Comparison of Energy Consumption with Regard to Type and Percentage of glazing, Location and Orientation in Classroom Spaces

Bharati Karmarkar

Thesis submitted to the faculty of the Virginia Polytechnic Institute and State University in partial fulfillment of the requirements for the degree of

Master of Science

in

Architecture

Dr. James R Jones, Chair

Prof. Robert Schubert

Prof. Michael G Ermann

May 3rd 2007

Blacksburg, Virginia

Key Words: Classroom spaces, GWAR (glazing to wall area ratio), energy loads, glazing type, sidelighting (daylighting)

Comparison of Energy Consumption with Regard to Type and Percentage of glazing, Location and Orientation in Classroom Spaces

Bharati Karmarkar

Dr. James R Jones, Chair

(ABSTRACT)

Much of the art of daylighting lies in the judicious placement of windows in relation to the interior, in order to achieve the desired levels of illumination and view. Studies have shown that the glazing size, location and type all impact the internal energy loads.

Schools are incorporating technology in classrooms to transform learning. The expanded presence of technology in the classroom has also affected how classrooms are designed. This study tries to determine a glazing ratio for classroom spaces of the future in regards to energy consumption as a combined function of climatic conditions, orientation, glazing types and window location.

A 35’x32’ base classroom is simulated using the E-Quest software. Energy consumption for the base case is compared to models with variable orientation (north and south), type of glazing (double pane, low e and special glazing), glazing percentage of the total wall area (base taken with reference to the required daylight factor) and classroom with and without clerestory windows.

Acknowledgement

This Thesis is dedicated to

Minal Panchal

For Everything

This thesis work would not have been possible without the guidance, support and encouragement of a number of people, I would like to take this opportunity to thank and express my gratitude to everyone who helped me complete my thesis.

I would like to thank my committee chair Dr. Jim Jones for his constant guidance and direction, for helping me though all my queries and doubts while working on my thesis. I would also like to thank my committee members Prof. Robert Schubert and Prof. Michael Ermann for all their inputs and insights towards my thesis, for providing me with a number of references and good links to various studies.

I wish to express my gratitude to all the administrative and library staff in the architecture department for helping me out whenever I needed their assistance. I am grateful to my parents, my sisters Rohinee and Kalpana and also my brother in law Manik for all the encouragement they have provided me throughout.

I would like to thank my graduate colleagues Sarah Elmasry, Manoj, Leena and Madhulika for their guidance through the initial phases of my thesis. I would also like to thank Shrikar and Vidya for their constant support and encouragement throughout my work. Special thanks to my dear friend Minal Panchal for being there for me, for all the joy, happiness and constant support she gave me, without her this thesis would not have been possible. I would like to acknowledge my roommates and friends payal, girisha, guneet alina, anirudh, brijesh and devdutta for being there for me throughout these two years.

And finally, I would like to thank everyone who helped me finish my graduate studies and who contributed to the wonderful time that I have had at Virginia Tech.

Table of Contents

List of Figures

List of Tables

Chapter1. Introduction

Much of the art of daylighting lies in the judicious placement of windows in relation to the interior, in order to achieve the desired levels of illumination and view. The use of daylight to compliment electrical lighting within a space not only helps to create a visually stimulating and productive environment, but also can reduce energy consumption when compared to non daylit spaces.

1.1 Background

With technology becoming ubiquitous in our lives the use of electric gadgets in a space has increased, leading to an increase in cooling loads and energy consumption. In such situations windows can play a crucial rule in helping to reduce energy demands. Advancements in glazing materials have further helped us to achieve a better balance of light transmittance and heat transfer.

A large number of studies and projects concerning energy smart schools are being implemented. Studies regarding factors impacting energy use in school spaces must also consider issues such as the introduction of technology within the classroom and the use of smart light controls such as dimmers. A number of studies that considered the glazing percentage show that factors such as glazing size, window orientation, ventilation rate, internal load, daylight utilization and climate have a large effect on the heating and cooling demand of a space. These studies have typically been focused on office buildings not schools.

