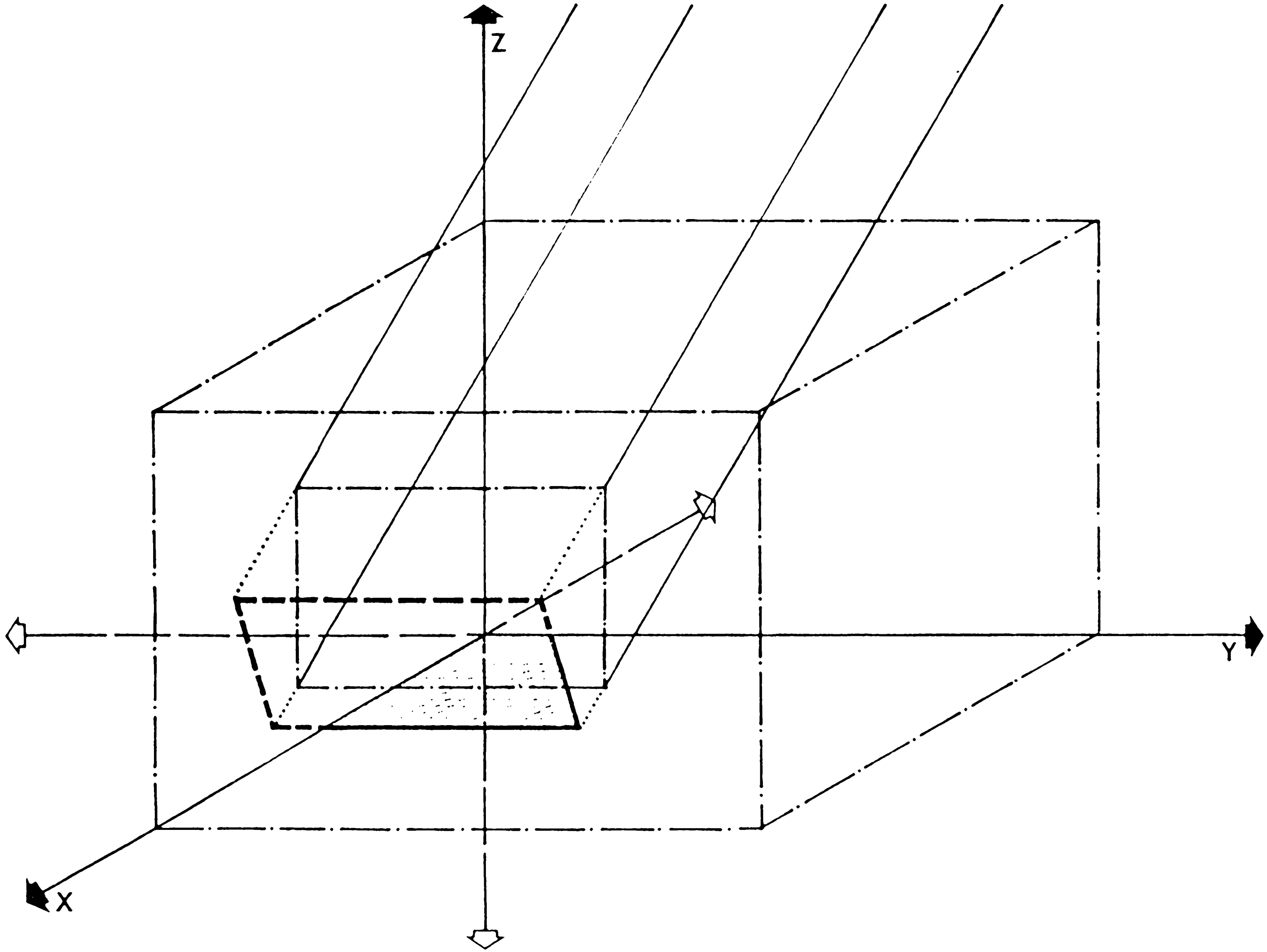

Figure 40. Window's Projection on Plane z = 0

$$\frac{y_{fk} - y_k}{\cos\beta} = \frac{0 - z_k}{\cos\gamma}$$

$$\cos\gamma\ (y_{fk} - y_k) = \cos\beta\ (-z_k)$$

$$y_{fk} - y_k = \frac{\cos\beta}{\cos\gamma}\ (-z_k)$$

$$y_{fk} = \frac{\cos\beta}{\cos\gamma}\ (-z_k) + y_k \qquad [B.30]$$

From equation [B.26]

$$x_{fl} = \frac{\cos\alpha}{\cos\gamma}\ (-z_l) + x_l \qquad [B.31]$$

$$y_{fl} = \frac{\cos\beta}{\cos\gamma}\ (-z_l) + y_l \qquad [B.32]$$

From equation [B.27]

$$x_{fm} = \frac{\cos\alpha}{\cos\gamma}\ (-z_m) + x_m \qquad [B.33]$$

$$y_{fm} = \frac{\cos\beta}{\cos\gamma}\ (-z_m) + y_m \qquad [B.34]$$

From equation [B.28]

$$x_{fn} = \frac{\cos\alpha}{\cos\gamma}\ (-z_n) + x_n \qquad [B.35]$$

$$y_{fn} = \frac{\cos\beta}{\cos\gamma}\ (-z_n) + y_n \qquad [B.36]$$

Appendix C. Intersection Points of Window Projection and Axes

Window's Lower Frame and Z-axis: line L-M ($x_{lm} = d,\ c \le y_{lm} \le c + a,\ z_{lm} = f$)

line O-H ($x_{doh} = 0,\ y_{doh} = 0,\ 0 \le z_{doh} \le h$)

$$z_{doh} = f - \frac{\cos\gamma}{\cos\alpha}(d) \qquad [C.1]$$

$$y_{lm} = \left(\frac{\cos\beta}{\cos\alpha}\right)(d) \qquad [C.2]$$

Window's Lower Frame and X-axis: line L-M ($x_{lm} = d,\ c \le y_{lm} \le c + a,\ z_{lm} = f$)

line O-D ($0 \le x_{dod} \le d,\ y_{dod} = 0,\ z_{dod} = 0$)

$$x_{dod} = d - \frac{\cos\alpha}{\cos\gamma}(f) \qquad [C.3]$$

$$y_{lm} = \left(\frac{\cos\beta}{\cos\gamma}\right)(f) \qquad [C.4]$$

Window's Lower Frame and Line W-Q: line L-M ($x_{lm} = d,\ c \le y_{lm} \le c + a,\ z_{lm} = f$)

line W-Q ($x_{dwq} = 0,\ y_{dwq} = w,\ 0 \le z_{dwq} \le h$)

$$z_{dwq} = f - \frac{\cos\gamma}{\cos\alpha}\,(d) \qquad [C.5]$$

$$y_{lm} = w + \left(\frac{\cos\beta}{\cos\alpha}\right)(d) \qquad [C.6]$$

Window's Lower Frame and Line W-R: line L-M ($x_{lm} = d,\ c \le y_{lm} \le c + a,\ z_{lm} = f$)

line W-R ($0 \le x_{dwr} \le d,\ y_{dwr} = w,\ z_{dwr} = 0$)

$$x_{dwr} = d - \frac{\cos\alpha}{\cos\gamma}\,(f) \qquad [C.7]$$

$$y_{lm} = w + \frac{\cos\beta}{\cos\gamma}\,(f) \qquad [C.8]$$

Window's Left Frame and Y-axis: line K-L ($x_{kl} = d,\ y_{kl} = c,\ f \le z_{kl} \le b + f$)

line O-W ($x_{low} = 0,\ 0 \le y_{low} \le w,\ z_{low} = 0$)

$$\frac{d - 0}{\cos\alpha} = \frac{c - y_{low}}{\cos\beta} = \frac{z_{kl} - 0}{\cos\gamma} \qquad [C.9]$$

From equation [C.9]

$$\frac{d - 0}{\cos\alpha} = \frac{c - y_{low}}{\cos\beta}$$

$$c - y_{low}\,(\cos\alpha) = \cos\beta\,(d)$$

$$y_{low} = c - \frac{\cos\beta}{\cos\alpha}\,(d) \qquad [C.10]$$

From equation [C.9]

$$\frac{d - 0}{\cos\alpha} = \frac{z_{kl} - 0}{\cos\gamma}$$

$$(z_{kl}) \cos\alpha = \cos\gamma \ (d)$$

$$z_{kl} = \left(\frac{\cos\gamma}{\cos\alpha}\right) (d) \qquad [C.11]$$

Window's Left Frame and X-axis: line K-L ($x_{kl} = d,\ y_{kn} = c,\ f \leq z_{kl} \leq b + f$)

line O-D ($0 \leq x_{lod} \leq d,\ y_{lod} = 0,\ z_{lod} = 0$)

$$\frac{d - x_{lod}}{\cos\alpha} = \frac{c - 0}{\cos\beta} = \frac{z_{kl} - 0}{\cos\gamma} \qquad [C.12]$$

From equation [C.12]

$$\frac{d - x_{lod}}{\cos\alpha} = \frac{c}{\cos\beta}$$

$$(c) \cos\alpha = \cos\beta \ (d - x_{lod})$$

$$x_{lod} = d - \frac{\cos\alpha}{\cos\beta} (c) \qquad [C.13]$$

From equation [C.12]

$$\frac{(c - 0)}{\cos\beta} = \frac{z_{kl} - 0}{\cos\gamma}$$

$$(c) \cos\gamma = \cos\beta \ (z_{kl})$$

$$z_{kl} = (c) \left(\frac{\cos\gamma}{\cos\beta}\right) \qquad [C.14]$$

Window's Left Frame and Line W-R: line K-L ($x_{kl} = d,\ y_{kl} = c,\ f \le z_{kl} \le b + f$)

line W-R ($0 \le x_{lwr} \le d,\ y_{lwr} = w,\ z_{lwr} = 0$)

$$\frac{d - x_{lwr}}{\cos\alpha} = \frac{c - w}{\cos\beta} = \frac{z_{kl}}{\cos\gamma} \qquad [C.15]$$

$$x_{lwr} = d - \left(\frac{\cos\alpha}{\cos\gamma}\right)(c - w) \qquad [C.16]$$

$$z_{kl} = \left(\frac{\cos\gamma}{\cos\beta}\right)(c - w) \qquad [C.17]$$

Window's Right Frame and Y-axis: line M-N ($x_{mn} = d,\ y_{mn} = c + a,\ f \le z_{mn} \le b + f$)

line O-W ($x_{row} = 0,\ 0 \le y_{row} \le w,\ z_{row} = 0$)

$$y_{row} = (c + a) - \left(\frac{\cos\beta}{\cos\alpha}\right)(d) \qquad [C.18]$$

$$z_{mn} = \left(\frac{\cos\gamma}{\cos\alpha}\right)(d) \qquad [C.19]$$

Window's Right Frame and X-axis: line M-N ($x_{mn} = d,\ y_{mn} = c + a,\ f \le z_{mn} \le b + f$)

line O-D ($0 \le x_{rod} \le d,\ y_{rod} = 0,\ z_{rod} = 0$)

$$x_{rod} = d - \frac{\cos\alpha}{\cos\beta}(c + a) \qquad [C.20]$$

$$z_{mn} = (c + a)\left(\frac{\cos\gamma}{\cos\beta}\right) \qquad [C.21]$$

Window's Right Frame and Line W-R: line M-N ($x_{mn} = d,\ y_{mn} = c + a,\ f \le z_{mn} \le b + f$)

line W-R ($0 \le x_{rwr} \le d,\ y_{rwr} = w,\ z_{rwr} = 0$)

$$x_{rwr} = d - \left(\frac{\cos\alpha}{\cos\beta}\right)(c + a - w) \qquad [C.22]$$

$$z_{mn} = \left(\frac{\cos \gamma}{\cos \beta} \right) (c + a - w) \qquad [C.23]$$

Appendix D. Inter-reflective Phenomenon of Light Transfer

Type 1

$$K_b\ (x_{bk} = 0, y_{bk}, z_{bk})$$

$$L_b\ (x_{bl} = 0, y_{bl}, z_{bl})$$

$$M_b\ (x_{bm} = 0, y_{bm}, z_{bm})$$

$$N_b\ (x_{bn} = 0, y_{bn}, z_{bn})$$

where

The coordinates of points $K_b, L_b, M_b, and\, N_b$ are known from equation [b.1] to [B.10].

Definition: Define (x_b, y_b, z_b) as the coordinates of a very small portion of the lighted area in the back wall , and (x_l, y_l, z_l) as the coordinates of any point in the left wall.

Hence, according to the above definition, $x_b = 0$, $y_{bl} \leq y_b \leq y_{bm}$, $z_{bl} \leq z_b \leq z_{bk}$, $0 \leq x_l \leq d$, $y_l = 0$, and $0 \leq z_l \leq h$ are known. Connect point K_b and N_b to define the upper

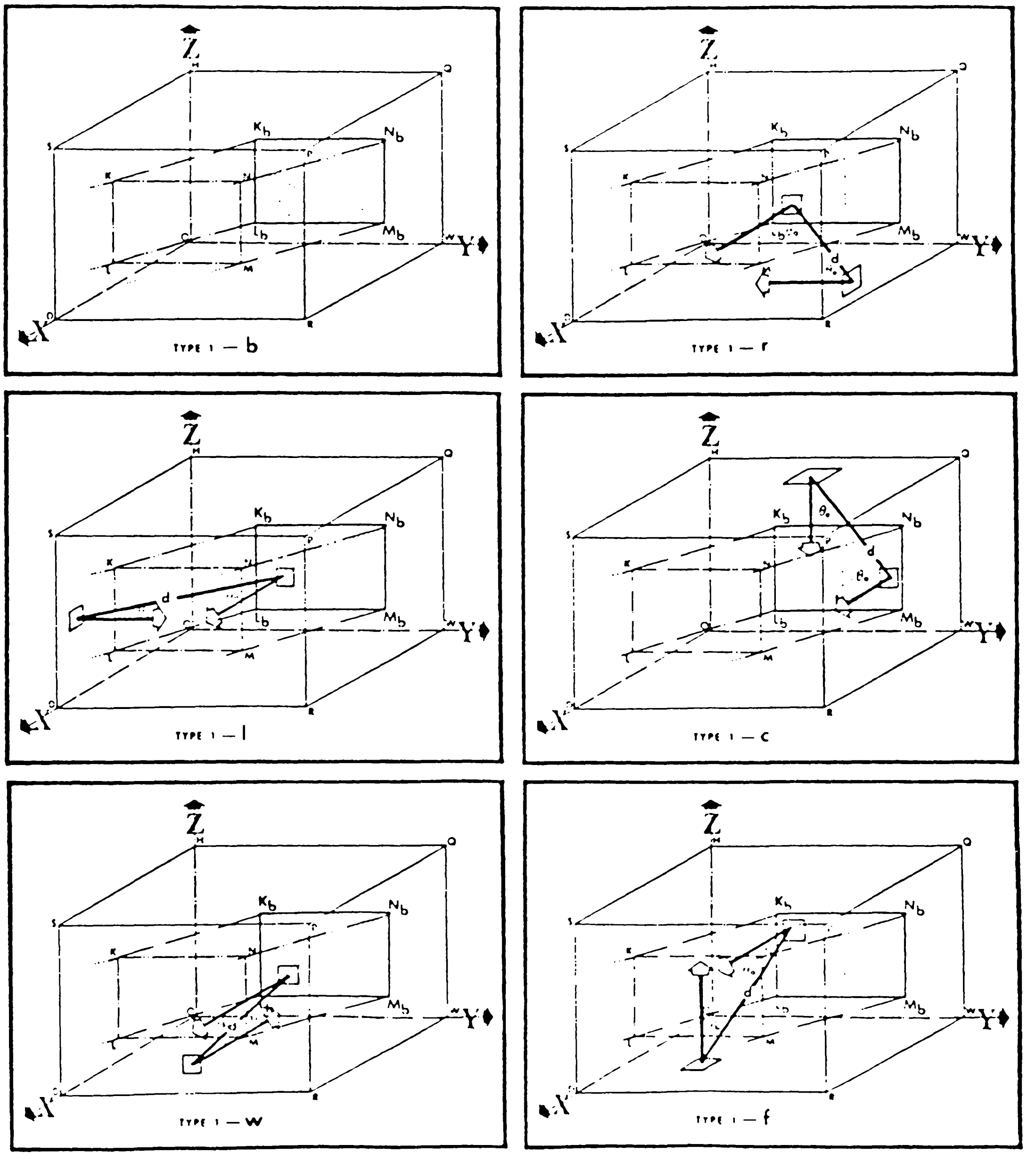

Figure 41. Direct Sunlight Transfer---Type 1

boundary of lighting area in the back wall and connect point L_b and M_b to define the lower boundary of the lighting area in the back wall. The upper and lower boundaries can be expressed as the following equations.

Line $K_b - N_b$

$$g(z) = z_{bk} + y_b \frac{z_{bn} - z_{bk}}{y_{bn} - y_{bk}}$$

Line $L_b - M_b$

$$f(z) = z_{bl} + y_b \frac{z_{bm} - z_{bl}}{y_{bm} - y_{bk}}$$

Therefore, the illuminance of any points in the left wall which were influenced by the lighting portion in the back wall can be expressed as:

Type 1-l (points in left wall)

$$E_{lb} = \int_{f(z)}^{g(z)} \int_{y_{bl}}^{y_{bm}} \frac{E_{dvb} T_g R_b \cos\theta_a \cos\theta_e}{r_{lb}^2 \pi} \, dy \, dz \qquad [D.1]$$

where

E_{dvb} = the direct vertical solar illuminance of the back wall

T_g = the transmission factor of the glass (0.85)

R_b = the reflectance factor of the back wall

r_{lb} = the distance between any point in left wall and any point at lighting area in back wall. $r_{lb} = \sqrt{(x_l - x_b)^2 + (y_l - y_b)^2 + (z_l - z_b)^2}$

$\cos\theta_a = \frac{x_l}{r_{lb}}$ ($0 \le x_l \le d$) θ_a is the angle between the normal line of the back wall and the line of distance

$\cos\theta_e = \frac{y_b}{r_{lb}}$ $y_{bl} \le y_b \le y_{bm}$ θ_e is the angle between the normal line of the left wall and the line of distance

Equation [D.1] can be reduced in the following form

$$E_{lb} = \int_{f(z)}^{g(z)} \int_{y_{bl}}^{y_{bm}} \frac{E_{dvb} T_g R_b y_b x_l}{r_{lb}^4 \pi} \, dy \, dz \qquad [D.2]$$

Repeating the above process to express the illuminance of any point in the other four surfaces (except the back wall itself), the intensity of light at any point in any interior surface can be expressed as the following form.

Type 1-w (points in window wall)

$$E_{wb} = \int_{f(z)}^{g(z)} \int_{y_{bl}}^{y_{bm}} \frac{E_{dvb} T_g R_b x_w x_w}{r_{wb}^4 \pi} dy\ dz \qquad [D.3]$$

Type 1-r (points in right wall)

$$E_{rb} = \int_{f(z)}^{g(z)} \int_{y_{bl}}^{y_{bm}} \frac{E_{dv} T_g R_b x_r y_r - y_b}{r_{rb}^4 \pi} dy\ dz \qquad [D.4]$$

Type 1-c (points in ceiling)

$$E_{cb} = \int_{f(z)}^{g(z)} \int_{y_{bl}}^{y_{bm}} \frac{E_{dvb} T_g R_b x_c z_c - z_b}{r_{cb}^4 \pi} dy\ dz \qquad [D.5]$$

Type 1-f (points in floor)

$$E_{fb} = \int_{f(z)}^{g(z)} \int_{y_{bl}}^{y_{bm}} \frac{E_{dvb} T_g R_b x_f z_b}{r_{fb}^4 \pi} dy\ dz \qquad [D.6]$$

Type 2

$$K_f\ (x_{fk}, y_{fk}, z_{fk} = 0)$$

$$L_f\ (x_{fl}, y_{fl}, z_{fl} = 0)$$

$$M_f\ (x_{fm}, y_{fm}, z_{fm} = 0)$$

$$N_f\ (x_{fn}, y_{fn}, z_{fn} = 0)$$

Line $N_f - M_f$

$$g(y) = y_{fn} + (x_f - x_{fn}) \frac{y_{fm} - y_{fn}}{x_{fm} - x_{fn}}$$

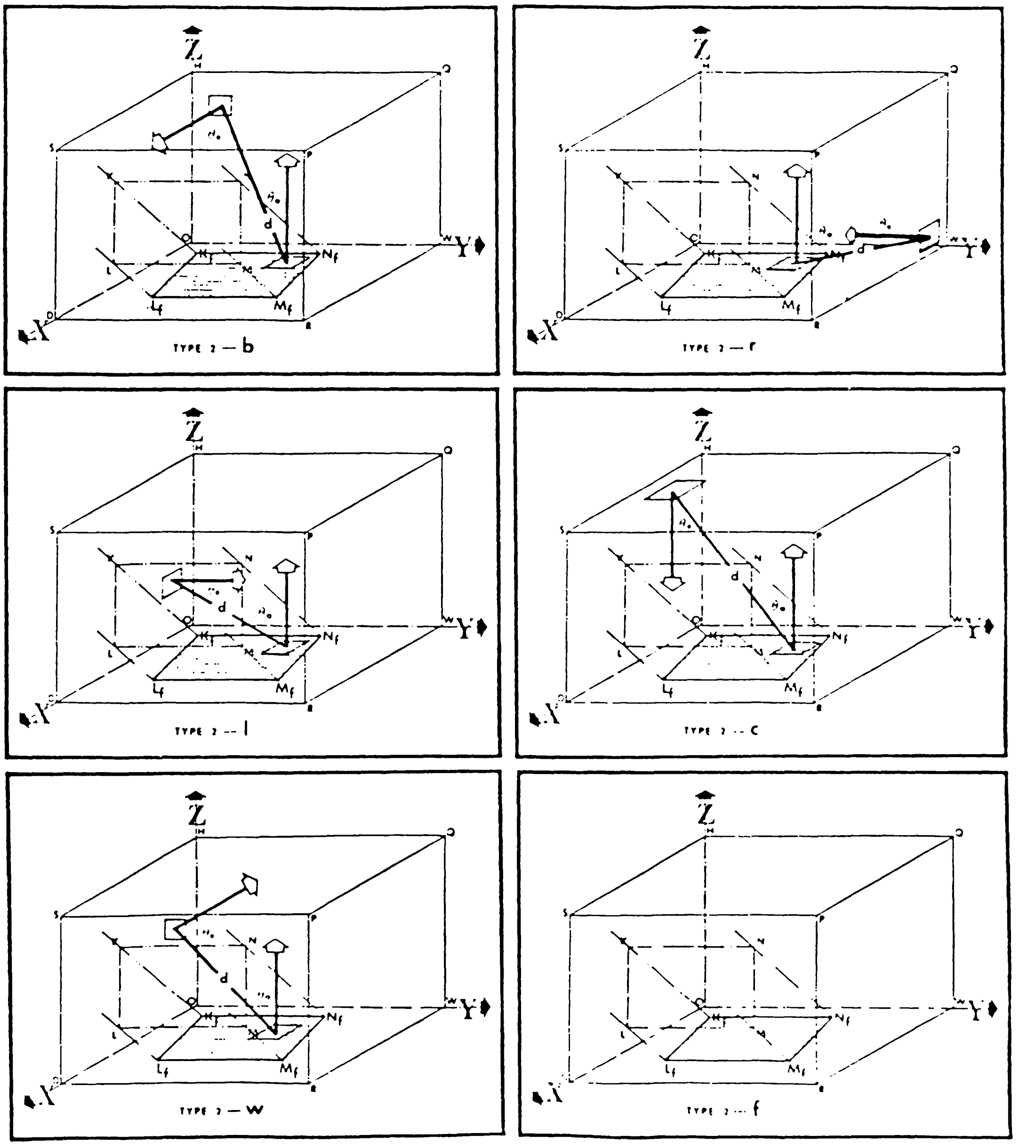

Figure 42. Direct Sunlight Transfer---Type 2

Line $K_f - L_f$

$$f(y) = y_{fk} + (x_f - x_{fk}) \frac{y_{fl} - y_{fk}}{x_{fl} - x_{fk}}$$

Type 2-l (points in left wall)

$$E_{lf} = \int_{f(y)}^{g(y)} \int_{x_{fk}}^{x_{fl}} \frac{E_{dh} T_g R_f \cos\theta_a \cos\theta_e}{r_{lf}^2 \pi} dx\, dy \qquad [D.7]$$

Equation [D.7] can be reduced in the following form

$$E_{lf} = \int_{f(y)}^{g(y)} \int_{x_{fk}}^{x_{fl}} \frac{E_{dh} T_g R_f y_f z_l}{r_{lf}^4 \pi} dx\, dy \qquad [D.8]$$

Type 2-w (points in window wall)

$$E_{wf} = \int_{f(y)}^{g(y)} \int_{x_{fk}}^{x_{fl}} \frac{E_{dh} T_g R_f (x_w - x_f) z_w}{r_{wf}^4 \pi} dx\, dy \qquad [D.9]$$

$$E_{rf} = \int_{f(y)}^{g(y)} \int_{x_{fk}}^{x_{fl}} \frac{E_{dh} T_g R_f z_r y_r - y_f}{r_{rf}^4 \pi} dx\, dy \qquad [D.10]$$

Type 2-c (points in ceiling)

$$E_{cf} = \int_{f(y)}^{g(y)} \int_{x_{fk}}^{x_{fl}} \frac{E_{dh} T_g R_f (h)(h)}{r_{cf}^4 \pi} dx\, dy \qquad [D.11]$$

Type 2-b (points in back wall)

$$E_{bf} = \int_{f(y)}^{g(y)} \int_{x_{fk}}^{x_{fl}} \frac{E_{dh} T_g R_f x_f z_b}{r_{bf}^4 \pi} dx\, dy \qquad [D.12]$$

Type 4

$$K_l \; (x_{lk}, y_{lk} = 0, z_{lk})$$

$$L_l \; (x_{ll}, y_{ll} = 0, z_{ll})$$

$$M_l \; (x_{lm}, y_{lm} = 0, z_{lm})$$

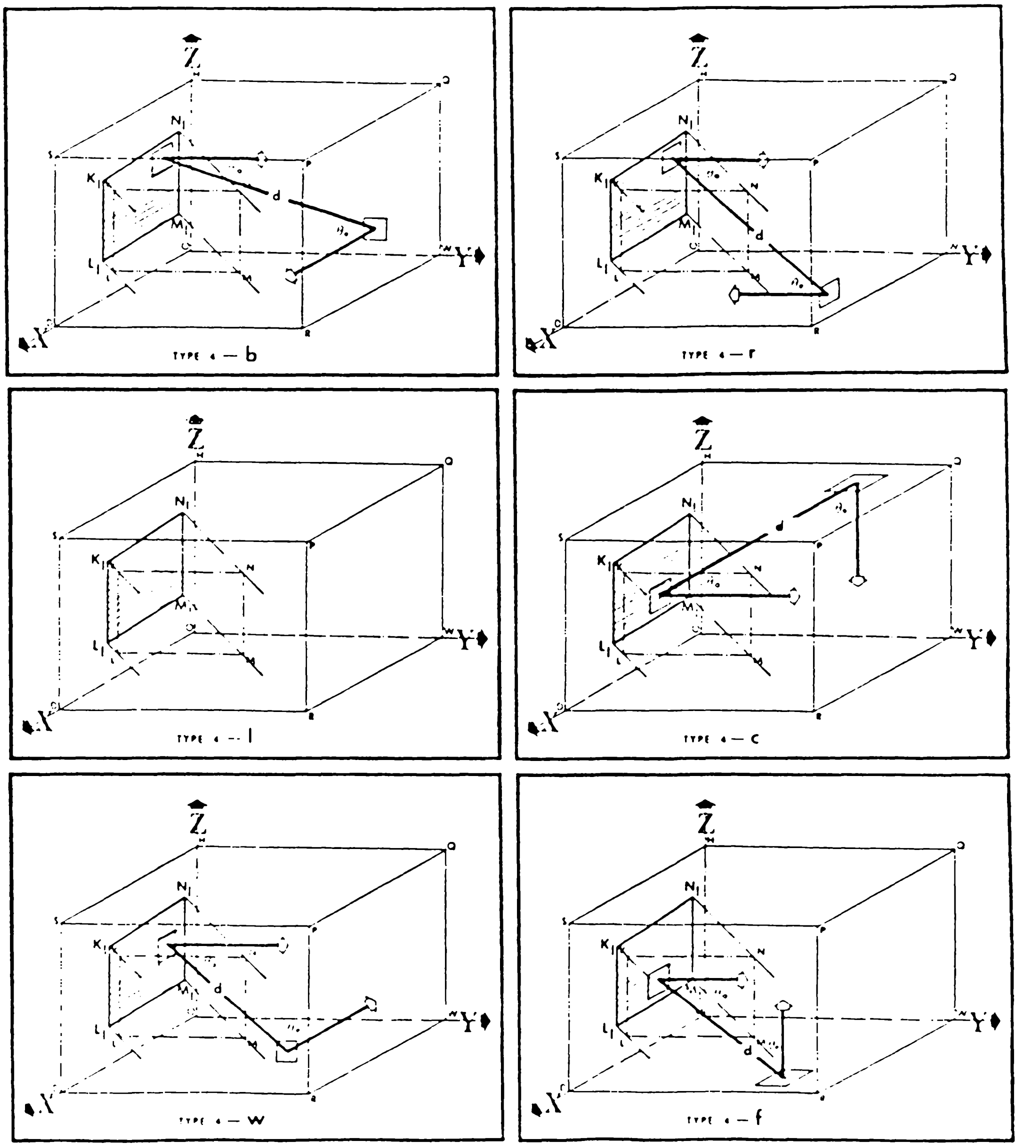

Figure 43. Direct Sunlight Transfer---Type 4

$$N_l \; (x_{ln} , y_{ln} = 0, z_{ln})$$

Line $N_l - K_l$

$$g(z) = z_{ln} + x_l \frac{z_{lk} - z_{ln}}{x_{lk} - x_{ln}}$$

Line $M_g - L_l$

$$f(z) = z_{lm} + x_l \frac{z_{ll} - z_{lm}}{x_{ll} - x_{lm}}$$

Type 4-b (points in back wall)

$$E_{bl} = \int_{f(z)}^{g(z)} \int_{x_{ln}}^{x_{lk}} \frac{E_{dvl} T_g R_l \cos \theta_a \cos \theta_e}{r_{bl}^2 \pi} dx \, dz \qquad [D.13]$$

Equation [D.13] can be reduced in the following form

$$E_{bl} = \int_{f(z)}^{g(z)} \int_{x_{ln}}^{x_{lk}} \frac{E_{dvl} T_g R_l y_b x_l}{r_{bl}^4 \pi} dx \, dz \qquad [D.14]$$

Type 4-w (points in window wall)

$$E_{wl} = \int_{f(z)}^{g(z)} \int_{x_{ln}}^{x_{lk}} \frac{E_{dvl} T_g R_l (x_w - x_l) y_w}{r_{wl}^4 \pi} dx \, dz \qquad [D.15]$$

Type 4-r (points in right wall)

$$E_{rl} = \int_{f(z)}^{g(z)} \int_{x_{ln}}^{x_{lk}} \frac{E_{dvl} T_g R_l w w}{r_{rl}^4 \pi} dx \, dz \qquad [D.16]$$

Type 4-c (points in ceiling)

$$E_{cl} = \int_{f(z)}^{g(z)} \int_{x_{ln}}^{x_{lk}} \frac{E_{dvl} T_g R_l y_c z_c - z_l}{r_{cl}^4 \pi} dx \, dz \qquad [D.17]$$

Type 4-f (points in floor)

$$E_{fl} = \int_{f(z)}^{g(z)} \int_{x_{ln}}^{x_{lk}} \frac{E_{dvl} T_g R_l y_f z_l}{r_{fl}^4 \pi} \, dx \, dz \qquad [D.18]$$

Appendix E. Calculation of Diffuse Daylight

Right Wall $(0 \leq x_r \leq d , y_r = w , 0 \leq z_r \leq h)$

(1) Points above the upper edge of the window $(0 \leq x_r \leq d , y_r = w , b + f \leq z_r \leq h)$

$$E_{RG} = \int_f^{b+f} \int_c^{a+c} \frac{E_G T_w \cos \theta_w \cos \theta r}{R_{RW}^2 \pi} \, dy \, dz \qquad [E.1]$$

(2) Points below the lower edge of the window $(0 \leq x_r \leq d , y_r = w , 0 \leq z_r \leq f)$

$$E_{RS} = \int_f^{b-f} \int_c^{a+c} \frac{E_H T_w \cos \theta_w \cos \theta r}{R_{RW}^2 \pi} \, dy \, dz \qquad [E.2]$$

(3) Points have the same height with window $(0 \leq x_r \leq d , y_r = w , f \leq z_r \leq b + f)$

$$E_{RGS} = \int_{z_r}^{b-f} \int_c^{a+c} \frac{I_G T_w \cos \theta_w \cos \theta r}{R_{RW}^2 \pi} \, dy \, dz + \int_f^{z_r} \int_c^{a+c} \frac{E_H T_w \cos \theta_w \cos \theta_r}{R_{RW}^2 \pi} \, dy \, dz \qquad [E.3]$$

$$R_{RW} = \sqrt{(d - x_r)^2 + (y_w - w)^2 + (z_w - z_r)^2} \qquad [E.4]$$

$$\cos \theta_w = | \cos \alpha_{RW} \cos \alpha_w | = | \frac{d - x_r}{R_{RW}} | \quad [E.5]$$

$$\cos \theta_r = | \cos \beta_{RW} \cos \beta_r | = | \frac{y_w - w}{R_{RW}} | \quad [E.6]$$

Back Wall ($x_b = 0, 0 \le y_b \le w, 0 \le z_b \le h$)

(1) Points above the upper edge of the window ($x_b = 0, 0 \le y_r \le w, b + f \le z_b \le h$)

$$E_{BG} = \int_f^{b+f} \int_c^{a+c} \frac{E_G T_w \cos \theta_w \cos \theta b}{R_{BW}^2 \pi} dy\, dz \quad [E.7]$$

(2) Points below the lower edge of the window ($x_b = 0, 0 \le y_b \le w, 0 \le z_b \le f$)

$$E_{BS} = \int_f^{b-f} \int_c^{a+c} \frac{E_H T_w \cos \theta_w \cos \theta b}{R_{BW}^2 \pi} dy\, dz \quad [E.8]$$

(3) Points have the same height with window ($x_b = 0, 0 \le y_b \le w, f \le z_b \le b + f$)

$$E_{BGS} = \int_{z_b}^{b+f} \int_c^{a+c} \frac{I_G T_w \cos \theta_w \cos \theta b}{R_{BW}^2 \pi} dy\, dz + \int_f^{z_b} \int_c^{a+c} \frac{E_H T_w \cos \theta_w \cos \theta_b}{R_{BW}^2 \pi} dy\, dz \quad [E.9]$$

$$R_{BW} = \sqrt{(d - x_b)^2 + (y_w - y_b)^2 + (z_w - z_b)^2} \quad [E.10]$$

$$\cos \theta_w = | \frac{d}{R_{BW}} | \quad [E.11]$$

$$\cos \theta_w = | \frac{d}{R_{BW}} | \quad [E.12]$$

Ceiling ($0 \le x_c \le d, o \le y_c \le w, z_c = 0$)

Since the points in the ceiling are higher than the upper edge of the window, the illuminance of the ceiling area which receives diffuse daylight directly from the exterior is only affected by the exterior ground. The following is the formula to calculate the illuminance of the ceiling area.

$$E_{CG} = \int_{f}^{b+f} \int_{c}^{a+c} \frac{E_G\, T_g \cos\theta_w \cos\theta_c}{R_{CW}^2\, \pi}\, dy\, dz \qquad [E.13]$$

$$R_{CW} = \sqrt{(d - x_c)^2 + (y_w - y_c)^2 + (z_w - z_c)^2} \qquad [E.14]$$

$$\cos\theta_w = \left| \frac{d - x_c}{R_{CW}} \right| \qquad [E.15]$$

$$\cos\theta_c = \left| \frac{z_w - h}{R_{CW}} \right| \qquad [E.16]$$

Floor $(0 \le x_f \le d,\ o \le y_f \le w,\ z_f = 0)$

$$E_{FS} = \int_{f}^{b+f} \int_{c}^{a+c} \frac{E_H\, T_g \cos\theta_w \cos\theta_f}{R_{FW}^2\, \pi}\, dy\, dz \qquad [E.17]$$

$$R_{FW} = \sqrt{(d - x_f)^2 + (y_w - y_f)^2 + (z_w - z_c)^2} \qquad [E.18]$$

$$\cos\theta_w = \left| \frac{d - x_f}{R_{FW}} \right| \qquad [E.19]$$

$$\cos\theta_f = \left| \frac{z_w - 0}{R_{FW}} \right| \qquad [E.20]$$

Light Exchange of Inter-Reflection Left Wall : $(0 \le x_l \le d,\ y_l = 0,\ 0 \le z_l \le h)$

Light Transfer From Window Wall to Left Wall

$$E_{Lw} = \int_0^h \int_0^w \frac{E_{WW} R_w \cos\theta_l \cos\theta_w}{R_{LW}^2 \pi} dy\, dz \qquad [E.21]$$

where

$$E_{WW} = E_{Wl} \text{ (from equation [E.46])}$$

Light Transfer From Right Wall to Left Wall

$$E_{Lr} = \int_0^h \int_0^d \frac{E_{RR} R_r \cos\theta_l \cos\theta_r}{R_{LR}^2 \pi} dx\, dz \qquad [E.22]$$

Light Transfer From Back Wall to Left Wall

$$E_{Lb} = \int_0^h \int_0^w \frac{E_{BB} R_b \cos\theta_l \cos\theta_b}{R_{LB}^2 \pi} dy\, dz \qquad [E.23]$$

Light Transfer From Ceiling to Left Wall

$$E_{Lc} = \int_0^d \int_0^w \frac{E_{CC} R_c \cos\theta_l \cos\theta_c}{R_{LC}^2 \pi} dx\, dy \qquad [E.24]$$

Light Transfer From Floor to Left Wall

$$E_{Lf} = \int_0^d \int_0^w \frac{E_{FF} R_f \cos\theta_l \cos\theta_f}{R_{LF}^2 \pi} dx\, dy \qquad [E.25]$$

$$E_{U} = E_{Lw} + E_{Lr} + E_{Lb} + I_{Lc} + E_{Lf} \qquad [E.26]$$

Equation [E.26] can calculate the intensity of illuminance which was affected by the inter-reflective phenomena among interior surfaces. In section 4.5, the intensity of illuminance in left the wall directly affected by exterior sources of diffuse daylight has been discussed in three portion. Therefore, to combine equation [E.26] and [4.10], or [4.11], or [4.12] for obtaining the total intensity of illuminance in the left wall. It is necessary to divide the surface into three parts for discussion.