This study looks into the factors which influence the overall energy load of a classroom space and how type of glass, percentage of glazing, orientation and location effect the overall energy consumption. The study looks into the two commonly used glazing types, Low - e glass and double pane clear glass windows as well as a special glazing material such as Azurite, controlite or Lite wall.

The Following introduces the products used in this study.

Controlite or Lite wall

(Manufacturer: CPI international, Lake Forest IL.)

The patented ControLite® design is comprised of a translucent 30mm (1.2 inch) polycarbonate glazing panel with built-in transparent revolving half-cylinders called Intelligent Light Controllers (ILCs). Each transparent ILC has an opaque, flat upper face, and the position of the ILC in relation to the sun determines the amount of sunlight transmitted through the panel.

Refer to image from the company's website www.cpidaylighting.com – Controlite panel

Fig: 1.1 Controlite panel (CPI international, http://www.cpidaylighting.com/)

Controlite offers variable light transmission from 6% to 60% and any desired light transmission in between these two extremes.

Table 1.1 Controlite Performance Properties

Controlite configuration	**Visible LT%**	**Total solar Transmission**	**Shading Coefficient**
In max LT position	0.60	0.53	0.64
In min LT position	0.06	0.07	0.18
Insulation "U" Value -0.27 Btu / sqft°Fh "R" Value – 3.70			

Azurite

(Manufacturer: PPG Idea Scapes, http://corporateportal.ppg.com/na/ideascapes/)

Azurlite® Glass incorporates a slight blue tint that provides a reduced glare and UV protection and also reduces solar heat gain along with a low shading coefficient and high visible light transmittance. (Azurlite 3.0 mm glass 1/2" airspace in insulating glass (IG) units)

Table 1.2 Azurlite Float Glass Performance Properties

(PPG Idea Scapes, http://corporateportal.ppg.com/na/ideascapes/)

Performance Properties	Monolithic Azurlite Glass	Azurlite Glass and Clear glass IG unit
Ultraviolet Light Transmittance	54%	30%
Visible Light Transmittance	77%	66%
U value winter Night Btu / sq ft °Fh R value	1.11 0.90	0.26 3.85
Shading Coefficient	0.67	0.45
Indoor glass Temperature (Winter Night – deg F)	16.8 deg	56.4 deg

1.2 Problem statement

School designers have begun to recognize the importance of daylight in helping students perform better. Research has shown that children in classrooms with more daylight scored higher on standardized tests in math and reading (Heschong Mahone study, 1999). The Heschong Mahone group conducted a study titled “Daylighting in Schools - an investigation into the relationship between daylighting and human performance”. In addition to higher test scores; children in rooms with daylight had lower absenteeism and fewer behavioral problems when compared to non-daylit spaces.

Increased daylighting in schools can result in downsizing electrical lighting and HVAC systems for cooling, saving energy and cost while reducing noise. The design of sidelighting in classroom spaces is very critical in order to achieve the right balance between ambient lighting requirements and loads for the heating and cooling demand of the spaces. The changing nature of the classrooms has introduced new issues like increased plug loads and flexible modular computer classroom spaces which have to be considered while designing the type, location of windows and the size of glazing.

1.3 Test hypothesis

Using energy consumption as the performance mandate the preferred glazing ratio for classroom spaces can be found as a combined function of climatic conditions, orientation, glazing type and window location.

1.4 Goals and Objectives

To study the percentage of window to wall area with regard to energy consumption as a function of Climate, Orientation, and Glazing type with reference to Prototypical Classroom Spaces and determine the preferred window to wall percentage.

Objectives

- To determine the window to wall ratio and combination of glazing to be used to achieve desired light levels in a typical classroom.
- To determine the effects of alternatives for size, proportion and placement of windows in different climatic conditions and orientations
- To study factors including Climate, Orientation, Window Area, Glazing type and their individual effects on the energy consumption in prototypical classroom spaces.
- Simultaneously consider the simulation results of all five variables to derive a preferred glazing ratio.

1.5 Important assumptions and limitations

1. The number of students, dimensions and geometry of the classroom base case are based on findings from literature, published case studies and as built classrooms.

2. Visual quality aspects such as glare, daylight room perception and visual interest have not been factored in depth for this study as it is assumed these interactions fall within the role of the designer.

3. In this study, construction type and thermal mass of the classroom space has been kept standard with no changes as a result of climatic variation.

4. The ventilation and HVAC system type (heat pumps) has been kept constant throughout the study. An attempt has been made to select a representative system for new construction and simulate a reasonable compromise for this issue.

1.6 Simulation tool - eQUEST

In this study the base model is derived from performance standards and case studies. The classroom is simulated with five different variables using the energy simulation tool eQUEST. The simulation "engine" within eQUEST is derived from the DOE-2 program. This energy simulation software caters to the whole building energy analysis. The simulation results further are analyzed to determine a preferred glazing type and percentage.

Chapter 2 Light in the learning environment

Information technology and changing instructional methodologies are greatly influencing the design of lighting in contemporary school spaces and learning environments. Till the 1950's natural light was the primary means of illuminating the classroom. Later with relatively low electric costs designers took advantage of the constancy of electric lighting strategies and daylighting took secondary importance. However now with the growing cost of energy and a better understanding of the psychological and biophysical effects of daylighting designers have begun to incorporate daylighting as a major component in their designs.

A taxonomy of sidelighting and toplighting schemes includes view windows, high sidelighting clerestory, clerestory with light shelves or louvers, wall wash top lighting, central top lighting, patterned top lighting, linear top lighting, and tubular skylights. A number of factors have to be taken into consideration while adopting any of the daylighting schemes into the interior space.

Daylighting apertures in the ceiling plane are known as toplighting. Toplighting reduces the likelihood of glare and allows for a more even distribution of daylight within the space. Single story spaces can easily be daylit using skylights and roof monitors although they typically are not applicable to multistory structures. Also toplighting does not provide a view or interaction with the outside other than through the sky. This can reduce the positive biophilia effects of daylight.

With the understanding of the importance of a view, view windows are now being integrated into the design of interior spaces including classrooms. A view window is vertical glazing at eye level; that helps to provide a view to the exterior and interior adjacent spaces. View windows are important for view, social communication, egress, ventilation and energy conservation.

Factors such as orientation, shading, reflectance from outside reflective surfaces, thermal comfort, view position relative to the teaching surface, security, durability and accessibility, noise transmission, balance with electric light all have to be considered when introducing view windows in a space such as classrooms. Distraction may also be an issue for classrooms with elementary-age students.

2.1 Benefits of daylighting in classroom spaces

Both skylights and view windows provide daylight within a space, however the benefits of a view window were found to be much more for a person's physiological and mental stimulation, and over all health. One of the hypotheses of the Heschong Mahone study was that a bright view of the outside stimulates the body's circadian system resulting in better regulation of the various hormones and neurotransmitters needed for peak mental and emotional performance; also that the outside view helps in reducing stress by allowing momentary but frequent mental relaxation which helps in better sustained and focused attention. A view also helps to relax the eye muscles by providing long range views which are essential for sedentary workers like students to help shift eye focal length, helping to promote eye health and good vision, which is very vital for young children. View windows also provide an important social function of communication.

<u>The Heschong Mahone Study</u>

In 1999 The Heschong Mahone group conducted a study titled "Daylighting in Schools - an investigation into the relationship between daylighting and human performance" The Heschong Mahone group findings showed a direct relation of not only energy savings with the help of daylight but also a key interrelation of increased student performance with the introduction of daylight within the classroom.

The findings related to energy savings were as follows:

Energy Savings with daylight

30 – 80 % lighting energy savings

5%to 50% whole building energy savings

10% to 20% reduction in peak electricity use

Their study also provided evidence of a relationship between high quality daylight in classrooms and a 20% improvement in student performance, suggesting a better student performance in stimulating well lit environments.

In their study three school districts were investigated - Seattle, WA – 62 elementary schools - Poudre, CO – 23 elementary schools, Capistrano, CA – 27 elementary schools. Their study analyzed over 8,000 students per districts with over 2,000 classrooms. Their study used multi-variate regression analysis, to control for up to 50 other influences, like demographics, teacher characteristics, special programs, classroom type etc.

Of the three districts sampled in the HMG 1999 study, test results were obtained from the same students from the first district over a two-year period (at the start of each academic year). This provided test results representing a yearly improvement effect of the students.