A. if $z_l \geq b + f$ (points in the left wall and above upper edge of the window), then

$$E_L = E_{LG} + E_U \qquad [E.27]$$

B. if $f \leq z_l \leq b + f$ (points in the left wall and have the same height with the window), then

$$E_L = E_{LGS} + E_U \qquad [E.28]$$

C. if $z_l \leq f$ (points in the left wall and below the lower edge of the window), then

$$E_L = E_{LS} + E_U \qquad [E.29]$$

Right Wall : $(0 \leq x_r \leq d , y_r = w , 0 \leq z_r \leq h)$

Light Transfer From the Left Wall to the Right Wall

$$E_{Rl} = \int_0^h \int_0^d \frac{E_{LL} R_l \cos\theta_r \cos\theta_l}{R_{RL}^2 \pi} dx\ dz \qquad [E.30]$$

Light Transfer From the Window Wall to the Right Wall

$$E_{Rw} = \int_0^h \int_0^w \frac{E_{Wl} R_w \cos\theta_r \cos\theta_w}{R_{RW}^2 \pi} dy\ dz \qquad [E.31]$$

Light Transfer From the Back Wall to the Right Wall

$$E_{Rb} = \int_0^h \int_0^w \frac{E_{BB} R_b \cos\theta_r \cos\theta_b}{R_{RB}^2 \pi} dy\ dz \qquad [E.32]$$

Light Transfer From the Ceiling to the Right Wall

$$E_{Rc} = \int_0^d \int_0^w \frac{E_{CC} R_c \cos\theta_r \cos\theta_c}{R_{RC}^2 \pi} dx\ dy \qquad [E.33]$$

Light Transfer From the Floor to the Right Wall

$$E_{Rf} = \int_0^d \int_0^w \frac{E_{FF} R_f \cos\theta_r \cos\theta_f}{R_{RF}^2 \pi} dx\ dy \qquad [E.34]$$

$$E_{RI} = E_{Rl} + E_{Rw} + E_{Rb} + I_{Rc} + E_{Rf} \qquad [E.35]$$

A. if $z_r \geq b + f$ (points in right wall and above upper edge of the window), then

$$E_R = E_{RG} + E_{RI} \qquad [E.36]$$

B. if $f \leq z_r \leq b + f$ (points in the right wall and have the same height with the window), then

$$E_R = E_{RGS} + E_{RI} \qquad [E.37]$$

C. if $z_r \leq f$ (points in the right wall and below the lower edge of the window), then

$$E_R = E_{RS} + E_{RI} \qquad [E.38]$$

Back Wall : $(x_b = 0, 0 \leq y_b \leq w, 0 \leq z_b \leq h)$

Light Transfer From the Left Wall to the Back Wall

$$E_{Bl} = \int_0^h \int_0^d \frac{E_{LL} R_l \cos\theta_b \cos\theta_l}{R_{BL}^2 \pi} \, dx \, dz \qquad [E.39]$$

Light Transfer From the Window Wall to the Back Wall

$$E_{Bw} = \int_0^h \int_0^w \frac{E_{Wl} R_w \cos\theta_b \cos\theta_w}{R_{BW}^2 \pi} \, dy \, dz \qquad [E.40]$$

Light Transfer From the Right Wall to the Back Wall

$$E_{Br} = \int_0^h \int_0^d \frac{E_{RR} R_r \cos\theta_b \cos\theta_r}{R_{BR}^2 \pi} \, dx \, dz \qquad [E.41]$$

Light Transfer From the Ceiling to the Back Wall

$$E_{Bc} = \int_0^d \int_0^w \frac{E_{CC} R_c \cos\theta_b \cos\theta_c}{R_{BC}^2 \pi} \, dx \, dy \qquad [E.42]$$

Light Transfer From the Floor to the Back Wall

$$E_{Bf} = \int_0^d \int_0^w \frac{E_{FF} R_f \cos\theta_b \cos\theta_f}{R_{BF}^2 \pi} \, dx \, dy \qquad [E.43]$$

$$E_{BI} = E_{Bl} + E_{Bw} + E_{Br} + I_{Bc} + E_{Bf} \qquad [E.44]$$

A. if $z_b \geq b + f$ (points in the back wall and above the upper edge of the window), then

$$E_B = E_{BG} + E_{BI} \qquad [E.45]$$

B. if $f \leq z_b \leq b + f$ (points in the back wall and have the same height with the window), then

$$E_B = E_{BGS} + E_{BI} \qquad [E.46]$$

C. if $z_b \le f$ (points in the back wall and below the lower edge of the window), then

$$E_B = E_{BS} + E_{BI} \qquad [E.47]$$

Ceiling : $(0 \le x_c \le d , 0 \le y_c \le w , z_c = h)$

Light Transfer From the Left Wall to the Ceiling

$$E_{Cl} = \int_0^h \int_0^d \frac{E_{LL} R_l \cos \theta_c \cos \theta_l}{R_{CL}^2 \pi} dx\ dz \qquad [E.48]$$

Light Transfer From the Window Wall to the Ceiling

$$E_{Cw} = \int_0^h \int_0^w \frac{E_{WI} R_w \cos \theta_c \cos \theta_w}{R_{CW}^2 \pi} dy\ dz \qquad [E.49]$$

Light Transfer From the Right Wall to the Ceiling

$$E_{Cr} = \int_0^h \int_0^d \frac{E_{RR} R_r \cos \theta_c \cos \theta_r}{R_{CR}^2 \pi} dx\ dz \qquad [E.50]$$

Light Transfer From the Back Wall to the Ceiling

$$E_{Cb} = \int_0^h \int_0^w \frac{E_{BB} R_b \cos \theta_c \cos \theta_b}{R_{CB}^2 \pi} dy\ dz \qquad [E.51]$$

Light Transfer From the Floor to the Ceiling

$$E_{Cf} = \int_0^d \int_0^w \frac{E_{FF} R_f \cos \theta_c \cos \theta_f}{R_{CF}^2 \pi} dx\ dy \qquad [E.52]$$