Table 2.1 Summary of findings - "Daylighting in Schools - an investigation into the relationship between daylighting and human performance" The Heschong Mahone Group, 1999

Summary	Capistrano Learning rate	Seattle Higher scores	Ft Collins Higher scores
Windows	15 – 23 %	13 – 15%	14 – 18 %
Skylights	19 – 20%	6 – 8 %	0-3 %
Daylight	20 – 26 %	9-13 %	7 %
Operable windows	7-8 %		

Daylight studies and classification

The Heschong Mahone study also involved the classification of daylight in relation to the different classroom spaces studied. The purpose of classifying the daylight in each space was to try to create a stable metric that described the opportunity for daylight over the course of the school year, as it is difficult to account for temporal variations (Heschong Mahone Group, 1999). The classification involved visiting a sample of schools and assigning three codes to each classroom based on a simple scale indicating the size and tint of windows, the presence and type of any sky lighting and the overall amount of daylighting expected. It was important that information on both skylights and windows be collected so that it can be analyzed independently or together. Additional information collected in these visits included the dimensions, geometry and transmissivity of the glazing, the presence of any fixed shading or obstructions and the expected distribution of light given the geometry of the glazing. The purpose of classifying the daylight was to create a rough prediction of potential daylight illumination levels and distribution in each classroom. The window and skylight codes were assigned separately to one another. The Daylight Codes were then assigned with consideration to the combined effect of the windows and skylights together. The tables on the following page show the code descriptions as they were applied in the US. - The Heschong Mahone study

Table 2.2 Daylight Code Guide, A qualitative rating of daylighting in classroom spaces used by The Heschong Mahone Group, 1999

Daylight Code		**Code Description**
5	Best Daylighting	Classroom is adequately lit with daylighting for most of the school year. Adequate daylight available throughout classroom.
4	Good Daylighting	Classroom has major daylight component and could occasionally be operated without any electric lights. Noticeable gradient in illumination levels.
3	Average Daylighting	Classroom has acceptable daylight levels directly next to windows or under skylights. Strong illumination gradient. Some electric lights could be turned off
2	Poor Daylighting	Illumination is always inadequate without electric lights. Glare a likely problem
1	Minimal Daylighting	Small token windows or top lighting.
0	No Daylighting	Classroom has no windows or top lighting.

Table 2.3 Window Scoring Scale (1999) - The Heschong Mahone Group, 1999

Window Ranking Scale				
Quality Description Code	Daylight Distribution Likely FC room avg.	SEATTLE	CAPISTRANO	FT COLLINS
Best 5	Even 50+fc	Window wall on two sides of room, high ceilings, clear glass, no sun penetration	Same as Seattle 150+sf windows	Did not occur
Good 4	Acceptable 30+fc	Shallow classroom with window wall on one side #5 with medium tint and/ or obstructions	Same as Seattle 100+sf windows	Did not occur
Adequate 3	Dark areas 15+fc	Deep classroom with window wall on short side #4 with medium tint and/ or obstructions # 5 with dark tint and/ or major obstructions	Same as Seattle 50+sf windows	8-13 % WFR medium tint
Poor 2	Glare from windows 5-10fc	Windows on one side 20%-50%of wall length # 3 with tint and/ or obstructions	Windows 30sf -50sf, no tint, windows 40sf-60sf, medium tint Windows 60sf – 80sf, dark tint	3-4% WFR Medium tint
Minimal 1	Very local 1-5fc	Windows < 20% of wall length Heavily obstructed windows	Windows 40sf or less, medium or dark tint Example most portables	1-2% WFR medium tint
None 0	None 0fc	No windows	No windows	No windows
District specific notes		Window percentages are of wall length, not area	960 – 1050sf typical classrooms	WFR = Average classroom window to floor area ratio.

The following photos are representative of each assigned Daylight code

Figure 2.1.1 Photographs of classrooms typifying the daylight code 4 (The Heschong Mahone Group, 1999) Windows and Classrooms: A Study of Student Performance and the Indoor Environment - CEC PIER 2003.