Appendix F. Diffuse Daylight Simulation Program List

Computation Program

```
10 TW=1 : CLS : WIDTH 40
20 LOCATE 10,1 : PRINT "INPUT THE DAYLIGHT AVAILABILITY";
30 LOCATE 12,7 : PRINT "(IN FOOTCANDLES)"; : INPUT E
40 CLS
50 LOCATE 6,1 : PRINT "PLEASE INPUT THE FOLLOWING INFORMATION";
60 LOCATE 8,1 : PRINT "TO RUN THIS PACKAGE OF DIFFUSE";
70 LOCATE 10,1 : PRINT "DAYLIGHT. (ASSUMING YOU WERE STAND";
80 LOCATE 12,1 : PRINT "OUTSIDE OF THE WINDOW)"
90 FOR I=1 TO 5000 : NEXT I : CLS
100 LOCATE 1,1 : PRINT "INPUT THE DEPTH OF THE ROOM"; : INPUT XD
110 LOCATE 3,1 :  PRINT "INPUT THE WIDTH OF THE ROOM"; : INPUT YW
120 LOCATE 5,1 :  PRINT "INPUT THE HEIGHT OF THE ROOM"; : INPUT ZH
130 LOCATE 7,1 : PRINT "INPUT THE DISTANCE BETWEEN THE";
140 LOCATE 8,7 : PRINT "LEFT WALL AND THE LEFT EDGE";
150 LOCATE 9,7 : PRINT "OF THE WINDOW"; : INPUT WDLEFT
160 LOCATE 11,1 : PRINT "INPUT THE DISTANCE BETWEEN"
170 LOCATE 12,7 : PRINT "THE RIGHT WALL AND THE RIGHT";
180 LOCATE 13,7 : PRINT "EDGE OF THE WINDOW"; : INPUT WDRIGHT
190 LOCATE 15,1 : PRINT "INPUT THE DISTANCE BETWEEN";
200 LOCATE 16,7 : PRINT "THE CEILING AND THE UPPER";
210 LOCATE 17,7 : PRINT "EDGE OF THE WINDOW"; : INPUT WDCEILING
220 LOCATE 19,1 : PRINT "INPUT THE DISTANCE BETWEEN";
230 LOCATE 20,7 : PRINT "THE FLOOR AND THE LOWER";
240 LOCATE 21,7 : PRINT "EDGE OF THE WINDOW"; : INPUT WDFLOOR  : CLS
250 LOCATE 1,1 : PRINT "INPUT THE HEIGHT OF THE REFERENCE";
260 LOCATE 2,7 : PRINT "PLANE WHICH YOU INTEND";
270 LOCATE 3,7 : PRINT "TO CALCULATE"; : INPUT REFHEIGHT
280 LOCATE 5,1 : PRINT "INPUT THE REFLECTANCE OF THE";
290 LOCATE 6,7 : PRINT "EXTERIOR GROUND"; : INPUT RG
300 LOCATE 8,1 : PRINT "INPUT THE REFLECTANCE OF THE";
310 LOCATE 9.7 : PRINT "INTERIOR SURFACES";
320 LOCATE 10,9 : PRINT "LEFT WALL-----"; : INPUT RL
```

```
330 LOCATE 11,9 : PRINT "BACK WALL-----"; : INPUT RB
340 LOCATE 12,9 : PRINT "RIGHT WALL----"; : INPUT RR
350 LOCATE 13,9 : PRINT "CEILING-------"; : INPUT RC
360 LOCATE 14,9 : PRINT "FLOOR---------"; : INPUT RF
370 LOCATE 15,9 : PRINT "WINDOW WALL---"; : INPUT RW
380 CLS  : WIDTH 80
390 DIM IW(6):  DIM IU(6) : DIM X(209,11)
400 OPEN "a: RPlane1.dat" FOR OUTPUT AS 1
410 K=0: XK=XD: XL=XK: XM=XK: XN=XK: YK=WDLEFT: YL=YK: YM=(YW-WDRIGHT): YN=YM
420 ZK=(ZH-WDCEILING): ZN=ZK: ZL=WDFLOOR: ZM=ZL
430 PPI=ATN(1) / 45 : PI=PPI*180
440 XSTEP=XD/18: YSTEP=YW/10: ZBEGIN=REFHEIGHT: AREA=XSTEP*YSTEP
450 IYI=YK: IYF=YM: IZI=ZL: IZF=ZK: INY=5: INZ=5
460 IF IZI<REFHEIGHT THEN IZI=(REFHEIGHT+ .001)
470 FOR I=1 TO 19: FOR J=1 TO 11
480 XBEGIN=(I-1)*XSTEP: YBEGIN=(J-1)*YSTEP:  ZSTEP=0
490 DIY=(IYF-IYI)/(INY*2): DIZ=(IZF-IZI)/(INZ*2)
500 GOSUB 980
510 K=K+1
520 PRINT USING "###";K; : PRINT #1, USING "###";K;
530 PRINT USING "###.####";XSTEP;YSTEP;ZSTEP;
540 PRINT #1, USING "###.####";XSTEP;YSTEP;ZSTEP;
550 PRINT USING "####.####";XBEGIN;YBEGIN;ZBEGIN;AREA;
560 PRINT #1,USING "####.####";XBEGIN;YBEGIN;ZBEGIN;AREA;
570 PRINT USING "#####.####";ITZ : PRINT #1, USING "#####.####";ITZ
580 X(K,1)=K: X(K,2)=XSTEP: X(K,3)=YSTEP: X(K,4)=ZSTEP: X(K,5)=XBEGIN
590 X(K,6)=YBEGIN: X(K,7)=ZBEGIN: X(K,8)=AREA: X(K,9)=ITZ
600 NEXT J: NEXT I
610 CLOSE #1
620 '####################################################################
740 GOTO 1090
750 ' ################ PARAMETERS TRANSFER TO SUBTINE ##########################
760 ' AAA---stand for the COS(THETA 1)
770 ' BBB---stand for the COS(THETA 2)
780 '   E---stand for the INTENSITY OF ILLUMINANCE OF THE SOURCE OBJECT
790 '  TW---stand for the TRANSMISIVE FACTOR OF WINDOW OR REFLECTANCE OF THE
                    SOURCE OBJECT
800 ' X, Y, Z------------ COORDINATES OF THE
CALCULATING POINT OR AREA
810 ' IX, IY, IZ--------- COORDINATES OF THE SOURCE OBJECTT
820 '
830 ' ####################################################################
840 '
850 REM THE DOUBLE INTEGRATION USING THE SIMPSON'S RULE
860 REM ****************************************************
870 REM
880 REM  PASSING VARIABLES FROM THE MAIN PROGRAM:
890 REM  IXI,IXF,IYI,IYF,INX,INY
900 REM  INX,INY :  NO. OF INCREAMENTS IN THE INTEGRATION
910 REM
920 REM   (IYF)   (IXF)
930 REM  INTIGY  INTIGX  FNT(IX,IY)  D<IX>  D<IY>
940 REM   (IYI)   (IXI)
950 REM
960 REM  DEFINE THE FUNCTION -- FNT(IX,IY) FROM LINE  390
970 REM
980 ITZ=0 : IW(4)=IZI :  FOR JJ=1 TO INZ
990 IW(5)=IW(4)+DIZ: IW(6)=IW(5)+DIZ: FOR ITT=4 TO 6: IZ=IW(ITT): ITY=0 : IW(1)=IYI
1000 FOR II=1 TO INY : IW(2)=IW(1)+DIY : IW(3)=IW(2)+DIY : FOR IT=1 TO 3 : IY=IW(IT)
1010 AAA=XD-XBEGIN: BBB=IZ-REFHEIGHT
1020 R#=(((XBEGIN-XD)¢2)+((YBEGIN-IY)¢2)+((IZ-REFHEIGHT)¢2))
1030 F=(E*TW*AAA*BBB)/((R#¢2)* (PI)):  IU(IT)=F : NEXT IT
1040 IQ=(IU(1)+IU(2)*4+IU(3))*DIY/3
1050 ITY=ITY+IQ : IW(1)=IW(3) : NEXT II : FZ=ITY : IU(ITT)=FZ : NEXT ITT
1060 IQ=(IU(4)+IU(5)*4+IU(6))*DIZ/3: ITZ=ITZ+IQ :
1070 IW(4)=IW(6) : NEXT JJ :  ERASE IW:  ERASE IU : RETURN
1080  DIM V(486,11)
1090 OPEN "a: Diffuse1.dat" FOR OUTPUT AS 2
1100 '#################################################################
1110 ' LEFT WALL
1120 K=0
1130 XLEFT=XD: YLEFT=0: ZLEFT=ZH
```

```
1140 XX=XLEFT: YY=YLEFT: ZZ=ZLEFT
1150 COUNTERA=3: ZCONST=0: ZV=ZL
1160 XSTEP=XX/9: YSTEP=YY/9
1170 FOR I=1 TO COUNTERA : FOR J=1 TO 9 : ZSTEP=ZV/COUNTERA
1180 XBEGIN=(J-.5)*XSTEP: YBEGIN=(J-.5)*YSTEP: ZBEGIN=ZCONST+(I-.5)*ZSTEP
1190 K=K+1
1200 PRINT USING "###";K;
1210 PRINT #2, USING "###";K;
1220 AREA=XSTEP * ZSTEP
1230 PRINT USING "###.####";XSTEP;YSTEP;ZSTEP;
1240 PRINT #2, USING "###.####";XSTEP;YSTEP;ZSTEP;
1250 GOSUB 1470
1260 PRINT USING "####.####";XBEGIN;YBEGIN;ZBEGIN;AREA;
1270 PRINT #2,USING "####.####";XBEGIN;YBEGIN;ZBEGIN;AREA;
1280 PRINT USING "#####.####";ITZ
1290 PRINT #2, USING "#####.####";ITZ
1300 V(K,1)=K: V(K,2)=XSTEP: V(K,3)=YSTEP: V(K,4)=ZSTEP: V(K,5)=XBEGIN
1310 V(K,6)=YBEGIN: V(K,7)=ZBEGIN: V(K,8)=AREA: V(K,9)=ITZ
1320 NEXT J: NEXT I
1330 IF ZBEGIN=(2.5 * ZSTEP) THEN 1340 ELSE 1350
1340 ZCONST=ZL : COUNTERA=4 : ZV=(ZK-ZL) :  GOTO 1170
1350 IF ZBEGIN=(ZL + 3.5*ZSTEP) THEN 1360 ELSE 1370
1360 ZCONST=ZK : COUNTERA=2 : ZV=ZH-ZK : GOTO 1170
1370 GOTO 1810
1380 ' ################ PARAMETERS TRANSFER TO SUBTINE ##########################
1390 ' AAA---stand for the COS(THETA 1)
1400 ' BBB---stand for the COS(THETA 2)
1410 '   E---stand for the INTENSITY OF ILLUMINANCE OF THE SOURCE OBJECT
1420 '  TW---stand for the TRANSMISIVE FACTOR OF WINDOW OR REFLECTANCE OF THE
                      SOURCE OBJECT
1430 ' X, Y, Z------------ COORDINATES OF THE CALCULATING POINT OR AREA
1440 ' IX, IY, IZ--------- COORDINATES OF THE SOURCE OBJECTT
1450 '
1460 ' ##########################################################################
1470 IF ZBEGIN>ZL AND ZBEGIN<ZK THEN 1480 ELSE GOTO 1490
1480 IYI=YK: IYF=YM: IZI=ZL: IZF=ZBEGIN: GOTO 1500
1490 IYI=YK: IYF=YM: IZI=ZL: IZF=ZK
1500 INY=2: DIY=(IYF-IYI)/(INY*2)
1510 INZ=2: DIZ=(IZF-IZI)/(INZ*2)
1520 ITZ=0 : IW(4)=IZI :  FOR JJ=1 TO INZ
1530 IW(5)=IW(4)+DIZ: IW(6)=IW(5)+DIZ: FOR ITT=4 TO 6: IZ=IW(ITT): ITY=0 : IW(1)=IYI
1540 FOR II=1 TO INY: IW(2)=IW(1)+DIY: IW(3)=IW(2)+DIY: FOR IT=1 TO 3: IY=IW(IT)
1550 AAA=XD-XBEGIN: BBB=IY
1560 R=(((XBEGIN-XD)c2)+((YBEGIN-IY)¢2)+((ZBEGIN-IZ)¢2))
1570 IF ZBEGIN<ZL THEN GOTO 1580 ELSE GOTO 1590
1580 F=((E*TW)*AAA*BBB)/((R¢2)*PI):  GOTO 1600
1590 F=((E*TW*RG)*AAA*BBB)/((R¢2)*PI): GOTO 1600
1600 IU(IT)=F : NEXT IT
1610 IQ=(IU(1)+IU(2)*4+IU(3))*DIY/3
1620 ITY=ITY+IQ : IW(1)=IW(3) : NEXT II : FZ=ITY : IU(ITT)=FZ : NEXT ITT
1630 IQ=(IU(4)+IU(5)*4+IU(6))*DIZ/3: ITZ=ITZ+IQ :  IW(4)=IW(6) : NEXT JJ
1640 IF ZBEGIN>ZL AND ZBEGIN<ZK THEN 1660 ELSE GOTO 1650
1650 RETURN
1660 IYI=YK: IYF=YM: IZI=ZBEGIN: IZF=ZK
1670 INY=2: DIY=(IYF-IYI)/(INY*2)
1680 INZ=2: DIZ=(IZF-IZI)/(INZ*2)
1690 IW(4)=IZI :  FOR JJ=1 TO INZ
1700 IW(5)=IW(4)+DIZ: IW(6)=IW(5)+DIZ: FOR ITT=4 TO 6: IZ=IW(ITT): ITY=0 : IW(1)=IYI
1710 FOR II=1 TO INY: IW(2)=IW(1)+DIY: IW(3)=IW(2)+DIY: FOR IT=1 TO 3: IY=IW(IT)
1720 AAA=XD-XBEGIN: BBB=IY
1730 R=(((XBEGIN-XD)¢2)+((YBEGIN-IY)¢2)+((ZBEGIN-IZ)¢2))
1740 F=((E*TW)*AAA*BBB)/((R¢2)*PI)
1750 IU(IT)=F : NEXT IT
1760 IQ=(IU(1)+IU(2)*4+IU(3))*DIY/3
1770 ITY=ITY+IQ : IW(1)=IW(3) : NEXT II : FZ=ITY : IU(ITT)=FZ : NEXT ITT
1780 IQ=(IU(4)+IU(5)*4+IU(6))*DIZ/3: ITZ=ITZ+IQ
1790 IW(4)=IW(6) : NEXT JJ
1800 RETURN
1810 '####################################################################
1820 ' BACK WALL
1830 XRIGHT=0: YRIGHT=YW: ZRIGHT=ZH
1840 XX=XRIGHT: YY=YRIGHT: ZZ=ZRIGHT
```

```
1850 COUNTERA=3: ZCONST=0: ZV=ZL
1860 XSTEP=XX/9: YSTEP=YY/9
1870 FOR I=1 TO COUNTERA : FOR J=1 TO 9 : ZSTEP=ZV/COUNTERA
1880 XBEGIN=(J-.5)*XSTEP: YBEGIN=(J-.5)*YSTEP: ZBEGIN=ZCONST+(I-.5)*ZSTEP
1890 K=K+1
1900 PRINT USING "###";K;
1910 PRINT #2, USING "###";K;
1920 AREA=YSTEP * ZSTEP
1930 PRINT USING "###.####";XSTEP;YSTEP;ZSTEP;
1940 PRINT #2, USING "###.####";XSTEP;YSTEP;ZSTEP;
1950 GOSUB 2090
1960 PRINT USING "####.####";XBEGIN;YBEGIN;ZBEGIN;AREA;
1970 PRINT #2,USING "####.####";XBEGIN;YBEGIN;ZBEGIN;AREA;
1980 PRINT USING "#####.####";ITZ
1990 PRINT #2, USING "#####.####";ITZ
2000 V(K,1)=K: V(K,2)=XSTEP: V(K,3)=YSTEP: V(K,4)=ZSTEP: V(K,5)=XBEGIN
2010 V(K,6)=YBEGIN: V(K,7)=ZBEGIN: V(K,8)=AREA: V(K,9)=ITZ
2020 NEXT J: NEXT I
2030 IF ZBEGIN=(2.5 * ZSTEP) THEN 2040 ELSE 2050
2040 ZCONST=ZL : COUNTERA=4 : ZV=(ZK-ZL) :  GOTO 1870
2050 IF ZBEGIN=(ZL + 3.5*ZSTEP) THEN 2060 ELSE 2070
2060 ZCONST=ZK : COUNTERA=2 : ZV=ZH-ZK : GOTO 1870
2070 GOTO 2430
2080 ' ################ PARAMETERS TRANSFER TO SUBTINE ##########################
2090 IF ZBEGIN>ZL AND ZBEGIN<ZK THEN 2100 ELSE GOTO 2110
2100 IYI=YK: IYF=YM: IZI=ZL: IZF=ZBEGIN: GOTO 2120
2110 IYI=YK: IYF=YM: IZI=ZL: IZF=ZK
2120 INY=2: DIY=(IYF-IYI)/(INY*2)
2130 INZ=2: DIZ=(IZF-IZI)/(INZ*2)
2140 ITZ=0 : IW(4)=IZI :  FOR JJ=1 TO INZ
2150 IW(5)=IW(4)+DIZ: IW(6)=IW(5)+DIZ: FOR ITT=4 TO 6: IZ=IW(ITT): ITY=0 : IW(1)=IYI
2160 FOR II=1 TO INY: IW(2)=IW(1)+DIY: IW(3)=IW(2)+DIY: FOR IT=1 TO 3: IY=IW(IT)
2170 AAA=XD: BBB=XD
2180 R=(((XBEGIN-XD)¢2)+((YBEGIN-IY)¢2)+((ZBEGIN-IZ)¢2))
2190 IF ZBEGIN<ZL THEN GOTO 2200 ELSE GOTO 2210
2200 F=((E*TW)*AAA*BBB)/((R¢2)*PI):  GOTO 2220
2210 F=((E*TW*RG)*AAA*BBB)/((R¢2)*PI): GOTO 2220
2220 IU(IT)=F : NEXT IT
2230 IQ=(IU(1)+IU(2)*4+IU(3))*DIY/3
2240 ITY=ITY+IQ : IW(1)=IW(3) : NEXT II : FZ=ITY : IU(ITT)=FZ : NEXT ITT
2250 IQ=(IU(4)+IU(5)*4+IU(6))*DIZ/3: ITZ=ITZ+IQ :  IW(4)=IW(6) : NEXT JJ
2260 IF ZBEGIN>ZL AND ZBEGIN<ZK THEN 2280 ELSE GOTO 2270
2270 RETURN
2280 IYI=YK: IYF=YM: IZI=ZBEGIN: IZF=ZK
2290 INY=2: DIY=(IYF-IYI)/(INY*2)
2300 INZ=2: DIZ=(IZF-IZI)/(INZ*2)
2310 IW(4)=IZI :  FOR JJ=1 TO INZ
2320 IW(5)=IW(4)+DIZ: IW(6)=IW(5)+DIZ: FOR ITT=4 TO 6: IZ=IW(ITT): ITY=0 : IW(1)=IYI
2330 FOR II=1 TO INY: IW(2)=IW(1)+DIY: IW(3)=IW(2)+DIY: FOR IT=1 TO 3: IY=IW(IT)
2340 AAA=XD: BBB=XD
2350 R=(((XBEGIN-XD)¢2)+((YBEGIN-IY)¢2)+((ZBEGIN-IZ)¢2))
2360 F=((E*TW)*AAA*BBB)/((R¢2)*PI)
2370 IU(IT)=F : NEXT IT
2380 IQ=(IU(1)+IU(2)*4+IU(3))*DIY/3
2390 ITY=ITY+IQ : IW(1)=IW(3) : NEXT II : FZ=ITY : IU(ITT)=FZ : NEXT ITT
2400 IQ=(IU(4)+IU(5)*4+IU(6))*DIZ/3: ITZ=ITZ+IQ
2410 IW(4)=IW(6) : NEXT JJ
2420 RETURN
2430 '#####################################################################
2440 ' RIGHT WALL
2450 XRIGH=XD: YRIGH=YW: ZRIGH=ZH
2460 XX=XRIGH: YY=YRIGH: ZZ=ZRIGH
2470 COUNTERA=3: ZCONST=0: ZV=ZL
2480 XSTEP=XX/9: YSTEP=0
2490 FOR I=1 TO COUNTERA : FOR J=1 TO 9 : ZSTEP=ZV/COUNTERA
2500 XBEGIN=(J-.5)*XSTEP: YBEGIN=YY: ZBEGIN=ZCONST+(I-.5)*ZSTEP
2510 K=K+1
2520 PRINT USING "###";K;
2530 PRINT #2, USING "###";K;
2540 AREA=XSTEP * ZSTEP
2550 PRINT USING "###.####";XSTEP;YSTEP;ZSTEP;
2560 PRINT #2, USING "###.####";XSTEP;YSTEP;ZSTEP;
```

```
2570 GOSUB 2720
2580 PRINT USING "####.####":XBEGIN:YBEGIN:ZBEGIN:AREA:
2590 PRINT #2,USING "####.####":XBEGIN;YBEGIN:ZBEGIN:AREA;
2600 PRINT USING "#####.####":ITZ
2610 PRINT #2, USING "#####.####":ITZ
2620 V(K,1)=K: V(K,2)=XSTEP: V(K,3)=YSTEP: V(K,4)=ZSTEP: V(K,5)=XBEGIN
2630 V(K,6)=YBEGIN: V(K,7)=ZBEGIN: V(K,8)=AREA: V(K,9)=ITZ
2640 NEXT J: NEXT I
2650 IF ZBEGIN=(2.5 * ZSTEP) THEN 2660 ELSE 2670
2660 ZCONST=ZL : COUNTERA=4 : ZV=(ZK-ZL) :  GOTO 2490
2670 IF ZBEGIN=(ZL + 3.5*ZSTEP) THEN 2680 ELSE 2700
2680 ZCONST=ZK : COUNTERA=2 : ZV=ZH-ZK : GOTO 2490
2690 'CLOSE #4
2700 GOTO 3060
2710 ' ################ PARAMETERS TRANSFER TO SUBTINE ##########################
2720 IF ZBEGIN>ZL AND ZBEGIN<ZK THEN 2730 ELSE GOTO 2740
2730 IYI=YK: IYF=YM: IZI=ZL: IZF=ZBEGIN: GOTO 2750
2740 IYI=YK: IYF=YM: IZI=ZL: IZF=ZK
2750 INY=2: DIY=(IYF-IYI)/(INY*2)
2760 INZ=2: DIZ=(IZF-IZI)/(INZ*2)
2770 ITZ=0 : IW(4)=IZI :  FOR JJ=1 TO INZ
2780 IW(5)=IW(4)+DIZ: IW(6)=IW(5)+DIZ: FOR ITT=4 TO 6: IZ=IW(ITT): ITY=0 : IW(1)=IYI
2790 FOR II=1 TO INY: IW(2)=IW(1)+DIY: IW(3)=IW(2)+DIY: FOR IT=1 TO 3: IY=IW(IT)
2800 AAA=XD-XBEGIN: BBB=YW-IY
2810 R=(((XBEGIN-XD)¢2)+((YBEGIN-IY)¢2)+((ZBEGIN-IZ)¢2))
2820 IF ZBEGIN<ZL THEN GOTO 2830 ELSE GOTO 2840
2830 F=((E*TW)*AAA*BBB)/((R¢2)*PI):  GOTO 2850
2840 F=((E*TW*RG)*AAA*BBB)/((R¢2)*PI): GOTO 2850
2850 IU(IT)=F : NEXT IT
2860 IQ=(IU(1)+IU(2)*4+IU(3))*DIY/3
2870 ITY=ITY+IQ : IW(1)=IW(3) : NEXT II : FZ=ITY : IU(ITT)=FZ : NEXT ITT
2880 IQ=(IU(4)+IU(5)*4+IU(6))*DIZ/3: ITZ=ITZ+IQ :  IW(4)=IW(6) : NEXT JJ
2890 IF ZBEGIN>ZL AND ZBEGIN<ZK THEN 2910 ELSE GOTO 2900
2900 RETURN
2910 IYI=YK: IYF=YM: IZI=ZBEGIN: IZF=ZK
2920 INY=2: DIY=(IYF-IYI)/(INY*2)
2930 INZ=2: DIZ=(IZF-IZI)/(INZ*2)
2940 IW(4)=IZI :  FOR JJ=1 TO INZ
2950 IW(5)=IW(4)+DIZ: IW(6)=IW(5)+DIZ: FOR ITT=4 TO 6: IZ=IW(ITT): ITY=0 : IW(1)=IYI
2960 FOR II=1 TO INY: IW(2)=IW(1)+DIY: IW(3)=IW(2)+DIY: FOR IT=1 TO 3: IY=IW(IT)
2970 AAA=XD-XBEGIN: BBB=YW-IY
2980 R=(((XBEGIN-XD)¢2)+((YBEGIN-IY)¢2)+((ZBEGIN-IZ)¢2))
2990 F=((E*TW)*AAA*BBB)/((R¢2)*PI)
3000 IU(IT)=F : NEXT IT
3010 IQ=(IU(1)+IU(2)*4+IU(3))*DIY/3
3020 ITY=ITY+IQ : IW(1)=IW(3) : NEXT II : FZ=ITY : IU(ITT)=FZ : NEXT ITT
3030 IQ=(IU(4)+IU(5)*4+IU(6))*DIZ/3: ITZ=ITZ+IQ
3040 IW(4)=IW(6) : NEXT JJ
3050 RETURN
3060 '#########################################################################
3070 ' FLOOR
3080 XLEFT=XD: YLEFT=YW: ZLEFT=KL
3090 XX=XLEFT: YY=YLEFT
3100 XSTEP=XX/9: YSTEP=YY/9: ZSTEP=0!: AREA=XSTEP*YSTEP
3110 FOR I=1 TO 9
3120 FOR J=1 TO 9
3130 XBEGIN=(I-.5)*XSTEP: YBEGIN=(J-.5)*YSTEP
3140 ZBEGIN=ZSTEP
3150 K=K+1
3160 PRINT USING "###":K;
3170 PRINT #2, USING "###":K;
3180 GOSUB 3310
3190 PRINT USING "###.####":XSTEP:YSTEP:ZSTEP:
3200 PRINT #2, USING "###.####":XSTEP:YSTEP:ZSTEP:
3210 PRINT USING "####.####":XBEGIN:YBEGIN:ZBEGIN:AREA:
3220 PRINT #2,USING "####.####":XBEGIN:YBEGIN;ZBEGIN:AREA;
3230 PRINT USING "#####.####":ITZ
3240 PRINT #2, USING "#####.####":ITZ
3250 V(K,1)=K: V(K,2)=XSTEP: V(K,3)=YSTEP: V(K,4)=ZSTEP: V(K,5)=XBEGIN
3260 V(K,6)=YBEGIN: V(K,7)=ZBEGIN: V(K,8)=AREA: V(K,9)=ITZ
3270 NEXT J: NEXT I
3280 'CLOSE #5
```

```
3290 GOTO 3510
3300 ' ################ PARAMETERS TRANSFER TO SUBTINE ##########################
3310 IYI=YK
3320 IYF=YM
3330 IZI=ZL
3340 IZF=ZK
3350 INY=2
3360 INZ=2
3370 DIY=(IYF-IYI)/(INY*2)
3380 DIZ=(IZF-IZI)/(INZ*2)
3390 ITZ=0 : IW(4)=IZI :  FOR JJ=1 TO INZ
3400 IW(5)=IW(4)+DIZ: IW(6)=IW(5)+DIZ: FOR ITT=4 TO 6: IZ=IW(ITT): ITY=0 : IW(1)=IYI
3410 FOR II=1 TO INY : IW(2)=IW(1)+DIY : IW(3)=IW(2)+DIY : FOR IT=1 TO 3 : IY=IW(IT)
3420 AAA=XD-XBEGIN: BBB=IZ
3430 R#=(((XBEGIN-XD)¢2)+((YBEGIN-IY)¢2)+((IZ)¢2))
3440 F=(E*TW*AAA*BBB)/((R#¢2)* (PI)):  ' PRINT XBEGIN;YBEGIN;ZBEGIN;IY;IZ
3450 IU(IT)=F : NEXT IT
3460 IQ=(IU(1)+IU(2)*4+IU(3))*DIY/3
3470 ITY=ITY+IQ : IW(1)=IW(3) : NEXT II : FZ=ITY : IU(ITT)=FZ : NEXT ITT
3480 IQ=(IU(4)+IU(5)*4+IU(6))*DIZ/3: ITZ=ITZ+IQ
3490 IW(4)=IW(6) : NEXT JJ
3500 RETURN
3510 '##########################################################################
3520 ' CEILING
3530 XLEFT=XD: YLEFT=YW: ZLEFT=KL
3540 XX=XLEFT: YY=YLEFT
3550 XSTEP=XX/9: YSTEP=YY/9: ZSTEP=0: AREA=XSTEP*YSTEP
3560 FOR I=1 TO 9:  FOR J=1 TO 9
3570 XBEGIN=(I-.5)*XSTEP: YBEGIN=(J-.5)*YSTEP
3580 ZBEGIN=ZH
3590 K=K+1
3600 PRINT USING "###";K;
3610 PRINT #2, USING "###";K;
3620 PRINT USING "###.####";XSTEP;YSTEP;ZSTEP;
3630 PRINT #2, USING "###.####";XSTEP;YSTEP;ZSTEP;
3640 GOSUB 3740
3650 PRINT USING "####.####";XBEGIN;YBEGIN;ZBEGIN;AREA;
3660 PRINT #2.USING "####.####";XBEGIN;YBEGIN;ZBEGIN;AREA;
3670 PRINT USING "#####.####";ITZ
3680 PRINT #2, USING "#####.####";ITZ
3690 V(K,1)=K: V(K,2)=XSTEP: V(K,3)=YSTEP: V(K,4)=ZSTEP: V(K,5)=XBEGIN
3700 V(K,6)=YBEGIN: V(K,7)=ZBEGIN: V(K,8)=AREA: V(K,9)=ITZ
3710 NEXT J: NEXT I: GOTO 3880
3720 'END
3730 ' ################ PARAMETERS TRANSFER TO SUBTINE ##########################
3740 ITZ=0 : IW(4)=IZI :  FOR JJ=1 TO INZ
3750 IW(5)=IW(4)+DIZ: IW(6)=IW(5)+DIZ: FOR ITT=4 TO 6: IZ=IW(ITT): ITY=0 : IW(1)=IYI
3760 FOR II=1 TO INY : IW(2)=IW(1)+DIY : IW(3)=IW(2)+DIY : FOR IT=1 TO 3 : IY=IW(IT)
3770 AAA=XD-XBEGIN: BBB=ZH-IZ
3780 R#=(((XBEGIN-XD)¢2)+((YBEGIN-IY)¢2)+((ZH-IZ)¢2))
3790 F=(E*TW*RG*AAA*BBB)/((R#¢2)* (PI))
3800 IU(IT)=F : NEXT IT
3810 IQ=(IU(1)+IU(2)*4+IU(3))*DIY/3
3820 ITY=ITY+IQ : IW(1)=IW(3) : NEXT II : FZ=ITY : IU(ITT)=FZ : NEXT ITT
3830 IQ=(IU(4)+IU(5)*4+IU(6))*DIZ/3: ITZ=ITZ+IQ
3840 IW(4)=IW(6) : NEXT JJ
3850 RETURN
3860 '##########################################################################
3870 ' WINDOW WALL
3880 XWIDO=XD: YWIDO=YW: ZWIDO=ZH
3890 ITZ=0
3900 ZZ=ZWIDO: YY=YWIDO
3910 XSTEP=0: YSTEP=YY/9: ZSTEP=ZZ/9: AREA=YSTEP*ZSTEP
3920 FOR I=1 TO 9:  FOR J=1 TO 9
3930 ZBEGIN=(I-.5)*ZSTEP: YBEGIN=(J-.5)*YSTEP
3940 XBEGIN=XD
3950 K=K+1
3960 PRINT USING "###";K;
3970 PRINT #2, USING "###";K;
3980 PRINT USING "###.####";XSTEP;YSTEP;ZSTEP;
3990 PRINT #2, USING "###.####";XSTEP;YSTEP;ZSTEP;
4000 'GOSUB 5450
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```
4010 PRINT USING "####.####":XBEGIN:YBEGIN:ZBEGIN:AREA:
4020 PRINT #2,USING "####.####":XBEGIN;YBEGIN;ZBEGIN;AREA;
4030 PRINT USING "#####.####":ITZ
4040 PRINT #2, USING "#####.####":ITZ
4050 V(K,1)=K: V(K,2)=XSTEP: V(K,3)=YSTEP: V(K,4)=ZSTEP: V(K,5)=XBEGIN
4060 V(K,6)=YBEGIN: V(K,7)=ZBEGIN: V(K,8)=AREA: V(K,9)=ITZ
4070 NEXT J: NEXT I : CLOSE #2: GOTO 4100
4080 '#########################################################################
4090 '#########################################################################
4100 OPEN "a: interdif.dat" FOR OUTPUT AS #3
4110 XW=V(486,5) : YW=V(163,6) : ZH=V(325,7)
4120 SKIN = 2 * PI
4130 FOR I=406 TO 486
4140 ' ########################################################################
4150 FOR K=1 TO 81
4160 R = (( V(K,5)-XW)¢2) + (( V(K,6)- V(I,6))¢2) + (( V(K,7) - V(I,7))¢2)
4170 'IF R< 10 THEN GOTO 4520
4180 INTERW = ( V(K,9) * RL * V(K,8) ) / ( SKIN * (R ) )
4190 V(I,10) = V(I,10) + INTERW
4200 NEXT K
4210 ' ########################################################################
4220 FOR K=82 TO 162
4230 R = (( V(K,5)-XW)¢2) + (( V(K,6)- V(I,6))¢2) + (( V(K,7) - V(I,7))¢2)
4240 'IF R< 10 THEN GOTO 4660
4250 INTERW = ( V(K,9) * RB * V(K,8) ) / ( SKIN * (R ) )
4260 V(I,10) = V(I,10) + INTERW
4270 NEXT K
4280 ' ########################################################################
4290 FOR K=163 TO 243
4300 R = (( V(K,5)-XW)¢2) + (( V(K,6)- V(I,6))¢2) + (( V(K,7) - V(I,7))¢2)
4310 'IF R< 10 THEN GOTO 4800
4320 INTERW = ( V(K,9) * RR * V(K,8) ) / ( SKIN * (R ) )
4330 V(I,10) = V(I,10) + INTERW
4340 NEXT K
4350 ' ########################################################################
4360 FOR K=244 TO 324
4370 R = (( V(K,5)-XW)¢2) + (( V(K,6)- V(I,6))¢2) + (( V(K,7) - V(I,7))¢2)
4380 'IF R< 10 THEN GOTO 4940
4390 INTERW = ( V(K,9) * RF * V(K,8) ) / ( SKIN * (R ) )
4400 V(I,10) = V(I,10) + INTERW
4410 NEXT K
4420 ' ########################################################################
4430 FOR K=325 TO 405
4440 R = (( V(K,5)-XW)¢2) + (( V(K,6)- V(I,6))¢2) + (( V(K,7) - V(I,7))¢2)
4450 'IF R< 10 THEN GOTO 5080
4460 INTERW = ( V(K,9) * RC * V(K,8) ) / ( SKIN * (R ) )
4470 V(I,10) = V(I,10) + INTERW  : NEXT K : PRINT I;V(I,10)
4480 V(I,11)=V(I,9)+V(I,10) : NEXT I
4490 '#########################################################################
4500 GOTO 5220
4510 ' ########################################################################
4520 IXI=V(K,5) - (.5) * V(K,2) : IXF=IXI + V(K,2)
4530 IZI=V(K,7) - (.5) * V(K,4) : IZF=IZI + V(K,4)
4540 INX=2 : INZ=2 :  DIX=( V(K,2) / (INX *2)) : DIZ= ( V(K,4) / (INZ *2))
4550 ITZ=0 : IW(4)=IZI :  FOR JJ=1 TO INZ
4560 IW(5)=IW(4)+DIZ: IW(6)=IW(5)+DIZ: FOR ITT=4 TO 6: IZ=IW(ITT): ITX=0 : IW(1)=IXI
4570 FOR II=1 TO INX : IW(2)=IW(1)+DIX : IW(3)=IW(2)+DIX : FOR IT=1 TO 3 : IX=IW(IT)
4580 AAA=XW-IX: BBB=V(I,6)
4590 R#=(((IX-XW)¢2)+((BBB)¢2)+((IZ- V(I,7))¢2))
4600 F=(V(K,9)*RL*AAA*BBB)/((R#¢2)* PI):  IU(IT)=F : NEXT IT
4610 IQ=(IU(1)+IU(2)*4+IU(3))*DIX/3
4620 ITX=ITX+IQ : IW(1)=IW(3) : NEXT II : FZ=ITX : IU(ITT)=FZ : NEXT ITT
4630 IQ=(IU(4)+IU(5)*4+IU(6))*DIZ/3: ITZ=ITZ+IQ
4640 IW(4)=IW(6) : NEXT JJ  : INTERW=ITZ/36: GOTO 4190
4650 ' ########################################################################
4660 IXI=V(K,6) - (.5) * V(K,3) : IXF=IXI + V(K,3)
4670 IZI=V(K,7) - (.5) * V(K,4) : IZF=IZI + V(K,4)
4680 INX=2 : INZ=2 :  DIX=( V(K,3) / (INX *2)) : DIZ= ( V(K,4) / (INZ *2))
4690 ITZ=0 : IW(4)=IZI :  FOR JJ=1 TO INZ
4700 IW(5)=IW(4)+DIZ: IW(6)=IW(5)+DIZ: FOR ITT=4 TO 6: IZ=IW(ITT): ITX=0 : IW(1)=IXI
4710 FOR II=1 TO INX : IW(2)=IW(1)+DIX : IW(3)=IW(2)+DIX : FOR IT=1 TO 3 : IX=IW(IT)
4720 AAA=XW
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4730 R#=(((XW)¢2)+((V(I,6)-IX)¢2)+((IZ- V(I,7))¢2))
4740 F=(V(K,9)*RB*AAA*AAA) / ((R# ¢ 2) * PI) : IU(IT)=F : NEXT IT
4750 IQ=(IU(1)+IU(2)*4+IU(3))*DIX/3
4760 ITX=ITX+IQ : IW(1)=IW(3) : NEXT II : FZ=ITX : IU(ITT)=FZ : NEXT ITT
4770 IQ=(IU(4)+IU(5)*4+IU(6))*DIZ/3: ITZ=ITZ+IQ
4780 IW(4)=IW(6) : NEXT JJ : INTERW=ITZ/36: GOTO 4260
4790 ' ########################################################################
4800 IXI=V(K,5) - (.5) * V(K,2) : IXF=IXI + V(K,2)
4810 IZI=V(K,7) - (.5) * V(K,4) : IZF=IZI + V(K,4)
4820 INX=2 : INZ=2 :  DIX=( V(K,2) / (INX *2)) : DIZ= ( V(K,4) / (INZ *2))
4830 ITZ=0 : IW(4)=IZI :  FOR JJ=1 TO INZ
4840 IW(5)=IW(4)+DIZ: IW(6)=IW(5)+DIZ: FOR ITT=4 TO 6: IZ=IW(ITT): ITX=0 : IW(1)=IXI
4850 FOR II=1 TO INX : IW(2)=IW(1)+DIX : IW(3)=IW(2)+DIX : FOR IT=1 TO 3 : IX=IW(IT)
4860 AAA=XW-IX: BBB=YW-V(I,6)
4870 R#=(((IX-XW)¢2)+((BBB)¢2)+((IZ- V(I,7))¢2))
4880 F=(V(K,9)*RR*AAA*BBB)/((R#¢2)* PI):  IU(IT)=F : NEXT IT
4890 IQ=(IU(1)+IU(2)*4+IU(3))*DIX/3
4900 ITX=ITX+IQ : IW(1)=IW(3) : NEXT II : FZ=ITX : IU(ITT)=FZ : NEXT ITT
4910 IQ=(IU(4)+IU(5)*4+IU(6))*DIZ/3: ITZ=ITZ+IQ
4920 IW(4)=IW(6) : NEXT JJ  : INTERW=ITZ/36: GOTO 4330
4930 '#########################################################################
4940 IXI=V(K,5) - (.5) * V(K,2) : IXF=IXI + V(K,2)
4950 IZI=V(K,6) - (.5) * V(K,3) : IZF=IZI + V(K,3)
4960 INX=2 : INZ=2 :  DIX=( V(K,2) / (INX *2)) : DIZ= ( V(K,3) / (INZ *2))
4970 ITZ=0 : IW(4)=IZI :  FOR JJ=1 TO INZ
4980 IW(5)=IW(4)+DIZ: IW(6)=IW(5)+DIZ: FOR ITT=4 TO 6: IZ=IW(ITT): ITX=0 : IW(1)=IXI
4990 FOR II=1 TO INX : IW(2)=IW(1)+DIX : IW(3)=IW(2)+DIX : FOR IT=1 TO 3 : IX=IW(IT)
5000 AAA=XW-IX: BBB=V(I,7)
5010 R#=(((IX-XW)¢2)+((V(I,6)-IZ)¢2)+(BBB¢2))
5020 F=(V(K,9)*RF*AAA*BBB)/((R#¢2)* PI):  IU(IT)=F : NEXT IT
5030 IQ=(IU(1)+IU(2)*4+IU(3))*DIX/3
5040 ITX=ITX+IQ : IW(1)=IW(3) : NEXT II : FZ=ITX : IU(ITT)=FZ : NEXT ITT
5050 IQ=(IU(4)+IU(5)*4+IU(6))*DIZ/3: ITZ=ITZ+IQ
5060 IW(4)=IW(6) : NEXT JJ : INTERW=ITZ/36: GOTO 4400
5070 '#########################################################################
5080 IXI=V(K,5) - (.5) * V(K,2) : IXF=IXI + V(K,2)
5090 IZI=V(K,6) - (.5) * V(K,3) : IZF=IZI + V(K,3)
5100 INX=2 : INZ=2 :  DIX=( V(K,2) / (INX *2)) : DIZ= ( V(K,3) / (INZ *2))
5110 ITZ=0 : IW(4)=IZI :  FOR JJ=1 TO INZ
5120 IW(5)=IW(4)+DIZ: IW(6)=IW(5)+DIZ: FOR ITT=4 TO 6: IZ=IW(ITT): ITX=0 : IW(1)=IXI
5130 FOR II=1 TO INX : IW(2)=IW(1)+DIX : IW(3)=IW(2)+DIX : FOR IT=1 TO 3 : IX=IW(IT)
5140 AAA=XW-IX: BBB=ZH-V(I,7)
5150 R#=(((IX-XW)¢2)+((BBB)¢2)+((IZ- V(I,6))¢2))
5160 F=(V(K,9)*RF*AAA*BBB)/((R#¢2)* PI):  IU(IT)=F : NEXT IT
5170 IQ=(IU(1)+IU(2)*4+IU(3))*DIX/3
5180 ITX=ITX+IQ : IW(1)=IW(3) : NEXT II : FZ=ITX : IU(ITT)=FZ : NEXT ITT
5190 IQ=(IU(4)+IU(5)*4+IU(6))*DIZ/3: ITZ=ITZ+IQ
5200 IW(4)=IW(6) : NEXT JJ : INTERW=ITZ/36: GOTO 4470
5210 '########################################################################
5220 FOR I=1 TO 81
5230 ' ########################################################################
5240 FOR K=406 TO 486
5250 R = (( V(K,5)-V(I,5))¢2)  +  ((V(K,6)-V(I,6))¢2 )  +  (( V(K,7) - V(I,7))¢2)
5260 'IF R<10 THEN GOTO 5600
5270 INTERW = ( V(K,11) * RW * V(K,8) ) / ( SKIN * (R ) )
5280 V(I,10) = V(I,10) + INTERW
5290 NEXT K
5300 ' ########################################################################
5310 FOR K=82 TO 162
5320 R = (( V(K,5)-V(I,5))¢2)  +  ((V(K,6)-V(I,6))¢2 )  +  (( V(K,7) - V(I,7))¢2)
5330 'IF R<10 THEN GOTO 5740
5340 INTERW = ( V(K,9) * RB * V(K,8) ) / ( SKIN * (R ) )
5350 V(I,10) = V(I,10) + INTERW
5360 NEXT K
5370 ' ########################################################################
5380 FOR K=163 TO 243
5390 R = (( V(K,5)-V(I,5))¢2)  +  ((V(K,6)-V(I,6))¢2 )  +  (( V(K,7) - V(I,7))¢2)
5400 'IF R<10 THEN GOTO 5880
5410 INTERW = ( V(K,9) * RR * V(K,8) ) / ( SKIN * (R ) )
5420 V(I,10) = V(I,10) + INTERW
5430 NEXT K
5440 ' ########################################################################
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5450 FOR K=244 TO 324
5460 R = (( V(K,5)-V(I,5))¢2) + ((V(K,6)-V(I,6))¢2 ) + (( V(K,7) - V(I,7))¢2)
5470 'IF R<10 THEN GOTO 6020
5480 INTERW = ( V(K,9) * RF * V(K,8) ) / ( SKIN * (R ) )
5490 V(I,10) = V(I,10) + INTERW
5500 NEXT K
5510 ' ##########################################################################
5520 FOR K=325 TO 405
5530 R = (( V(K,5)-V(I,5))¢2) + ((V(K,6)-V(I,6))¢2 ) + (( V(K,7) - V(I,7))¢2)
5540 'IF R<10 THEN GOTO 6160
5550 INTERW = ( V(K,9) * RC * V(K,8) ) / ( SKIN * (R ) )
5560 V(I,10) = V(I,10) + INTERW  : NEXT K : PRINT I;V(I,10): NEXT I
5570 '##########################################################################
5580 GOTO 6300
5590 ' ##########################################################################
5600 IXI=V(K,6) - (.5) * V(K,3) : IXF=IXI + V(K,3)
5610 IZI=V(K,7) - (.5) * V(K,4) : IZF=IZI + V(K,4)
5620 INX=2 : INZ=2 :  DIX=( V(K,3) / (INX *2)) : DIZ= ( V(K,4) / (INZ *2))
5630 ITZ=0 : IW(4)=IZI :  FOR JJ=1 TO INZ
5640 IW(5)=IW(4)+DIZ: IW(6)=IW(5)+DIZ: FOR ITT=4 TO 6: IZ=IW(ITT): ITX=0 : IW(1)=IXI
5650 FOR II=1 TO INX : IW(2)=IW(1)+DIX : IW(3)=IW(2)+DIX : FOR IT=1 TO 3 : IX=IW(IT)
5660 AAA=XW-V(I,5): BBB=IX
5670 R#=(((AAA)¢2)+((BBB)¢2)+((IZ- V(I,7))¢2))
5680 F=(V(K,11)*RW*AAA*BBB)/((R#¢2)* PI):  IU(IT)=F : NEXT IT
5690 IQ=(IU(1)+IU(2)*4+IU(3))*DIX/3
5700 ITX=ITX+IQ : IW(1)=IW(3) : NEXT II : FZ=ITX : IU(ITT)=FZ : NEXT ITT
5710 IQ=(IU(4)+IU(5)*4+IU(6))*DIZ/3: ITZ=ITZ+IQ
5720 IW(4)=IW(6) : NEXT JJ  : INTERW=ITZ/36: GOTO 5280
5730 '##########################################################################
5740 IXI=V(K,6) - (.5) * V(K,3) : IXF=IXI + V(K,3)
5750 IZI=V(K,7) - (.5) * V(K,4) : IZF=IZI + V(K,4)
5760 INX=2 : INZ=2 :  DIX=( V(K,3) / (INX *2)) : DIZ= ( V(K,4) / (INZ *2))
5770 ITZ=0 : IW(4)=IZI :  FOR JJ=1 TO INZ
5780 IW(5)=IW(4)+DIZ: IW(6)=IW(5)+DIZ: FOR ITT=4 TO 6: IZ=IW(ITT): ITX=0 : IW(1)=IXI
5790 FOR II=1 TO INX : IW(2)=IW(1)+DIX : IW(3)=IW(2)+DIX : FOR IT=1 TO 3 : IX=IW(IT)
5800 AAA=IX : BBB=V(I,5)
5810 R#=(((V(I,5)-V(K,5))¢2)+((V(I,6)-IX)¢2)+((IZ- V(I,7))¢2))
5820 F=(V(K,9)*RB*AAA*AAA)/((R#¢2)* PI):  IU(IT)=F : NEXT IT
5830 IQ=(IU(1)+IU(2)*4+IU(3))*DIX/3
5840 ITX=ITX+IQ : IW(1)=IW(3) : NEXT II : FZ=ITX : IU(ITT)=FZ : NEXT ITT
5850 IQ=(IU(4)+IU(5)*4+IU(6))*DIZ/3: ITZ=ITZ+IQ
5860 IW(4)=IW(6) : NEXT JJ : INTERW=ITZ/36: GOTO 5350
5870 ' ##########################################################################
5880 IXI=V(K,5) - (.5) * V(K,2) : IXF=IXI + V(K,2)
5890 IZI=V(K,7) - (.5) * V(K,4) : IZF=IZI + V(K,4)
5900 INX=2 : INZ=2 :  DIX=( V(K,2) / (INX *2)) : DIZ= ( V(K,4) / (INZ *2))
5910 ITZ=0 : IW(4)=IZI :  FOR JJ=1 TO INZ
5920 IW(5)=IW(4)+DIZ: IW(6)=IW(5)+DIZ: FOR ITT=4 TO 6: IZ=IW(ITT): ITX=0 : IW(1)=IXI
5930 FOR II=1 TO INX : IW(2)=IW(1)+DIX : IW(3)=IW(2)+DIX : FOR IT=1 TO 3 : IX=IW(IT)
5940 AAA=YW: BBB=YW
5950 R#=(((IX-V(I,5))¢2)+((BBB)¢2)+((IZ- V(I,7))¢2))
5960 F=(V(K,9)*RR*AAA*BBB)/((R#¢2)* PI):  IU(IT)=F : NEXT IT
5970 IQ=(IU(1)+IU(2)*4+IU(3))*DIX/3
5980 ITX=ITX+IQ : IW(1)=IW(3) : NEXT II : FZ=ITX : IU(ITT)=FZ : NEXT ITT
5990 IQ=(IU(4)+IU(5)*4+IU(6))*DIZ/3: ITZ=ITZ+IQ
6000 IW(4)=IW(6) : NEXT JJ  : INTERW=ITZ/36: GOTO 5420
6010 '##########################################################################
6020 IXI=V(K,5) - (.5) * V(K,2) : IXF=IXI + V(K,2)
6030 IZI=V(K,6) - (.5) * V(K,3) : IZF=IZI + V(K,3)
6040 INX=2 : INZ=2 :  DIX=( V(K,2) / (INX *2)) : DIZ= ( V(K,3) / (INZ *2))
6050 ITZ=0 : IW(4)=IZI :  FOR JJ=1 TO INZ
6060 IW(5)=IW(4)+DIZ: IW(6)=IW(5)+DIZ: FOR ITT=4 TO 6: IZ=IW(ITT): ITX=0 : IW(1)=IXI
6070 FOR II=1 TO INX : IW(2)=IW(1)+DIX : IW(3)=IW(2)+DIX : FOR IT=1 TO 3 : IX=IW(IT)
6080 AAA=V(I,7): BBB=IZ
6090 R#=(((IX-V(I,5))¢2)+((V(I,6)-IZ)¢2)+(V(I,7)¢2))
6100 F=(V(K,9)*RF*AAA*BBB)/((R#¢2)* PI):  IU(IT)=F : NEXT IT
6110 IQ=(IU(1)+IU(2)*4+IU(3))*DIX/3
6120 ITX=ITX+IQ : IW(1)=IW(3) : NEXT II : FZ=ITX : IU(ITT)=FZ : NEXT ITT
6130 IQ=(IU(4)+IU(5)*4+IU(6))*DIZ/3: ITZ=ITZ+IQ
6140 IW(4)=IW(6) : NEXT JJ : INTERW=ITZ/36: GOTO 5490
6150 '##########################################################################
6160 IXI=V(K,5) - (.5) * V(K,2) : IXF=IXI + V(K,2)
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6170 IZI=V(K,6) - (.5) * V(K,3) : IZF=IZI + V(K,3)
6180 INX=2 : INZ=2 :  DIX=( V(K,2) / (INX *2)) : DIZ= ( V(K,3) / (INZ *2))
6190 ITZ=0 : IW(4)=IZI :  FOR JJ=1 TO INZ
6200 IW(5)=IW(4)+DIZ: IW(6)=IW(5)+DIZ: FOR ITT=4 TO 6: IZ=IW(ITT): ITX=0 : IW(1)=IXI
6210 FOR II=1 TO INX : IW(2)=IW(1)+DIX : IW(3)=IW(2)+DIX : FOR IT=1 TO 3 : IX=IW(IT)
6220 AAA=IZ: BBB=ZH-V(I,7)
6230 R#=(((IX-V(I,5))¢2)+((BBB)¢2)+((IZ- V(I,6))¢2))
6240 F=(V(K,9)*RC*AAA*BBB)/((R#¢2)* PI):  IU(IT)=F : NEXT IT
6250 IQ=(IU(1)+IU(2)*4+IU(3))*DIX/3
6260 ITX=ITX+IQ : IW(1)=IW(3) : NEXT II : FZ=ITX : IU(ITT)=FZ : NEXT ITT
6270 IQ=(IU(4)+IU(5)*4+IU(6))*DIZ/3: ITZ=ITZ+IQ
6280 IW(4)=IW(6) : NEXT JJ  : INTERW=ITZ/36: GOTO 5560
6290 '############################################################################
6300 FOR I=82 TO 162
6310 ' ###########################################################################
6320 FOR K=1 TO 81
6330 R = (( V(K,5))¢2) + (( V(K,6)- V(I,6))¢2) + (( V(K,7) - V(I,7))¢2)
6340 'IF R<10 THEN GOTO 6680
6350 INTERW = ( V(K,9) * RL * V(K,8) ) / ( SKIN * (R ) )
6360 V(I,10) = V(I,10) + INTERW
6370 NEXT K
6380 ' ###########################################################################
6390 FOR K=406 TO 486
6400 R = (( V(K,5))¢2) + (( V(K,6)- V(I,6))¢2) + (( V(K,7) - V(I,7))¢2)
6410 'IF R<10 THEN GOTO 6820
6420 INTERW = ( V(K,11) * RW * V(K,8) ) / ( SKIN * (R ) )
6430 V(I,10) = V(I,10) + INTERW
6440 NEXT K
6450 ' ###########################################################################
6460 FOR K=163 TO 243
6470 R = (( V(K,5))¢2) + (( V(K,6)- V(I,6))¢2) + (( V(K,7) - V(I,7))¢2)
6480 'IF R<10 THEN GOTO 6960
6490 INTERW = ( V(K,9) * RR * V(K,8) ) / ( SKIN * (R ) )
6500 V(I,10) = V(I,10) + INTERW
6510 NEXT K
6520 ' ###########################################################################
6530 FOR K=244 TO 324
6540 R = (( V(K,5))¢2) + (( V(K,6)- V(I,6))¢2) + ( V(I,7) ¢2)
6550 'IF R<10 THEN GOTO 7100
6560 INTERW = ( V(K,9) * RF * V(K,8) ) / ( SKIN * (R ) )
6570 V(I,10) = V(I,10) + INTERW
6580 NEXT K
6590 ' ###########################################################################
6600 FOR K=325 TO 405
6610 R = (( V(K,5))¢2) + (( V(K,6)- V(I,6))¢2) + (( V(K,7) - V(I,7))¢2)
6620 'IF R<10 THEN GOTO 7240
6630 INTERW = ( V(K,9) * RC * V(K,8) ) / ( SKIN * (R ) )
6640 V(I,10) = V(I,10) + INTERW  : NEXT K : PRINT I:V(I,10): NEXT I
6650 '############################################################################
6660 GOTO 7380
6670 ' ###########################################################################
6680 IXI=V(K,5) - (.5) * V(K,2) : IXF=IXI + V(K,2)
6690 IZI=V(K,7) - (.5) * V(K,4) : IZF=IZI + V(K,4)
6700 INX=2 : INZ=2 :  DIX=( V(K,2) / (INX *2)) : DIZ= ( V(K,4) / (INZ *2))
6710 ITZ=0 : IW(4)=IZI :  FOR JJ=1 TO INZ
6720 IW(5)=IW(4)+DIZ: IW(6)=IW(5)+DIZ: FOR ITT=4 TO 6: IZ=IW(ITT): ITX=0 : IW(1)=IXI
6730 FOR II=1 TO INX : IW(2)=IW(1)+DIX : IW(3)=IW(2)+DIX : FOR IT=1 TO 3 : IX=IW(IT)
6740 AAA=IX: BBB=V(I,6)
6750 R#=(((IX)¢2)+((BBB)¢2)+((IZ- V(I,7))¢2))
6760 F=(V(K,9)*RL*AAA*BBB)/((R#¢2)* PI):  IU(IT)=F : NEXT IT
6770 IQ=(IU(1)+IU(2)*4+IU(3))*DIX/3
6780 ITX=ITX+IQ : IW(1)=IW(3) : NEXT II : FZ=ITX : IU(ITT)=FZ : NEXT ITT
6790 IQ=(IU(4)+IU(5)*4+IU(6))*DIZ/3: ITZ=ITZ+IQ
6800 IW(4)=IW(6) : NEXT JJ  : INTERW=ITZ/36: GOTO 6360
6810 ' ###########################################################################
6820 IXI=V(K,6) - (.5) * V(K,3) : IXF=IXI + V(K,3)
6830 IZI=V(K,7) - (.5) * V(K,4) : IZF=IZI + V(K,4)
6840 INX=2 : INZ=2 :  DIX=( V(K,3) / (INX *2)) : DIZ= ( V(K,4) / (INZ *2))
6850 ITZ=0 : IW(4)=IZI :  FOR JJ=1 TO INZ
6860 IW(5)=IW(4)+DIZ: IW(6)=IW(5)+DIZ: FOR ITT=4 TO 6: IZ=IW(ITT): ITX=0 : IW(1)=IXI
6870 FOR II=1 TO INX : IW(2)=IW(1)+DIX : IW(3)=IW(2)+DIX : FOR IT=1 TO 3 : IX=IW(IT)
6880 AAA=XW
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6890 R#=(((XW)¢2)+((V(I,6)-IX)¢2)+((IZ- V(I,7))¢2))
6900 F=(V(K,11)*RW*AAA*AAA)/((R#¢2)* PI):  IU(IT)=F : NEXT IT
6910 IQ=(IU(1)+IU(2)*4+IU(3))*DIX/3
6920 ITX=ITX+IQ : IW(1)=IW(3) : NEXT II : FZ=ITX : IU(ITT)=FZ : NEXT ITT
6930 IQ=(IU(4)+IU(5)*4+IU(6))*DIZ/3: ITZ=ITZ+IQ
6940 IW(4)=IW(6) : NEXT JJ : INTERW=ITZ/36: GOTO 6430
6950 ' ###########################################################################
6960 IXI=V(K,5) - (.5) * V(K,2) : IXF=IXI  +  V(K,2)
6970 IZI=V(K,7) - (.5) * V(K,4) : IZF=IZI  +  V(K,4)
6980 INX=2 : INZ=2 :  DIX=( V(K,2) / (INX *2)) : DIZ=  ( V(K,4) / (INZ *2))
6990 ITZ=0 : IW(4)=IZI :  FOR JJ=1 TO INZ
7000 IW(5)=IW(4)+DIZ: IW(6)=IW(5)+DIZ: FOR ITT=4 TO 6: IZ=IW(ITT): ITX=0 : IW(1)=IXI
7010 FOR II=1 TO INX : IW(2)=IW(1)+DIX : IW(3)=IW(2)+DIX : FOR IT=1 TO 3 : IX=IW(IT)
7020 AAA=IX: BBB=YW-V(I,6)
7030 R#=(((IX)¢2)+((BBB)¢2)+((IZ- V(I,7))¢2))
7040 F=(V(K,9)*RR*AAA*BBB)/((R#¢2)* PI):  IU(IT)=F : NEXT IT
7050 IQ=(IU(1)+IU(2)*4+IU(3))*DIX/3
7060 ITX=ITX+IQ : IW(1)=IW(3) : NEXT II : FZ=ITX : IU(ITT)=FZ : NEXT ITT
7070 IQ=(IU(4)+IU(5)*4+IU(6))*DIZ/3: ITZ=ITZ+IQ
7080 IW(4)=IW(6) : NEXT JJ  : INTERW=ITZ/36: GOTO 6500
7090 '###########################################################################
7100 IXI=V(K,5) - (.5) * V(K,2) : IXF=IXI  +  V(K,2)
7110 IZI=V(K,6) - (.5) * V(K,3) : IZF=IZI  +  V(K,3)
7120 INX=2 : INZ=2 :  DIX=( V(K,2) / (INX *2)) : DIZ=  ( V(K,3) / (INZ *2))
7130 ITZ=0 : IW(4)=IZI :  FOR JJ=1 TO INZ
7140 IW(5)=IW(4)+DIZ: IW(6)=IW(5)+DIZ: FOR ITT=4 TO 6: IZ=IW(ITT): ITX=0 : IW(1)=IXI
7150 FOR II=1 TO INX : IW(2)=IW(1)+DIX : IW(3)=IW(2)+DIX : FOR IT=1 TO 3 : IX=IW(IT)
7160 AAA=IX: BBB=V(I,7)
7170 R#=(((IX)¢2)+((V(I,6)-IZ)¢2)+(BBB¢2))
7180 F=(V(K,9)*RF*AAA*BBB)/((R#¢2)* PI):  IU(IT)=F : NEXT IT
7190 IQ=(IU(1)+IU(2)*4+IU(3))*DIX/3
7200 ITX=ITX+IQ : IW(1)=IW(3) : NEXT II : FZ=ITX : IU(ITT)=FZ : NEXT ITT
7210 IQ=(IU(4)+IU(5)*4+IU(6))*DIZ/3: ITZ=ITZ+IQ
7220 IW(4)=IW(6) : NEXT JJ : INTERW=ITZ/36: GOTO 6570
7230 '###########################################################################
7240 IXI=V(K,5) - (.5) * V(K,2) : IXF=IXI  +  V(K,2)
7250 IZI=V(K,6) - (.5) * V(K,3) : IZF=IZI  +  V(K,3)
7260 INX=2 : INZ=2 :  DIX=( V(K,2) / (INX *2)) : DIZ=  ( V(K,3) / (INZ *2))
7270 ITZ=0 : IW(4)=IZI :  FOR JJ=1 TO INZ
7280 IW(5)=IW(4)+DIZ: IW(6)=IW(5)+DIZ: FOR ITT=4 TO 6: IZ=IW(ITT): ITX=0 : IW(1)=IXI
7290 FOR II=1 TO INX : IW(2)=IW(1)+DIX : IW(3)=IW(2)+DIX : FOR IT=1 TO 3 : IX=IW(IT)
7300 AAA=IX: BBB=ZH-V(I,7)
7310 R#=(((IX)¢2)+((BBB)¢2)+((IZ- V(I,6))¢2))
7320 F=(V(K,9)*RC*AAA*BBB)/((R#¢2)* PI):  IU(IT)=F : NEXT IT
7330 IQ=(IU(1)+IU(2)*4+IU(3))*DIX/3
7340 ITX=ITX+IQ : IW(1)=IW(3) : NEXT II : FZ=ITX : IU(ITT)=FZ : NEXT ITT
7350 IQ=(IU(4)+IU(5)*4+IU(6))*DIZ/3: ITZ=ITZ+IQ
7360 IW(4)=IW(6) : NEXT JJ : INTERW=ITZ/36: GOTO 6640
7370 '###########################################################################
7380 FOR I=163 TO 243
7390 ' ###########################################################################
7400 FOR K=406 TO 486
7410 R  =  (( V(K,5)-V(I,5))¢2)  +  ((V(K,6)-V(I,6))¢2 )  +  (( V(K,7) - V(I,7))¢2)
7420 'IF R<10 THEN GOTO 7770
7430 INTERW  =  ( V(K,11) * RW * V(K,8) ) / ( SKIN * (R ) )
7440 V(I,10)  =  V(I,10)  +  INTERW
7450 NEXT K
7460 ' ###########################################################################
7470 FOR K=82 TO 162
7480 R  =  (( V(K,5)-V(I,5))¢2)  +  ((V(K,6)-V(I,6))¢2 )  +  (( V(K,7) - V(I,7))¢2)
7490 'IF R<10 THEN GOTO 7910
7500 INTERW  =  ( V(K,9) * RB * V(K,8) ) / ( SKIN * (R ) )
7510 V(I,10)  =  V(I,10)  +  INTERW
7520 NEXT K
7530 ' ###########################################################################
7540 FOR K=1 TO 81
7550 R  =  (( V(K,5)-V(I,5))¢2)  +  ((V(K,6)-V(I,6))¢2 )  +  (( V(K,7) - V(I,7))¢2)
7560 'IF R<10 THEN GOTO 8050
7570 INTERW  =  ( V(K,9) * RL * V(K,8) ) / ( SKIN * (R ) )
7580 V(I,10)  =  V(I,10)  +  INTERW
7590 NEXT K
7600 ' ###########################################################################
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7610 FOR K=244 TO 324
7620 R = (( V(K,5)-V(I,5))¢2) + ((V(K,6)-V(I,6))¢2 ) + (( V(K,7) - V(I,7))¢2)
7630 'IF R<10 THEN GOTO 8190
7640 INTERW = ( V(K,9) * RF * V(K,8) ) / ( SKIN * (R ) )
7650 V(I,10) = V(I,10) + INTERW
7660 NEXT K
7670 ' ##########################################################################
7680 FOR K=325 TO 405
7690 R = (( V(K,5)-V(I,5))¢2) + ((V(K,6)-V(I,6))¢2 ) + (( V(K,7) - V(I,7))¢2)
7700 'IF R<10 THEN GOTO 8330
7710 INTERW = ( V(K,9) * RC * V(K,8) ) / ( SKIN * (R ) )
7720 V(I,10) = V(I,10) + INTERW : NEXT K : PRINT I;V(I,10): NEXT I
7730 '###########################################################################
7740 GOTO 8460
7750 ' ##########################################################################
7760 ' ##########################################################################
7770 IXI=V(K,6) - (.5) * V(K,3) : IXF=IXI + V(K,3)
7780 IZI=V(K,7) - (.5) * V(K,4) : IZF=IZI + V(K,4)
7790 INX=2 : INZ=2 : DIX=( V(K,3) / (INX *2)) : DIZ= ( V(K,4) / (INZ *2))
7800 ITZ=0 : IW(4)=IZI : FOR JJ=1 TO INZ
7810 IW(5)=IW(4)+DIZ: IW(6)=IW(5)+DIZ: FOR ITT=4 TO 6: IZ=IW(ITT): ITX=0 : IW(1)=IXI
7820 FOR II=1 TO INX : IW(2)=IW(1)+DIX : IW(3)=IW(2)+DIX : FOR IT=1 TO 3 : IX=IW(IT)
7830 AAA=XW-V(I,5): BBB=YW-IX
7840 R#=(((AAA)¢2)+((BBB)¢2)+((IZ- V(I,7))¢2))
7850 F=(V(K,11)*RW*AAA*BBB)/((R#¢2)* PI): IU(IT)=F : NEXT IT
7860 IQ=(IU(1)+IU(2)*4+IU(3))*DIX/3
7870 ITX=ITX+IQ : IW(1)=IW(3) : NEXT II : FZ=ITX : IU(ITT)=FZ : NEXT ITT
7880 IQ=(IU(4)+IU(5)*4+IU(6))*DIZ/3: ITZ=ITZ+IQ
7890 IW(4)=IW(6) : NEXT JJ : INTERW=ITZ/36: GOTO 7440
7900 '##########################################################################
7910 IXI=V(K,6) - (.5) * V(K,3) : IXF=IXI + V(K,3)
7920 IZI=V(K,7) - (.5) * V(K,4) : IZF=IZI + V(K,4)
7930 INX=2 : INZ=2 : DIX=( V(K,3) / (INX *2)) : DIZ= ( V(K,4) / (INZ *2))
7940 ITZ=0 : IW(4)=IZI : FOR JJ=1 TO INZ
7950 IW(5)=IW(4)+DIZ: IW(6)=IW(5)+DIZ: FOR ITT=4 TO 6: IZ=IW(ITT): ITX=0 : IW(1)=IXI
7960 FOR II=1 TO INX : IW(2)=IW(1)+DIX : IW(3)=IW(2)+DIX : FOR IT=1 TO 3 : IX=IW(IT)
7970 AAA=V(I,5): BBB=YW-IX
7980 R#=(((V(I,5)-V(K,5))¢2)+((V(I,6)-IX)¢2)+((IZ- V(I,7))¢2))
7990 F=(V(K,9)*RB*AAA*AAA)/((R#¢2)* PI): IU(IT)=F : NEXT IT
8000 IQ=(IU(1)+IU(2)*4+IU(3))*DIX/3
8010 ITX=ITX+IQ : IW(1)=IW(3) : NEXT II : FZ=ITX : IU(ITT)=FZ : NEXT ITT
8020 IQ=(IU(4)+IU(5)*4+IU(6))*DIZ/3: ITZ=ITZ+IQ
8030 IW(4)=IW(6) : NEXT JJ : INTERW=ITZ/36: GOTO 7510
8040 ' ##########################################################################
8050 IXI=V(K,5) - (.5) * V(K,2) : IXF=IXI + V(K,2)
8060 IZI=V(K,7) - (.5) * V(K,4) : IZF=IZI + V(K,4)
8070 INX=2 : INZ=2 : DIX=( V(K,2) / (INX *2)) : DIZ= ( V(K,4) / (INZ *2))
8080 ITZ=0 : IW(4)=IZI : FOR JJ=1 TO INZ
8090 IW(5)=IW(4)+DIZ: IW(6)=IW(5)+DIZ: FOR ITT=4 TO 6: IZ=IW(ITT): ITX=0 : IW(1)=IXI
8100 FOR II=1 TO INX : IW(2)=IW(1)+DIX : IW(3)=IW(2)+DIX : FOR IT=1 TO 3 : IX=IW(IT)
8110 AAA=YW: BBB=YW
8120 R#=(((IX-V(I,5))¢2)+((BBB)¢2)+((IZ- V(I,7))¢2))
8130 F=(V(K,9)*RL*AAA*BBB)/((R#¢2)* PI): IU(IT)=F : NEXT IT
8140 IQ=(IU(1)+IU(2)*4+IU(3))*DIX/3
8150 ITX=ITX+IQ : IW(1)=IW(3) : NEXT II : FZ=ITX : IU(ITT)=FZ : NEXT ITT
8160 IQ=(IU(4)+IU(5)*4+IU(6))*DIZ/3: ITZ=ITZ+IQ
8170 IW(4)=IW(6) : NEXT JJ : INTERW=ITZ/36: GOTO 7580
8180 '##########################################################################
8190 IXI=V(K,5) - (.5) * V(K,2) : IXF=IXI + V(K,2)
8200 IZI=V(K,6) - (.5) * V(K,3) : IZF=IZI + V(K,3)
8210 INX=2 : INZ=2 : DIX=( V(K,2) / (INX *2)) : DIZ= ( V(K,3) / (INZ *2))
8220 ITZ=0 : IW(4)=IZI : FOR JJ=1 TO INZ
8230 IW(5)=IW(4)+DIZ: IW(6)=IW(5)+DIZ: FOR ITT=4 TO 6: IZ=IW(ITT): ITX=0 : IW(1)=IXI
8240 FOR II=1 TO INX : IW(2)=IW(1)+DIX : IW(3)=IW(2)+DIX : FOR IT=1 TO 3 : IX=IW(IT)
8250 AAA=V(I,7): BBB=YW-IZ
8260 R#=(((IX-V(I,5))¢2)+((V(I,6)-IZ)¢2)+(V(I,7)¢2))
8270 F=(V(K,9)*RF*AAA*BBB)/((R#¢2)* PI): IU(IT)=F : NEXT IT
8280 IQ=(IU(1)+IU(2)*4+IU(3))*DIX/3
8290 ITX=ITX+IQ : IW(1)=IW(3) : NEXT II : FZ=ITX : IU(ITT)=FZ : NEXT ITT
8300 IQ=(IU(4)+IU(5)*4+IU(6))*DIZ/3: ITZ=ITZ+IQ
8310 IW(4)=IW(6) : NEXT JJ : INTERW=ITZ/36: GOTO 7650
8320 '##########################################################################
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8330 IXI=V(K,5) - (.5) * V(K,2) : IXF=IXI + V(K,2)
8340 IZI=V(K,6) - (.5) * V(K,3) : IZF=IZI + V(K,3)
8350 INX=2 : INZ=2 :  DIX=( V(K,2) / (INX *2)) : DIZ= ( V(K,3) / (INZ *2))
8360 ITZ=0 : IW(4)=IZI :  FOR JJ=1 TO INZ
8370 IW(5)=IW(4)+DIZ: IW(6)=IW(5)+DIZ: FOR ITT=4 TO 6: IZ=IW(ITT): ITX=0 : IW(1)=IXI
8380 FOR II=1 TO INX : IW(2)=IW(1)+DIX : IW(3)=IW(2)+DIX : FOR IT=1 TO 3 : IX=IW(IT)
8390 AAA=YW-IZ: BBB=ZH-V(I,7)
8400 R#=(((IX-V(I,5))c2)+((BBB)c2)+((IZ- V(I,6))¢2))
8410 F=(V(K,9)*RC*AAA*BBB)/((R#¢2)* PI):  IU(IT)=F : NEXT IT
8420 IQ=(IU(1)+IU(2)*4+IU(3))*DIX/3
8430 ITX=ITX+IQ : IW(1)=IW(3) : NEXT II : FZ=ITX : IU(ITT)=FZ : NEXT ITT
8440 IQ=(IU(4)+IU(5)*4+IU(6))*DIZ/3: ITZ=ITZ+IQ
8450 IW(4)=IW(6) : NEXT JJ : INTERW=ITZ/36: GOTO 7720
8460 '##########################################################################
8470 FOR I=244 TO 324
8480 ' #########################################################################
8490 FOR K=1 TO 81
8500 R = (( V(K,5)-V(I,5))¢2) + (( V(K,6)- V(I,6))¢2) + (( V(K,7))¢2)
8510 'IF R<10 THEN GOTO 8920
8520 INTERW = ( V(K,9) * RL * V(K,8) ) / ( SKIN * (R ) )
8530 V(I,10) = V(I,10) + INTERW
8540 NEXT K
8550 ' #########################################################################
8560 FOR K=406 TO 486
8570 R = (( V(K,5)-V(I,5))¢2) + (( V(K,6)- V(I,6))¢2) + (( V(K,7))¢2)
8580 'IF R<10 THEN GOTO 9060
8590 INTERW = ( V(K,11) * RW * V(K,8) ) / ( SKIN * (R ) )
8600 V(I,10) = V(I,10) + INTERW
8610 NEXT K
8620 ' #########################################################################
8630 FOR K=163 TO 243
8640 R = (( V(K,5)-V(I,5))¢2) + (( V(K,6)- V(I,6))¢2) + (( V(K,7))¢2)
8650 'IF R<10 THEN GOTO 9200
8660 INTERW = ( V(K,9) * RR * V(K,8) ) / ( SKIN * (R ) )
8670 V(I,10) = V(I,10) + INTERW
8680 NEXT K
8690 ' #########################################################################
8700 FOR K=82 TO 162
8710 R = (( V(K,5)-V(I,5))¢2) + (( V(K,6)- V(I,6))¢2) + (( V(K,7))¢2)
8720 'F R<10 THEN GOTO 9340
8730 INTERW = ( V(K,9) * RB * V(K,8) ) / ( SKIN * (R ) )
8740 V(I,10) = V(I,10) + INTERW
8750 NEXT K
8760 ' #########################################################################
8770 FOR K=325 TO 405
8780 R = (( V(K,5)-V(I,5))¢2) + (( V(K,6)- V(I,6))¢2) + (( V(K,7))¢2)
8790 'IF R<10 THEN GOTO 9480
8800 INTERW = ( V(K,9) * RC * V(K,8) ) / ( SKIN * (R ) )
8810 V(I,10) = V(I,10) + INTERW  : NEXT K : PRINT I;V(I,10): NEXT I
8820 '##########################################################################
8830 'FOR II= 1 TO 486
8840 'PRINT USING "###";V(II,1);
8850 'PRINT #2, USING "###";V(II,1);
8860 'PRINT USING "####.####";V(II,2);V(II,3);V(II,4);V(II,5);V(II,6);V(II,7);V(II,8);V(II,9)
8870 'PRINT #2, USING "####.####";V(II,2);V(II,3);V(II,4);V(II,5);V(II,6);V(II,7);V(II,8);V(II,9)
8880 'NEXT II
8890 'CLOSE #2
8900 GOTO 9620
8910 ' #########################################################################
8920 IXI=V(K,5) - (.5) * V(K,2) : IXF=IXI + V(K,2)
8930 IZI=V(K,7) - (.5) * V(K,4) : IZF=IZI + V(K,4)
8940 INX=2 : INZ=2 :  DIX=( V(K,2) / (INX *2)) : DIZ= ( V(K,4) / (INZ *2))
8950 ITZ=0 : IW(4)=IZI :  FOR JJ=1 TO INZ
8960 IW(5)=IW(4)+DIZ: IW(6)=IW(5)+DIZ: FOR ITT=4 TO 6: IZ=IW(ITT): ITX=0 : IW(1)=IXI
8970 FOR II=1 TO INX : IW(2)=IW(1)+DIX : IW(3)=IW(2)+DIX : FOR IT=1 TO 3 : IX=IW(IT)
8980 AAA=IZ: BBB=V(I,6)
8990 R#=(((IX-V(I,5))c2)+((BBB)¢2)+((IZ- V(I,7))¢2))
9000 F=(V(K,9)*RL*AAA*BBB)/((R#¢2)* PI):  IU(IT)=F : NEXT IT
9010 IQ=(IU(1)+IU(2)*4+IU(3))*DIX/3
9020 ITX=ITX+IQ : IW(1)=IW(3) : NEXT II : FZ=ITX : IU(ITT)=FZ : NEXT ITT
9030 IQ=(IU(4)+IU(5)*4+IU(6))*DIZ/3: ITZ=ITZ+IQ
9040 IW(4)=IW(6) : NEXT JJ  : INTERW=ITZ/36: GOTO 8530
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9050 ' ##########################################################################
9060 IXI=V(K,6) - (.5) * V(K,3) : IXF=IXI + V(K,3)
9070 IZI=V(K,7) - (.5) * V(K,4) : IZF=IZI + V(K,4)
9080 INX=2 : INZ=2 :  DIX=( V(K,3) / (INX *2)) : DIZ= ( V(K,4) / (INZ *2))
9090 ITZ=0 : IW(4)=IZI :  FOR JJ=1 TO INZ
9100 IW(5)=IW(4)+DIZ: IW(6)=IW(5)+DIZ: FOR ITT=4 TO 6: IZ=IW(ITT): ITX=0 : IW(1)=IXI
9110 FOR II=1 TO INX : IW(2)=IW(1)+DIX : IW(3)=IW(2)+DIX : FOR IT=1 TO 3 : IX=IW(IT)
9120 AAA=XW-V(I,5) : BBB=IZ
9130 R#=(((AAA)¢2)+((V(I,6)-IX) ¢ 2)+((IZ)¢2))
9140 F=(V(K,11)*RW*AAA*BBB)/((R#¢2)* PI):  IU(IT)=F : NEXT IT
9150 IQ=(IU(1)+IU(2)*4+IU(3))*DIX/3
9160 ITX=ITX+IQ : IW(1)=IW(3) : NEXT II : FZ=ITX : IU(ITT)=FZ : NEXT ITT
9170 IQ=(IU(4)+IU(5)*4+IU(6))*DIZ/3: ITZ=ITZ+IQ
9180 IW(4)=IW(6) : NEXT JJ : INTERW=ITZ/36: GOTO 8600
9190 ' ##########################################################################
9200 IXI=V(K,5) - (.5) * V(K,2) : IXF=IXI + V(K,2)
9210 IZI=V(K,7) - (.5) * V(K,4) : IZF=IZI + V(K,4)
9220 INX=2 : INZ=2 :  DIX=( V(K,2) / (INX *2)) : DIZ= ( V(K,4) / (INZ *2))
9230 ITZ=0 : IW(4)=IZI :  FOR JJ=1 TO INZ
9240 IW(5)=IW(4)+DIZ: IW(6)=IW(5)+DIZ: FOR ITT=4 TO 6: IZ=IW(ITT): ITX=0 : IW(1)=IXI
9250 FOR II=1 TO INX : IW(2)=IW(1)+DIX : IW(3)=IW(2)+DIX : FOR IT=1 TO 3 : IX=IW(IT)
9260 AAA=IZ: BBB=YW-V(I,6)
9270 R#=(((IX-V(I,5))¢2)+((BBB)¢2)+((IZ- V(I,7))¢2))
9280 F=(V(K,9)*RR*AAA*BBB)/((R#¢2)* PI):  IU(IT)=F : NEXT IT
9290 IQ=(IU(1)+IU(2)*4+IU(3))*DIX/3
9300 ITX=ITX+IQ : IW(1)=IW(3) : NEXT II : FZ=ITX : IU(ITT)=FZ : NEXT ITT
9310 IQ=(IU(4)+IU(5)*4+IU(6))*DIZ/3: ITZ=ITZ+IQ
9320 IW(4)=IW(6) : NEXT JJ  : INTERW=ITZ/36: GOTO 8670
9330 '##########################################################################
9340 IXI=V(K,6) - (.5) * V(K,3) : IXF=IXI + V(K,3)
9350 IZI=V(K,7) - (.5) * V(K,4) : IZF=IZI + V(K,4)
9360 INX=2 : INZ=2 :  DIX=( V(K,3) / (INX *2)) : DIZ= ( V(K,4) / (INZ *2))
9370 ITZ=0 : IW(4)=IZI :  FOR JJ=1 TO INZ
9380 IW(5)=IW(4)+DIZ: IW(6)=IW(5)+DIZ: FOR ITT=4 TO 6: IZ=IW(ITT): ITX=0 : IW(1)=IXI
9390 FOR II=1 TO INX : IW(2)=IW(1)+DIX : IW(3)=IW(2)+DIX : FOR IT=1 TO 3 : IX=IW(IT)
9400 AAA=IZ: BBB=V(I,5)
9410 R#=(((BBB)¢2)+((V(I,6)-IX)¢2)+((V(I,7)-IZ)¢2))
9420 F=(V(K,9)*RB*AAA*BBB)/((R#¢2)* PI):  IU(IT)=F : NEXT IT
9430 IQ=(IU(1)+IU(2)*4+IU(3))*DIX/3
9440 ITX=ITX+IQ : IW(1)=IW(3) : NEXT II : FZ=ITX : IU(ITT)=FZ : NEXT ITT
9450 IQ=(IU(4)+IU(5)*4+IU(6))*DIZ/3: ITZ=ITZ+IQ
9460 IW(4)=IW(6) : NEXT JJ : INTERW=ITZ/36: GOTO 8740
9470 '##########################################################################
9480 IXI=V(K,5) - (.5) * V(K,2) : IXF=IXI + V(K,2)
9490 IZI=V(K,6) - (.5) * V(K,3) : IZF=IZI + V(K,3)
9500 INX=2 : INZ=2 :  DIX=( V(K,2) / (INX *2)) : DIZ= ( V(K,3) / (INZ *2))
9510 ITZ=0 : IW(4)=IZI :  FOR JJ=1 TO INZ
9520 IW(5)=IW(4)+DIZ: IW(6)=IW(5)+DIZ: FOR ITT=4 TO 6: IZ=IW(ITT): ITX=0 : IW(1)=IXI
9530 FOR II=1 TO INX : IW(2)=IW(1)+DIX : IW(3)=IW(2)+DIX : FOR IT=1 TO 3 : IX=IW(IT)
9540 AAA=ZH: BBB=ZH
9550 R#=(((IX-V(I,5))¢2)+((BBB)¢2)+((IZ- V(I,6))¢2))
9560 F=(V(K,9)*RC*AAA*BBB)/((R#¢2)* PI):  IU(IT)=F : NEXT IT
9570 IQ=(IU(1)+IU(2)*4+IU(3))*DIX/3
9580 ITX=ITX+IQ : IW(1)=IW(3) : NEXT II : FZ=ITX : IU(ITT)=FZ : NEXT ITT
9590 IQ=(IU(4)+IU(5)*4+IU(6))*DIZ/3: ITZ=ITZ+IQ
9600 IW(4)=IW(6) : NEXT JJ : INTERW=ITZ/36: GOTO 8810
9610 '##########################################################################
9620 FOR I=325 TO 405
9630 ' ##########################################################################
9640 FOR K=406 TO 486
9650 R = (( V(K,5)-V(I,5))¢2) + ((V(K,6)-V(I,6))¢2 ) + (( V(K,7) - V(I,7))¢2)
9660 'IF R<10 THEN GOTO 10080
9670 INTERW = ( V(K,11) * RW * V(K,8) ) / ( SKIN * (R ) )
9680 V(I,10) = V(I,10) + INTERW
9690 NEXT K
9700 ' ##########################################################################
9710 FOR K=82 TO 162
9720 R = (( V(K,5)-V(I,5))¢2) + ((V(K,6)-V(I,6))¢2 ) + (( V(K,7) - V(I,7))¢2)
9730 'IF R<10 THEN GOTO 10220
9740 INTERW = ( V(K,9) * RB * V(K,8) ) / ( SKIN * (R ) )
9750 V(I,10) = V(I,10) + INTERW
9760 NEXT K
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9770 ' ##########################################################################
9780 FOR K=1 TO 81
9790 R = (( V(K,5)-V(I,5))¢2) + ((V(K,6)-V(I,6))¢2 ) + (( V(K,7) - V(I,7))¢2)
9800 'IF R<10 THEN GOTO 10360
9810 INTERW = ( V(K,9) * RL * V(K,8) ) / ( SKIN * (R ) )
9820 V(I,10) = V(I,10) + INTERW
9830 NEXT K
9840 ' ##########################################################################
9850 FOR K=244 TO 324
9860 R = (( V(K,5)-V(I,5))¢2) + ((V(K,6)-V(I,6))¢2 ) + (( V(K,7) - V(I,7))¢2)
9870 'IF R<10 THEN GOTO 10500
9880 INTERW = ( V(K,9) * RF * V(K,8) ) / ( SKIN * (R ) )
9890 V(I,10) = V(I,10) + INTERW
9900 NEXT K
9910 ' ##########################################################################
9920 FOR K=163 TO 243
9930 R = (( V(K,5)-V(I,5))¢2) + ((V(K,6)-V(I,6))¢2 ) + (( V(K,7) - V(I,7))¢2)
9940 'IF R<10 THEN GOTO 10640
9950 INTERW = ( V(K,9) * RR * V(K,8) ) / ( SKIN * (R ) )
9960 V(I,10) = V(I,10) + INTERW  : NEXT K : PRINT I;V(I,10): NEXT I
9970 '###########################################################################
9980 FOR I=1 TO 486
9990 V(I,11)=V(I,9)+V(I,10)
10000 PRINT USING "###";V(I,1);
10010 PRINT #3, USING "###";V(I,1);
10020 PRINT USING "####.####";V(I,5);V(I,6);V(I,7);V(I,8);V(I,9);V(I,10);V(I,11)
10030 PRINT #3,USING "####.####";V(I,5);V(I,6);V(I,7);V(I,8);V(I,9);V(I,10);V(I,11)
10040 NEXT I
10050 CLOSE #3
10060 GOTO 10780
10070 ' ##########################################################################
10080 IXI=V(K,6) - (.5) * V(K,3) : IXF=IXI + V(K,3)
10090 IZI=V(K,7) - (.5) * V(K,4) : IZF=IZI + V(K,4)
10100 INX=2 : INZ=2 :  DIX=( V(K,3) / (INX *2)) : DIZ= ( V(K,4) / (INZ *2))
10110 ITZ=0 : IW(4)=IZI :  FOR JJ=1 TO INZ
10120 IW(5)=IW(4)+DIZ: IW(6)=IW(5)+DIZ: FOR ITT=4 TO 6: IZ=IW(ITT): ITX=0 : IW(1)=IXI
10130 FOR II=1 TO INX : IW(2)=IW(1)+DIX : IW(3)=IW(2)+DIX : FOR IT=1 TO 3 : IX=IW(IT)
10140 AAA=XW-V(I,5): BBB=ZH-IZ
10150 R#=(((AAA)¢2)+((BBB)¢2)+((IX- V(I,6))¢2))
10160 F=(V(K,11)*RW*AAA*BBB)/((R#¢2)* PI):  IU(IT)=F : NEXT IT
10170 IQ=(IU(1)+IU(2)*4+IU(3))*DIX/3
10180 ITX=ITX+IQ : IW(1)=IW(3) : NEXT II : FZ=ITX : IU(ITT)=FZ : NEXT ITT
10190 IQ=(IU(4)+IU(5)*4+IU(6))*DIZ/3: ITZ=ITZ+IQ
10200 IW(4)=IW(6) : NEXT JJ  : INTERW=ITZ/36: GOTO 9680
10210 '##########################################################################
10220 IXI=V(K,6) - (.5) * V(K,3) : IXF=IXI + V(K,3)
10230 IZI=V(K,7) - (.5) * V(K,4) : IZF=IZI + V(K,4)
10240 INX=2 : INZ=2 :  DIX=( V(K,3) / (INX *2)) : DIZ= ( V(K,4) / (INZ *2))
10250 ITZ=0 : IW(4)=IZI :  FOR JJ=1 TO INZ
10260 IW(5)=IW(4)+DIZ: IW(6)=IW(5)+DIZ: FOR ITT=4 TO 6: IZ=IW(ITT): ITX=0 : IW(1)=IXI
10270 FOR II=1 TO INX : IW(2)=IW(1)+DIX : IW(3)=IW(2)+DIX : FOR IT=1 TO 3 : IX=IW(IT)
10280 AAA=V(I,5): BBB=ZH-IZ
10290 R#=(((V(I,5))¢2)+((V(I,6)-IX)¢2)+((BBB)¢2))
10300 F=(V(K,9)*RB*AAA*AAA)/((R#¢2)* PI):  IU(IT)=F : NEXT IT
10310 IQ=(IU(1)+IU(2)*4+IU(3))*DIX/3
10320 ITX=ITX+IQ : IW(1)=IW(3) : NEXT II : FZ=ITX : IU(ITT)=FZ : NEXT ITT
10330 IQ=(IU(4)+IU(5)*4+IU(6))*DIZ/3: ITZ=ITZ+IQ
10340 IW(4)=IW(6) : NEXT JJ : INTERW=ITZ/36: GOTO 9750
10350 ' ##########################################################################
10360 IXI=V(K,5) - (.5) * V(K,2) : IXF=IXI + V(K,2)
10370 IZI=V(K,7) - (.5) * V(K,4) : IZF=IZI + V(K,4)
10380 INX=2 : INZ=2 :  DIX=( V(K,2) / (INX *2)) : DIZ= ( V(K,4) / (INZ *2))
10390 ITZ=0 : IW(4)=IZI :  FOR JJ=1 TO INZ
10400 IW(5)=IW(4)+DIZ: IW(6)=IW(5)+DIZ: FOR ITT=4 TO 6: IZ=IW(ITT): ITX=0 : IW(1)=IXI
10410 FOR II=1 TO INX : IW(2)=IW(1)+DIX : IW(3)=IW(2)+DIX : FOR IT=1 TO 3 : IX=IW(IT)
10420 AAA=V(I,6): BBB=ZH-IZ
10430 R#=(((IX-V(I,5))¢2)+((BBB)¢2)+((V(I,7))¢2))
10440 F=(V(K,9)*RL*AAA*BBB)/((R#¢2)* PI):  IU(IT)=F : NEXT IT
10450 IQ=(IU(1)+IU(2)*4+IU(3))*DIX/3
10460 ITX=ITX+IQ : IW(1)=IW(3) : NEXT II : FZ=ITX : IU(ITT)=FZ : NEXT ITT
10470 IQ=(IU(4)+IU(5)*4+IU(6))*DIZ/3: ITZ=ITZ+IQ
10480 IW(4)=IW(6) : NEXT JJ  : INTERW=ITZ/36: GOTO 9820
```

```
10490 '###########################################################################
10500 IXI=V(K,5) - (.5) * V(K,2) : IXF=IXI + V(K,2)
10510 IZI=V(K,6) - (.5) * V(K,3) : IZF=IZI + V(K,3)
10520 INX=2 : INZ=2 :  DIX=( V(K,2) / (INX *2)) : DIZ= ( V(K,3) / (INZ *2))
10530 ITZ=0 : IW(4)=IZI :  FOR JJ=1 TO INZ
10540 IW(5)=IW(4)+DIZ: IW(6)=IW(5)+DIZ: FOR ITT=4 TO 6: IZ=IW(ITT): ITX=0 : IW(1)=IXI
10550 FOR II=1 TO INX : IW(2)=IW(1)+DIX : IW(3)=IW(2)+DIX : FOR IT=1 TO 3 : IX=IW(IT)
10560 AAA=ZH: BBB=ZH
10570 R#=(((IX-V(I,5))c2)+((V(I,6)-IZ)c2)+(V(I,7)c2))
10580 F=(V(K,9)*RF*AAA*BBB)/((R#c2)* PI):  IU(IT)=F : NEXT IT
10590 IQ=(IU(1)+IU(2)*4+IU(3))*DIX/3
10600 ITX=ITX+IQ : IW(1)=IW(3) : NEXT II : FZ=ITX : IU(ITT)=FZ : NEXT ITT
10610 IQ=(IU(4)+IU(5)*4+IU(6))*DIZ/3: ITZ=ITZ+IQ
10620 IW(4)=IW(6) : NEXT JJ : INTERW=ITZ/36: GOTO 9890
10630 '###########################################################################
10640 IXI=V(K,5) - (.5) * V(K,2) : IXF=IXI + V(K,2)
10650 IZI=V(K,7) - (.5) * V(K,4) : IZF=IZI + V(K,4)
10660 INX=2 : INZ=2 :  DIX=( V(K,2) / (INX *2)) : DIZ= ( V(K,4) / (INZ *2))
10670 ITZ=0 : IW(4)=IZI :  FOR JJ=1 TO INZ
10680 IW(5)=IW(4)+DIZ: IW(6)=IW(5)+DIZ: FOR ITT=4 TO 6: IZ=IW(ITT): ITX=0 : IW(1)=IXI
10690 FOR II=1 TO INX : IW(2)=IW(1)+DIX : IW(3)=IW(2)+DIX : FOR IT=1 TO 3 : IX=IW(IT)
10700 AAA=YW-V(I,6): BBB=ZH-IZ
10710 R#=(((IX-V(I,5))c2)+((AAA)c2)+((IZ- V(I,7))c2))
10720 F=(V(K,9)*RR*AAA*BBB)/((R#c2)* PI):  IU(IT)=F : NEXT IT
10730 IQ=(IU(1)+IU(2)*4+IU(3))*DIX/3
10740 ITX=ITX+IQ : IW(1)=IW(3) : NEXT II : FZ=ITX : IU(ITT)=FZ : NEXT ITT
10750 IQ=(IU(4)+IU(5)*4+IU(6))*DIZ/3: ITZ=ITZ+IQ
10760 IW(4)=IW(6) : NEXT JJ : INTERW=ITZ/36: GOTO 9960
10770 '###########################################################################
10780 FOR I=1 TO 209
10790 ' ##########################################################################
10800 FOR K=1 TO 81
10810 IF X(I,6)=0 THEN GOTO 10910
10820 ZLOW =  V(K,7)-(.5)*V(K,4) : ZHIG = ZLOW + V(K,4)
10830 IF ZLOW < 2.5 AND ZHIG < = 2.5 THEN GOTO 10890
10840 R = (( V(K,5)-X(I,5))c2) + (( V(K,6)- X(I,6))c2) + (( V(K,7)-X(I,7))¢2)
10850 'IF R<10 THEN GOTO 11560
10860 INTERW = ( V(K,11) * RL * V(K,8) ) / ( SKIN * (R ) )
10870 IF ZLOW < 2.5 AND ZHIG > 2.5 THEN INTERW=INTERW * (ZHIG-2.5)/V(K,4)
10880 X(I,10) = X(I,10) + INTERW
10890 NEXT K
10900 '######################################################################
10910 FOR K=406 TO 486
10920 IF X(I,5) = V(406,5) THEN 11030
10930 ZLOW =  V(K,7)-(.5)*V(K,4) : ZHIG = ZLOW + V(K,4)
10940 IF ZLOW < 2.5 AND ZHIG < = 2.5 THEN GOTO 11000
10950 R = (( V(K,5)-X(I,5))c2) + (( V(K,6)- X(I,6))¢2) + (( V(K,7)-X(I,7))¢2)
10960 'IF R<10 THEN GOTO 11710
10970 INTERW = ( V(K,11) * RW * V(K,8) ) / ( SKIN * (R ) )
10980 IF ZLOW < 2.5 AND ZHIG > 2.5 THEN INTERW=INTERW * (ZHIG-2.5)/V(K,4)
10990 X(I,10) = X(I,10) + INTERW
11000 NEXT K
11010 ' ##########################################################################
11020 FOR K=163 TO 243
11030 IF X(I,6)=V(163,6) THEN GOTO 11130
11040 ZLOW =  V(K,7)-(.5)*V(K,4) : ZHIG = ZLOW + V(K,4)
11050 IF ZLOW < 2.5 AND ZHIG < = 2.5 THEN GOTO 11110
11060 R = (( V(K,5)-X(I,5))¢2) + (( V(K,6)- X(I,6))c2) + (( V(K,7)-X(I,7))¢2)
11070 'IF R<10 THEN GOTO 11860
11080 INTERW = ( V(K,11) * RR * V(K,8) ) / ( SKIN * (R ) )
11090 IF ZLOW < 2.5 AND ZHIG > 2.5 THEN INTERW=INTERW * (ZHIG-2.5)/V(K,4)
11100 X(I,10) = X(I,10) + INTERW
11110 NEXT K
11120 ' ##########################################################################
11130 FOR K=82 TO 162
11140 IF X(I,5)= 0 THEN GOTO 11240
11150 ZLOW =  V(K,7)-(.5)*V(K,4) : ZHIG = ZLOW + V(K,4)
11160 IF ZLOW < 2.5 AND ZHIG < = 2.5 THEN GOTO 11220
11170 R = (( V(K,5)-X(I,5))¢2) + (( V(K,6)- X(I,6))¢2) + (( V(K,7)-X(I,7))¢2)
11180 'IF R<10 THEN GOTO 12010
11190 INTERW = ( V(K,11) * RB * V(K,8) ) / ( SKIN * (R ) )
11200 IF ZLOW < 2.5 AND ZHIG > 2.5 THEN INTERW=INTERW * (ZHIG-2.5)/V(K,4)
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11210 X(I,10) = X(I,10) + INTERW
11220 NEXT K
11230 ' ##########################################################################
11240 FOR K=325 TO 405
11250 R = (( V(K,5)-X(I,5))¢2) + (( V(K,6)- X(I,6))¢2) + (( V(K,7)-X(I,7))¢2)
11260 INTERW = ( V(K,11) * RC * V(K,8) ) / ( SKIN * (R ) )
11270 X(I,10) = X(I,10) + INTERW  : NEXT K : PRINT I;X(I,10): NEXT I
11280 '###########################################################################
11290 OPEN "a: RPlane2.dat" FOR OUTPUT AS #4
11300 OPEN "a: Bi-Spine.dat" FOR OUTPUT AS #5
11310 PRINT #4, "DIFFUSE DAYLIGHT AVAILABILITY IS ";E;" FOODCANDLE"
11320 PRINT #4, "TRANSMISSION FACTOR OF THE WINDOW IS ";TW
11330 PRINT #4, "THE DEPTH OF THE ROOM IS ";XD;" FEET"
11340 PRINT #4, "THE WIDTH OF THE ROOM IS ";YW;" FEET"
11350 PRINT #4, "THE HEIGHT OF THE ROOM IS ";ZH;" FEET"
11360 PRINT #4, "THE DISTANCE BETWEEN THE LEFT EDGE OF THE WINDOW AND
          THE LEFT WALL IS ";WDLEFT;" FEET"
11370 PRINT #4, "THE DISTANCE BETWEEN THE RIGHT EDGE OF THE WINDOW AND
          THE RIGHT WALL IS ";WDRIGHT;" FEET"
11380 PRINT #4, "THE DISTANCE BETWEEN THE UPPER EDGE OF THE WINDOW AND
          THE CEILING IS ";WDCEILING;" FEET"
11390 PRINT #4, "THE DISTANCE BETWEEN THE LOWER EDGE OF THE WINDOW AND
          THE FLOOR IS ";WDFLOOR;" FEET"
11400 PRINT #4, "THE REFLECTANCE OF THE EXTERIOR GROUND IS ";RG
11410 PRINT #4, "THE REFLECTANCE OF THE INTERIOR SURFACES ARE"
11420 PRINT #4, "   LEFT WALL------";RL;"   BACK WALL------";RB
11430 PRINT #4, "   RIGHT WALL-----";RR;"   WINDOW WALL----";RW
11440 PRINT #4, "   CEILING--------";RC;"   FLOOR----------";RF
11450 FOR I=1 TO 209
11460 X(I,11)=X(I,9) + X(I,10)
11470 PRINT USING "###";X(I,1);
11480 PRINT #4, USING "###";X(I,1);
11490 PRINT USING "####.####";X(I,5);X(I,6);X(I,7);X(I,8);X(I,9);X(I,10);X(I,11)
11500 PRINT #4, USING "####.####";X(I,5);X(I,6);X(I,7);X(I,8);X(I,9);X(I,10);X(I,11)
11510 PRINT #5, USING "####.####";X(I,5);X(I,6);X(I,11)
11520 NEXT I
11530 CLOSE #4 : CLOSE #5
11540 GOTO 12630
11550 ' ##########################################################################
11560 IXI=V(K,5) - (.5) * V(K,2) : IXF=IXI + V(K,2)
11570 IF ZLOW < 2.5 AND ZHIG > 2.5 THEN IZI=2.5 ELSE IZI=ZLOW
11580 IZF=ZHIG
11590 INX=2 : INZ=2 :  DIX=( V(K,2) / (INX *2)) : DIZ= ( V(K,4) / (INZ *2))
11600 ITZ=0 : IW(4)=IZI :  FOR JJ=1 TO INZ
11610 IW(5)=IW(4)+DIZ: IW(6)=IW(5)+DIZ: FOR ITT=4 TO 6: IZ=IW(ITT): ITX=0 : IW(1)=IXI
11620 FOR II=1 TO INX : IW(2)=IW(1)+DIX : IW(3)=IW(2)+DIX : FOR IT=1 TO 3 : IX=IW(IT)
11630 AAA=IZ-2.5: BBB=X(I,6)
11640 R#=(((IX-X(I,5))¢2)+((BBB)¢2)+((AAA)¢2))
11650 F=(V(K,11)*RL*AAA*BBB)/((R#¢2)* PI):  IU(IT)=F : NEXT IT
11660 IQ=(IU(1)+IU(2)*4+IU(3))*DIX/3
11670 ITX=ITX+IQ : IW(1)=IW(3) : NEXT II : FZ=ITX : IU(ITT)=FZ : NEXT ITT
11680 IQ=(IU(4)+IU(5)*4+IU(6))*DIZ/3: ITZ=ITZ+IQ
11690 IW(4)=IW(6) : NEXT JJ  : INTERW=ITZ/36: GOTO 10880
11700 ' ##########################################################################
11710 IXI=V(K,6) - (.5) * V(K,3) : IXF=IXI + V(K,3)
11720 IF ZLOW < 2.5 AND ZHIG > 2.5 THEN IZI=2.5 ELSE IZI=ZLOW
11730 IZF=ZHIG
11740 INX=2 : INZ=2 :  DIX=( V(K,3) / (INX *2)) : DIZ= ( V(K,4) / (INZ *2))
11750 ITZ=0 : IW(4)=IZI :  FOR JJ=1 TO INZ
11760 IW(5)=IW(4)+DIZ: IW(6)=IW(5)+DIZ: FOR ITT=4 TO 6: IZ=IW(ITT): ITX=0 : IW(1)=IXI
11770 FOR II=1 TO INX : IW(2)=IW(1)+DIX : IW(3)=IW(2)+DIX : FOR IT=1 TO 3 : IX=IW(IT)
11780 AAA=V(K,5)-X(I,5) : BBB=IZ-2.5
11790 R#=(((AAA)¢2)+((X(I,6)-IX) ¢ 2)+((BBB)¢2))
11800 F=(V(K,11)*RW*AAA*BBB)/((R#¢2)* PI):  IU(IT)=F : NEXT IT
11810 IQ=(IU(1)+IU(2)*4+IU(3))*DIX/3
11820 ITX=ITX+IQ : IW(1)=IW(3) : NEXT II : FZ=ITX : IU(ITT)=FZ : NEXT ITT
11830 IQ=(IU(4)+IU(5)*4+IU(6))*DIZ/3: ITZ=ITZ+IQ
11840 IW(4)=IW(6) : NEXT JJ : INTERW=ITZ/36: GOTO 10990
11850 ' ##########################################################################
11860 IXI=V(K,5) - (.5) * V(K,2) : IXF=IXI + V(K,2)
11870 IF ZLOW < 2.5 AND ZHIG > 2.5 THEN IZI=2.5 ELSE IZI=ZLOW
11880 IZF=ZHIG
```

```
11890 INX=2 : INZ=2 :  DIX=( V(K,2) / (INX *2)) : DIZ=  ( V(K,4) / (INZ *2))
11900 ITZ=0 : IW(4)=IZI :  FOR JJ=1 TO INZ
11910 IW(5)=IW(4)+DIZ: IW(6)=IW(5)+DIZ: FOR ITT=4 TO 6: IZ=IW(ITT): ITX=0 : IW(1)=IXI
11920 FOR II=1 TO INX : IW(2)=IW(1)+DIX : IW(3)=IW(2)+DIX : FOR IT=1 TO 3 : IX=IW(IT)
11930 AAA=IZ-2.5: BBB=V(K,6)-X(I,6)
11940 R#=(((IX-X(I,5))¢2)+((BBB)¢2)+((AAA)¢2))
11950 F=(V(K,11)*RR*AAA*BBB)/((R#¢2)* PI):  IU(IT)=F : NEXT IT
11960 IQ=(IU(1)+IU(2)*4+IU(3))*DIX/3
11970 ITX=ITX+IQ : IW(1)=IW(3) : NEXT II : FZ=ITX : IU(ITT)=FZ : NEXT ITT
11980 IQ=(IU(4)+IU(5)*4+IU(6))*DIZ/3: ITZ=ITZ+IQ
11990 IW(4)=IW(6) : NEXT JJ  : INTERW=ITZ/36: GOTO 11100
12000 '########################################################################
12010 IXI=V(K,6) - (.5) * V(K,3) : IXF=IXI  +  V(K,3)
12020 IF ZLOW  <  2.5 AND ZHIG  >  2.5 THEN IZI=2.5 ELSE IZI=ZLOW
12030 IZF=ZHIG
12040 INX=2 : INZ=2 :  DIX=( V(K,3) / (INX *2)) : DIZ=  ( V(K,4) / (INZ *2))
12050 ITZ=0 : IW(4)=IZI :  FOR JJ=1 TO INZ
12060 IW(5)=IW(4)+DIZ: IW(6)=IW(5)+DIZ: FOR ITT=4 TO 6: IZ=IW(ITT): ITX=0 : IW(1)=IXI
12070 FOR II=1 TO INX : IW(2)=IW(1)+DIX : IW(3)=IW(2)+DIX : FOR IT=1 TO 3 : IX=IW(IT)
12080 AAA=IZ-2.5: BBB=X(I,5)
12090 R#=(((BBB)¢2)+((X(I,6)-IX)¢2)+((AAA)¢2))
12100 F=(V(K,11)*RB*AAA*BBB)/((R#¢2)* PI):  IU(IT)=F : NEXT IT
12110 IQ=(IU(1)+IU(2)*4+IU(3))*DIX/3
12120 ITX=ITX+IQ : IW(1)=IW(3) : NEXT II : FZ=ITX : IU(ITT)=FZ : NEXT ITT
12130 IQ=(IU(4)+IU(5)*4+IU(6))*DIZ/3: ITZ=ITZ+IQ
12140 IW(4)=IW(6) : NEXT JJ : INTERW=ITZ/36: GOTO 11210
12150 '########################################################################
12630 FOR I=1 TO 209
12640 ZP=X(I,11)
12650 IF ZP>ZPICTURE THEN 12661 ELSE GOTO 12670
12661 ZPICTURE=ZP : XPICTURE=X(I,5) : YPICTURE=X(I,6)
12670 NEXT I
12700 OPEN "a: camera.dat" FOR OUTPUT AS #6
12710 XVIEW=10 *XD : YVIEW=10*YW : ZVIEW=12 * ZPICTURE
12720 XSCREEN=.5 * XVIEW : YSCREEN=.5 * YVIEW : ZSCREEN=.5 * ZVIEW
12730 PRINT #6,"2,";"2"
12740 PRINT #6,XVIEW;",";YVIEW;",";ZVIEW
12750 PRINT #6,XSCREEN;",";YSCREEN;",";ZSCREEN
12760 PRINT #6,XD;",";YW
12770 PRINT #6,"n"
12780 PRINT #6,XD;",";YW;",";ZPICTURE;",";XPICTURE;",";YPICTURE
12790 CLOSE #6
12800 END
```

Graphic Representation Program

```
5 CLS
10 'C**-----------------------------------------------------------------
20 'C** PROGRAM FOR CUBIC SPLINE FITTING ,PERSPECTION   FOR A SURFACE
30 'C**-----------------------------------------------------------------
31 'FOR I=1 TO 80: PRINT "-";: NEXT I
32 'FOR I=1 TO 3: PRINT: NEXT I
33 'PRINT   "SURFACE PATCH PROGRAM ---- PUT INPUT DATA IN DISKETE   A: "
34 'FOR I=1 TO 3: PRINT: NEXT I
35 'FOR I=1 TO 80: PRINT "-";: NEXT I
36 'INPUT "READY";OK$
40 CLS: SCREEN 2: WINDOW (-320,-100)-(320,100): KY=.8: KC=.6: PAI=3.141592
      : KEY OFF: C=1
45 OPEN "a: bi-spine.dat" FOR INPUT AS #1
46 OPEN "a: camera.dat" FOR INPUT AS #2
47 MA=11: NA=19: NU=4:  DIM V(NA,MA,3): INPUT #2,NDU,NDV
48 FOR I=1 TO NA: FOR J=1 TO MA: INPUT #1,V(I,J,1),V(I,J,2),V(I,J,3): NEXT J,I
49 CLR=1: RAD=5: NY=NDV*(MA-1)+1: NX=NDU*(NA-1)+1
50 ND=3: DT=1/NU: DIM F(19,ND),P(3),Q(3),DIR(3),Z(NU,3),CHLINE(MA,NA-1,4,ND),
CVLINE(NA,MA-1,4,ND),COE(4,4),PP(NDU,NDV),PPP(NY,NX,ND)
51 INPUT #2,P(1),P(2),P(3): INPUT #2,Q(1),Q(2),Q(3)
52 INPUT #2,DX,DY: INPUT #2,O$  : IF (Y$="Y" OR Y$="y") THEN PERS=1
53 GOSUB 4000 : FRAME=1: INPUT #2,SCX,SCY,SCZ: CLS
54 LINE(-320,-100)-(320,100),1,B: GOSUB 9000: 'LOCATE 2,2: PRINT P(1);P(2)
 ;P(3);" TO ";Q(1);Q(2);Q(3);"   X,Y,Z AXIS  =";SCX;SCY;SCZ
55 FOR IS=1 TO 2
56 IF IS=1 THEN NLINE=NA: NP=MA : GOTO 58
57 NLINE=MA: NP=NA
58 DIM CO(NP,4,ND)
59 FOR KK=1 TO NLINE : G=0
60  FOR I=0 TO NP-1
70   FOR K=1 TO 3
75   IF IS=1 THEN F(I,K)=V(KK,I+1,K) ELSE F(I,K)=V(I+1,KK,K)
76    NEXT K
80  NEXT I
85  FOR I=0 TO NP-1: X=F(I,1): Y=F(I,2): Z=F(I,3)
86  GOSUB 4300  : GOSUB 4330: IF PERS=1 THEN GOSUB 4470
87  GOSUB 4230  : XX=X*320/DX: YY=Y*100/DY: PSET(XX,KY*YY),C
88  NEXT I
90 'C** GOSUB CSPLINE
92   GOSUB 500
93 '-------------------------------------------------------------------
95  FOR I=1 TO NP-1
96   FOR J=1 TO 4
97    FOR K=1 TO ND
98     IF IS=2 THEN CHLINE(KK,I,J,K)=CO(I,J,K) ELSE CVLINE(KK,I,J,K)=CO(I,J,K)
99    NEXT K,J,I
110 NEXT KK
115 ERASE CO
120 NEXT IS
121 GOTO 230
122 'C**
123 'C**-----------------------------------------------------------------
124 FOR L=1 TO ND
126  FOR II=1 TO MA-1
128   FOR JJ=1 TO NA-1
130    FOR K=1 TO 4
132     COE(1,K)=CHLINE(II,JJ,K,L)
134     COE(2,K)=CVLINE(JJ+1,II,K,L)
136     COE(3,K)=CHLINE(II+1,JJ,K,L)
138     COE(4,K)=CVLINE(JJ,II,K,L)
140    NEXT K
142   P00=V(JJ,II,L)
144   P10=V(JJ+1,II,L)
146   P11=V(JJ+1,II+1,L)
148   P01=V(JJ,II+1,L)
```

```
152 'C**-----------------------------------------------------------------
153 DIM PX(NDV+1,NDU+1)
154 GOSUB 8000 'PATCH
156 FOR I=0 TO NDV
158  FOR J=0 TO NDU
160   PPP(I+(II-1)*NDV+1,J+(JJ-1)*NDU+1,L)=PX(I,J)
162   NEXT J,I
163 ERASE PX
164 NEXT JJ,II,L
165 BL=1
167 FOR I=1 TO NY: G=0: FOR J=1 TO NX
168  X=PPP(I,J,1): Y=PPP(I,J,2): Z=PPP(I,J,3)
169 GOSUB 4300  : GOSUB 4330: IF PERS=1 THEN GOSUB 4470
170 GOSUB 4230  : XX=X*320/DX: YY=Y*100/DY: GOSUB 2100
172 NEXT J,I
174 FOR J=1 TO NX: G=0: FOR I=1 TO NY
176  X=PPP(I,J,1): Y=PPP(I,J,2): Z=PPP(I,J,3)
178 GOSUB 4300  : GOSUB 4330: IF PERS=1 THEN GOSUB 4470
180 GOSUB 4230  : XX=X*320/DX: YY=Y*100/DY: GOSUB 2100
182 NEXT I,J
230 C$=INKEY$: IF C$="" THEN 230
240 CLOSE #1,#2
250 END
295 DATA 2,0,0
300 DATA 0,0,0
310 DATA 1,0,0
320 DATA 1,1,0
330 DATA 0,1,0
335 DATA 0,2,0
340 DATA 0,0,0
350 DATA 1,0,0
360 DATA 1,0,1
370 DATA 0,0,1
375 DATA 0,0,2
380 DATA 0,0,0
390 DATA 0,1,0
400 DATA 0,1,1
410 DATA 0,0,1
500 'C**-----------------------------------------------------------------
510 'C**     SUBROUTINE C-SPLINE (ID,NP,F(NP,ND),NU
520 'C**
530 'C**     ND= NO. OF DIMENSION ,NP=NO OF POINT,F=FUNCTION (X,Y,Z)
540 'C**     NU= NO. OF SEGMENT IN BETWEEN TWO POINT
550 'C**
560 'C**-----------------------------------------------------------------
570 'C** CALCULATE LENGTH OF EACH SEGMENT
580 'C**-----------------------------------------------------------------
590 M=NP-1
600 DIM LINV(M),LINV2(M),L(M),FP(M+1,ND),A(M+1,M+1),B(M+1),X(M+1)
610 DIM FF(NU),FFF(NU,ND),AX(M+1,M+1)
620 FOR I=1 TO M
630  L2=0!
640  FOR J=1 TO ND : L2=(F(I,J)-F(I-1,J))¢2+L2: NEXT J
650  L(I)=SQR(L2): LINV(I)=1/L(I): LINV2(I)=LINV(I)¢2
660 NEXT I
670 'C**-----------------------------------------------------------------
680 'C** SET A MATRIX
690 'C**-----------------------------------------------------------------
700 AX(1,1)=4*LINV(1): AX(1,2)=2*LINV(1)
710 FOR I=2 TO M
720  AX(I,I)=4!*(LINV(I-1)+LINV(I)): AX(I,I-1)=AX(I-1,I): AX(I,I+1)=2!*LINV(I)
730 NEXT I
740 AX(M+1,M+1)=4*LINV(M): AX(M+1,M)=2*LINV(M)
750 'C**-----------------------------------------------------------------
760 'C** SET B MATRIX  AND PUT A MATRIX
770 'C**-----------------------------------------------------------------
780 FOR L=1 TO ND
785  FOR J=1 TO NP: FOR I=1 TO NP: A(I,J)=AX(I,J): NEXT I,J
790  B(1)=6*(F(1,L)-F(0,L))*LINV2(1): S1=B(1)
800  FOR I=2 TO M : S2=6*(F(I,L)-F(I-1,L))*LINV2(I): B(I)=S1+S2: S1=S2: NEXT I
805  B(M+1)=6*(F(M,L)-F(M-1,L))*LINV2(M)
810 'C**-----------------------------------------------------------------
```

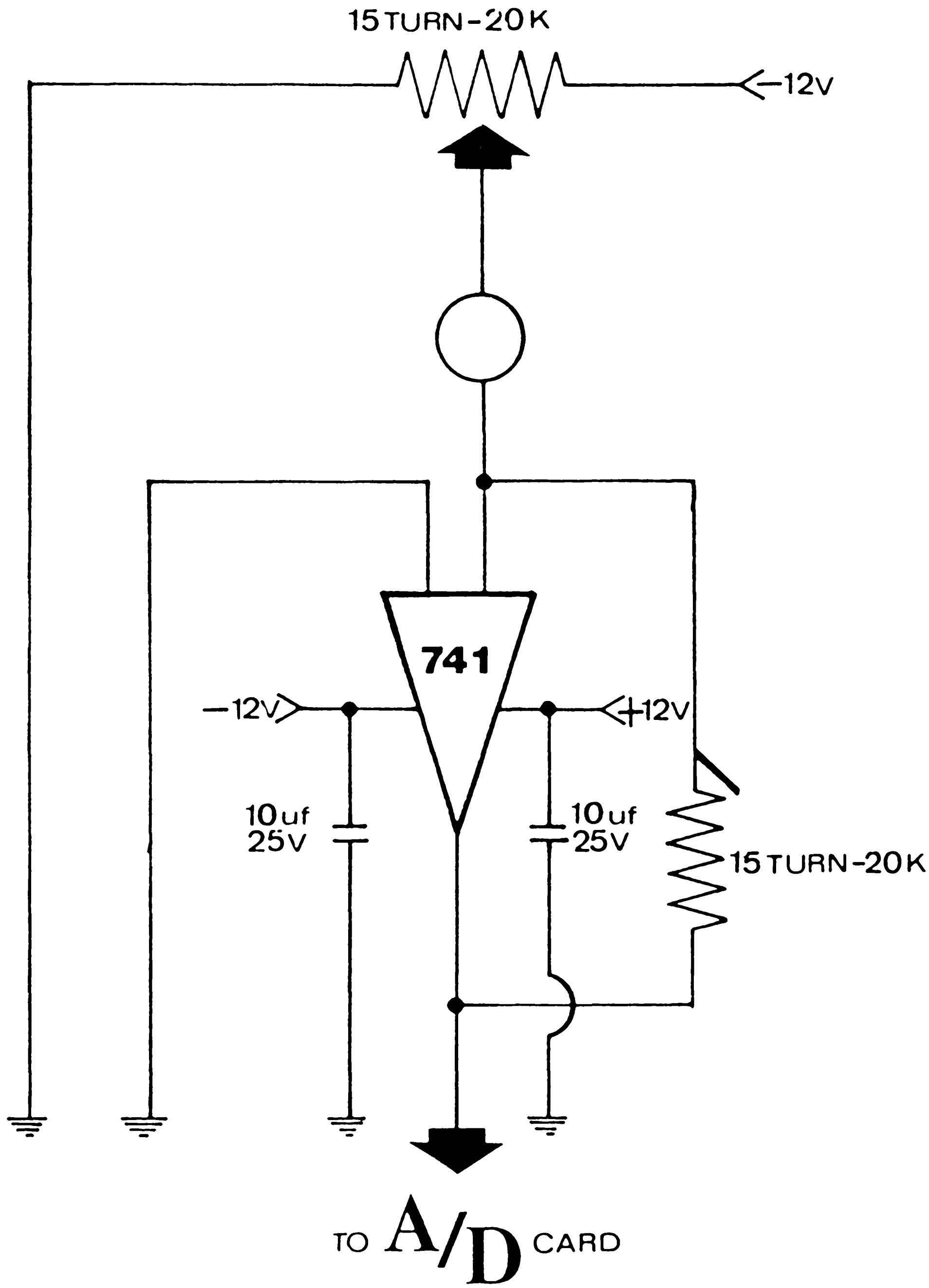
```
815 'FOR I=1 TO NP: FOR J=1 TO NP: PRINT A(I,J),: NEXT J: PRINT B(I): NEXT I
820  N=NP: GOSUB 7000 'INV
825 'FOR I=1 TO NP: PRINT X(I): NEXT I
830 'C**-----------------------------------------------------------------
840  FOR I=1 TO M+1: FP(I-1,L)=X(I): NEXT I
850 NEXT L
860 'C**-----------------------------------------------------------------
870 'C** TRACE THE CURVE
880 'C**-----------------------------------------------------------------
890 FOR I=1 TO NP-1
900  FOR J=1 TO ND
910  F0=F(I-1,J): F1=F(I,J): FP0=FP(I-1,J): FP1=FP(I,J)
920  AA=2*F0-2*F1+L(I)*FP0+L(I)*FP1: BB=-3*F0+3*F1-2*L(I)*FP0-L(I)*FP1
     : CC=L(I)*       FP0: DD=F0
925 CO(I,1,J)=AA: CO(I,2,J)=BB: CO(I,3,J)=CC: CO(I,4,J)=DD
930 'C**-----------------------------------------------------------------
940  GOSUB 5000  'DIFSCH
950 'C**-----------------------------------------------------------------
960   FOR K=0 TO NU: FFF(K,J)=FF(K): NEXT K
970  NEXT J
975 IF (IS=2 AND I=NP-1) THEN GOTO 985
980  GOSUB 2000  'PLOT
985 NEXT I
987 ERASE LINV,LINV2,L,FP,A,B,X,FF,FFF,AX
990 RETURN
1000 END
2000 'C**-----------------------------------------------------------------
2010 'C** SUB ROUTINE PLOT NP,FFF(K.J)
2020 'C**-----------------------------------------------------------------
2045 FOR K=0 TO NU: FOR J=1 TO 3: Z(K,J)=FFF(K,J): NEXT J,K
2050 FOR K=0 TO NU
2060  X=Z(K,1): Y=Z(K,2): Z=Z(K,3): GOSUB 4300: GOSUB 4330: IF PERS=1 THEN
      GOSUB 4470
2065  GOSUB 4230: XX=X*320/DX: YY=Y*100/DY
2066 IF (IS=1 AND KK=NLINE) THEN GOTO 2080
2070  GOSUB 2100   'GRAPHICS
2080 NEXT K
2090 RETURN
2095 END
2100 'C**-----------------------------------------------------------------
2110 '** SUBROUTINE GRAPHICS (XX,YY,C,G)
2120 'C**-----------------------------------------------------------------
2130 GX=XX: GY=KY*YY
2140 IF G=0 THEN PSET (GX,GY),C: G=1
2150 LINE -(GX,GY),C,,&HFFFF
2151 'IF BL=0 THEN LINE -(GX,GY),C: ELSE LINE -(GX,GY),C,,&H5555
2160 RETURN
2170 END
2180 'C**-----------------------------------------------------------------
2190 'C** SUBROUTINE CIRCLE
2200 'C**-----------------------------------------------------------------
2210 'CIRCLE(XX,KY*YY),RAD,CLR,KC
2220 RETURN
2230 END
4000 'C**-----------------------------------------------------------------
4010 'C** SUBROUTINE DIRCOS (TO DETEMINE XTH,YTH,ZTH FOR GIVEN VIEW DIRECTION)
4020 'C** VIEW FROM POINT (P1,P2,P3) TO (Q1,Q2,Q3)
4030 'C** PERS=1 (WITH PERSPECTION) PERS=0 (NO PERSPECTION)
4040 'C**-----------------------------------------------------------------
4050 'C** COMPUTE DIRECTION COSINE
4060 H=0
4070 FOR I=1 TO 3
4080  DIR(I)=P(I)-Q(I): H=DIR(I)¢2+H
4090 NEXT I
4100 H=SQR(H)
4110 FOR I=1 TO 3
4120  DIR(I)=DIR(I)/H
4130 NEXT I
4140 IF DIR(3)=0 THEN GOTO 4160
4150 T=DIR(2)/DIR(3): XTH=ATN(T)
4160 TT=SQR(DIR(2)¢2+DIR(3)¢2): IF TT=0 THEN YTH=0: ELSE YTH=-ATN(DIR(1)/TT)
4170 'C** FIND CX,CY--- ZTH
```

```
4175 'C** PERFORM (0,0,50)-(0,0,0) TO DETEMINE ZTH
4180 TX=-Q(1): TY=-Q(2): TZ=-Q(3)
4190 X=0: Y=0: Z=50: GOSUB 4300: GOSUB 4330 : IF PERS=1 THEN GOSUB 4470
4200 X1=X: Y1=Y
4210 X=0: Y=0: Z=0: GOSUB 4300: GOSUB 4330: IF PERS=1 THEN GOSUB 4470
4211 X0=X: Y0=Y: CX=X1-X0: CY=Y1-Y0
4212 IF(CX=0 AND CY=0)THEN GTH=0 ELSE IF CY=0 THEN GTH=-PAI/2 ELSE GTH=ATN(CX/CY)+PAI
4225 RETURN
4230 'C** SUBROUTINE T-Z-ROTAION-T
4240 XW=X-X0: YW=Y-Y0: X=XW*COS(GTH)-YW*SIN(GTH)+X0: Y=XW*SIN(GTH)+YW*COS(GTH)+Y0
4250 RETURN
4300 'C**  TRANSLATION
4310 X=X+TX: Y=Y+TY: Z=Z+TZ
4320 RETURN
4328 'C**-------------------------------------------------------------------
4330 'C**  X-Y ROTATION
4335 'C**-------------------------------------------------------------------
4340 XW=X: YW=Y: ZW=Z
4350 X=XW
4360 Y=YW*COS(XTH)-ZW*SIN(XTH)
4370 Z=YW*SIN(XTH)+ZW*COS(XTH)
4380 XW=X: YW=Y: ZW=Z
4390 X=XW*COS(YTH)+ZW*SIN(YTH)
4400 Y=YW
4410 Z=-XW*SIN(YTH)+ZW*COS(YTH)
4420 RETURN
4470 'C** PESPECTIVE
4480 X=H*X/(H-Z): Y=H*Y/(H-Z)
4490 RETURN
5000 'C**-------------------------------------------------------------------
5010 'C** SUBROUTINE DIFSCH (AA,BB,CC,DD,NU,DT)
5020 'C**-------------------------------------------------------------------
5030 DT2=DT*DT: DT3=DT2*DT
5040 A0=DD: A1=DT*((AA*DT+BB)*DT+CC): A2=DT2*((6*DT*AA)+2*BB): A3=6*AA*DT3
5050 FOR K=0 TO NU
5060 FF(K)=A0: A0=A0+A1: A1=A1+A2: A2=A2+A3: NEXT K
5070 RETURN
5080 END
7000 REM---SOLVE SIMULTANEOUS LINEAR EQUATIONS---
7010 REM---SUBROUTINE LEQ---
7020 FOR K=1 TO N-1
7030   AMAX=ABS(A(K,K))  :  IMAX=K
7040   FOR I=K+1 TO N
7050     AIK=ABS(A(I,K))
7060     IF AIK>AMAX THEN AMAX=AIK :  IMAX=I
7070   NEXT I
7080   IF IMAX=K GOTO 7130
7090     FOR J=K TO N
7100       SWAP A(K,J),A(IMAX,J)
7110     NEXT J
7120     SWAP B(K),B(IMAX)
7130   P=A(K,K)
7140   FOR J=K+1 TO N
7150     A(K,J)=A(K,J)/P
7160   NEXT J
7170   B(K)=B(K)/P
7180   FOR I=K+1 TO N
7190     Q=A(I,K)
7200     FOR J=K+1 TO N
7210       A(I,J)=A(I,J)-Q*A(K,J)
7220     NEXT J
7230     B(I)=B(I)-Q*B(K)
7240   NEXT I
7250 NEXT K
7260 X(N)=B(N)/A(N,N)
7270 FOR K=N-1 TO 1 STEP -1
7280   S=0
7290   FOR J=K+1 TO N
7300     S=A(K,J)*X(J)+S
7310   NEXT J
7320   X(K)=B(K)-S
7330 NEXT K
```