Figure 2.1.2 Photographs of classrooms typifying the daylight code 4 (The Heschong Mahone Group, 1999) Windows and Classrooms: A Study of Student Performance and the Indoor Environment - CEC PIER 2003.

Daylight code 4 Classroom, North windows (left) and south windows (right) Classrooms that received a daylight code of 4 were very similar to a classroom with a 5, but has less control over the daylight.

Figure 2.1.3 Photographs of classrooms typifying the daylight code3 (The Heschong Mahone Group, 1999) Windows and Classrooms: A Study of Student Performance and the Indoor Environment - CEC PIER 2003.

Daylight code 3 Classroom, North windows (left) and south windows (right)

Classrooms with code 3 have acceptable daylight levels directly next to windows, and could be operated without some of the electric lights for a good percentage of the time. An illumination gradient was perceivable.

Figure 2.1.4 Photographs of classrooms typifying the daylight code2 (The Heschong Mahone Group, 1999) Windows and Classrooms: A Study of Student Performance and the Indoor Environment - CEC PIER 2003.

Daylight code 2 classroom, North windows (left) and south windows (right) Classroom with code 2 have poor daylighting, with strong illumination gradient. Glare was a likely problem. Illumination was inadequate without supplementary artificial light.

Two more significant studies have suggested that daylighting in classrooms can promote overall health and physical development, daylight is an effective stimulant to the human visual and circadian system and it also provides psychological benefit of an accompanied view.

In a study of 90 Swedish elementary schools students, researchers tracked behavior, health, and cortisol levels (a stress hormone) over the course of a year in four classrooms with varying daylight levels. The results indicate work in classrooms without daylight upset the basic hormone pattern which in turn may have an effect on the student's ability to concentrate and also eventually have an impact on annual body growth and absenteeism (Kuller R and C Lindsten, 1992).

In a second study in Alberta Canada over a two year period, children attending elementary school with full spectrum light were compared with children in classrooms with conventional lighting (Hathaway W, 1995). The results suggested that students in the full spectrum light classrooms had fewer days of absence per year as well as enhanced health effects.

Daylighting also helped in downsizing the HVAC systems and in reducing noise levels in the classrooms and library thus leading to better learning environments. Daylighting is a key aspect of any high performance school. The benefits of daylighting in schools is seen in the improved academic performance of students, improved health, a connection to the environment, which helps to enrich the learning experience and also supporting the argument that well designed daylighting strategies help reduce energy consumption in buildings. A large number of studies have also shown that investments in daylighting of schools pay back in 3 to 9 years and in most cases add little to the first cost of the building, indicating that daylighting is one of the best building related investments for the learning environment (Nicklas and Bailey,1996).

Daylighting and windows

Fenestration can have a large impact on heating and cooling loads. Design Standards such as ASHRAE standard 90.1 allow total fenestration area to be no more than 40% of the total wall area without integrating additional strategies such as thermal mass and external shades. Visual comfort highly depends on the positioning and location of the window and occupant, and shading and glazing materials used for view windows. Well designed view windows can be a delight, however poorly designed windows can lead to problems of glare and thermal comfort. Certain daylighting techniques have limitations, it is usually seen that good daylighting results can be achieved using two daylighting strategies together.

Table 2.4 Daylighting patterns – IESNA, Selection Criteria for Daylight strategy.

(Source IESNA Lighting Handbook, 9th Edition, with permission from IESNA)

Design Criteria	View Windows	High Sidelight	High Sidelight w/ Light Shelf or Louvers	Wall Wash Toplight	Central & Patterned Toplight	Linear Toplight	Atria & Light Well	Tubular Skylights
Uniform Light Distribution	○○	◉	●	●	●●	◉	◉	◉
Low Glare	○	●	●●	●●	●	●	●	●/○
View	●●	○	○○	○○	○	●/○	●●	○○
Reduced Energy Costs	○	●	●	●	●●	●	●	●
Low First Cost	●	●	○	●	●●	●	○○	●●
Cost Effectiveness	●	●	●	●	●	●	●	●●
Safety/Security Concerns	○	●	●/○	●	●	●	●/○	●●
Low Maintenance	○	●	●	●	●	●	○	●

●● Extremely good application ● Good application ○ Poor application ○○ Extremely poor application ◉ Depends on space layout and number and distribution of daylight apertures ●/○ Mixed benefits

Many states and local governments have adopted standards such as ASHRAE 90.1 that require fenestration to meet the required standard for heat loss and solar gain. These standards limit the skylight area to 5% of the roof and the windows to 40% of the wall area unless additional design strategies such as external shading and active daylight dimming is implemented The Illuminating Engineering Society of North America, (IESNA) recommends the consideration of the following criteria in relationto the lighting of a space.