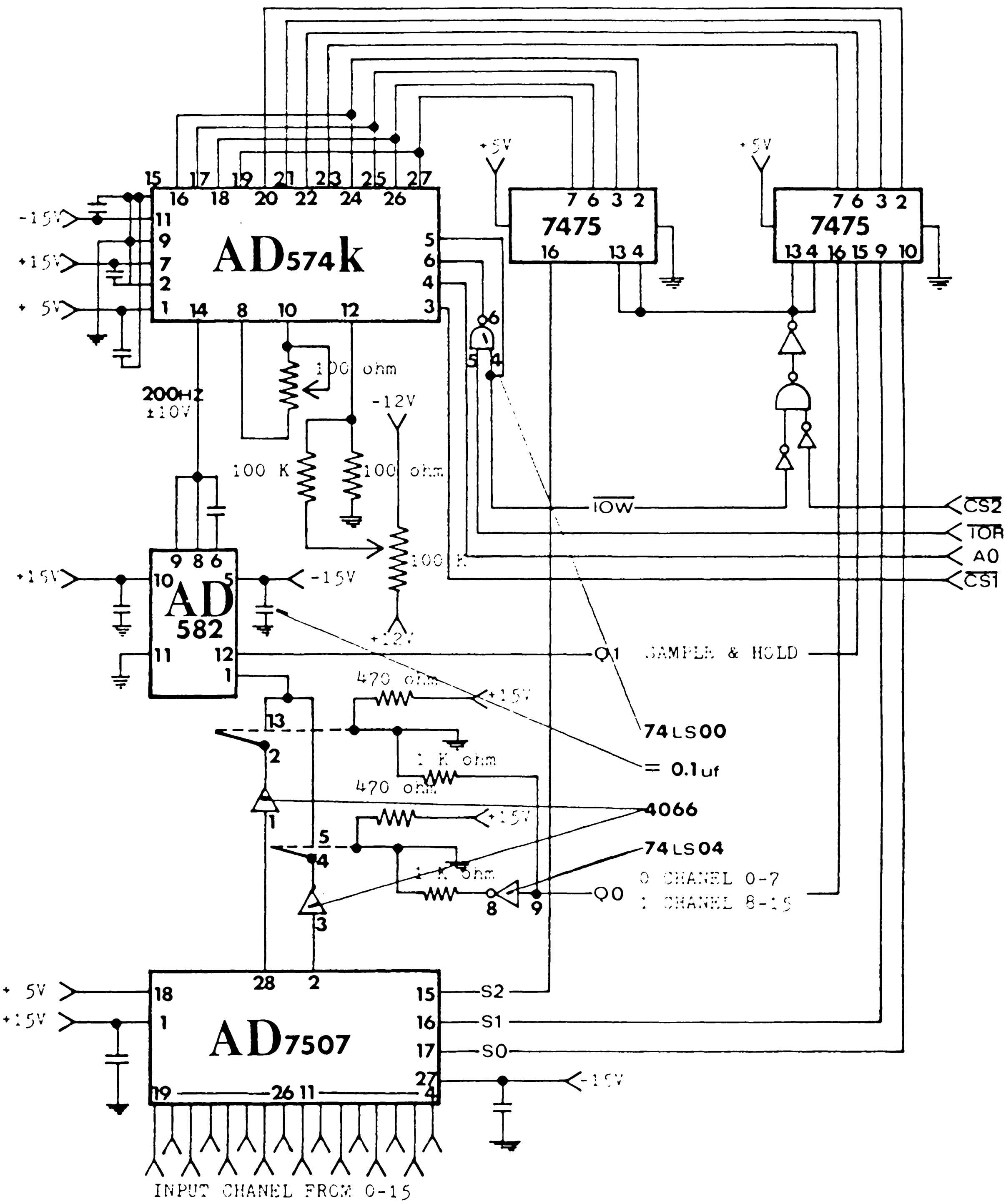
```
7340 RETURN
8000 'C**-----------------------------------------------------------------
8010 'C** SUBROUTINE PATCH(NDU,NDV,P00,P10,P11,P01,COE(4,4))
8020 DU=1!/NDU: DV=1!/NDV
8025 VV=0
8030 FOR I=0 TO NDV
8040  P0V=(((COE(4,1)*VV+COE(4,2))*VV)+COE(4,3))*VV+COE(4,4)
8050  P1V=(((COE(2,1)*VV+COE(2,2))*VV)+COE(2,3))*VV+COE(2,4)
8055  UU=0
8060  FOR J=0 TO NDU
8070  PU0=(((COE(1,1)*UU+COE(1,2))*UU)+COE(1,3))*UU+COE(1,4)
8080  PU1=(((COE(3,1)*UU+COE(3,2))*UU)+COE(3,3))*UU+COE(3,4)
8090  P1UV=(1-UU)*P0V+UU*P1V
8100  P2UV=(1-VV)*PU0+VV*PU1
8110  P3UV=(1-UU)*(1-VV)*P00+(1-UU)*VV*P01+UU*(1-VV)*P10+UU*VV*P11
8120  PUV=P1UV+P2UV-P3UV
8130  PX(I,J)=PUV : UU=UU+DU
8140  NEXT J
8150  VV=VV+DV
8160  NEXT I
8170 RETURN
9000 'C**-----------------------------------------------------------------
9010 'C**  PLOT FRAME
9020 'C**-----------------------------------------------------------------
9030 FOR II=1 TO 3
9035  G=0: FOR JJ=1 TO 5
9037  READ FX,FY,FZ: X=FX*SCX: Y=FY*SCY: Z=FZ*SCZ
9040  GOSUB 4300  : GOSUB 4330: IF PERS=1 THEN GOSUB 4470
9050  GOSUB 4230  : XX=X*320/DX: YY=Y*100/DY: GOSUB 2100
9060 NEXT JJ,II
9065 X=.5*SCX: Y=.5*SCY: Z=0
9067  GOSUB 4300  : GOSUB 4330: IF PERS=1 THEN GOSUB 4470
9068  GOSUB 4230  : XX=X*320/DX: YY=Y*100/DY*KY: 'PAINT (XX,YY),C,C
9070 RETURN
```

Appendix G. Instrument Calibration and Design

Schematic Design of CL909L



Schematic Design of A/D Card



Calibration Procedures: CL909I

1. Test the ranges of both the reference photometer (J-16) and cells to be calibrated (CL909L).

2. Set up the number of date entries to be recorded---based on the step changes of the illuminance condition that can be set up by the switches in the Skydome Daylight Simulator.

3.

   a. turn on the computer and the power for the data acquisition system.
   b. Put the standard J-16 and photocell to be calibrate at the center of the Skydome.
   c. Check the level(make sure they are horizontal).
   d. Turn on the lights to get the specified degree of illuminance.
   e. Record the reading of J-16, and the data from the calibrated cell at the same time.
   f. Repeat steps (D and E) until all steps of illuminance are reached and the data are record.
   g. Repeat steps (B, C, D, and E) until all 16 cells are measured.

4.

   a. Sort the data fro the J-16 and calibrated photocell under all steps of illuminance.
   b. Run the SAS program under CMS to find the calibrated function between the values read from the J-16 and the data recorded from the cell to be calibrated.
   c. Repeat steps A and B until the calibration functions for all 16 photocells are finished.

5. Those calibration functions are ready for programming in further study.

A/D Converter Card

To perform a calibration on the A/D converter card, first power down the host IBM PC, and remove the computer's top cover. This premise access to the top edge of the A/D converter card. On This top edge, immediately beside the AD574ak converter, are two potentiometers (R1 and R2, see schematic design). R1 is used to perform full scale adjust in the following calibration procedure; R2 is used to perform zero adjust in the calibration procedure. Following is the procedures to calibrate A/D converter card.

1. Write software, base on the address number of IBM PC, to provide continuous readings of each channel and display them on a terminal.

2. Allow one hour for the entire system to warm up and stabilize before calibration.

3. Input (1/4096) x 10V = 2.44 mV signal and adjust potentiometer R2 for 1 count on the digital output.

4. Input (4094.5/4096) x 10V = 9.9951V signal and adjust potentiometer R1 for 4095 count on the digital output.

The full scale calibration error is the deviation of the actual level at the last transition from the ideal level(9.9951V). This error, which is typically 0.05 to 0.1% of full scale, can be trimmed out by the method which is described in the data book of the Analog Device Company, page 10-61. The full scale calibration error over temperature is given with and without the initial error trimmed out. The temperature coefficients for each grade indicate the maximum change in the full scale gain from the initial value using the internal 10 volt reference.

Program List

```
10 REM "TEST AND CALIBRATION CHANNEL 1 TO 16"
20 CLS : INPUT "GIVE THE NUMBER OF OBSERVATIONS YOU NEED "; KK
30 DIM A(KK),B(KK),C(KK),D(KK),E(KK),F(KK),G(KK),H(KK),I(KK),J(KK),K(KK),L(KK),M(KK),N(KK),O(KK),P(KK)
40 OUT 772,227
50 OPEN "b: to.dat" FOR OUTPUT AS #1
60 '###########################################################################
70 '   OPEN THE HARDWARE OF PC
80 '   READ AND SAVE THE DATA IN ROM
90 '###########################################################################
100 CLS : PRINT "TO START COLLECT DATA, PLEASE PRESS '9'"
110 A$=INKEY$
120 IF A$="9" THEN 130 ELSE GOTO 110
130 FOR K=1 TO KK
140 OUT 772,226
150 OUT 768,0 : FOR Q=1 TO 1 : NEXT Q
160 DM=INP(768) : DL=INP(769) : DM=(DM*16)+(DL/16) : A(K)=INT(DM)
170 OUT 772,230
180 OUT 768,0 : TOTA=TOTA + A(K)
190 DM=INP(768) : DL=INP(769) : DM=(DM*16)+(DL/16) : B(K)=INT(DM)
200 OUT 772,234
210 OUT 768,0 : TOTB=TOTB + B(K)
220 DM=INP(768) : DL=INP(769) : DM=(DM*16)+(DL/16) : C(K)=INT(DM)
230 OUT 772,238
240 OUT 768,0 : TOTC=TOTC + C(K)
250 DM=INP(768) : DL=INP(769) : DM=(DM*16)+(DL/16) : D(K)=INT(DM)
260 OUT 772,242
270 OUT 768,0 : TOTD=TOTD + D(K)
280 DM=INP(768) : DL=INP(769) : DM=(DM*16)+(DL/16) : E(K)=INT(DM)
290 OUT 772,246
300 OUT 768,0 : TOTE=TOTE + E(K)
310 DM=INP(768) : DL=INP(769) : DM=(DM*16)+(DL/16) : F(K)=INT(DM)
320 OUT 772,250
330 OUT 768,0 : TOTF=TOTF + F(K)
340 DM=INP(768) : DL=INP(769) : DM=(DM*16)+(DL/16) : G(K)=INT(DM)
350 OUT 772,195
360 OUT 768,0 : TOTG=TOTG + G(K)
370 DM=INP(768) : DL=INP(769) : DM=(DM*16)+(DL/16) : H(K)=INT(DM)
380 OUT 772,225
390 OUT 768,0 : TOTH=TOTH + H(K)
400 DM=INP(768) : DL=INP(769) : DM=(DM*16)+(DL/16) : I(K)=INT(DM)
410 OUT 772,229
420 OUT 768,0 : TOTI=TOTI + I(K)
430 DM=INP(768) : DL=INP(769) : DM=(DM*16)+(DL/16) : J(K)=INT(DM)
440 OUT 772,233
450 OUT 768,0 : TOTJ=TOTJ + J(K)
460 DM=INP(768) : DL=INP(769) : DM=(DM*16)+(DL/16) : K(K)=INT(DM)
470 OUT 772,237
480 OUT 768,0 : TOTK=TOTK + K(K)
490 DM=INP(768) : DL=INP(769) : DM=(DM*16)+(DL/16) : L(K)=INT(DM)
500 OUT 772,241
510 OUT 768,0 : TOTL=TOTL + L(K)
520 DM=INP(768) : DL=INP(769) : DM=(DM*16)+(DL/16) : M(K)=INT(DM)
530 OUT 772,245
540 OUT 768,0 : TOTM=TOTM + M(K)
550 DM=INP(768) : DL=INP(769) : DM=(DM*16)+(DL/16) : N(K)=INT(DM)
560 OUT 772,249
570 OUT 768,0 : TOTN=TOTN + N(K)
580 DM=INP(768) : DL=INP(769) : DM=(DM*16)+(DL/16) : O(K)=INT(DM)
590 OUT 772,163
600 OUT 768,0 : TOTO=TOTO + O(K)
610 DM=INP(768) : DL=INP(769) : DM=(DM*16)+(DL/16) : P(K)=INT(DM) : TOTP=TOTP + P(K)
620 NEXT K : PRINT "DATA COLLECTING COMPLETED"
630 '###########################################################################
640 '
650 '     PRINT DATA IN SCREEN AND WRITE DATA TO DISK
660 '
670 '###########################################################################
680 FOR I=1 TO KK
690 PRINT USING "#####";A(I);B(I);C(I);D(I);E(I);F(I);G(I);H(I);I(I);J(I);K(I);L(I);M(I);N(I);O(I);P(I)
```

```
700 PRINT #1, USING "#####";A(I);B(I);C(I);D(I);E(I);F(I);G(I);H(I);I(I);J(I);K(I);L(I);M(I);N(I);O(I);P(I)
710 NEXT I
720 '#####################################################################################
730 '
740 '     AVERAGE THE DATA AND CALCULATE THE STANDARD DEVIATION
750 '
760 '#####################################################################################
770 AVA=TOTA/KK : AVB=TOTB/KK : AVC=TOTC/KK : AVD=TOTD/KK : AVE=TOTE/KK
780 AVF=TOTF/KK : AVG=TOTG/KK : AVH=TOTH/KK : AVI=TOTI/KK : AVJ=TOTJ/KK
790 AVK=TOTK/KK : AVL=TOTL/KK : AVM=TOTM/KK : AVN=TOTN/KK : AVO=TOTO/KK : AVP=TOTP/KK
800 ERA=0 : ERB=0 : ERC=0 : ERD=0 : ERE=0 : ERF=0 : ERG=0 : ERH=0
810 ERI=0 : ERJ=0 : ERK=0 : ERLL=0 : ERM=0 : ERN=0 : ERO=0 : ERP=0
820 FOR J=1 TO KK
830 ERQA=A(J)-AVA : ERQB=B(J)-AVB : ERQC=C(J)-AVC : ERQD=D(J)-AVD
840 ERQE=E(J)-AVE : ERQF=F(J)-AVF : ERQG=G(J)-AVG : ERQH=H(J)-AVH
850 ERQI=I(J)-AVI : ERQJ=J(J)-AVJ : ERQK=K(J)-AVK : ERQL=L(J)-AVL
860 ERQM=M(J)-AVM : ERQN=N(J)-AVN : ERQO=O(J)-AVO : ERQP=P(J)-AVP
870 ERSA=ERQA ¢ 2 : ERSB=ERQB ¢ 2 : ERSC=ERQC ¢ 2 : ERSD=ERQD ¢ 2
880 ERSE=ERQE ¢ 2 : ERSF=ERQF ¢ 2 : ERSG=ERQG ¢ 2 : ERSH=ERQH ¢ 2
890 ERSI=ERQI ¢ 2 : ERSJ=ERQJ ¢ 2 : ERSK=ERQK ¢ 2 : ERSL=ERQL ¢ 2
900 ERSM=ERQM ¢ 2 : ERSN=ERQN ¢ 2 : ERSO=ERQO ¢ 2 : ERSP=ERQP ¢ 2
910 ERA=ERA+ERSA : ERB=ERB+ERSB : ERC=ERC+ERSC : ERD=ERD+ERSD
920 ERE=ERE+ERSE : ERF=ERF+ERSF : ERG=ERG+ERSG : ERH=ERH+ERSH
930 ERI=ERI+ERSI : ERJ=ERJ+ERSJ : ERK=ERK+ERSK : ERLL=ERLL+ERSL
940 ERM=ERM+ERSM : ERN=ERN+ERSN : ERO=ERO+ERSO : ERP=ERP+ERSP
950 NEXT J
960 ESA=ERA/KK : ESB=ERB/KK : ESC=ERC/KK : ESD=ERD/KK
970 ESE=ERE/KK : ESF=ERF/KK : ESG=ERG/KK : ESH=ERH/KK
980 ESI=ERI/KK : ESJ=ERJ/KK : ESK=ERK/KK : ESL=ERLL/KK
990 ESM=ERM/KK : ESN=ERN/KK : ESO=ERO/KK : ESP=ERP/KK
1000 SDA=SQR(ESA) : SDB=SQR(ESB) : SDC=SQR(ESC) : SDD=SQR(ESD)
1010 SDE=SQR(ESE) : SDF=SQR(ESF) : SDG=SQR(ESG) : SDH=SQR(ESH)
1020 SDI=SQR(ESI) : SDJ=SQR(ESJ) : SDK=SQR(ESK) : SDL=SQR(ESL)
1030 SDM=SQR(ESM) : SDN=SQR(ESN) : SDO=SQR(ESO) : SDP=SQR(ESP)
1040 PRINT "THE AVERAGE OF CHANNEL 1 IS---------------";AVA
1050 PRINT #1, "THE AVERAGE OF CHANNEL 1 IS---------------";AVA
1060 PRINT "THE STANDARD DEVIATION OF CHANNEL 1 IS ----";SDA
1070 PRINT #1, "THE STANDARD DEVIATION OF CHANNEL 1 IS ----";SDA
1080 PRINT "THE AVERAGE OF CHANNEL 2 IS---------------";AVB
1090 PRINT #1, "THE AVERAGE OF CHANNEL 2 IS---------------";AVB
1100 PRINT "THE STANDARD DEVIATION OF CHANNEL 2 IS ----";SDB
1110 PRINT #1, "THE STANDARD DEVIATION OF CHANNEL 2 IS ----";SDB
1120 PRINT "THE AVERAGE OF CHANNEL 3 IS---------------";AVC
1130 PRINT #1, "THE AVERAGE OF CHANNEL 3 IS---------------";AVC
1140 PRINT "THE STANDARD DEVIATION OF CHANNEL 3 IS ----";SDC
1150 PRINT #1, "THE STANDARD DEVIATION OF CHANNEL 3 IS ----";SDC
1160 PRINT "THE AVERAGE OF CHANNEL 4 IS---------------";AVD
1170 PRINT #1, "THE AVERAGE OF CHANNEL 4 IS---------------";AVD
1180 PRINT "THE STANDARD DEVIATION OF CHANNEL 4 IS ----";SDD
1190 PRINT #1, "THE STANDARD DEVIATION OF CHANNEL 4 IS ----";SDD
1200 PRINT "THE AVERAGE OF CHANNEL 5 IS---------------";AVE
1210 PRINT #1, "THE AVERAGE OF CHANNEL 5 IS---------------";AVE
1220 PRINT "THE STANDARD DEVIATION OF CHANNEL 5 IS ----";SDE
1230 PRINT #1, "THE STANDARD DEVIATION OF CHANNEL 5 IS ----";SDE
1240 PRINT "THE AVERAGE OF CHANNEL 6 IS---------------";AVF
1250 PRINT #1, "THE AVERAGE OF CHANNEL 6 IS---------------";AVF
1260 PRINT "THE STANDARD DEVIATION OF CHANNEL 6 IS ----";SDF
1270 PRINT #1, "THE STANDARD DEVIATION OF CHANNEL 6 IS ----";SDF
1280 PRINT "THE AVERAGE OF CHANNEL 7 IS---------------";AVG
1290 PRINT #1, "THE AVERAGE OF CHANNEL 7 IS---------------";AVG
1300 PRINT "THE STANDARD DEVIATION OF CHANNEL 7 IS ----";SDG
1310 PRINT #1, "THE STANDARD DEVIATION OF CHANNEL 7 IS ----";SDG
1320 PRINT "THE AVERAGE OF CHANNEL 8 IS---------------";AVH
1330 PRINT #1, "THE AVERAGE OF CHANNEL 8 IS---------------";AVH
1340 PRINT "THE STANDARD DEVIATION OF CHANNEL 8 IS ----";SDH
1350 PRINT #1, "THE STANDARD DEVIATION OF CHANNEL 8 IS ----";SDH
1360 PRINT "THE AVERAGE OF CHANNEL 9 IS---------------";AVI
1370 PRINT #1, "THE AVERAGE OF CHANNEL 9 IS---------------";AVI
1380 PRINT "THE STANDARD DEVIATION OF CHANNEL 9 IS ----";SDI
1390 PRINT #1, "THE STANDARD DEVIATION OF CHANNEL 9 IS ----";SDI
1400 PRINT "THE AVERAGE OF CHANNEL 10 IS---------------";AVJ
1410 PRINT #1, "THE AVERAGE OF CHANNEL 10 IS---------------";AVJ
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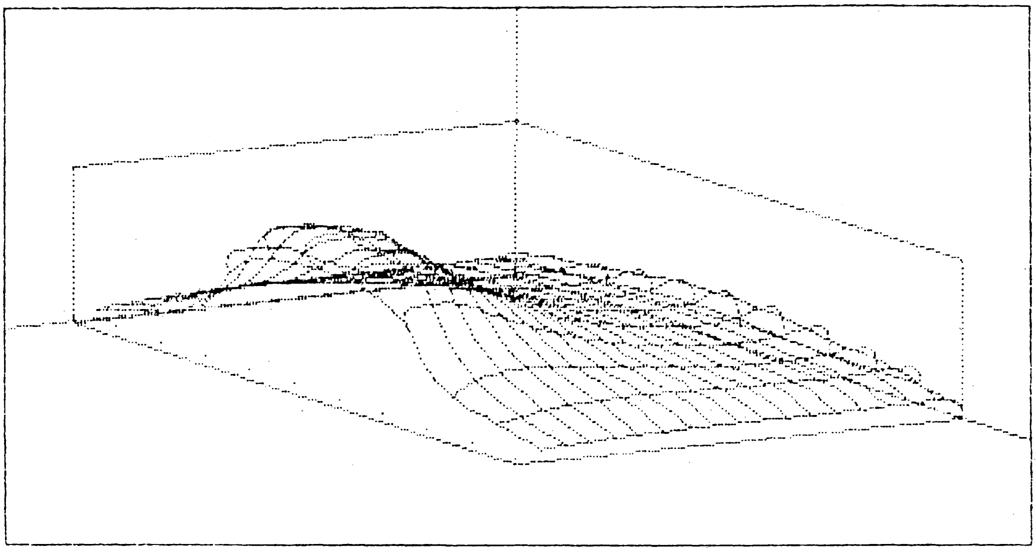
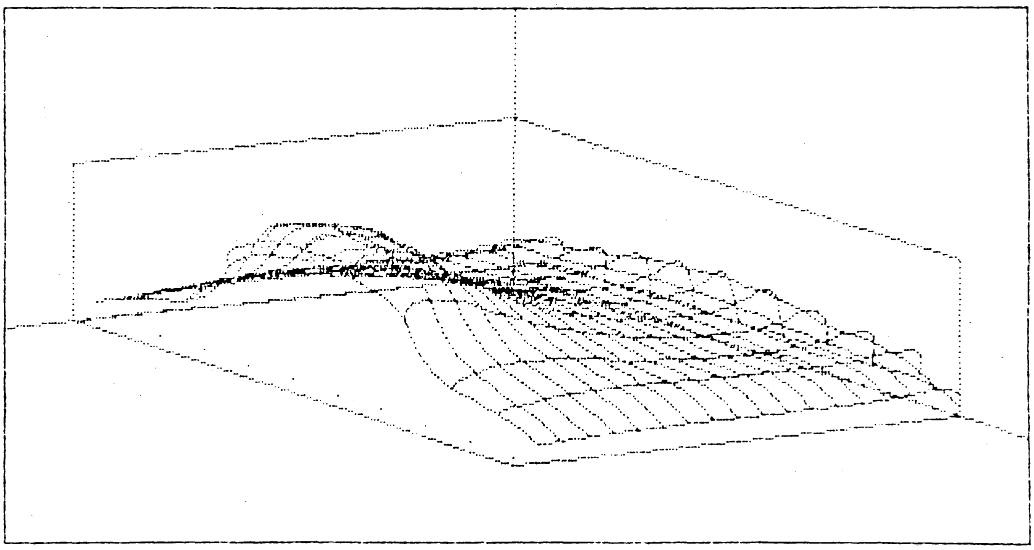
1420 PRINT "THE STANDARD DEVIATION OF CHANNEL 10 IS ----";SDJ
1430 PRINT #1, "THE STANDARD DEVIATION OF CHANNEL 10 IS ----";SDJ
1440 PRINT "THE AVERAGE OF CHANNEL  11 IS---------------";AVK
1450 PRINT #1, "THE AVERAGE OF CHANNEL  11 IS---------------";AVK
1460 PRINT "THE STANDARD DEVIATION OF CHANNEL 11 IS ----";SDK
1470 PRINT #1, "THE STANDARD DEVIATION OF CHANNEL 11 IS ----";SDK
1480 PRINT "THE AVERAGE OF CHANNEL  12 IS---------------";AVL
1490 PRINT #1, "THE AVERAGE OF CHANNEL  12 IS---------------";AVL
1500 PRINT "THE STANDARD DEVIATION OF CHANNEL 12 IS ----";SDL
1510 PRINT #1, "THE STANDARD DEVIATION OF CHANNEL 12 IS ----";SDL
1520 PRINT "THE AVERAGE OF CHANNEL  13 IS---------------";AVM
1530 PRINT #1, "THE AVERAGE OF CHANNEL  13 IS---------------";AVM
1540 PRINT "THE STANDARD DEVIATION OF CHANNEL 13 IS ----";SDM
1550 PRINT #1, "THE STANDARD DEVIATION OF CHANNEL 13 IS ----";SDM
1560 PRINT "THE AVERAGE OF CHANNEL  14 IS---------------";AVN
1570 PRINT #1, "THE AVERAGE OF CHANNEL  14 IS---------------";AVN
1580 PRINT "THE STANDARD DEVIATION OF CHANNEL 14 IS ----";SDN
1590 PRINT #1, "THE STANDARD DEVIATION OF CHANNEL 14 IS ----";SDN
1600 PRINT "THE AVERAGE OF CHANNEL  15 IS---------------";AVO
1610 PRINT #1, "THE AVERAGE OF CHANNEL  15 IS---------------";AVO
1620 PRINT "THE STANDARD DEVIATION OF CHANNEL 15 IS ----";SDO
1630 PRINT #1, "THE STANDARD DEVIATION OF CHANNEL 15 IS ----";SDO
1640 PRINT "THE AVERAGE OF CHANNEL  16 IS---------------";AVP
1650 PRINT #1, "THE AVERAGE OF CHANNEL  16 IS---------------";AVP
1660 PRINT "THE STANDARD DEVIATION OF CHANNEL 16 IS ----";SDP
1670 PRINT #1, "THE STANDARD DEVIATION OF CHANNEL 16 IS ----";SDP
1680 CLOSE #1
1690 END
```

Appendix H. Data of Scale Model Studies and Computer Simulation

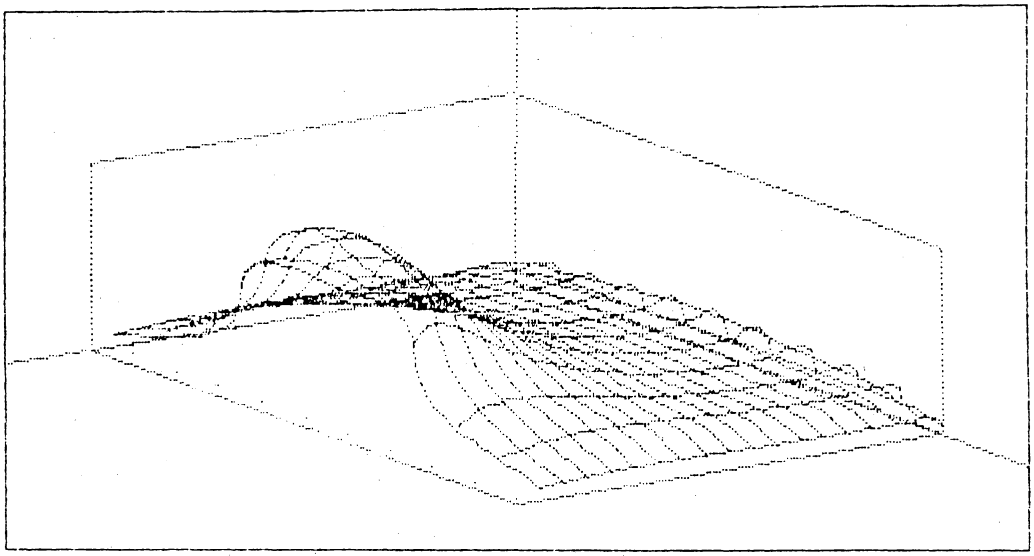
Case 1



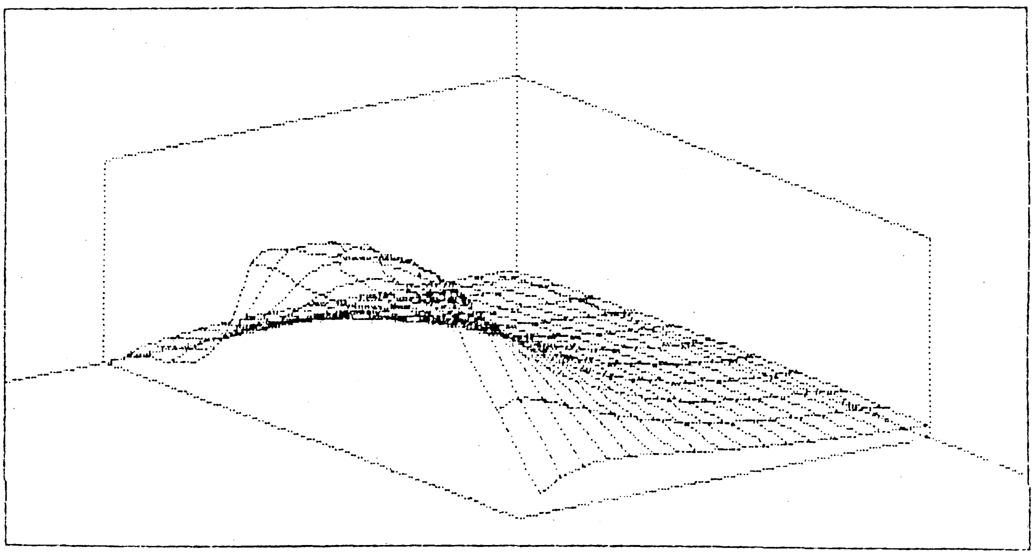
Case 2



Case 3



Case 4



CASE 1

DIGITAL CODE

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	252	758	341	507	171	371	381	552	477	355	368	319	358	325	295	287
2	256	754	339	505	174	368	384	552	479	351	368	320	360	322	297	271
3	255	757	349	501	170	373	379	552	478	351	369	320	351	323	301	285
4	251	755	343	507	173	372	379	557	479	351	363	317	359	323	287	283
5	257	763	336	506	175	369	376	555	479	351	368	315	358	321	287	279
6	255	762	340	499	175	371	378	552	478	360	369	322	360	320	296	281
7	264	758	346	504	171	369	381	555	477	351	368	322	361	323	295	287
8	259	757	344	512	174	371	382	555	479	347	368	322	362	329	295	288
9	255	753	339	507	174	369	378	557	479	349	365	317	357	324	297	277
10	258	760	339	500	178	375	376	553	479	351	371	322	360	323	297	285
11	256	754	346	504	176	371	379	553	476	351	368	321	360	328	297	275
12	255	757	341	507	176	371	384	553	478	353	369	322	360	327	299	287
13	255	755	336	506	177	376	377	560	475	351	368	321	362	329	304	287
14	257	753	338	508	179	369	377	559	479	351	368	320	360	328	298	287
15	256	755	338	507	176	373	379	555	479	350	365	320	360	328	305	287
16	259	756	336	508	173	373	379	558	479	351	363	316	356	321	298	274
17	255	762	344	497	177	371	377	552	478	351	370	321	360	327	299	287
18	260	755	339	505	184	369	375	555	479	351	369	318	354	322	301	281
19	256	760	344	497	176	373	373	552	477	355	368	317	360	321	298	277
20	257	758	346	504	176	375	380	552	477	351	369	321	361	325	298	289
21	251	753	338	506	176	370	376	559	478	351	363	315	354	323	300	281
22	252	761	341	501	176	370	371	552	479	358	367	322	351	326	298	286
23	264	756	341	506	171	373	379	555	479	351	366	317	355	323	301	281
24	255	761	341	500	176	371	376	552	479	351	369	320	360	321	298	281
25	256	759	343	497	176	372	376	552	482	351	369	320	360	321	297	279
26	251	757	348	505	175	374	382	556	479	351	368	321	360	328	297	283
27	255	760	335	505	174	370	376	558	477	360	367	315	355	321	301	280
28	247	757	343	504	175	373	384	553	475	351	370	322	361	324	295	287
29	260	754	336	509	184	374	378	558	479	351	365	315	355	323	298	285
30	256	760	335	503	176	371	373	553	485	351	369	318	355	321	300	280
31	249	756	348	500	174	373	382	555	479	351	365	317	362	328	298	287
32	255	761	337	504	184	373	376	552	484	360	369	320	351	320	298	281
33	256	765	340	501	180	373	375	553	479	360	368	320	354	319	298	276
34	255	759	345	502	176	375	377	552	479	351	370	321	360	327	300	287
35	247	753	337	506	177	369	375	557	479	351	367	315	357	320	298	289
36	256	762	339	499	176	376	377	555	483	360	367	320	355	319	295	271
37	253	760	344	502	176	378	376	552	479	351	370	321	361	325	301	290
38	255	751	338	503	175	367	376	557	484	355	366	318	351	321	297	281
39	255	758	346	498	176	376	379	552	475	351	369	322	360	325	296	283
40	257	757	338	505	167	376	376	556	481	351	369	318	351	321	298	284
41	251	759	346	500	167	376	381	553	477	351	369	320	360	328	304	287
42	256	757	346	503	167	376	381	556	475	351	363	320	360	328	302	287
43	256	751	339	508	177	369	377	558	479	351	362	317	355	319	298	280
44	254	762	344	497	174	373	380	554	477	351	368	323	359	328	299	287
45	258	755	337	508	176	372	379	555	479	351	365	317	351	322	297	277
46	256	759	340	499	181	373	376	554	479	355	368	317	357	320	302	282
47	255	762	344	504	177	376	381	552	475	351	369	321	359	327	304	279
48	261	757	340	508	180	370	375	556	479	351	363	320	355	323	298	283
49	256	763	338	499	177	373	376	552	479	353	367	319	357	323	287	285
50	258	753	344	505	184	370	378	558	482	351	367	316	360	321	287	280

	Digital Code		Footcandles
THE AVERAGE OF CHANNEL 1 IS---------------	255.48	=	6.226464
THE AVERAGE OF CHANNEL 2 IS---------------	757.6	=	20.22385
THE AVERAGE OF CHANNEL 3 IS---------------	341.1	=	27.43341
THE AVERAGE OF CHANNEL 4 IS---------------	503.56	=	21.22456
THE AVERAGE OF CHANNEL 5 IS---------------	175.7	=	5.596794
THE AVERAGE OF CHANNEL 6 IS---------------	372.22	=	6.273486

THE AVERAGE OF CHANNEL 7 IS--------------- 377.96 = 9.943903

THE AVERAGE OF CHANNEL 8 IS--------------- 554.52 = 13.64221

THE AVERAGE OF CHANNEL 9 IS--------------- 478.72 = 10.18611

THE AVERAGE OF CHANNEL 10 IS--------------- 352.3 = 6.459985

THE AVERAGE OF CHANNEL 11 IS--------------- 367.36 = 5.978459

THE AVERAGE OF CHANNEL 12 IS--------------- 319.2 = 7.065303

THE AVERAGE OF CHANNEL 13 IS--------------- 357.6 = 8.01644

THE AVERAGE OF CHANNEL 14 IS--------------- 323.68 = 7.156512

THE AVERAGE OF CHANNEL 15 IS--------------- 297.72 = 6.355923

THE AVERAGE OF CHANNEL 16 IS--------------- 282.66 = 105.9381

OBSERVATIONS IN FOOTCANDLES

	1	2	3	4	5	6	7	8	9	10	11	12	13	14		
1	6.087	20.250	27.421	21.532	5.380	6.239	10.070	13.515	10.125	6.543	5.996	7.058	8.031	7.195	6.263	108.101
2	6.247	19.994	27.177	21.353	5.518	6.155	10.195	13.515	10.196	6.420	5.996	7.095	8.105	7.107	6.331	100.189
3	6.207	20.185	28.408	20.998	5.334	6.296	9.987	13.515	10.161	6.420	6.022	7.095	7.777	7.137	6.469	107.103
4	6.047	20.057	27.666	21.532	5.472	6.267	9.987	13.768	10.196	6.420	5.862	6.984	8.068	7.137	5.992	106.107
5	6.288	20.573	26.813	21.442	5.564	6.183	9.864	13.667	10.196	6.420	5.996	6.911	8.031	7.078	5.992	104.124
6	6.207	20.508	27.299	20.822	5.564	6.239	9.946	13.515	10.161	6.697	6.022	7.169	8.105	7.049	6.297	105.114
7	6.574	20.250	28.036	21.264	5.380	6.183	10.070	13.667	10.125	6.420	5.996	7.169	8.141	7.137	6.263	108.101
8	6.369	20.185	27.789	21.983	5.518	6.239	10.111	13.667	10.196	6.299	5.996	7.169	8.178	7.313	6.263	108.602
9	6.207	19.930	27.177	21.532	5.518	6.183	9.946	13.768	10.196	6.360	5.915	6.984	7.994	7.166	6.331	103.136
10	6.328	20.378	27.177	20.910	5.704	6.352	9.864	13.565	10.196	6.420	6.076	7.169	8.105	7.137	6.331	107.103
11	6.247	19.994	28.036	21.264	5.611	6.239	9.987	13.565	10.090	6.420	5.996	7.132	8.105	7.284	6.331	102.151
12	6.207	20.185	27.421	21.532	5.611	6.239	10.195	13.565	10.161	6.481	6.022	7.169	8.105	7.254	6.400	108.101
13	6.207	20.057	26.813	21.442	5.658	6.381	9.905	13.923	10.056	6.420	5.996	7.132	8.178	7.313	6.574	108.101
14	6.288	19.930	27.055	21.621	5.752	6.183	9.905	13.871	10.196	6.420	5.996	7.095	8.105	7.284	6.366	108.101
15	6.247	20.057	27.055	21.532	5.611	6.296	9.987	13.667	10.196	6.390	5.915	7.095	8.105	7.284	6.609	108.101
16	6.369	20.121	26.813	21.621	5.472	6.296	9.987	13.820	10.196	6.420	5.862	6.947	7.958	7.078	6.366	101.660
17	6.207	20.508	27.789	20.647	5.658	6.239	9.905	13.515	10.161	6.420	6.049	7.132	8.105	7.254	6.400	108.101
18	6.410	20.057	27.177	21.353	5.989	6.183	9.823	13.667	10.196	6.420	6.022	7.021	7.885	7.107	6.469	105.114
19	6.247	20.378	27.789	20.647	5.611	6.296	9.742	13.515	10.125	6.543	5.996	6.984	8.105	7.078	6.366	103.136
20	6.288	20.250	28.036	21.264	5.611	6.352	10.028	13.515	10.125	6.420	6.022	7.132	8.141	7.195	6.366	109.103
21	6.047	19.930	27.055	21.442	5.611	6.211	9.864	13.871	10.161	6.420	5.862	6.911	7.885	7.137	6.435	105.114
22	6.087	20.443	27.421	20.998	5.611	6.211	9.662	13.515	10.196	6.635	5.969	7.169	7.777	7.225	6.366	107.602
23	6.574	20.121	27.421	21.442	5.380	6.296	9.987	13.667	10.196	6.420	5.942	6.984	7.922	7.137	6.469	105.114
24	6.207	20.443	27.421	20.910	5.611	6.239	9.864	13.515	10.196	6.420	6.022	7.095	8.105	7.078	6.366	105.114
25	6.247	20.314	27.666	20.647	5.611	6.267	9.864	13.515	10.303	6.420	6.022	7.095	8.105	7.078	6.331	104.124
26	6.047	20.185	28.283	21.353	5.564	6.324	10.111	13.717	10.196	6.420	5.996	7.132	8.105	7.284	6.331	106.107
27	6.207	20.378	26.692	21.353	5.518	6.211	9.864	13.820	10.125	6.697	5.969	6.911	7.922	7.078	6.469	104.618
28	5.889	20.185	27.666	21.264	5.564	6.296	10.195	13.565	10.056	6.420	6.049	7.169	8.141	7.166	6.263	108.101
29	6.410	19.994	26.813	21.711	5.989	6.324	9.946	13.820	10.196	6.420	5.915	6.911	7.922	7.137	6.366	107.103
30	6.247	20.378	26.692	21.175	5.611	6.239	9.742	13.565	10.411	6.420	6.022	7.021	7.922	7.078	6.435	104.618
31	5.968	20.121	28.283	20.910	5.518	6.296	10.111	13.667	10.196	6.420	5.915	6.984	8.178	7.284	6.366	108.101
32	6.207	20.443	26.934	21.264	5.989	6.296	9.864	13.515	10.375	6.697	6.022	7.095	7.777	7.049	6.366	105.114
33	6.247	20.703	27.299	20.998	5.799	6.296	9.823	13.565	10.196	6.697	5.996	7.095	7.885	7.020	6.366	102.643
34	6.207	20.314	27.912	21.086	5.611	6.352	9.905	13.515	10.196	6.420	6.049	7.132	8.105	7.254	6.435	108.101
35	5.889	19.930	26.934	21.442	5.658	6.183	9.823	13.768	10.196	6.420	5.969	6.911	7.994	7.049	6.366	109.103
36	6.247	20.508	27.177	20.822	5.611	6.381	9.905	13.667	10.339	6.697	5.969	7.095	7.922	7.020	6.263	100.189
37	6.127	20.378	27.789	21.086	5.611	6.438	9.864	13.515	10.196	6.420	6.049	7.132	8.141	7.195	6.469	109.604
38	6.207	19.804	27.055	21.175	5.564	6.127	9.864	13.768	10.375	6.543	5.942	7.021	7.777	7.078	6.331	105.114
39	6.207	20.250	28.036	20.734	5.611	6.381	9.987	13.515	10.056	6.420	6.022	7.169	8.105	7.195	6.297	106.107
40	6.288	20.185	27.055	21.353	5.198	6.381	9.864	13.717	10.267	6.420	6.022	7.021	7.777	7.078	6.366	106.605
41	6.047	20.314	28.036	20.910	5.198	6.381	10.070	13.565	10.125	6.420	6.022	7.095	8.105	7.284	6.574	108.101
42	6.247	20.185	28.036	21.175	5.198	6.381	10.070	13.717	10.056	6.420	5.862	7.095	8.105	7.284	6.504	108.101
43	6.247	19.804	27.177	21.621	5.658	6.183	9.905	13.820	10.196	6.420	5.836	6.984	7.922	7.020	6.366	104.618
44	6.167	20.508	27.789	20.647	5.518	6.296	10.028	13.616	10.125	6.420	5.996	7.207	8.068	7.284	6.400	108.101
45	6.328	20.057	26.934	21.621	5.611	6.267	9.987	13.667	10.196	6.420	5.915	6.984	7.777	7.107	6.331	103.136
46	6.247	20.314	27.299	20.822	5.846	6.296	9.864	13.616	10.196	6.543	5.996	6.984	7.994	7.049	6.504	105.610
47	6.207	20.508	27.789	21.264	5.658	6.381	10.070	13.515	10.056	6.420	6.022	7.132	8.068	7.254	6.574	104.124
48	6.451	20.185	27.299	21.621	5.799	6.211	9.823	13.717	10.196	6.420	5.862	7.095	7.922	7.137	6.366	106.107

49	6.247	20.573	27.055	20.822	5.658	6.296	9.864	13.515	10.196	6.481	5.969	7.058	7.994	7.137	5.992	107.103
50	6.328	19.930	27.789	21.353	5.989	6.211	9.946	13.820	10.303	6.420	5.969	6.947	8.105	7.078	5.992	104.618

INPUT DATA

DIFFUSE DAYLIGHT AVAILABILITY IS 105.9381 FOODCANDLE
TRANSMISSION FACTOR OF THE WINDOW IS 1
THE DEPTH OF THE ROOM IS 15 FEET
THE WIDTH OF THE ROOM IS 26 FEET
THE HEIGHT OF THE ROOM IS 12 FEET
THE DISTANCE BETWEEN THE LEFT EDGE OF THE WINDOW AND THE LEFT WALL IS 7 FEET
THE DISTANCE BETWEEN THE RIGHT EDGE OF THE WINDOW AND THE RIGHT WALL IS 7 FEET
THE DISTANCE BETWEEN THE UPPER EDGE OF THE WINDOW AND THE CEILING IS 2 FEET
THE DISTANCE BETWEEN THE LOWER EDGE OF THE WINDOW AND THE FLOOR IS 4 FEET
THE REFLECTANCE OF THE EXTERIOR GROUND IS .31
THE REFLECTANCE OF THE INTERIOR SURFACES ARE
LEFT WALL------ .51 BACK WALL------ .51
RIGHT WALL----- .51 WINDOW WALL---- .51
CEILING-------- .76 FLOOR---------- .06

OUTPUT DATA

P	X-axis	Y-axis	Z-axis	Exter Area to P	Inter-Direct to p	Total Reflec at P	Received
1	0.0000	0.0000	2.5000	2.1667	0.9874	0.8289	1.8164
2	0.0000	2.6000	2.5000	2.1667	1.3116	1.9983	3.3099
3	0.0000	5.2000	2.5000	2.1667	1.6715	1.6979	3.3694
4	0.0000	7.8000	2.5000	2.1667	2.0111	1.6029	3.6141
5	0.0000	10.4000	2.5000	2.1667	2.2571	1.5742	3.8313
6	0.0000	13.0000	2.5000	2.1667	2.3472	1.5683	3.9155
7	0.0000	15.6000	2.5000	2.1667	2.2571	1.5742	3.8313
8	0.0000	18.2000	2.5000	2.1667	2.0111	1.6029	3.6141
9	0.0000	20.8000	2.5000	2.1667	1.6715	1.6979	3.3694
10	0.0000	23.4000	2.5000	2.1667	1.3116	1.9983	3.3099
11	0.0000	26.0000	2.5000	2.1667	0.9874	0.8289	1.8164
12	0.8333	0.0000	2.5000	2.1667	1.0638	2.8618	3.9255
13	0.8333	2.6000	2.5000	2.1667	1.4409	5.4761	6.9170
14	0.8333	5.2000	2.5000	2.1667	1.8694	5.9152	7.7846
15	0.8333	7.8000	2.5000	2.1667	2.2810	6.6884	8.9694
16	0.8333	10.4000	2.5000	2.1667	2.5824	7.4394	10.0219
17	0.8333	13.0000	2.5000	2.1667	2.6933	7.7622	10.4554
18	0.8333	15.6000	2.5000	2.1667	2.5824	7.4394	10.0219
19	0.8333	18.2000	2.5000	2.1667	2.2810	6.6884	8.9694
20	0.8333	20.8000	2.5000	2.1667	1.8694	5.9152	7.7846
21	0.8333	23.4000	2.5000	2.1667	1.4408	5.4761	6.9170
22	0.8333	26.0000	2.5000	2.1667	1.0638	2.8618	3.9255
23	1.6667	0.0000	2.5000	2.1667	1.1443	2.5544	3.6987
24	1.6667	2.6000	2.5000	2.1667	1.5836	4.9422	6.5258
25	1.6667	5.2000	2.5000	2.1667	2.0957	5.0450	7.1408
26	1.6667	7.8000	2.5000	2.1667	2.5973	5.3933	7.9906
27	1.6667	10.4000	2.5000	2.1667	2.9686	5.7035	8.6720
28	1.6667	13.0000	2.5000	2.1667	3.1057	5.8253	8.9310
29	1.6667	15.6000	2.5000	2.1667	2.9686	5.7035	8.6720
30	1.6667	18.2000	2.5000	2.1667	2.5973	5.3933	7.9906
31	1.6667	20.8000	2.5000	2.1667	2.0957	5.0450	7.1408
32	1.6667	23.4000	2.5000	2.1667	1.5836	4.9422	6.5258
33	1.6667	26.0000	2.5000	2.1667	1.1443	2.5544	3.6987
34	2.5000	0.0000	2.5000	2.1667	1.2285	2.3137	3.5422
35	2.5000	2.6000	2.5000	2.1667	1.7405	4.5667	6.3072
36	2.5000	5.2000	2.5000	2.1667	2.3549	4.4842	6.8391
37	2.5000	7.8000	2.5000	2.1667	2.9693	4.6759	7.6452
38	2.5000	10.4000	2.5000	2.1667	3.4292	4.8642	8.2934
39	2.5000	13.0000	2.5000	2.1667	3.5998	4.9386	8.5384

40	2.5000	15.6000	2.5000	2.1667	3.4292	4.8642	8.2934
41	2.5000	18.2000	2.5000	2.1667	2.9693	4.6759	7.6452
42	2.5000	20.8000	2.5000	2.1667	2.3549	4.4842	6.8391
43	2.5000	23.4000	2.5000	2.1667	1.7405	4.5667	6.3072
44	2.5000	26.0000	2.5000	2.1667	1.2285	2.3137	3.5422
45	3.3333	0.0000	2.5000	2.1667	1.3151	2.1436	3.4587
46	3.3333	2.6000	2.5000	2.1667	1.9122	4.3283	6.2405
47	3.3333	5.2000	2.5000	2.1667	2.6517	4.1206	6.7723
48	3.3333	7.8000	2.5000	2.1667	3.4083	4.2242	7.6325
49	3.3333	10.4000	2.5000	2.1667	3.9813	4.3534	8.3347
50	3.3333	13.0000	2.5000	2.1667	4.1944	4.4065	8.6009
51	3.3333	15.6000	2.5000	2.1667	3.9813	4.3534	8.3347
52	3.3333	18.2000	2.5000	2.1667	3.4083	4.2242	7.6325
53	3.3333	20.8000	2.5000	2.1667	2.6517	4.1206	6.7723
54	3.3333	23.4000	2.5000	2.1667	1.9122	4.3283	6.2405
55	3.3333	26.0000	2.5000	2.1667	1.3151	2.1436	3.4587
56	4.1667	0.0000	2.5000	2.1667	1.4022	2.0207	3.4229
57	4.1667	2.6000	2.5000	2.1667	2.0983	4.1721	6.2704
58	4.1667	5.2000	2.5000	2.1667	2.9913	3.8725	6.8638
59	4.1667	7.8000	2.5000	2.1667	3.9283	3.9157	7.8440
60	4.1667	10.4000	2.5000	2.1667	4.6459	4.0073	8.6532
61	4.1667	13.0000	2.5000	2.1667	4.9134	4.0472	8.9606
62	4.1667	15.6000	2.5000	2.1667	4.6459	4.0073	8.6532
63	4.1667	18.2000	2.5000	2.1667	3.9283	3.9157	7.8440
64	4.1667	20.8000	2.5000	2.1667	2.9913	3.8725	6.8638
65	4.1667	23.4000	2.5000	2.1667	2.0983	4.1721	6.2704
66	4.1667	26.0000	2.5000	2.1667	1.4022	2.0207	3.4229
67	5.0000	0.0000	2.5000	2.1667	1.4874	1.9288	3.4162
68	5.0000	2.6000	2.5000	2.1667	2.2975	4.0632	6.3607
69	5.0000	5.2000	2.5000	2.1667	3.3791	3.6954	7.0745
70	5.0000	7.8000	2.5000	2.1667	4.5460	3.6952	8.2412
71	5.0000	10.4000	2.5000	2.1667	5.4493	3.7607	9.2100
72	5.0000	13.0000	2.5000	2.1667	5.7861	3.7917	9.5778
73	5.0000	15.6000	2.5000	2.1667	5.4493	3.7607	9.2100
74	5.0000	18.2000	2.5000	2.1667	4.5460	3.6952	8.2412
75	5.0000	20.8000	2.5000	2.1667	3.3791	3.6954	7.0745
76	5.0000	23.4000	2.5000	2.1667	2.2975	4.0632	6.3607
77	5.0000	26.0000	2.5000	2.1667	1.4874	1.9288	3.4162
78	5.8333	0.0000	2.5000	2.1667	1.5669	1.8582	3.4250
79	5.8333	2.6000	2.5000	2.1667	2.5068	3.9817	6.4885
80	5.8333	5.2000	2.5000	2.1667	3.8199	3.5638	7.3837
81	5.8333	7.8000	2.5000	2.1667	5.2814	3.5327	8.8141
82	5.8333	10.4000	2.5000	2.1667	6.4236	3.5801	10.0036
83	5.8333	13.0000	2.5000	2.1667	6.8484	3.6049	10.4533
84	5.8333	15.6000	2.5000	2.1667	6.4236	3.5801	10.0036
85	5.8333	18.2000	2.5000	2.1667	5.2814	3.5327	8.8141
86	5.8333	20.8000	2.5000	2.1667	3.8199	3.5638	7.3837
87	5.8333	23.4000	2.5000	2.1667	2.5068	3.9817	6.4885
88	5.8333	26.0000	2.5000	2.1667	1.5669	1.8582	3.4250
89	6.6667	0.0000	2.5000	2.1667	1.6356	1.8030	3.4385
90	6.6667	2.6000	2.5000	2.1667	2.7206	3.9143	6.6349
91	6.6667	5.2000	2.5000	2.1667	4.3171	3.4622	7.7793
92	6.6667	7.8000	2.5000	2.1667	6.1578	3.4102	9.5680
93	6.6667	10.4000	2.5000	2.1667	7.6076	3.4454	11.0530
94	6.6667	13.0000	2.5000	2.1667	8.1433	3.4661	11.6094
95	6.6667	15.6000	2.5000	2.1667	7.6076	3.4454	11.0530
96	6.6667	18.2000	2.5000	2.1667	6.1578	3.4102	9.5680
97	6.6667	20.8000	2.5000	2.1667	4.3171	3.4622	7.7793
98	6.6667	23.4000	2.5000	2.1667	2.7206	3.9143	6.6349
99	6.6667	26.0000	2.5000	2.1667	1.6356	1.8030	3.4385
100	7.5000	0.0000	2.5000	2.1667	1.6869	1.7595	3.4464
101	7.5000	2.6000	2.5000	2.1667	2.9294	3.8526	6.7821
102	7.5000	5.2000	2.5000	2.1667	4.8707	3.3805	8.2512
103	7.5000	7.8000	2.5000	2.1667	7.2018	3.3161	10.5179
104	7.5000	10.4000	2.5000	2.1667	9.0471	3.3439	12.3910
105	7.5000	13.0000	2.5000	2.1667	9.7204	3.3621	13.0825
106	7.5000	15.6000	2.5000	2.1667	9.0471	3.3439	12.3910
107	7.5000	18.2000	2.5000	2.1667	7.2018	3.3161	10.5179
108	7.5000	20.8000	2.5000	2.1667	4.8707	3.3805	8.2512
109	7.5000	23.4000	2.5000	2.1667	2.9294	3.8526	6.7821
110	7.5000	26.0000	2.5000	2.1667	1.6869	1.7595	3.4464
111	8.3333	0.0000	2.5000	2.1667	1.7125	1.7254	3.4379

112	8.3333	2.6000	2.5000	2.1667	3.1184	3.7899	6.9083
113	8.3333	5.2000	2.5000	2.1667	5.4739	3.3123	8.7861
114	8.3333	7.8000	2.5000	2.1667	8.4415	3.2430	11.6846
115	8.3333	10.4000	2.5000	2.1667	10.7926	3.2672	14.0598
116	8.3333	13.0000	2.5000	2.1667	11.6325	3.2842	14.9166
117	8.3333	15.6000	2.5000	2.1667	10.7926	3.2672	14.0598
118	8.3333	18.2000	2.5000	2.1667	8.4415	3.2430	11.6846
119	8.3333	20.8000	2.5000	2.1667	5.4739	3.3123	8.7861
120	8.3333	23.4000	2.5000	2.1667	3.1184	3.7899	6.9083
121	8.3333	26.0000	2.5000	2.1667	1.7125	1.7254	3.4379
122	9.1667	0.0000	2.5000	2.1667	1.7024	1.6994	3.4018
123	9.1667	2.6000	2.5000	2.1667	3.2649	3.7224	6.9873
124	9.1667	5.2000	2.5000	2.1667	6.1070	3.2538	9.3608
125	9.1667	7.8000	2.5000	2.1667	9.9029	3.1863	13.0892
126	9.1667	10.4000	2.5000	2.1667	12.8934	3.2102	16.1036
127	9.1667	13.0000	2.5000	2.1667	13.9266	3.2269	17.1535
128	9.1667	15.6000	2.5000	2.1667	12.8934	3.2102	16.1036
129	9.1667	18.2000	2.5000	2.1667	9.9029	3.1863	13.0892
130	9.1667	20.8000	2.5000	2.1667	6.1070	3.2538	9.3608
131	9.1667	23.4000	2.5000	2.1667	3.2649	3.7224	6.9873
132	9.1667	26.0000	2.5000	2.1667	1.7024	1.6994	3.4018
133	10.0000	0.0000	2.5000	2.1667	1.6454	1.6812	3.3267
134	10.0000	2.6000	2.5000	2.1667	3.3369	3.6475	6.9843
135	10.0000	5.2000	2.5000	2.1667	6.7276	3.2036	9.9312
136	10.0000	7.8000	2.5000	2.1667	11.5999	3.1439	14.7438
137	10.0000	10.4000	2.5000	2.1667	15.3817	3.1703	18.5520
138	10.0000	13.0000	2.5000	2.1667	16.6234	3.1875	19.8109
139	10.0000	15.6000	2.5000	2.1667	15.3817	3.1703	18.5520
140	10.0000	18.2000	2.5000	2.1667	11.5999	3.1439	14.7438
141	10.0000	20.8000	2.5000	2.1667	6.7276	3.2036	9.9312
142	10.0000	23.4000	2.5000	2.1667	3.3369	3.6475	6.9843
143	10.0000	26.0000	2.5000	2.1667	1.6454	1.6812	3.3267
144	10.8333	0.0000	2.5000	2.1667	1.5306	1.6716	3.2022
145	10.8333	2.6000	2.5000	2.1667	3.2916	3.5663	6.8579
146	10.8333	5.2000	2.5000	2.1667	7.2520	3.1627	10.4147
147	10.8333	7.8000	2.5000	2.1667	13.5125	3.1161	16.6287
148	10.8333	10.4000	2.5000	2.1667	18.2329	3.1471	21.3800
149	10.8333	13.0000	2.5000	2.1667	19.6703	3.1656	22.8359
150	10.8333	15.6000	2.5000	2.1667	18.2329	3.1471	21.3800
151	10.8333	18.2000	2.5000	2.1667	13.5125	3.1161	16.6287
152	10.8333	20.8000	2.5000	2.1667	7.2520	3.1627	10.4147
153	10.8333	23.4000	2.5000	2.1667	3.2916	3.5663	6.8579
154	10.8333	26.0000	2.5000	2.1667	1.5306	1.6716	3.2022
155	11.6667	0.0000	2.5000	2.1667	1.3487	1.6728	3.0215
156	11.6667	2.6000	2.5000	2.1667	3.0780	3.4831	6.5611
157	11.6667	5.2000	2.5000	2.1667	7.5275	3.1352	10.6627
158	11.6667	7.8000	2.5000	2.1667	15.5293	3.1063	18.6356
159	11.6667	10.4000	2.5000	2.1667	21.2656	3.1440	24.4096
160	11.6667	13.0000	2.5000	2.1667	22.8329	3.1643	25.9972
161	11.6667	15.6000	2.5000	2.1667	21.2656	3.1440	24.4096
162	11.6667	18.2000	2.5000	2.1667	15.5293	3.1063	18.6356
163	11.6667	20.8000	2.5000	2.1667	7.5275	3.1352	10.6627
164	11.6667	23.4000	2.5000	2.1667	3.0780	3.4831	6.5611
165	11.6667	26.0000	2.5000	2.1667	1.3487	1.6728	3.0215
166	12.5000	0.0000	2.5000	2.1667	1.0959	1.6892	2.7851
167	12.5000	2.6000	2.5000	2.1667	2.6456	3.4097	6.0553
168	12.5000	5.2000	2.5000	2.1667	7.2909	3.1304	10.4213
169	12.5000	7.8000	2.5000	2.1667	17.2836	3.1234	20.4071
170	12.5000	10.4000	2.5000	2.1667	23.8772	3.1703	27.0475
171	12.5000	13.0000	2.5000	2.1667	25.4285	3.1934	28.6219
172	12.5000	15.6000	2.5000	2.1667	23.8772	3.1703	27.0475
173	12.5000	18.2000	2.5000	2.1667	17.2836	3.1234	20.4071
174	12.5000	20.8000	2.5000	2.1667	7.2909	3.1304	10.4213
175	12.5000	23.4000	2.5000	2.1667	2.6456	3.4097	6.0553
176	12.5000	26.0000	2.5000	2.1667	1.0959	1.6892	2.7851
177	13.3333	0.0000	2.5000	2.1667	0.7759	1.7279	2.5038
178	13.3333	2.6000	2.5000	2.1667	1.9644	3.3657	5.3301
179	13.3333	5.2000	2.5000	2.1667	6.1430	3.1671	9.3101
180	13.3333	7.8000	2.5000	2.1667	17.6360	3.1903	20.8263
181	13.3333	10.4000	2.5000	2.1667	24.3177	3.2540	27.5717
182	13.3333	13.0000	2.5000	2.1667	25.6205	3.2830	28.9035
183	13.3333	15.6000	2.5000	2.1667	24.3177	3.2540	27.5717

184	13.3333	18.2000	2.5000	2.1667	17.6360	3.1903	20.8263
185	13.3333	20.8000	2.5000	2.1667	6.1430	3.1671	9.3101
186	13.3333	23.4000	2.5000	2.1667	1.9644	3.3657	5.3301
187	13.3333	26.0000	2.5000	2.1667	0.7759	1.7279	2.5038
188	14.1667	0.0000	2.5000	2.1667	0.4027	1.7870	2.1898
189	14.1667	2.6000	2.5000	2.1667	1.0533	3.3650	4.4182
190	14.1667	5.2000	2.5000	2.1667	3.6703	3.2722	6.9426
191	14.1667	7.8000	2.5000	2.1667	13.3006	3.3681	16.6688
192	14.1667	10.4000	2.5000	2.1667	18.0925	3.4978	21.5903
193	14.1667	13.0000	2.5000	2.1667	18.8730	3.5560	22.4290
194	14.1667	15.6000	2.5000	2.1667	18.0925	3.4978	21.5903
195	14.1667	18.2000	2.5000	2.1667	13.3006	3.3681	16.6688
196	14.1667	20.8000	2.5000	2.1667	3.6703	3.2722	6.9426
197	14.1667	23.4000	2.5000	2.1667	1.0533	3.3650	4.4182
198	14.1667	26.0000	2.5000	2.1667	0.4027	1.7870	2.1898
199	15.0000	0.0000	2.5000	2.1667	0.0000	0.9999	0.9999
200	15.0000	2.6000	2.5000	2.1667	0.0000	2.0493	2.0493
201	15.0000	5.2000	2.5000	2.1667	0.0000	1.8841	1.8841
202	15.0000	7.8000	2.5000	2.1667	0.0000	1.8424	1.8424
203	15.0000	10.4000	2.5000	2.1667	0.0000	1.8257	1.8257
204	15.0000	13.0000	2.5000	2.1667	0.0000	1.7886	1.7886
205	15.0000	15.6000	2.5000	2.1667	0.0000	1.7103	1.7103
206	15.0000	18.2000	2.5000	2.1667	0.0000	1.5873	1.5873
207	15.0000	20.8000	2.5000	2.1667	0.0000	1.4284	1.4284
208	15.0000	23.4000	2.5000	2.1667	0.0000	1.2488	1.2488
209	15.0000	26.0000	2.5000	2.1667	0.0000	1.0654	1.0654

CASE 2

DIGITAL CODE

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	
1	311	791	350	517	220	446	427	589	528	422	449	379	412	385	359	287
2	319	793	345	517	220	447	415	593	527	415	448	374	410	386	361	282
3	320	795	346	518	222	439	419	592	528	415	448	379	413	386	359	284
4	311	787	352	519	213	446	422	595	523	414	448	377	411	386	359	283
5	314	796	348	511	225	450	418	592	528	415	450	379	413	385	358	282
6	314	787	357	520	211	445	426	594	523	415	447	371	414	385	362	284
7	315	798	347	511	217	448	418	592	525	411	446	376	411	384	362	281
8	311	793	346	511	218	448	419	593	528	415	445	376	410	386	355	282
9	312	796	348	511	217	448	419	589	529	415	450	378	410	377	351	273
10	313	792	355	514	213	449	426	592	522	415	451	378	414	385	357	287
11	307	792	345	520	218	443	422	592	523	415	447	375	409	384	354	282
12	311	794	347	515	217	446	415	589	528	415	447	375	406	384	361	282
13	315	797	351	510	215	450	421	585	523	424	451	379	410	384	349	275
14	311	792	359	515	207	452	426	592	523	415	450	379	411	386	351	285
15	317	791	346	515	222	447	422	594	528	415	443	374	411	386	362	279
16	309	798	351	511	221	447	419	586	519	415	451	379	411	384	351	279
17	313	794	354	520	218	448	427	587	519	415	450	378	413	386	360	285
18	314	791	348	517	215	447	418	592	528	413	443	371	407	384	360	287
19	320	787	343	519	218	447	422	592	523	415	443	374	411	385	351	283
20	320	795	346	515	220	446	422	591	523	415	448	379	413	386	355	282
21	320	788	350	517	213	439	422	592	526	415	447	375	410	386	360	281
22	317	797	356	511	225	449	420	586	523	415	447	379	413	384	353	277
23	309	791	356	520	215	447	426	592	522	415	451	378	415	387	357	271
24	307	792	355	513	213	450	426	594	523	414	448	378	415	387	360	287
25	316	793	346	519	217	446	415	592	528	415	450	371	412	384	362	285
26	314	794	357	513	213	449	426	592	522	415	451	378	413	386	362	279
27	315	792	346	519	218	446	419	591	529	419	450	375	407	378	351	275
28	307	792	356	516	215	447	427	592	524	415	450	379	411	387	358	287
29	320	790	347	520	216	448	425	591	523	414	447	371	407	385	351	279
30	311	794	350	511	218	450	419	587	525	415	449	378	409	383	351	283
31	305	790	351	518	213	446	423	593	526	413	442	373	411	378	357	273
32	305	795	352	512	218	442	415	591	523	415	449	375	408	378	350	281
33	306	789	353	515	218	451	426	590	521	415	446	375	410	385	359	281
34	310	794	346	511	224	447	419	591	523	415	443	375	409	384	351	282
35	312	789	344	511	217	443	419	590	525	415	447	371	408	379	351	272
36	312	794	352	510	213	449	419	585	521	415	451	379	411	384	350	279
37	313	790	355	515	215	449	424	592	517	415	447	376	413	386	359	283
38	315	791	346	512	220	442	415	593	528	411	448	376	411	386	360	284
39	314	795	347	511	221	449	419	587	523	419	451	377	411	384	351	277
40	305	790	354	520	214	447	425	591	523	415	443	376	413	384	368	286
41	314	791	348	517	214	443	419	593	529	415	448	371	411	384	361	279
42	311	791	347	514	215	447	420	589	527	418	449	376	411	381	351	282
43	316	790	356	517	213	447	423	593	523	414	443	371	410	378	354	278
44	307	798	354	509	217	449	423	587	521	415	447	379	412	386	368	281
45	312	788	346	520	213	448	423	591	521	414	446	375	410	384	360	287
46	315	791	346	513	220	447	415	588	528	418	448	375	408	386	351	281
47	311	793	354	509	218	451	422	586	521	414	451	384	413	379	361	281
48	314	791	354	517	215	439	422	593	526	415	446	374	407	380	360	280
49	312	796	356	511	221	449	424	590	519	415	450	379	414	389	358	282
50	311	794	346	513	215	448	422	593	528	415	443	374	411	386	355	279

	Digital code		Footcandles
THE AVERAGE OF CHANNEL 1 IS---------------	312.66	=	8.733468
THE AVERAGE OF CHANNEL 2 IS---------------	792.44	=	22.55093
THE AVERAGE OF CHANNEL 3 IS---------------	350.2	=	28.55699
THE AVERAGE OF CHANNEL 4 IS---------------	514.8	=	22.23839
THE AVERAGE OF CHANNEL 5 IS---------------	216.88	=	7.658163

THE AVERAGE OF CHANNEL 6 IS--------------- 446.86 = 8.553894

THE AVERAGE OF CHANNEL 7 IS--------------- 421.3 = 11.89579

THE AVERAGE OF CHANNEL 8 IS--------------- 590.72 = 15.58967

THE AVERAGE OF CHANNEL 9 IS--------------- 524.32 = 11.95169

THE AVERAGE OF CHANNEL 10 IS--------------- 415.24 = 8.516497

THE AVERAGE OF CHANNEL 11 IS--------------- 447.66 = 8.311368

THE AVERAGE OF CHANNEL 12 IS--------------- 376.06 = 9.164115

THE AVERAGE OF CHANNEL 13 IS--------------- 410.88 = 9.9088

THE AVERAGE OF CHANNEL 14 IS--------------- 384.04 = 8.980862

THE AVERAGE OF CHANNEL 15 IS--------------- 356.74 = 8.539268

THE AVERAGE OF CHANNEL 16 IS--------------- 281.12 = 105.1735

OBSERVATIONS IN FOOTCANDLES

	1	2	3	4	5	6	7	8	9	10	11	12	13	14		
1	8.655	22.451	28.532	22.440	7.826	8.526	12.178	15.492	12.107	8.754	8.353	9.278	9.953	9.008	8.629	108.101
2	9.037	22.590	27.912	22.440	7.826	8.558	11.591	15.720	12.065	8.508	8.322	9.233	9.874	9.037	8.709	105.610
3	9.085	22.729	28.036	22.533	7.934	8.298	11.784	15.663	12.107	8.508	8.322	9.278	9.992	9.037	8.629	106.605
4	8.655	22.176	28.782	22.625	7.452	8.526	11.930	15.835	11.896	8.473	8.322	9.200	9.914	9.037	8.629	106.107
5	8.797	22.799	28.283	21.892	8.098	8.657	11.735	15.663	12.107	8.508	8.385	9.278	9.992	9.008	8.589	105.610
6	8.797	22.176	29.410	22.718	7.346	8.493	12.128	15.777	11.896	8.508	8.291	9.107	10.032	9.008	8.749	106.605
7	8.845	22.939	28.159	21.892	7.665	8.591	11.735	15.663	11.980	8.369	8.259	9.162	9.914	8.980	8.749	105.114
8	8.655	22.590	28.036	21.892	7.718	8.591	11.784	15.720	12.107	8.508	8.228	9.162	9.874	9.037	8.471	105.610
9	8.702	22.799	28.283	21.892	7.665	8.591	11.784	15.492	12.150	8.508	8.385	9.239	9.874	8.782	8.314	101.169
10	8.750	22.520	29.158	22.165	7.452	8.624	12.128	15.663	11.854	8.508	8.416	9.239	10.032	9.008	8.550	108.101
11	8.467	22.520	27.912	22.718	7.718	8.428	11.930	15.663	11.896	8.508	8.291	9.123	9.835	8.980	8.431	105.610
12	8.655	22.659	28.159	22.257	7.665	8.526	11.591	15.492	12.107	8.508	8.291	9.123	9.719	8.980	8.709	105.610
13	8.845	22.869	28.657	21.802	7.558	8.657	11.881	15.267	11.896	8.824	8.416	9.278	9.874	8.980	8.236	102.151
14	8.655	22.520	29.663	22.257	7.138	8.723	12.128	15.663	11.896	8.508	8.385	9.278	9.914	9.037	8.314	107.103
15	8.940	22.451	28.036	22.257	7.934	8.558	11.930	15.777	12.107	8.508	8.166	9.233	9.914	9.037	8.749	104.124
16	8.561	22.939	28.657	21.892	7.890	8.558	11.784	15.323	11.730	8.508	8.416	9.278	9.914	8.980	8.314	104.124
17	8.750	22.659	29.032	22.718	7.718	8.591	12.178	15.379	11.730	8.508	8.385	9.239	9.992	9.037	8.669	107.103
18	8.797	22.451	28.283	22.440	7.558	8.558	11.735	15.663	12.107	8.439	8.166	9.107	9.758	8.980	8.669	108.101
19	9.085	22.176	27.666	22.625	7.718	8.558	11.930	15.663	11.896	8.508	8.166	9.233	9.914	9.008	8.314	106.107
20	9.085	22.729	28.036	22.257	7.826	8.526	11.930	15.606	11.896	8.508	8.322	9.278	9.992	9.037	8.471	105.610
21	9.085	22.244	28.532	22.440	7.452	8.298	11.930	15.663	12.023	8.508	8.291	9.123	9.874	9.037	8.669	105.114
22	8.940	22.869	29.284	21.892	8.098	8.624	11.832	15.323	11.896	8.508	8.291	9.278	9.992	8.980	8.392	103.136
23	8.561	22.451	29.284	22.718	7.558	8.558	12.128	15.663	11.854	8.508	8.416	9.239	10.072	9.065	8.550	100.189
24	8.467	22.520	29.158	22.074	7.452	8.657	12.128	15.777	11.896	8.473	8.322	9.239	10.072	9.065	8.669	108.101
25	8.893	22.590	28.036	22.625	7.665	8.526	11.591	15.663	12.107	8.508	8.385	9.107	9.953	8.980	8.749	107.103
26	8.797	22.659	29.410	22.074	7.452	8.624	12.128	15.663	11.854	8.508	8.416	9.239	9.992	9.037	8.749	104.124
27	8.845	22.520	28.036	22.625	7.718	8.526	11.784	15.606	12.150	8.648	8.385	9.123	9.758	8.814	8.314	102.151
28	8.467	22.520	29.284	22.348	7.558	8.558	12.178	15.663	11.938	8.508	8.385	9.278	9.914	9.065	8.589	108.101
29	9.085	22.382	28.159	22.718	7.611	8.591	12.078	15.606	11.896	8.473	8.291	9.107	9.758	9.008	8.314	104.124
30	8.655	22.659	28.532	21.892	7.718	8.657	11.784	15.379	11.980	8.508	8.353	9.239	9.835	8.951	8.314	106.107
31	8.374	22.382	28.657	22.533	7.452	8.526	11.979	15.720	12.023	8.439	8.135	9.191	9.914	8.814	8.550	101.169
32	8.374	22.729	28.782	21.983	7.718	8.395	11.591	15.606	11.896	8.508	8.353	9.123	9.797	8.814	8.275	105.114
33	8.420	22.313	28.907	22.257	7.718	8.690	12.128	15.549	11.813	8.508	8.259	9.123	9.874	9.008	8.629	105.114
34	8.608	22.659	28.036	21.892	8.043	8.558	11.784	15.606	11.896	8.508	8.166	9.123	9.835	8.980	8.314	105.610
35	8.702	22.313	27.789	21.892	7.665	8.428	11.784	15.549	11.980	8.508	8.291	9.107	9.797	8.845	8.314	100.679
36	8.702	22.659	28.782	21.802	7.452	8.624	11.784	15.267	11.813	8.508	8.416	9.278	9.914	8.980	8.275	104.124
37	8.750	22.382	29.158	22.257	7.558	8.624	12.029	15.663	11.648	8.508	8.291	9.162	9.992	9.037	8.629	106.107
38	8.845	22.451	28.036	21.983	7.826	8.395	11.591	15.720	12.107	8.369	8.322	9.162	9.914	9.037	8.669	106.605
39	8.797	22.729	28.159	21.892	7.880	8.624	11.784	15.379	11.896	8.648	8.416	9.200	9.914	8.980	8.314	103.136
40	8.374	22.382	29.032	22.718	7.505	8.558	12.078	15.606	11.896	8.508	8.166	9.162	9.992	8.980	8.990	107.602
41	8.797	22.451	28.283	22.440	7.505	8.428	11.784	15.720	12.150	8.508	8.322	9.107	9.914	8.980	8.709	104.124
42	8.655	22.451	28.159	22.165	7.558	8.558	11.832	15.492	12.065	8.613	8.353	9.162	9.914	8.895	8.314	105.610
43	8.893	22.382	29.284	22.440	7.452	8.558	11.979	15.720	11.896	8.473	8.166	9.107	9.874	8.814	8.431	103.629
44	8.467	22.939	29.032	21.711	7.665	8.624	11.979	15.379	11.813	8.508	8.291	9.278	9.953	9.037	8.990	105.114
45	8.702	22.244	28.036	22.718	7.452	8.591	11.979	15.606	11.813	8.473	8.259	9.123	9.874	8.980	8.669	108.101
46	8.845	22.451	28.036	22.074	7.826	8.558	11.591	15.436	12.107	8.613	8.322	9.123	9.797	9.037	8.314	105.114
47	8.655	22.590	29.032	21.711	7.718	8.690	11.930	15.323	11.813	8.473	8.416	9.477	9.992	8.845	8.709	105.114
48	8.797	22.451	29.032	22.440	7.558	8.298	11.930	15.720	12.023	8.508	8.259	9.233	9.758	8.867	8.669	104.618

49	8.702	22.799	29 284	21.892	7.880	8 624	12.029	15 549	11 730	8 508	8.385	9.278	10 032	9 123	8 589	105 610
50	8.655	22.659	28.036	22.074	7.558	8.591	11.930	15.720	12.107	8.508	8 166	9.233	9.914	9.037	8.471	104.124

INPUT DATA

DIFFUSE DAYLIGHT AVAILABILITY IS 105.1735 FOODCANDLE
TRANSMISSION FACTOR OF THE WINDOW IS 1
THE DEPTH OF THE ROOM IS 15 FEET
THE WIDTH OF THE ROOM IS 26 FEET
THE HEIGHT OF THE ROOM IS 12 FEET
THE DISTANCE BETWEEN THE LEFT EDGE OF THE WINDOW AND THE LEFT WALL IS 7 FEET
THE DISTANCE BETWEEN THE RIGHT EDGE OF THE WINDOW AND THE RIGHT WALL IS 7 FEET
THE DISTANCE BETWEEN THE UPPER EDGE OF THE WINDOW AND THE CEILING IS 2 FEET
THE DISTANCE BETWEEN THE LOWER EDGE OF THE WINDOW AND THE FLOOR IS 4 FEET
THE REFLECTANCE OF THE EXTERIOR GROUND IS .31
THE REFLECTANCE OF THE INTERIOR SURFACES ARE
LEFT WALL------ .76 BACK WALL------ .76
RIGHT WALL----- .76 WINDOW WALL---- .76
CEILING-------- .76 FLOOR---------- .06