- Appearance of space and luminaries
- Color appearance
- Daylighting integration and control
- Direct glare
- Flicker and strobe
- Light distribution on tasks and surfaces
- Light distribution on task plane
- Luminance of room surfaces
- Points of interest
- Reflected glare
- Shadows
- Source / task / and eye geometry
- Surface characteristics
- System control and flexibility

The IESNA recommendations for general visual tasks are as follows:

Table 2.5 IESNA Recommended Illumination Levels for General Visual Tasks

(Source: IESNA Lighting Handbook, 9th Edition, with permission from IESNA)

Category	Description	Recommended Illumination
Orientation and simple visuals	Public spaces (corridors, entrance canopy) Simple orientation for short visits (waiting rooms, elevators) Working spaces where simple visual tasks are performed (lobbies, corridors, locker rooms)	3fc 5fc 10fc
Common visual tasks	Performance of visual tasks of higher contrast and large size (meeting rooms, storage areas, copy rooms) Performance of visual tasks of	30fc 50fc

	high contrast and small size or visual tasks of low contrast and large size (filing, open offices, private offices)	
	Performance of visual tasks of low contrast and small size (feature displays and inspection areas)	100fc
	Performance of visual tasks near threshold (Surgery and sewing)	300 – 1000fc

Factors to consider for daylighting in classrooms

A number of issues need to be understood to achieve good quality lighting in the classroom. Factors such as lighting intensity, visual comfort, color, uniformity and balanced brightness have to be considered. Quality issues for school lighting also include light levels on walls and ceilings, control of direct and reflected glare, uniformity, daylight, color rendering and color temperature.

A large number of standards and recommendations from educational bodies have tried to fix the percentage of daylight aperture to be incorporated in classroom spaces. Certain state boards of education recommend that the area allocated for windows in elementary classrooms be equivalent to at least 8% of the total floor space, and for middle schools and high schools the recommendation is between 6 – 8 %. (North Carolina State Board of education 1998)

In classroom spaces illumination, distribution, luminary and daylight integration are the most important factors to be considered. Light quality is the most important criteria in school lighting. The lighting designer has to consider factors such as age of the viewer, the importance of speed and accuracy of the viewing task, type, size and number of visual tasks. Classrooms have a combination of high contrast, large size tasks and high contrast small size tasks (considering normal and adult education) and moderate needs of speed and accuracy. The illumination range for a well lit classroom is from 30 – 250 fc throughout the day. More illumination is generally better and increases visual performance but only up to a point

For designing daylit schools it is important to understand the principles of solar orientation, climate conditions and shading systems. It is also important to use a combination of indirect and task lighting. Daylight can be used to provide ambient illumination – often on the order of 20- 30 footcandles, individual work areas can be supplemented with electric task lights. It is important to maximize the use of diffuse daylight and minimize the penetration of direct beam sunlight. Poorly designed daylight and electric lighting can cause visual discomfort, disabling glare and undesirable solar heat gain.

Lighting and the computer / projection screen

Good contrast is very important for the performance of visual tasks. It is recommended that illumination on the projection screen from daylight or electric lights be limited to a maximum of 5 vertical foot candles, which results in a 10:1 contrast ratio, which is acceptable for most video presentations. Computer screens especially laptops are fast becoming a vital component of the new classroom. Computer screens are adequately bright in rooms lighted to 30 footcandles or more. In these cases the careful positioning and juxtaposition of windows and skylights is very important.

The IESNA has specified the illumination criteria for daylit classrooms and teaching technologies and impacts on lighting requirements. According to the different medium of instruction used, the required external illumination, the sensitivity to ambient light and the recommended provisions are as below:

Table 2.6 IESNA Teaching Technologies and Impacts (IESNA Lighting Handbook, 9th Edition, with permission from IESNA)

Medium	Requires external illumination	Sensitivity to ambient light	Recommended provisions
Chalkboard (black or green)	Yes, at least 30-40 vertical footcandles are recommended	Not at all	None
Marker board (white or gray)	Yes, at least 10 – 15 vertical footcandles are recommended	Specular finish can cause bright flashes	Should not be opposite windows; curved screens can be affected by skylights windows and lights from many angles.
Television (CRT)	No	Specular (glass) screen is subject to bright flashes from windows and lights; room may need to be darkened for best visibility.	Should not be opposite windows; curved screens can be affected by skylights. Windows and lights from many angles.
Video display (flat panel)	No	Room may need to be Darkened for best visibility	Should not be opposite windows or directly washed by skylights.
Rear projection(self contained)	No	Room may need to be Darkened for best visibility	Should not be opposite windows or directly washed by skylights.
Smart screen with self Contained rear projection	No	Room will need to be darkened	Room will require darkening shades
Front screen video projection	No	Room will need to be darkened	Room will require darkening shades
Conventional overhead projection	No	Almost none	None
Conventional film and slide	No	Room will need to be darkened	Room will require darkening shades

Table 2.7 IESNA Illumination Criteria for Daylit Classrooms (Source: IESNA Lighting Handbook, 9th Edition, with permission from IESNA)

Activity (Scene)	Task Light level (average at desk in classroom)	Acceptable Variation of task light level	Other considerations
Reading, artwork, social time etc.	45 footcandles (minimum of 30fc)	30-250 footcandles	Daylight Glare controls required
Normal Lecture Chalkboard or whiteboard	45 footcandles (minimum of 30 footcandles)	30 -250 footcandles, dimming to lower levels may be useful	Additional vertical surface lighting for board should be considered.
Screen Lecture	15 footcandles	Dim to lower levels is permissible; higher levels should probably not be used.	Maximum of 5 vertical footcandles at any point on screen; room use shades required.

2.2.1 Previous studies on daylighting

A number of studies have been previously done on the subject of the effects and benefits of daylighting on students, as well as energy related issues of daylighting. The following studies were used as a guide and reference for the present study.

1. **The Cool Daylighting Design Approach Workbook,** Volume 2 – Schools, Light Forms, Santa Barbara, CA, Energy Center of Wisconsin

The cool daylighting design approach Workbook focuses on the method of Comparative Analysis. Comparative analysis is based on the integrated whole-building environmental design approach. The study simulated four types of classrooms using the Energy 10 software. In this workbook, comparative analysis documents the cost and performance of standard or "Base Case" classroom solutions in Wisconsin, then compares the cost and performance of "prototypical" daylighting solutions. The Workbook Base Cases and Prototypes are presented on a per room basis. Typical classroom-related spaces, such as perimeter and core classrooms, are presented. A worksheet is used to record performance and cost factors for the base case and Prototype alternative. Simple math is used to compare the net differences in first cost, HVAC CFM and tons of cooling output, peak kW, ductwork, etc., between the two solutions.

2. **Windows of Opportunities - The Glazed Area and its Impact on the Energy Balance of a building**. Dissertation presented at the University of Uppsala from the faculty of science and technology. May 2006

The following paper studies the impact of window area on the energy balance of a building which are investigated by simulations in DEROB –LTH. The glazed area is varied in three types of buildings with different types of glazing and for several climates. One low energy house was compared to a less insulated house but identical in size and layout. Three different types of glazing were used , uncoated double glazing, double glazing with one low-e pane, and triple glazing with two low-e coated panes. Climates with variations in solar radiation, mean temperature, altitude and latitude were chosen. The third type of building simulated is an office model with two types of Switchable glazing and one solar control glazing unit for three different climates.

The results of the study for Terraced houses were:

- If energy efficient windows are chosen, the flexibility of choosing the glazed area and building orientation is higher.
- Choosing a larger area resulted in a higher heating demand for uncoated double glazing in the standard house.
- Choosing energy efficient glazing gave a decrease in heating demand for an increased glazed area facing south in the standard house.