OUTPUT DATA

P	X-axis	Y-axis	Z-axis	Exter Area to P	Inter-Direct to P	Total Reflec at P	Received
1	0.0000	0.0000	2.5000	2.1667	0.9803	1.1516	2.1319
2	0.0000	2.6000	2.5000	2.1667	1.3022	3.1358	4.4380
3	0.0000	5.2000	2.5000	2.1667	1.6594	2.5592	4.2187
4	0.0000	7.8000	2.5000	2.1667	1.9966	2.3555	4.3522
5	0.0000	10.4000	2.5000	2.1667	2.2409	2.2806	4.5215
6	0.0000	13.0000	2.5000	2.1667	2.3303	2.2618	4.5921
7	0.0000	15.6000	2.5000	2.1667	2.2409	2.2806	4.5215
8	0.0000	18.2000	2.5000	2.1667	1.9966	2.3555	4.3522
9	0.0000	20.8000	2.5000	2.1667	1.6594	2.5592	4.2187
10	0.0000	23.4000	2.5000	2.1667	1.3022	3.1358	4.4380
11	0.0000	26.0000	2.5000	2.1667	0.9803	1.1516	2.1319
12	0.8333	0.0000	2.5000	2.1667	1.0561	4.4488	5.5049
13	0.8333	2.6000	2.5000	2.1667	1.4305	8.7416	10.1721
14	0.8333	5.2000	2.5000	2.1667	1.8559	9.1931	11.0490
15	0.8333	7.8000	2.5000	2.1667	2.2646	10.2428	12.5074
16	0.8333	10.4000	2.5000	2.1667	2.5638	11.3107	13.8744
17	0.8333	13.0000	2.5000	2.1667	2.6738	11.7759	14.4497
18	0.8333	15.6000	2.5000	2.1667	2.5638	11.3107	13.8744
19	0.8333	18.2000	2.5000	2.1667	2.2646	10.2428	12.5074
20	0.8333	20.8000	2.5000	2.1667	1.8559	9.1931	11.0490
21	0.8333	23.4000	2.5000	2.1667	1.4305	8.7416	10.1721
22	0.8333	26.0000	2.5000	2.1667	1.0561	4.4488	5.5049
23	1.6667	0.0000	2.5000	2.1667	1.1361	3.9294	5.0655
24	1.6667	2.6000	2.5000	2.1667	1.5721	7.8649	9.4370
25	1.6667	5.2000	2.5000	2.1667	2.0806	7.8206	9.9012
26	1.6667	7.8000	2.5000	2.1667	2.5785	8.2365	10.8151
27	1.6667	10.4000	2.5000	2.1667	2.9471	8.6443	11.5914
28	1.6667	13.0000	2.5000	2.1667	3.0833	8.8085	11.8918
29	1.6667	15.6000	2.5000	2.1667	2.9471	8.6443	11.5914
30	1.6667	18.2000	2.5000	2.1667	2.5786	8.2365	10.8151
31	1.6667	20.8000	2.5000	2.1667	2.0806	7.8206	9.9012
32	1.6667	23.4000	2.5000	2.1667	1.5721	7.8649	9.4370
33	1.6667	26.0000	2.5000	2.1667	1.1361	3.9294	5.0655
34	2.5000	0.0000	2.5000	2.1667	1.2196	3.5233	4.7429
35	2.5000	2.6000	2.5000	2.1667	1.7280	7.2446	8.9726
36	2.5000	5.2000	2.5000	2.1667	2.3379	6.9334	9.2713
37	2.5000	7.8000	2.5000	2.1667	2.9478	7.1202	10.0680
38	2.5000	10.4000	2.5000	2.1667	3.4044	7.3479	10.7524
39	2.5000	13.0000	2.5000	2.1667	3.5738	7.4419	11.0157
40	2.5000	15.6000	2.5000	2.1667	3.4044	7.3479	10.7524

41	2.5000	18.2000	2.5000	2.1667	2.9478	7.1202	10.0680
42	2.5000	20.8000	2.5000	2.1667	2.3379	6.9334	9.2713
43	2.5000	23.4000	2.5000	2.1667	1.7280	7.2446	8.9726
44	2.5000	26.0000	2.5000	2.1667	1.2196	3.5233	4.7429
45	3.3333	0.0000	2.5000	2.1667	1.3056	3.2366	4.5421
46	3.3333	2.6000	2.5000	2.1667	1.8984	6.8458	8.7442
47	3.3333	5.2000	2.5000	2.1667	2.6325	6.3551	8.9876
48	3.3333	7.8000	2.5000	2.1667	3.3837	6.4132	9.7969
49	3.3333	10.4000	2.5000	2.1667	3.9525	6.5538	10.5064
50	3.3333	13.0000	2.5000	2.1667	4.1642	6.6161	10.7803
51	3.3333	15.6000	2.5000	2.1667	3.9525	6.5538	10.5064
52	3.3333	18.2000	2.5000	2.1667	3.3837	6.4132	9.7969
53	3.3333	20.8000	2.5000	2.1667	2.6325	6.3551	8.9876
54	3.3333	23.4000	2.5000	2.1667	1.8984	6.8458	8.7442
55	3.3333	26.0000	2.5000	2.1667	1.3056	3.2366	4.5421
56	4.1667	0.0000	2.5000	2.1667	1.3921	3.0298	4.4220
57	4.1667	2.6000	2.5000	2.1667	2.0831	6.5804	8.6635
58	4.1667	5.2000	2.5000	2.1667	2.9697	5.9580	8.9277
59	4.1667	7.8000	2.5000	2.1667	3.9000	5.9275	9.8274
60	4.1667	10.4000	2.5000	2.1667	4.6124	6.0122	10.6245
61	4.1667	13.0000	2.5000	2.1667	4.8779	6.0548	10.9328
62	4.1667	15.6000	2.5000	2.1667	4.6124	6.0122	10.6245
63	4.1667	18.2000	2.5000	2.1667	3.9000	5.9275	9.8274
64	4.1667	20.8000	2.5000	2.1667	2.9697	5.9580	8.9277
65	4.1667	23.4000	2.5000	2.1667	2.0831	6.5804	8.6635
66	4.1667	26.0000	2.5000	2.1667	1.3921	3.0298	4.4220
67	5.0000	0.0000	2.5000	2.1667	1.4767	2.8761	4.3528
68	5.0000	2.6000	2.5000	2.1667	2.2809	6.3932	8.6741
69	5.0000	5.2000	2.5000	2.1667	3.3547	5.6734	9.0281
70	5.0000	7.8000	2.5000	2.1667	4.5132	5.5786	10.0919
71	5.0000	10.4000	2.5000	2.1667	5.4099	5.6242	11.0341
72	5.0000	13.0000	2.5000	2.1667	5.7443	5.6534	11.3977
73	5.0000	15.6000	2.5000	2.1667	5.4099	5.6242	11.0341
74	5.0000	18.2000	2.5000	2.1667	4.5132	5.5786	10.0919
75	5.0000	20.8000	2.5000	2.1667	3.3547	5.6734	9.0281
76	5.0000	23.4000	2.5000	2.1667	2.2809	6.3932	8.6741
77	5.0000	26.0000	2.5000	2.1667	1.4767	2.8761	4.3528
78	5.8333	0.0000	2.5000	2.1667	1.5555	2.7594	4.3150
79	5.8333	2.6000	2.5000	2.1667	2.4887	6.2535	8.7422
80	5.8333	5.2000	2.5000	2.1667	3.7923	5.4621	9.2544
81	5.8333	7.8000	2.5000	2.1667	5.2433	5.3212	10.5645
82	5.8333	10.4000	2.5000	2.1667	6.3772	5.3391	11.7163
83	5.8333	13.0000	2.5000	2.1667	6.7989	5.3589	12.1578
84	5.8333	15.6000	2.5000	2.1667	6.3772	5.3391	11.7163
85	5.8333	18.2000	2.5000	2.1667	5.2433	5.3212	10.5645
86	5.8333	20.8000	2.5000	2.1667	3.7923	5.4621	9.2544
87	5.8333	23.4000	2.5000	2.1667	2.4887	6.2535	8.7422
88	5.8333	26.0000	2.5000	2.1667	1.5555	2.7594	4.3150
89	6.6667	0.0000	2.5000	2.1667	1.6238	2.6700	4.2937
90	6.6667	2.6000	2.5000	2.1667	2.7009	6.1408	8.8418
91	6.6667	5.2000	2.5000	2.1667	4.2860	5.3003	9.5862
92	6.6667	7.8000	2.5000	2.1667	6.1134	5.1278	11.2412
93	6.6667	10.4000	2.5000	2.1667	7.5527	5.1269	12.6796
94	6.6667	13.0000	2.5000	2.1667	8.0845	5.1403	13.2248
95	6.6667	15.6000	2.5000	2.1667	7.5527	5.1269	12.6796
96	6.6667	18.2000	2.5000	2.1667	6.1134	5.1278	11.2412
97	6.6667	20.8000	2.5000	2.1667	4.2860	5.3003	9.5862
98	6.6667	23.4000	2.5000	2.1667	2.7009	6.1408	8.8418
99	6.6667	26.0000	2.5000	2.1667	1.6238	2.6700	4.2937
100	7.5000	0.0000	2.5000	2.1667	1.6747	2.6019	4.2766
101	7.5000	2.6000	2.5000	2.1667	2.9083	6.0427	8.9509
102	7.5000	5.2000	2.5000	2.1667	4.8355	5.1729	10.0085
103	7.5000	7.8000	2.5000	2.1667	7.1498	4.9814	12.1312
104	7.5000	10.4000	2.5000	2.1667	8.9818	4.9686	13.9504
105	7.5000	13.0000	2.5000	2.1667	9.6503	4.9779	14.6282
106	7.5000	15.6000	2.5000	2.1667	8.9818	4.9686	13.9504
107	7.5000	18.2000	2.5000	2.1667	7.1498	4.9814	12.1312
108	7.5000	20.8000	2.5000	2.1667	4.8355	5.1729	10.0085
109	7.5000	23.4000	2.5000	2.1667	2.9083	6.0427	8.9509
110	7.5000	26.0000	2.5000	2.1667	1.6747	2.6019	4.2766
111	8.3333	0.0000	2.5000	2.1667	1.7001	2.5515	4.2516
112	8.3333	2.6000	2.5000	2.1667	3.0959	5.9489	9.0447

113	8.3333	5.2000	2.5000	2.1667	5.4343	5.0707	10.5050
114	8.3333	7.8000	2.5000	2.1667	8.3806	4.8711	13.2517
115	8.3333	10.4000	2.5000	2.1667	10.7147	4.8523	15.5670
116	8.3333	13.0000	2.5000	2.1667	11.5485	4.8594	16.4079
117	8.3333	15.6000	2.5000	2.1667	10.7147	4.8523	15.5670
118	8.3333	18.2000	2.5000	2.1667	8.3806	4.8711	13.2517
119	8.3333	20.8000	2.5000	2.1667	5.4343	5.0707	10.5050
120	8.3333	23.4000	2.5000	2.1667	3.0959	5.9489	9.0447
121	8.3333	26.0000	2.5000	2.1667	1.7001	2.5515	4.2516
122	9.1667	0.0000	2.5000	2.1667	1.6901	2.5171	4.2072
123	9.1667	2.6000	2.5000	2.1667	3.2413	5.8542	9.0955
124	9.1667	5.2000	2.5000	2.1667	6.0629	4.9883	11.0512
125	9.1667	7.8000	2.5000	2.1667	9.8314	4.7905	14.6219
126	9.1667	10.4000	2.5000	2.1667	12.8003	4.7707	17.5710
127	9.1667	13.0000	2.5000	2.1667	13.8260	4.7772	18.6032
128	9.1667	15.6000	2.5000	2.1667	12.8003	4.7707	17.5710
129	9.1667	18.2000	2.5000	2.1667	9.8314	4.7905	14.6219
130	9.1667	20.8000	2.5000	2.1667	6.0629	4.9883	11.0512
131	9.1667	23.4000	2.5000	2.1667	3.2413	5.8542	9.0955
132	9.1667	26.0000	2.5000	2.1667	1.6901	2.5171	4.2072
133	10.0000	0.0000	2.5000	2.1667	1.6336	2.4987	4.1322
134	10.0000	2.6000	2.5000	2.1667	3.3128	5.7550	9.0678
135	10.0000	5.2000	2.5000	2.1667	6.6790	4.9240	11.6031
136	10.0000	7.8000	2.5000	2.1667	11.5162	4.7373	16.2535
137	10.0000	10.4000	2.5000	2.1667	15.2707	4.7206	19.9913
138	10.0000	13.0000	2.5000	2.1667	16.5034	4.7277	21.2311
139	10.0000	15.6000	2.5000	2.1667	15.2707	4.7206	19.9913
140	10.0000	18.2000	2.5000	2.1667	11.5162	4.7373	16.2535
141	10.0000	20.8000	2.5000	2.1667	6.6790	4.9240	11.6031
142	10.0000	23.4000	2.5000	2.1667	3.3128	5.7550	9.0678
143	10.0000	26.0000	2.5000	2.1667	1.6336	2.4987	4.1322
144	10.8333	0.0000	2.5000	2.1667	1.5195	2.4981	4.0176
145	10.8333	2.6000	2.5000	2.1667	3.2679	5.6539	8.9218
146	10.8333	5.2000	2.5000	2.1667	7.1997	4.8805	12.0802
147	10.8333	7.8000	2.5000	2.1667	13.4150	4.7127	18.1278
148	10.8333	10.4000	2.5000	2.1667	18.1013	4.7027	22.8040
149	10.8333	13.0000	2.5000	2.1667	19.5283	4.7116	24.2399
150	10.8333	15.6000	2.5000	2.1667	18.1013	4.7027	22.8040
151	10.8333	18.2000	2.5000	2.1667	13.4150	4.7127	18.1278
152	10.8333	20.8000	2.5000	2.1667	7.1997	4.8805	12.0802
153	10.8333	23.4000	2.5000	2.1667	3.2679	5.6539	8.9218
154	10.8333	26.0000	2.5000	2.1667	1.5195	2.4981	4.0176
155	11.6667	0.0000	2.5000	2.1667	1.3390	2.5202	3.8591
156	11.6667	2.6000	2.5000	2.1667	3.0558	5.5585	8.6142
157	11.6667	5.2000	2.5000	2.1667	7.4732	4.8655	12.3387
158	11.6667	7.8000	2.5000	2.1667	15.4172	4.7237	20.1409
159	11.6667	10.4000	2.5000	2.1667	21.1122	4.7235	25.8357
160	11.6667	13.0000	2.5000	2.1667	22.6681	4.7351	27.4032
161	11.6667	15.6000	2.5000	2.1667	21.1122	4.7235	25.8357
162	11.6667	18.2000	2.5000	2.1667	15.4172	4.7237	20.1409
163	11.6667	20.8000	2.5000	2.1667	7.4732	4.8655	12.3387
164	11.6667	23.4000	2.5000	2.1667	3.0558	5.5585	8.6142
165	11.6667	26.0000	2.5000	2.1667	1.3390	2.5202	3.8591
166	12.5000	0.0000	2.5000	2.1667	1.0880	2.5740	3.6620
167	12.5000	2.6000	2.5000	2.1667	2.6265	5.4890	8.1155
168	12.5000	5.2000	2.5000	2.1667	7.2383	4.8964	12.1346
169	12.5000	7.8000	2.5000	2.1667	17.1589	4.7868	21.9457
170	12.5000	10.4000	2.5000	2.1667	23.7049	4.8003	28.5051
171	12.5000	13.0000	2.5000	2.1667	25.2450	4.8159	30.0610
172	12.5000	15.6000	2.5000	2.1667	23.7049	4.8003	28.5051
173	12.5000	18.2000	2.5000	2.1667	17.1589	4.7868	21.9457
174	12.5000	20.8000	2.5000	2.1667	7.2383	4.8964	12.1346
175	12.5000	23.4000	2.5000	2.1667	2.6265	5.4890	8.1155
176	12.5000	26.0000	2.5000	2.1667	1.0880	2.5740	3.6620
177	13.3333	0.0000	2.5000	2.1667	0.7703	2.6738	3.4441
178	13.3333	2.6000	2.5000	2.1667	1.9502	5.4802	7.4304
179	13.3333	5.2000	2.5000	2.1667	6.0986	5.0079	11.1065
180	13.3333	7.8000	2.5000	2.1667	17.5087	4.9438	22.4525
181	13.3333	10.4000	2.5000	2.1667	24.1422	4.9832	29.1253
182	13.3333	13.0000	2.5000	2.1667	25.4356	5.0081	30.4437
183	13.3333	15.6000	2.5000	2.1667	24.1422	4.9832	29.1253
184	13.3333	18.2000	2.5000	2.1667	17.5087	4.9438	22.4525

185	13.3333	20.8000	2.5000	2.1667	6.0986	5.0079	11.1065
186	13.3333	23.4000	2.5000	2.1667	1.9502	5.4801	7.4304
187	13.3333	26.0000	2.5000	2.1667	0.7703	2.6738	3.4441
188	14.1667	0.0000	2.5000	2.1667	0.3998	2.8164	3.2162
189	14.1667	2.6000	2.5000	2.1667	1.0457	5.5547	6.6003
190	14.1667	5.2000	2.5000	2.1667	3.6439	5.2510	8.8949
191	14.1667	7.8000	2.5000	2.1667	13.2046	5.3065	18.5111
192	14.1667	10.4000	2.5000	2.1667	17.9619	5.4563	23.4182
193	14.1667	13.0000	2.5000	2.1667	18.7368	5.5303	24.2671
194	14.1667	15.6000	2.5000	2.1667	17.9619	5.4563	23.4182
195	14.1667	18.2000	2.5000	2.1667	13.2046	5.3065	18.5111
196	14.1667	20.8000	2.5000	2.1667	3.6439	5.2510	8.8949
197	14.1667	23.4000	2.5000	2.1667	1.0457	5.5547	6.6003
198	14.1667	26.0000	2.5000	2.1667	0.3998	2.8164	3.2162
199	15.0000	0.0000	2.5000	2.1667	0.0000	1.3679	1.3679
200	15.0000	2.6000	2.5000	2.1667	0.0000	3.1525	3.1525
201	15.0000	5.2000	2.5000	2.1667	0.0000	2.7648	2.7648
202	15.0000	7.8000	2.5000	2.1667	0.0000	2.6211	2.6211
203	15.0000	10.4000	2.5000	2.1667	0.0000	2.5452	2.5452
204	15.0000	13.0000	2.5000	2.1667	0.0000	2.4639	2.4639
205	15.0000	15.6000	2.5000	2.1667	0.0000	2.3440	2.3440
206	15.0000	18.2000	2.5000	2.1667	0.0000	2.1757	2.1757
207	15.0000	20.8000	2.5000	2.1667	0.0000	1.9650	1.9650
208	15.0000	23.4000	2.5000	2.1667	0.0000	1.7273	1.7273
209	15.0000	26.0000	2.5000	2.1667	0.0000	1.4818	1.4818

CASE 3

DIGITAL CODE

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	229	726	336	497	177	356	336	449	414	335	320	282	305	262	248	301
2	242	725	334	496	184	357	336	452	409	335	320	275	309	259	249	302
3	233	719	333	499	178	356	341	455	411	335	315	280	305	260	248	304
4	230	720	331	503	180	351	337	454	414	333	320	277	303	256	239	296
5	235	708	340	495	176	360	336	448	407	337	312	277	307	256	248	291
6	233	716	340	494	181	355	340	449	405	334	320	280	303	262	243	296
7	242	716	331	501	174	353	337	450	407	333	311	273	306	260	248	299
8	233	717	333	501	177	351	335	448	411	337	313	280	305	258	247	287
9	232	715	340	489	180	359	333	444	406	337	320	278	303	259	248	293
10	230	716	341	497	178	354	341	452	402	334	320	280	307	263	250	299
11	238	718	333	498	184	355	335	448	409	336	313	272	309	259	248	299
12	233	724	331	499	174	355	335	452	406	337	313	272	308	262	248	297
13	238	719	332	494	179	356	335	450	409	335	320	273	303	257	239	296
14	233	723	332	494	181	356	335	449	409	339	314	277	306	256	245	296
15	234	723	336	492	184	358	340	443	407	331	320	280	303	259	248	289
16	229	720	337	496	177	355	339	448	405	335	313	275	303	259	250	300
17	234	724	334	493	180	356	335	447	409	339	315	280	306	255	243	283
18	233	720	340	493	175	364	337	448	407	335	313	275	307	258	248	295
19	235	711	332	500	180	353	336	450	407	335	313	276	304	260	247	299
20	241	719	332	491	180	354	335	449	409	337	320	277	304	258	245	279
21	234	719	339	492	176	360	334	448	410	335	321	280	306	260	239	296
22	227	721	339	491	177	357	339	448	405	335	313	277	309	261	248	299
23	231	720	331	495	178	351	334	448	410	341	320	275	305	253	245	288
24	230	724	332	500	182	353	333	448	407	335	320	276	305	258	248	285
25	235	721	344	494	176	355	337	448	407	335	320	276	305	258	245	295
26	233	718	337	495	174	353	338	449	407	334	313	276	304	255	248	297
27	234	720	329	491	179	351	333	447	409	335	320	273	301	251	243	296
28	230	720	341	491	177	357	339	449	408	337	320	277	307	261	245	299
29	233	715	329	504	177	351	335	449	410	335	312	273	303	255	248	292
30	233	719	340	491	178	354	334	444	406	334	320	277	305	255	243	297
31	232	720	341	496	184	360	344	449	403	333	313	276	307	259	247	301
32	232	721	329	495	184	354	331	445	409	335	314	276	306	257	245	292
33	234	722	338	495	180	359	339	448	403	335	320	281	305	259	247	299
34	238	716	332	501	181	356	339	451	403	333	312	273	308	259	239	302
35	239	724	331	497	175	351	337	451	411	338	320	276	307	259	245	293
36	233	723	329	492	178	364	337	447	407	337	320	280	305	258	249	295
37	233	720	337	503	176	355	339	447	410	335	313	275	307	259	247	299
38	240	719	336	497	182	356	333	447	407	337	320	280	306	258	245	296
39	233	723	340	495	180	357	335	448	408	337	320	275	305	257	247	287
40	233	720	340	495	177	355	339	450	404	334	320	280	305	260	252	289
41	234	724	342	492	176	355	335	448	414	338	320	273	307	257	248	292
42	233	720	339	496	175	358	335	448	407	336	320	275	306	257	245	289
43	242	720	342	495	180	355	341	452	406	335	315	280	308	261	247	301
44	242	718	333	499	177	347	336	451	407	337	313	277	304	257	248	292
45	237	725	334	490	177	360	339	449	405	337	315	278	307	261	248	298
46	242	718	332	499	177	356	335	451	410	335	312	272	307	257	245	296
47	229	722	333	494	181	357	335	447	407	338	320	277	303	260	247	291
48	233	724	337	493	184	356	334	445	406	337	320	276	301	255	242	288
49	234	724	331	496	177	353	331	448	407	337	315	280	304	257	244	289
50	236	720	342	493	177	355	338	450	478	332	313	274	305	261	249	295

	Digital Code		Footcandles
THE AVERAGE OF CHANNEL 1 IS---------------	234.42	=	5.402162
THE AVERAGE OF CHANNEL 2 IS---------------	719.98	=	17.91579
THE AVERAGE OF CHANNEL 3 IS---------------	335.54	=	26.75721
THE AVERAGE OF CHANNEL 4 IS---------------	495.58	=	20.52354
THE AVERAGE OF CHANNEL 5 IS---------------	178.62	=	5.733622

THE AVERAGE OF CHANNEL 6 IS--------------- 355.5 = 5.809397

THE AVERAGE OF CHANNEL 7 IS--------------- 336.44 = 8.396097

THE AVERAGE OF CHANNEL 8 IS--------------- 448.7 = 9.397279

THE AVERAGE OF CHANNEL 9 IS--------------- 409.08 = 8.010584

THE AVERAGE OF CHANNEL 10 IS--------------- 335.62 = 5.960666

THE AVERAGE OF CHANNEL 11 IS--------------- 316.78 = 4.696993

THE AVERAGE OF CHANNEL 12 IS--------------- 276.66 = 5.575272

THE AVERAGE OF CHANNEL 13 IS--------------- 305.38 = 6.212394

THE AVERAGE OF CHANNEL 14 IS--------------- 258.26 = 5.330738

THE AVERAGE OF CHANNEL 15 IS--------------- 246.14 = 4.696534

THE AVERAGE OF CHANNEL 16 IS--------------- 294.58 = 111.9105

OBSERVATIONS IN FOOTCANDLES

	1	2	3	4	5	6	7	8	9	10	11	12	13	14		
1	5.204	18.271	26.813	20.647	5.658	5.823	8.379	9.408	8.171	5.942	4.774	5.753	6.200	5.430	4.752	115.167
2	5.695	18.211	26.571	20.560	5.989	5.850	8.379	9.350	8.008	5.942	4.774	5.521	6.330	5.350	4.782	115.677
3	5.353	17.859	26.451	20.822	5.704	5.823	8.577	9.450	8.073	5.942	4.655	5.686	6.200	5.377	4.752	116.699
4	5.241	17.917	26.211	21.175	5.799	5.687	8.418	9.416	8.171	5.884	4.774	5.587	6.135	5.271	4.485	112.628
5	5.428	17.225	27.299	20.473	5.611	5.933	8.379	9.372	7.943	6.001	4.583	5.587	6.265	5.271	4.752	110.107
6	5.353	17.684	27.299	20.387	5.846	5.796	8.537	9.408	7.879	5.913	4.774	5.686	6.135	5.430	4.603	112.628
7	5.695	17.684	26.211	20.998	5.518	5.741	8.418	9.284	7.943	5.884	4.560	5.455	6.233	5.377	4.752	114.150
8	5.353	17.742	26.451	20.998	5.658	5.687	8.339	9.372	8.073	6.001	4.607	5.686	6.200	5.324	4.722	108.101
9	5.315	17.626	27.299	19.957	5.799	5.905	8.261	9.227	7.911	6.001	4.774	5.620	6.135	5.350	4.752	111.113
10	5.241	17.684	27.421	20.647	5.704	5.769	8.577	9.350	7.783	5.913	4.774	5.686	6.265	5.457	4.813	114.150
11	5.542	17.800	26.451	20.734	5.989	5.796	8.339	9.372	8.008	5.972	4.607	5.422	6.330	5.350	4.752	114.150
12	5.353	18.152	26.211	20.822	5.518	5.796	8.339	9.350	7.911	6.001	4.607	5.422	6.298	5.430	4.752	113.135
13	5.542	17.859	26.331	20.387	5.752	5.823	8.339	9.284	8.008	5.942	4.774	5.455	6.135	5.297	4.485	112.628
14	5.353	18.093	26.331	20.387	5.846	5.823	8.339	9.408	8.008	6.060	4.631	5.587	6.233	5.271	4.662	112.628
15	5.390	18.093	26.813	20.214	5.989	5.878	8.537	9.191	7.943	5.826	4.774	5.686	6.135	5.350	4.752	109.103
16	5.204	17.917	26.934	20.560	5.658	5.796	8.497	9.372	7.879	5.942	4.607	5.521	6.135	5.350	4.813	114.658
17	5.390	18.152	26.571	20.300	5.799	5.823	8.339	9.336	8.008	6.060	4.655	5.686	6.233	5.245	4.603	106.107
18	5.353	17.917	27.299	20.300	5.564	6.043	8.418	9.372	7.943	5.942	4.607	5.521	6.265	5.324	4.752	112.123
19	5.428	17.396	26.331	20.910	5.799	5.741	8.379	9.284	7.943	5.942	4.607	5.553	6.168	5.377	4.722	114.150
20	5.656	17.859	26.331	20.128	5.799	5.769	8.339	9.408	8.008	6.001	4.774	5.587	6.168	5.324	4.662	104.124
21	5.390	17.859	27.177	20.214	5.611	5.933	8.300	9.372	8.040	5.942	4.798	5.686	6.233	5.377	4.485	112.628
22	5.130	17.976	27.177	20.128	5.658	5.850	8.497	9.372	7.879	5.942	4.607	5.587	6.330	5.403	4.752	114.150
23	5.278	17.917	26.211	20.473	5.704	5.687	8.300	9.372	8.040	6.120	4.774	5.521	6.200	5.192	4.662	108.602
24	5.241	18.152	26.331	20.910	5.894	5.741	8.261	9.372	7.943	5.942	4.774	5.553	6.200	5.324	4.752	107.103
25	5.428	17.976	27.789	20.387	5.611	5.796	8.418	9.372	7.943	5.942	4.774	5.553	6.200	5.324	4.662	112.123
26	5.353	17.800	26.934	20.473	5.518	5.741	8.458	9.408	7.943	5.913	4.607	5.553	6.168	5.245	4.752	113.135
27	5.390	17.917	25.972	20.128	5.752	5.687	8.261	9.336	8.008	5.942	4.774	5.455	6.071	5.140	4.603	112.628
28	5.241	17.917	27.421	20.128	5.658	5.850	8.497	9.408	7.976	6.001	4.774	5.587	6.265	5.403	4.662	114.150
29	5.353	17.626	25.972	21.264	5.658	5.687	8.339	9.408	8.040	5.942	4.583	5.455	6.135	5.245	4.752	110.610
30	5.353	17.859	27.299	20.128	5.704	5.769	8.300	9.227	7.911	5.913	4.774	5.587	6.200	5.245	4.603	113.135
31	5.315	17.917	27.421	20.560	5.989	5.933	8.696	9.408	7.815	5.884	4.607	5.553	6.265	5.350	4.722	115.167
32	5.315	17.976	25.972	20.473	5.989	5.769	8.183	9.263	8.008	5.942	4.631	5.553	6.233	5.297	4.662	110.610
33	5.390	18.034	27.055	20.473	5.799	5.905	8.497	9.372	7.815	5.942	4.774	5.720	6.200	5.350	4.722	114.150
34	5.542	17.684	26.331	20.998	5.846	5.823	8.497	9.317	7.815	5.884	4.583	5.455	6.298	5.350	4.485	115.677
35	5.580	18.152	26.211	20.647	5.564	5.687	8.418	9.317	8.073	6.031	4.774	5.553	6.265	5.350	4.662	111.113
36	5.353	18.093	25.972	20.214	5.704	6.043	8.418	9.336	7.943	6.001	4.774	5.686	6.200	5.324	4.782	112.123
37	5.353	17.917	26.934	21.175	5.611	5.796	8.497	9.336	8.040	5.942	4.607	5.521	6.265	5.350	4.722	114.150
38	5.618	17.859	26.813	20.647	5.894	5.823	8.261	9.336	7.943	6.001	4.774	5.686	6.233	5.324	4.662	112.628
39	5.353	18.093	27.299	20.473	5.799	5.850	8.339	9.372	7.976	6.001	4.774	5.521	6.200	5.297	4.722	108.101
40	5.353	17.917	27.299	20.473	5.658	5.796	8.497	9.284	7.847	5.913	4.774	5.686	6.200	5.377	4.873	109.103
41	5.390	18.152	27.544	20.214	5.611	5.796	8.339	9.372	8.171	6.031	4.774	5.455	6.265	5.297	4.752	110.610
42	5.353	17.917	27.177	20.560	5.564	5.878	8.339	9.372	7.943	5.972	4.774	5.521	6.233	5.297	4.662	109.103
43	5.695	17.917	27.544	20.473	5.799	5.796	8.577	9.350	7.911	5.942	4.655	5.686	6.298	5.403	4.722	115.167
44	5.695	17.800	26.451	20.822	5.658	5.580	8.379	9.317	7.943	6.001	4.607	5.587	6.168	5.297	4.752	110.610
45	5.503	18.211	26.571	20.043	5.658	5.933	8.497	9.408	7.879	6.001	4.655	5.620	6.265	5.403	4.752	113.642
46	5.695	17.800	26.331	20.822	5.658	5.823	8.339	9.317	8.040	5.942	4.583	5.422	6.265	5.297	4.662	112.628

47	5.204	18.034	26.451	20.387	5.846	5.850	8.339	9.336	7.943	6.031	4.774	5.587	6.135	5.377	4.722	110.107
48	5.353	18.152	26.934	20.300	5.989	5.823	8.300	9.263	7.911	6.001	4.774	5.553	6.071	5.245	4.573	108.602
49	5.390	18.152	26.211	20.560	5.658	5.741	8.183	9.372	7.943	6.001	4.655	5.686	6.168	5.297	4.633	109.103
50	5.466	17.917	27.544	20.300	5.658	5.796	8.458	9.284	10.161	5.855	4.607	5.488	6.200	5.403	4.782	112.123

INPUT DATA

DIFFUSE DAYLIGHT AVAILABILITY IS 111.9105 FOODCANDLE
TRANSMISSION FACTOR OF THE WINDOW IS 1
THE DEPTH OF THE ROOM IS 12 FEET
THE WIDTH OF THE ROOM IS 18 FEET
THE HEIGHT OF THE ROOM IS 10 FEET
THE DISTANCE BETWEEN THE LEFT EDGE OF THE WINDOW AND THE LEFT WALL IS 5 FEET
THE DISTANCE BETWEEN THE RIGHT EDGE OF THE WINDOW AND THE RIGHT WALL IS 5 FEET
THE DISTANCE BETWEEN THE UPPER EDGE OF THE WINDOW AND THE CEILING IS 2.5 FEET
THE DISTANCE BETWEEN THE LOWER EDGE OF THE WINDOW AND THE FLOOR IS 3.5 FEET
THE REFLECTANCE OF THE EXTERIOR GROUND IS .31
THE REFLECTANCE OF THE INTERIOR SURFACES ARE
LEFT WALL------ .51 BACK WALL------ .51
RIGHT WALL----- .51 WINDOW WALL---- .51
CEILING-------- .84 FLOOR---------- .06

OUTPUT DATA

P	X-axis	Y-axis	Z-axis	Exter Area to P	Inter-Direct to P	Total Reflec at P	Received
1	0.0000	0.0000	2.5000	1.2000	0.7578	0.6906	1.4484
2	0.0000	1.8000	2.5000	1.2000	0.9637	1.7265	2.6902
3	0.0000	3.6000	2.5000	1.2000	1.1812	1.4495	2.6307
4	0.0000	5.4000	2.5000	1.2000	1.3790	1.3511	2.7301
5	0.0000	7.2000	2.5000	1.2000	1.5191	1.3141	2.8332
6	0.0000	9.0000	2.5000	1.2000	1.5698	1.3046	2.8744
7	0.0000	10.8000	2.5000	1.2000	1.5191	1.3141	2.8332
8	0.0000	12.6000	2.5000	1.2000	1.3790	1.3511	2.7301
9	0.0000	14.4000	2.5000	1.2000	1.1812	1.4495	2.6307
10	0.0000	16.2000	2.5000	1.2000	0.9637	1.7265	2.6902
11	0.0000	18.0000	2.5000	1.2000	0.7578	0.6906	1.4484
12	0.6667	0.0000	2.5000	1.2000	0.8274	2.4325	3.2599
13	0.6667	1.8000	2.5000	1.2000	1.0713	4.7039	5.7752
14	0.6667	3.6000	2.5000	1.2000	1.3348	4.9591	6.2939
15	0.6667	5.4000	2.5000	1.2000	1.5785	5.4826	7.0611
16	0.6667	7.2000	2.5000	1.2000	1.7531	5.9995	7.7527
17	0.6667	9.0000	2.5000	1.2000	1.8168	6.2224	8.0392
18	0.6667	10.8000	2.5000	1.2000	1.7531	5.9995	7.7527
19	0.6667	12.6000	2.5000	1.2000	1.5785	5.4826	7.0611
20	0.6667	14.4000	2.5000	1.2000	1.3348	4.9591	6.2939
21	0.6667	16.2000	2.5000	1.2000	1.0713	4.7039	5.7752
22	0.6667	18.0000	2.5000	1.2000	0.8274	2.4325	3.2599
23	1.3333	0.0000	2.5000	1.2000	0.9029	2.1023	3.0053
24	1.3333	1.8000	2.5000	1.2000	1.1927	4.1394	5.3322
25	1.3333	3.6000	2.5000	1.2000	1.5133	4.0952	5.6085
26	1.3333	5.4000	2.5000	1.2000	1.8158	4.2612	6.0770
27	1.3333	7.2000	2.5000	1.2000	2.0351	4.4216	6.4567
28	1.3333	9.0000	2.5000	1.2000	2.1156	4.4853	6.6008
29	1.3333	10.8000	2.5000	1.2000	2.0351	4.4216	6.4567
30	1.3333	12.6000	2.5000	1.2000	1.8158	4.2612	6.0770
31	1.3333	14.4000	2.5000	1.2000	1.5133	4.0952	5.6085
32	1.3333	16.2000	2.5000	1.2000	1.1927	4.1394	5.3322
33	1.3333	18.0000	2.5000	1.2000	0.9029	2.1023	3.0053
34	2.0000	0.0000	2.5000	1.2000	0.9844	1.8790	2.8634
35	2.0000	1.8000	2.5000	1.2000	1.3294	3.8134	5.1428
36	2.0000	3.6000	2.5000	1.2000	1.7216	3.6224	5.3440
37	2.0000	5.4000	2.5000	1.2000	2.0994	3.6803	5.7797
38	2.0000	7.2000	2.5000	1.2000	2.3771	3.7638	6.1410
39	2.0000	9.0000	2.5000	1.2000	2.4795	3.7988	6.2783

40	2.0000	10.8000	2.5000	1.2000	2.3771	3.7638	6.1410
41	2.0000	12.6000	2.5000	1.2000	2.0994	3.6803	5.7797
42	2.0000	14.4000	2.5000	1.2000	1.7216	3.6224	5.3440
43	2.0000	16.2000	2.5000	1.2000	1.3294	3.8134	5.1428
44	2.0000	18.0000	2.5000	1.2000	0.9844	1.8790	2.8634
45	2.6667	0.0000	2.5000	1.2000	1.0714	1.7314	2.8027
46	2.6667	1.8000	2.5000	1.2000	1.4828	3.6291	5.1119
47	2.6667	3.6000	2.5000	1.2000	1.9650	3.3378	5.3028
48	2.6667	5.4000	2.5000	1.2000	2.4404	3.3321	5.7724
49	2.6667	7.2000	2.5000	1.2000	2.7947	3.3766	6.1713
50	2.6667	9.0000	2.5000	1.2000	2.9262	3.3981	6.3242
51	2.6667	10.8000	2.5000	1.2000	2.7947	3.3766	6.1713
52	2.6667	12.6000	2.5000	1.2000	2.4404	3.3321	5.7724
53	2.6667	14.4000	2.5000	1.2000	1.9650	3.3378	5.3028
54	2.6667	16.2000	2.5000	1.2000	1.4828	3.6291	5.1119
55	2.6667	18.0000	2.5000	1.2000	1.0714	1.7314	2.8027
56	3.3333	0.0000	2.5000	1.2000	1.1628	1.6282	2.7910
57	3.3333	1.8000	2.5000	1.2000	1.6542	3.5211	5.1753
58	3.3333	3.6000	2.5000	1.2000	2.2498	3.1532	5.4030
59	3.3333	5.4000	2.5000	1.2000	2.8524	3.1018	5.9542
60	3.3333	7.2000	2.5000	1.2000	3.3082	3.1201	6.4282
61	3.3333	9.0000	2.5000	1.2000	3.4782	3.1327	6.6109
62	3.3333	10.8000	2.5000	1.2000	3.3082	3.1201	6.4282
63	3.3333	12.6000	2.5000	1.2000	2.8524	3.1018	5.9542
64	3.3333	14.4000	2.5000	1.2000	2.2498	3.1532	5.4030
65	3.3333	16.2000	2.5000	1.2000	1.6542	3.5211	5.1753
66	3.3333	18.0000	2.5000	1.2000	1.1628	1.6282	2.7910
67	4.0000	0.0000	2.5000	1.2000	1.2572	1.5528	2.8100
68	4.0000	1.8000	2.5000	1.2000	1.8441	3.4538	5.2979
69	4.0000	3.6000	2.5000	1.2000	2.5833	3.0269	5.6102
70	4.0000	5.4000	2.5000	1.2000	3.3529	2.9413	6.2942
71	4.0000	7.2000	2.5000	1.2000	3.9438	2.9407	6.8845
72	4.0000	9.0000	2.5000	1.2000	4.1654	2.9472	7.1126
73	4.0000	10.8000	2.5000	1.2000	3.9439	2.9407	6.8845
74	4.0000	12.6000	2.5000	1.2000	3.3529	2.9413	6.2942
75	4.0000	14.4000	2.5000	1.2000	2.5833	3.0269	5.6102
76	4.0000	16.2000	2.5000	1.2000	1.8441	3.4538	5.2979
77	4.0000	18.0000	2.5000	1.2000	1.2572	1.5528	2.8100
78	4.6667	0.0000	2.5000	1.2000	1.3516	1.4959	2.8475
79	4.6667	1.8000	2.5000	1.2000	2.0518	3.4106	5.4625
80	4.6667	3.6000	2.5000	1.2000	2.9732	2.9364	5.9096
81	4.6667	5.4000	2.5000	1.2000	3.9637	2.8253	6.7890
82	4.6667	7.2000	2.5000	1.2000	4.7361	2.8109	7.5470
83	4.6667	9.0000	2.5000	1.2000	5.0266	2.8130	7.8396
84	4.6667	10.8000	2.5000	1.2000	4.7361	2.8109	7.5470
85	4.6667	12.6000	2.5000	1.2000	3.9637	2.8253	6.7890
86	4.6667	14.4000	2.5000	1.2000	2.9732	2.9364	5.9096
87	4.6667	16.2000	2.5000	1.2000	2.0518	3.4106	5.4625
88	4.6667	18.0000	2.5000	1.2000	1.3516	1.4959	2.8475
89	5.3333	0.0000	2.5000	1.2000	1.4418	1.4521	2.8939
90	5.3333	1.8000	2.5000	1.2000	2.2749	3.3777	5.6526
91	5.3333	3.6000	2.5000	1.2000	3.4273	2.8679	6.2952
92	5.3333	5.4000	2.5000	1.2000	4.7123	2.7385	7.4509
93	5.3333	7.2000	2.5000	1.2000	5.7294	2.7146	8.4440
94	5.3333	9.0000	2.5000	1.2000	6.1123	2.7136	8.8259
95	5.3333	10.8000	2.5000	1.2000	5.7294	2.7146	8.4440
96	5.3333	12.6000	2.5000	1.2000	4.7123	2.7385	7.4509
97	5.3333	14.4000	2.5000	1.2000	3.4273	2.8679	6.2952
98	5.3333	16.2000	2.5000	1.2000	2.2749	3.3777	5.6526
99	5.3333	18.0000	2.5000	1.2000	1.4418	1.4521	2.8939
100	6.0000	0.0000	2.5000	1.2000	1.5217	1.4181	2.9398
101	6.0000	1.8000	2.5000	1.2000	2.5072	3.3484	5.8556
102	6.0000	3.6000	2.5000	1.2000	3.9522	2.8129	6.7650
103	6.0000	5.4000	2.5000	1.2000	5.6324	2.6716	8.3041
104	6.0000	7.2000	2.5000	1.2000	6.9808	2.6416	9.6224
105	6.0000	9.0000	2.5000	1.2000	7.4868	2.6386	10.1254
106	6.0000	10.8000	2.5000	1.2000	6.9808	2.6416	9.6224
107	6.0000	12.6000	2.5000	1.2000	5.6324	2.6716	8.3041
108	6.0000	14.4000	2.5000	1.2000	3.9522	2.8129	6.7650
109	6.0000	16.2000	2.5000	1.2000	2.5072	3.3484	5.8556
110	6.0000	18.0000	2.5000	1.2000	1.5217	1.4181	2.9398
111	6.6667	0.0000	2.5000	1.2000	1.5826	1.3917	2.9744

112	6.6667	1.8000	2.5000	1.2000	2.7373	3.3140	6.0514
113	6.6667	3.6000	2.5000	1.2000	4.5500	2.7656	7.3155
114	6.6667	5.4000	2.5000	1.2000	6.7642	2.6186	9.3828
115	6.6667	7.2000	2.5000	1.2000	8.5619	2.5854	11.1473
116	6.6667	9.0000	2.5000	1.2000	9.2299	2.5814	11.8114
117	6.6667	10.8000	2.5000	1.2000	8.5619	2.5854	11.1473
118	6.6667	12.6000	2.5000	1.2000	6.7642	2.6186	9.3828
119	6.6667	14.4000	2.5000	1.2000	4.5500	2.7656	7.3155
120	6.6667	16.2000	2.5000	1.2000	2.7373	3.3140	6.0514
121	6.6667	18.0000	2.5000	1.2000	1.5826	1.3917	2.9744
122	7.3333	0.0000	2.5000	1.2000	1.6133	1.3720	2.9854
123	7.3333	1.8000	2.5000	1.2000	2.9456	3.2716	6.2172
124	7.3333	3.6000	2.5000	1.2000	5.2132	2.7226	7.9358
125	7.3333	5.4000	2.5000	1.2000	8.1531	2.5758	10.7289
126	7.3333	7.2000	2.5000	1.2000	10.5584	2.5422	13.1005
127	7.3333	9.0000	2.5000	1.2000	11.4344	2.5380	13.9724
128	7.3333	10.8000	2.5000	1.2000	10.5584	2.5422	13.1005
129	7.3333	12.6000	2.5000	1.2000	8.1531	2.5758	10.7289
130	7.3333	14.4000	2.5000	1.2000	5.2132	2.7226	7.9358
131	7.3333	16.2000	2.5000	1.2000	2.9456	3.2716	6.2172
132	7.3333	18.0000	2.5000	1.2000	1.6133	1.3720	2.9854
133	8.0000	0.0000	2.5000	1.2000	1.5998	1.3588	2.9586
134	8.0000	1.8000	2.5000	1.2000	3.1004	3.2151	6.3156
135	8.0000	3.6000	2.5000	1.2000	5.9141	2.6826	8.5967
136	8.0000	5.4000	2.5000	1.2000	9.8430	2.5418	12.3848
137	8.0000	7.2000	2.5000	1.2000	13.0621	2.5101	15.5722
138	8.0000	9.0000	2.5000	1.2000	14.1930	2.5063	16.6993
139	8.0000	10.8000	2.5000	1.2000	13.0621	2.5101	15.5722
140	8.0000	12.6000	2.5000	1.2000	9.8430	2.5418	12.3848
141	8.0000	14.4000	2.5000	1.2000	5.9141	2.6826	8.5967
142	8.0000	16.2000	2.5000	1.2000	3.1004	3.2151	6.3156
143	8.0000	18.0000	2.5000	1.2000	1.5998	1.3588	2.9586
144	8.6667	0.0000	2.5000	1.2000	1.5262	1.3529	2.8791
145	8.6667	1.8000	2.5000	1.2000	3.1547	3.1462	6.3009
146	8.6667	3.6000	2.5000	1.2000	6.5844	2.6465	9.2308
147	8.6667	5.4000	2.5000	1.2000	11.8592	2.5171	14.3764
148	8.6667	7.2000	2.5000	1.2000	16.1439	2.4894	18.6333
149	8.6667	9.0000	2.5000	1.2000	17.5606	2.4866	20.0471
150	8.6667	10.8000	2.5000	1.2000	16.1439	2.4894	18.6333
151	8.6667	12.6000	2.5000	1.2000	11.8593	2.5171	14.3764
152	8.6667	14.4000	2.5000	1.2000	6.5844	2.6465	9.2308
153	8.6667	16.2000	2.5000	1.2000	3.1547	3.1462	6.3010
154	8.6667	18.0000	2.5000	1.2000	1.5262	1.3529	2.8791
155	9.3333	0.0000	2.5000	1.2000	1.3776	1.3566	2.7342
156	9.3333	1.8000	2.5000	1.2000	3.0449	3.0658	6.1107
157	9.3333	3.6000	2.5000	1.2000	7.0798	2.6182	9.6979
158	9.3333	5.4000	2.5000	1.2000	14.1597	2.5051	16.6649
159	9.3333	7.2000	2.5000	1.2000	19.7691	2.4830	22.2521
160	9.3333	9.0000	2.5000	1.2000	21.4511	2.4816	23.9327
161	9.3333	10.8000	2.5000	1.2000	19.7691	2.4830	22.2521
162	9.3333	12.6000	2.5000	1.2000	14.1598	2.5051	16.6649
163	9.3333	14.4000	2.5000	1.2000	7.0798	2.6182	9.6979
164	9.3333	16.2000	2.5000	1.2000	3.0449	3.0658	6.1107
165	9.3333	18.0000	2.5000	1.2000	1.3776	1.3566	2.7342
166	10.0000	0.0000	2.5000	1.2000	1.1433	1.3750	2.5183
167	10.0000	1.8000	2.5000	1.2000	2.6983	2.9872	5.6855
168	10.0000	3.6000	2.5000	1.2000	7.1223	2.6070	9.7293
169	10.0000	5.4000	2.5000	1.2000	16.4896	2.5140	19.0036
170	10.0000	7.2000	2.5000	1.2000	23.5398	2.4989	26.0387
171	10.0000	9.0000	2.5000	1.2000	25.3573	2.4994	27.8567
172	10.0000	10.8000	2.5000	1.2000	23.5398	2.4989	26.0387
173	10.0000	12.6000	2.5000	1.2000	16.4896	2.5140	19.0036
174	10.0000	14.4000	2.5000	1.2000	7.1223	2.6070	9.7293
175	10.0000	16.2000	2.5000	1.2000	2.6983	2.9872	5.6855
176	10.0000	18.0000	2.5000	1.2000	1.1433	1.3750	2.5183
177	10.6667	0.0000	2.5000	1.2000	0.8233	1.4178	2.2411
178	10.6667	1.8000	2.5000	1.2000	2.0573	2.9331	4.9903
179	10.6667	3.6000	2.5000	1.2000	6.2391	2.6338	8.8729
180	10.6667	5.4000	2.5000	1.2000	17.8652	2.5653	20.4305
181	10.6667	7.2000	2.5000	1.2000	25.8483	2.5608	28.4091
182	10.6667	9.0000	2.5000	1.2000	27.5070	2.5646	30.0716
183	10.6667	10.8000	2.5000	1.2000	25.8483	2.5608	28.4091

184	10.6667	12.6000	2.5000	1.2000	17.8652	2.5653	20.4305
185	10.6667	14.4000	2.5000	1.2000	6.2391	2.6338	8.8729
186	10.6667	16.2000	2.5000	1.2000	2.0573	2.9331	4.9904
187	10.6667	18.0000	2.5000	1.2000	0.8233	1.4178	2.2411
188	11.3333	0.0000	2.5000	1.2000	0.4321	1.4951	1.9272
189	11.3333	1.8000	2.5000	1.2000	1.1236	2.9457	4.0693
190	11.3333	3.6000	2.5000	1.2000	3.8566	2.7521	6.6086
191	11.3333	5.4000	2.5000	1.2000	14.6841	2.7485	17.4325
192	11.3333	7.2000	2.5000	1.2000	21.2288	2.8010	24.0298
193	11.3333	9.0000	2.5000	1.2000	22.3073	2.8301	25.1374
194	11.3333	10.8000	2.5000	1.2000	21.2288	2.8010	24.0298
195	11.3333	12.6000	2.5000	1.2000	14.6841	2.7485	17.4326
196	11.3333	14.4000	2.5000	1.2000	3.8566	2.7521	6.6087
197	11.3333	16.2000	2.5000	1.2000	1.1236	2.9457	4.0693
198	11.3333	18.0000	2.5000	1.2000	0.4321	1.4951	1.9272
199	12.0000	0.0000	2.5000	1.2000	0.0000	0.7880	0.7880
200	12.0000	1.8000	2.5000	1.2000	0.0000	1.7514	1.7514
201	12.0000	3.6000	2.5000	1.2000	0.0000	1.5480	1.5480
202	12.0000	5.4000	2.5000	1.2000	0.0000	1.4648	1.4648
203	12.0000	7.2000	2.5000	1.2000	0.0000	1.4167	1.4167
204	12.0000	9.0000	2.5000	1.2000	0.0000	1.3683	1.3683
205	12.0000	10.8000	2.5000	1.2000	0.0000	1.3029	1.3029
206	12.0000	12.6000	2.5000	1.2000	0.0000	1.2153	1.2153
207	12.0000	14.4000	2.5000	1.2000	0.0000	1.1072	1.1072
208	12.0000	16.2000	2.5000	1.2000	0.0000	0.9855	0.9855
209	12.0000	18.0000	2.5000	1.2000	0.0000	0.8589	0.8589

CASE 4

DIGITAL CODE

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	225	816	397	628	387	322	350	529	511	434	243	232	274	223	230	295
2	223	806	404	636	384	328	355	523	505	431	241	231	272	225	223	295
3	224	807	401	634	383	323	360	528	506	429	235	232	272	222	225	287
4	221	807	397	636	384	327	351	527	508	431	239	232	274	226	229	297
5	228	806	398	633	383	320	358	530	507	429	240	232	272	225	230	296
6	228	806	399	634	384	322	353	528	508	431	239	232	271	232	223	302
7	226	807	407	631	383	323	358	529	504	428	240	233	271	228	226	298
8	223	807	399	635	386	315	353	531	509	431	239	227	269	223	227	296
9	226	811	400	629	390	322	351	524	510	434	239	234	270	223	226	289
10	226	806	406	635	381	319	358	530	507	431	239	232	270	229	221	304
11	223	807	396	633	388	320	355	528	511	431	239	232	272	229	229	287
12	225	807	394	629	386	320	351	528	508	431	239	230	267	223	223	291
13	221	811	407	624	384	324	351	526	508	431	240	223	272	223	223	292
14	224	807	405	623	383	325	351	524	505	431	241	232	271	223	229	302
15	223	805	400	630	384	324	351	527	505	431	239	232	272	228	222	304
16	226	807	406	636	384	325	356	524	507	434	243	236	273	223	227	299
17	225	810	400	635	384	325	355	525	507	430	241	233	273	229	225	298
18	228	810	396	630	391	321	352	529	508	430	240	231	269	225	227	304
19	223	813	396	627	389	322	351	528	512	436	239	230	270	223	226	283
20	225	812	403	630	383	327	356	527	510	433	239	232	273	229	223	302
21	232	807	401	635	384	322	357	529	508	427	239	231	269	226	225	298
22	229	812	396	627	388	321	351	522	510	432	240	230	270	223	223	292
23	227	812	408	624	386	323	357	525	504	430	239	233	273	232	229	301
24	228	807	396	634	392	320	352	527	505	430	235	232	272	232	229	297
25	225	808	398	634	386	320	351	528	508	431	237	231	271	227	229	293
26	229	816	400	631	389	322	349	528	509	434	239	232	270	223	226	294
27	224	812	408	631	382	323	360	529	506	430	240	233	271	232	223	303
28	225	804	393	635	381	321	351	528	511	433	241	229	267	222	228	287
29	229	811	405	630	384	325	353	525	505	431	240	231	270	223	223	291
30	223	807	406	633	381	322	356	530	507	430	239	232	270	223	228	298
31	228	815	391	628	388	322	352	528	511	436	240	229	269	223	223	293
32	225	812	405	632	383	323	357	525	508	429	235	234	271	228	230	307
33	231	807	393	634	383	322	353	529	511	433	239	232	270	222	225	285
34	224	810	408	630	388	325	358	529	506	431	235	232	271	229	227	296
35	225	816	395	630	389	320	351	529	512	431	240	231	272	232	226	295
36	230	812	396	632	387	320	350	528	511	433	238	230	270	223	227	287
37	224	814	408	627	388	325	358	528	506	431	240	232	267	223	223	302
38	231	806	399	633	388	320	355	527	510	430	238	229	267	223	223	289
39	232	807	391	628	379	321	350	525	511	436	244	231	270	222	225	293
40	219	803	400	625	375	319	351	525	504	426	235	229	269	223	226	293
41	232	804	394	628	384	320	353	527	506	428	238	232	270	224	232	298
42	229	812	395	631	387	322	348	525	511	436	239	229	266	222	223	294
43	219	808	404	628	384	325	356	524	508	433	235	231	271	225	222	298
44	229	806	395	636	382	321	357	529	507	432	242	232	271	229	229	302
45	227	812	400	636	386	321	354	528	511	433	243	229	271	223	225	287
46	223	811	399	623	384	325	352	528	511	435	243	232	272	225	229	279
47	226	807	403	627	384	325	352	524	507	435	242	233	274	225	227	297
48	222	807	401	633	383	317	353	528	508	432	235	231	269	227	225	297
49	223	812	400	627	390	320	351	528	509	432	238	227	271	223	232	290
50	226	814	400	629	391	322	349	523	508	435	242	232	268	223	225	287

	Digital Code		Footcandles
THE AVERAGE OF CHANNEL 1 IS---------------	225.78	=	5.085308
THE AVERAGE OF CHANNEL 2 IS---------------	809.18	=	23.73391
THE AVERAGE OF CHANNEL 3 IS---------------	399.98	=	35.07364
THE AVERAGE OF CHANNEL 4 IS---------------	630.78	=	34.50483
THE AVERAGE OF CHANNEL 5 IS---------------	385.14	=	19.80439

THE AVERAGE OF CHANNEL 6 IS-------------- 322.16 = 4.935068

THE AVERAGE OF CHANNEL 7 IS-------------- 353.46 = 9.078573

THE AVERAGE OF CHANNEL 8 IS-------------- 527.06 = 12.31528

THE AVERAGE OF CHANNEL 9 IS-------------- 508.1 = 11.28864

THE AVERAGE OF CHANNEL 10 IS-------------- 431.64 = 9.097114

THE AVERAGE OF CHANNEL 11 IS-------------- 239.28 = 3.015401

THE AVERAGE OF CHANNEL 12 IS-------------- 231.18 = 4.168409

THE AVERAGE OF CHANNEL 13 IS-------------- 270.58 = 5.130078

THE AVERAGE OF CHANNEL 14 IS-------------- 225.36 = 4.482742

THE AVERAGE OF CHANNEL 15 IS-------------- 226.02 = 4.112148

THE AVERAGE OF CHANNEL 16 IS-------------- 294.88 = 112.0621

OBSERVATIONS IN FOOTCANDLES

	1	2	3	4	5	6	7	8	9	10	11	12	13	14		
1	5.057	24.228	34.666	34.172	19.983	4.931	8.938	12.405	11.404	9.182	3.088	4.192	5.232	4.424	4.225	112.123
2	4.984	23.506	35.627	35.134	19.695	5.083	9.142	12.130	11.166	9.074	3.049	4.163	5.172	4.474	4.027	112.123
3	5.020	23.577	35.214	34.892	19.600	4.956	9.235	12.359	11.206	9.002	2.932	4.192	5.172	4.399	4.083	108.101
4	4.912	23.577	34.666	35.134	19.695	5.058	8.978	12.313	11.285	9.074	3.010	4.192	5.232	4.499	4.196	113.135
5	5.167	23.506	34.802	34.772	19.600	4.881	9.265	12.451	11.245	9.002	3.029	4.192	5.172	4.474	4.225	112.628
6	5.167	23.506	34.939	34.892	19.695	4.931	9.060	12.359	11.285	9.074	3.010	4.192	5.143	4.650	4.027	115.677
7	5.093	23.577	36.043	34.531	19.600	4.956	9.265	12.405	11.127	8.967	3.029	4.221	5.143	4.549	4.112	113.642
8	4.984	23.577	34.939	35.013	19.887	4.756	9.060	12.498	11.324	9.074	3.010	4.049	5.083	4.424	4.140	112.628
9	5.093	23.865	35.076	34.292	20.273	4.931	8.978	12.175	11.364	9.182	3.010	4.250	5.113	4.424	4.112	109.103
10	5.093	23.506	35.904	35.013	19.411	4.856	9.265	12.451	11.245	9.074	3.010	4.192	5.113	4.574	3.972	116.699
11	4.984	23.577	34.530	34.772	20.079	4.881	9.142	12.359	11.404	9.074	3.010	4.192	5.172	4.574	4.196	108.101
12	5.057	23.577	34.258	34.292	19.887	4.881	8.978	12.359	11.285	9.074	3.010	4.134	5.024	4.424	4.027	110.107
13	4.912	23.865	36.043	33.697	19.695	4.982	8.978	12.267	11.285	9.074	3.029	3.936	5.172	4.424	4.027	110.610
14	5.020	23.577	35.766	33.579	19.600	5.007	8.978	12.175	11.166	9.074	3.049	4.192	5.143	4.424	4.196	115.677
15	4.984	23.435	35.076	34.411	19.695	4.982	8.978	12.313	11.166	9.074	3.010	4.192	5.172	4.549	4.000	116.699
16	5.093	23.577	35.904	35.134	19.695	5.007	9.183	12.175	11.245	9.182	3.088	4.308	5.202	4.424	4.140	114.150
17	5.057	23.793	35.076	35.013	19.695	5.007	9.142	12.221	11.245	9.038	3.049	4.221	5.202	4.574	4.083	113.642
18	5.167	23.793	34.530	34.411	20.370	4.906	9.019	12.405	11.285	9.038	3.029	4.163	5.083	4.474	4.140	116.699
19	4.984	24.010	34.530	34.053	20.176	4.931	8.978	12.359	11.445	9.255	3.010	4.134	5.113	4.424	4.112	106.107
20	5.057	23.937	35.489	34.411	19.600	5.058	9.183	12.313	11.364	9.146	3.010	4.192	5.202	4.574	4.027	115.677
21	5.315	23.577	35.214	35.013	19.695	4.931	9.224	12.405	11.285	8.931	3.010	4.163	5.083	4.499	4.083	113.642
22	5.204	23.937	34.530	34.053	20.079	4.906	8.978	12.085	11.364	9.110	3.029	4.134	5.113	4.424	4.027	110.610
23	5.130	23.937	36.182	33.697	19.887	4.956	9.224	12.221	11.127	9.038	3.010	4.221	5.202	4.650	4.196	115.167
24	5.167	23.577	34.530	34.892	20.468	4.881	9.019	12.313	11.166	9.038	2.932	4.192	5.172	4.650	4.196	113.135
25	5.057	23.649	34.802	34.892	19.887	4.881	8.978	12.359	11.285	9.074	2.971	4.163	5.143	4.524	4.196	111.113
26	5.204	24.228	35.076	34.531	20.176	4.931	8.897	12.359	11.324	9.182	3.010	4.192	5.113	4.424	4.112	111.618
27	5.020	23.937	36.182	34.531	19.505	4.956	9.235	12.405	11.206	9.038	3.029	4.221	5.143	4.650	4.027	116.188
28	5.057	23.363	34.122	35.013	19.411	4.906	8.978	12.359	11.404	9.146	3.049	4.106	5.024	4.399	4.168	108.101
29	5.204	23.865	35.766	34.411	19.695	5.007	9.060	12.221	11.166	9.074	3.029	4.163	5.113	4.424	4.027	110.107
30	4.984	23.577	35.904	34.772	19.411	4.931	9.183	12.451	11.245	9.038	3.010	4.192	5.113	4.424	4.168	113.642
31	5.167	24.155	33.852	34.172	20.079	4.931	9.019	12.359	11.404	9.255	3.029	4.106	5.083	4.424	4.027	111.113
32	5.057	23.937	35.766	34.651	19.600	4.956	9.224	12.221	11.285	9.002	2.932	4.250	5.143	4.549	4.225	118.236
33	5.278	23.577	34.122	34.892	19.600	4.931	9.060	12.405	11.404	9.146	3.010	4.192	5.113	4.399	4.083	107.103
34	5.020	23.793	36.182	34.411	20.079	5.007	9.265	12.405	11.206	9.074	2.932	4.192	5.143	4.574	4.140	112.628
35	5.057	24.228	34.394	34.411	20.176	4.881	8.978	12.405	11.445	9.074	3.029	4.163	5.172	4.650	4.112	112.123
36	5.241	23.937	34.530	34.651	19.983	4.881	8.938	12.359	11.404	9.146	2.990	4.134	5.113	4.424	4.140	108.101
37	5.020	24.082	36.182	34.053	20.079	5.007	9.265	12.359	11.206	9.074	3.029	4.192	5.024	4.424	4.027	115.677
38	5.278	23.506	34.939	34.772	20.079	4.881	9.142	12.313	11.364	9.038	2.990	4.106	5.024	4.424	4.027	109.103
39	5.315	23.577	33.852	34.172	19.222	4.906	8.938	12.221	11.404	9.255	3.108	4.163	5.113	4.399	4.083	111.113
40	4.840	23.292	35.076	33.816	18.848	4.856	8.978	12.221	11.127	8.895	2.932	4.106	5.083	4.424	4.112	111.113
41	5.315	23.363	34.258	34.172	19.695	4.881	9.060	12.313	11.206	8.967	2.990	4.192	5.113	4.449	4.282	113.642
42	5.204	23.937	34.394	34.531	19.983	4.931	8.857	12.221	11.404	9.255	3.010	4.106	4.995	4.399	4.027	111.618
43	4.840	23.649	35.627	34.172	19.695	5.007	9.183	12.175	11.285	9.146	2.932	4.163	5.143	4.474	4.000	113.642
44	5.204	23.506	34.394	35.134	19.505	4.906	9.224	12.405	11.245	9.110	3.069	4.192	5.143	4.574	4.196	115.677
45	5.130	23.937	35.076	35.134	19.887	4.906	9.101	12.359	11.404	9.146	3.088	4.106	5.143	4.424	4.083	108.101
46	4.984	23.865	34.939	33.579	19.695	5.007	9.019	12.359	11.404	9.218	3.088	4.192	5.172	4.474	4.196	104.124
47	5.093	23.577	35.489	34.053	19.695	5.007	9.019	12.175	11.245	9.218	3.069	4.221	5.232	4.474	4.140	113.135
48	4.948	23.577	35.214	34.772	19.600	4.806	9.060	12.359	11.285	9.110	2.932	4.163	5.083	4.524	4.083	113.135

49	4 984	23.937	35 076	34.053	20.273	4 881	8 978	12 359	11.324	9.110	2 990	4 049	5.143	4.424	4.282	109.604
50	5.093	24.082	35.076	34.292	20 370	4.931	8.897	12.130	11.285	9.218	3.069	4.192	5.054	4.424	4.083	108.101

INPUPT DATA

DIFFUSE DAYLIGHT AVAILABILITY IS 112.0621 FOODCANDLE
TRANSMISSION FACTOR OF THE WINDOW IS 1
THE DEPTH OF THE ROOM IS 14 FEET
THE WIDTH OF THE ROOM IS 19 FEET
THE HEIGHT OF THE ROOM IS 12 FEET
THE DISTANCE BETWEEN THE LEFT EDGE OF THE WINDOW AND THE LEFT WALL IS 5 FEET
THE DISTANCE BETWEEN THE RIGHT EDGE OF THE WINDOW AND THE RIGHT WALL IS 2 FEET
THE DISTANCE BETWEEN THE UPPER EDGE OF THE WINDOW AND THE CEILING IS 2 FEET
THE DISTANCE BETWEEN THE LOWER EDGE OF THE WINDOW AND THE FLOOR IS 3 FEET
THE REFLECTANCE OF THE EXTERIOR GROUND IS .31
THE REFLECTANCE OF THE INTERIOR SURFACES ARE
LEFT WALL------ .06 BACK WALL------ .06
RIGHT WALL----- .06 WINDOW WALL---- .06
CEILING-------- .06 FLOOR---------- .06

OUTPUT DATA

P	X-axis	Y-axis	Z-axis	Exter Area to P	Inter-Direct to P	Total Reflec at P	Received
1	0.0000	0.0000	2.5000	1.4778	1.5156	0.0547	1.5702
2	0.0000	1.9000	2.5000	1.4778	1.8648	0.1939	2.0586
3	0.0000	3.8000	2.5000	1.4778	2.2300	0.1558	2.3858
4	0.0000	5.7000	2.5000	1.4778	2.5738	0.1399	2.7137
5	0.0000	7.6000	2.5000	1.4778	2.8521	0.1342	2.9862
6	0.0000	9.5000	2.5000	1.4778	3.0246	0.1349	3.1595
7	0.0000	11.4000	2.5000	1.4778	3.0649	0.1411	3.2061
8	0.0000	13.3000	2.5000	1.4778	2.9669	0.1539	3.1208
9	0.0000	15.2000	2.5000	1.4778	2.7457	0.1766	2.9223
10	0.0000	17.1000	2.5000	1.4778	2.4344	0.2213	2.6557
11	0.0000	19.0000	2.5000	1.4778	2.0764	0.0519	2.1283
12	0.7778	0.0000	2.5000	1.4778	1.6486	0.3275	1.9761
13	0.7778	1.9000	2.5000	1.4778	2.0583	0.6536	2.7119
14	0.7778	3.8000	2.5000	1.4778	2.4937	0.7141	3.2078
15	0.7778	5.7000	2.5000	1.4778	2.9087	0.8018	3.7105
16	0.7778	7.6000	2.5000	1.4778	3.2472	0.8893	4.1365
17	0.7778	9.5000	2.5000	1.4778	3.4579	0.9442	4.4020
18	0.7778	11.4000	2.5000	1.4778	3.5073	0.9439	4.4512
19	0.7778	13.3000	2.5000	1.4778	3.3874	0.8985	4.2860
20	0.7778	15.2000	2.5000	1.4778	3.1176	0.8357	3.9533
21	0.7778	17.1000	2.5000	1.4778	2.7400	0.7819	3.5219
22	0.7778	19.0000	2.5000	1.4778	2.3099	0.3858	2.6956
23	1.5556	0.0000	2.5000	1.4778	1.7927	0.2771	2.0698
24	1.5556	1.9000	2.5000	1.4778	2.2745	0.5712	2.8457
25	1.5556	3.8000	2.5000	1.4778	2.7958	0.5818	3.3776
26	1.5556	5.7000	2.5000	1.4778	3.2991	0.6174	3.9165
27	1.5556	7.6000	2.5000	1.4778	3.7130	0.6535	4.3665
28	1.5556	9.5000	2.5000	1.4778	3.9716	0.6795	4.6511
29	1.5556	11.4000	2.5000	1.4778	4.0323	0.6902	4.7225
30	1.5556	13.3000	2.5000	1.4778	3.8851	0.6860	4.5710
31	1.5556	15.2000	2.5000	1.4778	3.5542	0.6736	4.2279
32	1.5556	17.1000	2.5000	1.4778	3.0938	0.6743	3.7681
33	1.5556	19.0000	2.5000	1.4778	2.5747	0.3189	2.8935
34	2.3333	0.0000	2.5000	1.4778	1.9478	0.2412	2.1890
35	2.3333	1.9000	2.5000	1.4778	2.5156	0.5230	3.0386
36	2.3333	3.8000	2.5000	1.4778	3.1422	0.5048	3.6469
37	2.3333	5.7000	2.5000	1.4778	3.7559	0.5206	4.2765
38	2.3333	7.6000	2.5000	1.4778	4.2646	0.5426	4.8072
39	2.3333	9.5000	2.5000	1.4778	4.5834	0.5609	5.1443
40	2.3333	11.4000	2.5000	1.4778	4.6583	0.5719	5.2302
41	2.3333	13.3000	2.5000	1.4778	4.4767	0.5765	5.0531

42	2.3333	15.2000	2.5000	1.4778	4.0691	0.5818	4.6509
43	2.3333	17.1000	2.5000	1.4778	3.5048	0.6143	4.1191
44	2.3333	19.0000	2.5000	1.4778	2.8751	0.2718	3.1468
45	3.1111	0.0000	2.5000	1.4778	2.1130	0.2158	2.3289
46	3.1111	1.9000	2.5000	1.4778	2.7835	0.4956	3.2791
47	3.1111	3.8000	2.5000	1.4778	3.5399	0.4562	3.9961
48	3.1111	5.7000	2.5000	1.4778	4.2921	0.4587	4.7508
49	3.1111	7.6000	2.5000	1.4778	4.9206	0.4720	5.3926
50	3.1111	9.5000	2.5000	1.4778	5.3155	0.4860	5.8015
51	3.1111	11.4000	2.5000	1.4778	5.4083	0.4974	5.9057
52	3.1111	13.3000	2.5000	1.4778	5.1833	0.5079	5.6912
53	3.1111	15.2000	2.5000	1.4778	4.6788	0.5263	5.2051
54	3.1111	17.1000	2.5000	1.4778	3.9833	0.5839	4.5672
55	3.1111	19.0000	2.5000	1.4778	3.2157	0.2389	3.4546
56	3.8889	0.0000	2.5000	1.4778	2.2869	0.1969	2.4838
57	3.8889	1.9000	2.5000	1.4778	3.0798	0.4798	3.5596
58	3.8889	3.8000	2.5000	1.4778	3.9966	0.4236	4.4202
59	3.8889	5.7000	2.5000	1.4778	4.9238	0.4160	5.3397
60	3.8889	7.6000	2.5000	1.4778	5.7043	0.4231	6.1274
61	3.8889	9.5000	2.5000	1.4778	6.1952	0.4343	6.6295
62	3.8889	11.4000	2.5000	1.4778	6.3104	0.4464	6.7569
63	3.8889	13.3000	2.5000	1.4778	6.0309	0.4619	6.4928
64	3.8889	15.2000	2.5000	1.4778	5.4037	0.4914	5.8952
65	3.8889	17.1000	2.5000	1.4778	4.5418	0.5709	5.1128
66	3.8889	19.0000	2.5000	1.4778	3.6013	0.2148	3.8161
67	4.6667	0.0000	2.5000	1.4778	2.4664	0.1822	2.6486
68	4.6667	1.9000	2.5000	1.4778	3.4050	0.4701	3.8751
69	4.6667	3.8000	2.5000	1.4778	4.5208	0.4005	4.9213
70	4.6667	5.7000	2.5000	1.4778	5.6701	0.3850	6.0551
71	4.6667	7.6000	2.5000	1.4778	6.6444	0.3875	7.0319
72	4.6667	9.5000	2.5000	1.4778	7.2565	0.3967	7.6533
73	4.6667	11.4000	2.5000	1.4778	7.3999	0.4098	7.8097
74	4.6667	13.3000	2.5000	1.4778	7.0518	0.4299	7.4817
75	4.6667	15.2000	2.5000	1.4778	6.2690	0.4692	6.7382
76	4.6667	17.1000	2.5000	1.4778	5.1949	0.5682	5.7631
77	4.6667	19.0000	2.5000	1.4778	4.0364	0.1963	4.2327
78	5.4444	0.0000	2.5000	1.4778	2.6469	0.1703	2.8172
79	5.4444	1.9000	2.5000	1.4778	3.7576	0.4639	4.2216
80	5.4444	3.8000	2.5000	1.4778	5.1211	0.3832	5.5043
81	5.4444	5.7000	2.5000	1.4778	6.5543	0.3616	6.9158
82	5.4444	7.6000	2.5000	1.4778	7.7763	0.3606	8.1369
83	5.4444	9.5000	2.5000	1.4778	8.5413	0.3685	8.9098
84	5.4444	11.4000	2.5000	1.4778	8.7196	0.3827	9.1023
85	5.4444	13.3000	2.5000	1.4778	8.2860	0.4068	8.6928
86	5.4444	15.2000	2.5000	1.4778	7.3056	0.4550	7.7607
87	5.4444	17.1000	2.5000	1.4778	5.9595	0.5725	6.5320
88	5.4444	19.0000	2.5000	1.4778	4.5246	0.1818	4.7063
89	6.2222	0.0000	2.5000	1.4778	2.8209	0.1606	2.9815
90	6.2222	1.9000	2.5000	1.4778	4.1333	0.4588	4.5921
91	6.2222	3.8000	2.5000	1.4778	5.8055	0.3694	6.1749
92	6.2222	5.7000	2.5000	1.4778	7.6041	0.3430	7.9472
93	6.2222	7.6000	2.5000	1.4778	9.1441	0.3395	9.4836
94	6.2222	9.5000	2.5000	1.4778	10.1002	0.3466	10.4468
95	6.2222	11.4000	2.5000	1.4778	10.3216	0.3618	10.6834
96	6.2222	13.3000	2.5000	1.4778	9.7822	0.3896	10.1718
97	6.2222	15.2000	2.5000	1.4778	8.5518	0.4459	8.9977
98	6.2222	17.1000	2.5000	1.4778	6.8549	0.5805	7.4354
99	6.2222	19.0000	2.5000	1.4778	5.0673	0.1700	5.2374
100	7.0000	0.0000	2.5000	1.4778	2.9775	0.1524	3.1299
101	7.0000	1.9000	2.5000	1.4778	4.5225	0.4538	4.9762
102	7.0000	3.8000	2.5000	1.4778	6.5799	0.3574	6.9373
103	7.0000	5.7000	2.5000	1.4778	8.8526	0.3278	9.1804
104	7.0000	7.6000	2.5000	1.4778	10.8013	0.3225	11.1238
105	7.0000	9.5000	2.5000	1.4778	11.9942	0.3291	12.3233
106	7.0000	11.4000	2.5000	1.4778	12.2674	0.3453	12.6127
107	7.0000	13.3000	2.5000	1.4778	11.5997	0.3762	11.9759
108	7.0000	15.2000	2.5000	1.4778	10.0543	0.4396	10.4939
109	7.0000	17.1000	2.5000	1.4778	7.9022	0.5909	8.4931
110	7.0000	19.0000	2.5000	1.4778	5.6620	0.1604	5.8224
111	7.7778	0.0000	2.5000	1.4778	3.1011	0.1454	3.2465
112	7.7778	1.9000	2.5000	1.4778	4.9076	0.4467	5.3543
113	7.7778	3.8000	2.5000	1.4778	7.4450	0.3463	7.7912

114	7.7778	5.7000	2.5000	1.4778	10.3385	0.3146	10.6531
115	7.7778	7.6000	2.5000	1.4778	12.8133	0.3082	13.1215
116	7.7778	9.5000	2.5000	1.4778	14.2939	0.3146	14.6086
117	7.7778	11.4000	2.5000	1.4778	14.6274	0.3316	14.9590
118	7.7778	13.3000	2.5000	1.4778	13.8084	0.3651	14.1735
119	7.7778	15.2000	2.5000	1.4778	11.8703	0.4345	12.3048
120	7.7778	17.1000	2.5000	1.4778	9.1236	0.6009	9.7245
121	7.7778	19.0000	2.5000	1.4778	6.2983	0.1523	6.4506
122	8.5556	0.0000	2.5000	1.4778	3.1705	0.1394	3.3099
123	8.5556	1.9000	2.5000	1.4778	5.2585	0.4372	5.6957
124	8.5556	3.8000	2.5000	1.4778	8.3906	0.3351	8.7256
125	8.5556	5.7000	2.5000	1.4778	12.1067	0.3026	12.4094
126	8.5556	7.6000	2.5000	1.4778	15.2581	0.2958	15.5540
127	8.5556	9.5000	2.5000	1.4778	17.0775	0.3022	17.3797
128	8.5556	11.4000	2.5000	1.4778	17.4773	0.3199	17.7973
129	8.5556	13.3000	2.5000	1.4778	16.4883	0.3553	16.8436
130	8.5556	15.2000	2.5000	1.4778	14.0693	0.4293	14.4986
131	8.5556	17.1000	2.5000	1.4778	10.5395	0.6092	11.1487
132	8.5556	19.0000	2.5000	1.4778	6.9521	0.1456	7.0976
133	9.3333	0.0000	2.5000	1.4778	3.1584	0.1342	3.2926
134	9.3333	1.9000	2.5000	1.4778	5.5267	0.4235	5.9501
135	9.3333	3.8000	2.5000	1.4778	9.3854	0.3233	9.7088
136	9.3333	5.7000	2.5000	1.4778	14.2090	0.2915	14.5005
137	9.3333	7.6000	2.5000	1.4778	18.2270	0.2848	18.5118
138	9.3333	9.5000	2.5000	1.4778	20.4237	0.2913	20.7150
139	9.3333	11.4000	2.5000	1.4778	20.8903	0.3095	21.1997
140	9.3333	13.3000	2.5000	1.4778	19.7254	0.3459	20.0713
141	9.3333	15.2000	2.5000	1.4778	16.7360	0.4228	17.1588
142	9.3333	17.1000	2.5000	1.4778	12.1645	0.6123	12.7768
143	9.3333	19.0000	2.5000	1.4778	7.5754	0.1399	7.7153
144	10.1111	0.0000	2.5000	1.4778	3.0324	0.1297	3.1621
145	10.1111	1.9000	2.5000	1.4778	5.6370	0.4055	6.0425
146	10.1111	3.8000	2.5000	1.4778	10.3576	0.3108	10.6684
147	10.1111	5.7000	2.5000	1.4778	16.7064	0.2809	16.9873
148	10.1111	7.6000	2.5000	1.4778	21.8203	0.2749	22.0952
149	10.1111	9.5000	2.5000	1.4778	24.3959	0.2816	24.6775
150	10.1111	11.4000	2.5000	1.4778	24.9189	0.2999	25.2188
151	10.1111	13.3000	2.5000	1.4778	23.5998	0.3366	23.9364
152	10.1111	15.2000	2.5000	1.4778	19.9733	0.4142	20.3875
153	10.1111	17.1000	2.5000	1.4778	13.9974	0.6085	14.6059
154	10.1111	19.0000	2.5000	1.4778	8.0797	0.1352	8.2149
155	10.8889	0.0000	2.5000	1.4778	2.7584	0.1259	2.8843
156	10.8889	1.9000	2.5000	1.4778	5.4816	0.3825	5.8641
157	10.8889	3.8000	2.5000	1.4778	11.1543	0.2975	11.4518
158	10.8889	5.7000	2.5000	1.4778	19.6764	0.2709	19.9473
159	10.8889	7.6000	2.5000	1.4778	26.1271	0.2660	26.3931
160	10.8889	9.5000	2.5000	1.4778	29.0028	0.2730	29.2758
161	10.8889	11.4000	2.5000	1.4778	29.5611	0.2911	29.8522
162	10.8889	13.3000	2.5000	1.4778	28.1590	0.3270	28.4860
163	10.8889	15.2000	2.5000	1.4778	23.9029	0.4028	24.3057
164	10.8889	17.1000	2.5000	1.4778	16.0000	0.5940	16.5939
165	10.8889	19.0000	2.5000	1.4778	8.3076	0.1315	8.4391
166	11.6667	0.0000	2.5000	1.4778	2.3089	0.1229	2.4318
167	11.6667	1.9000	2.5000	1.4778	4.9214	0.3558	5.2771
168	11.6667	3.8000	2.5000	1.4778	11.4575	0.2841	11.7416
169	11.6667	5.7000	2.5000	1.4778	23.2278	0.2618	23.4897
170	11.6667	7.6000	2.5000	1.4778	31.1193	0.2585	31.3778
171	11.6667	9.5000	2.5000	1.4778	34.0748	0.2658	34.3406
172	11.6667	11.4000	2.5000	1.4778	34.6779	0.2834	34.9613
173	11.6667	13.3000	2.5000	1.4778	33.3514	0.3177	33.6691
174	11.6667	15.2000	2.5000	1.4778	28.6280	0.3890	29.0170
175	11.6667	17.1000	2.5000	1.4778	18.0270	0.5678	18.5948
176	11.6667	19.0000	2.5000	1.4778	7.9925	0.1291	8.1216
177	12.4444	0.0000	2.5000	1.4778	1.6759	0.1210	1.7969
178	12.4444	1.9000	2.5000	1.4778	3.8168	0.3269	4.1437
179	12.4444	3.8000	2.5000	1.4778	10.6027	0.2718	10.8745
180	12.4444	5.7000	2.5000	1.4778	27.3857	0.2547	27.6404
181	12.4444	7.6000	2.5000	1.4778	36.0369	0.2533	36.2902
182	12.4444	9.5000	2.5000	1.4778	38.6730	0.2611	38.9341
183	12.4444	11.4000	2.5000	1.4778	39.6598	0.2780	39.9378
184	12.4444	13.3000	2.5000	1.4778	38.7983	0.3097	39.1081
185	12.4444	15.2000	2.5000	1.4778	33.8620	0.3739	34.2359

186	12.4444	17.1000	2.5000	1.4778	19.5167	0.5293	20.0459
187	12.4444	19.0000	2.5000	1.4778	6.7230	0.1284	6.8514
188	13.2222	0.0000	2.5000	1.4778	0.8845	0.1205	1.0051
189	13.2222	1.9000	2.5000	1.4778	2.1179	0.3000	2.4178
190	13.2222	3.8000	2.5000	1.4778	7.2444	0.2626	7.5069
191	13.2222	5.7000	2.5000	1.4778	29.5055	0.2521	29.7576
192	13.2222	7.6000	2.5000	1.4778	35.7931	0.2540	36.0471
193	13.2222	9.5000	2.5000	1.4778	37.4091	0.2631	37.6722
194	13.2222	11.4000	2.5000	1.4778	40.4426	0.2788	40.7214
195	13.2222	13.3000	2.5000	1.4778	42.1336	0.3064	42.4400
196	13.2222	15.2000	2.5000	1.4778	35.1838	0.3605	35.5443
197	13.2222	17.1000	2.5000	1.4778	18.0808	0.4847	18.5655
198	13.2222	19.0000	2.5000	1.4778	4.0342	0.1301	4.1643
199	14.0000	0.0000	2.5000	1.4778	0.0000	0.0739	0.0739
200	14.0000	1.9000	2.5000	1.4778	0.0000	0.2095	0.2095
201	14.0000	3.8000	2.5000	1.4778	0.0000	0.1769	0.1769
202	14.0000	5.7000	2.5000	1.4778	0.0000	0.1595	0.1595
203	14.0000	7.6000	2.5000	1.4778	0.0000	0.1489	0.1489
204	14.0000	9.5000	2.5000	1.4778	0.0000	0.1410	0.1410
205	14.0000	11.4000	2.5000	1.4778	0.0000	0.1334	0.1334
206	14.0000	13.3000	2.5000	1.4778	0.0000	0.1251	0.1251
207	14.0000	15.2000	2.5000	1.4778	0.0000	0.1156	0.1156
208	14.0000	17.1000	2.5000	1.4778	0.0000	0.1050	0.1050
209	14.0000	19.0000	2.5000	1.4778	0.0000	0.0938	0.0938

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