  In the low energy house the difference between different glazing areas was smaller than for the other cases. An increased area also resulted in an increased peak load for heating for all the simulated cases.
- Looking only at the cooling requirement for the low energy house, the optimum would be to reduce the window glass area facing south to zero. Using shading devices or solar control coated glazing on the windows facing south would be a good way of reducing the cooling demand during the summer as well as on sunny days during spring and fall

The results of the study for office buildings were:

- The results show that there is a great energy saving potential if switchable windows are used when compared to the double low-e windows.
- The cooling demand is halved for the climate of Rome and almost diminished for Stockholm and Brussels. The heating demand is only marginally influenced by using the switchable windows.

3. **Life Cycle Cost Optimization of Buildings with Regard to Energy Use, Thermal Indoor Environment and Daylight.** Toke R Nielsen Department of Civil Engineering, Technical University of Denmark, Lyngby, Denmark

This paper discusses performance optimization and outlines an optimization method based on minimization of the life cycle cost constrained by performance requirements. Many different performance requirements can be included in the optimization. The performance requirements discussed in this paper are heating demand, thermal indoor environment and daylight. To illustrate the optimization method it is applied to performance optimization of an office room. The paper shows that optimization is a valuable tool in the building design process.

4. **How Much Energy Do Sidelighting Strategies Save?** Martin Moeck, Younju Yoon, William Bahnfleth, and Richard Mistrick, The Pennsylvania State University-Department of Architectural Engineering

This study examines the impacts of exterior overhang, roller shade, and blind devices on the total yearly energy loads for a prototypical classroom space situated in Boulder, Colorado. The measured bidirectional transmittance characteristics for a roller shade were applied to the yearly daylight availability analysis. Coordinated modeling, with an advanced daylight and electric lighting simulation program and a building thermal simulation program based on hourly weather data was used to compute yearly total building energy use. Annual lighting, cooling and heating loads for a side-lit space using the shading devices were compared with those of a base case with no shading device.

5. **Daylighting in Schools -A New Zealand Perspective,** Mr. Quentin Jackson 2006, School of Architecture, Victoria University of Wellington.

This project replicates the Daylighting in Schools project a study in the United States entitled "Daylighting in Schools" conducted by the Heschong Mahone Group (HMG) in 1999 and methodology in New Zealand – a different educational, socio-economic and financial climate. It addressed the question of the replicabiity of the scientific result produced by HMG and the concerns that have been expressed about the applicability of this 'American data' to New Zealand. An initial testing phase and a more comprehensive test of the methodology was conducted in a total of 42 classrooms, evaluating the test score improvements of 8 primary students over a 12 month period.

The conclusions of this research are:

• The research methodology can be successfully replicated by another research team, in another economic social and educational framework;

• 8,000 students in approximately 265+ classrooms in 27+ schools would have to
be surveyed for the results of the analysis to be generalisable at a 95% confidence level to all students in schools in New Zealand;

6. **The effect of glazing type and size on annual heating and cooling demand for Swedish offices.** Helena Bülow-Hübe, MSc, Lund University, Institute of Technology, Dept. of Building Science, Sweden

The study was performed in order to determine optimal design for office windows for Swedish climates, with parametric study of heating and cooling demand. In addition, the effect of a daylight-linked lighting control system was also investigated. The daylight savings were calculated with ADELINE 2.0, while the thermal simulations were performed with DEROB-LTH. The studied windows included clear and low-e glazing with U-values ranging from 1 to 3 W^2K. The sensitivity to window size and orientation, internal load, wall insulation, and ventilation was also studied.

The results of the study showed that superinsulated windows outperform all other glazing types. For south orientation, the superwindow is a net energy saver. For this case cooling demand was the second lowest amongst glazing types tested. The differences in cooling demand was, however, small. A comparison with different climates in Sweden revealed substantial differences in heating demands, while cooling demands were similar. The study shows that cooling demands can mainly be reduced by: increasing the ventilation rate, reducing the window size or the internal load, or by dimming the electric lighting in response to daylight. Windows oriented towards north also yields significantly lower cooling demands. The heating demand can be reduced by using highly insulating windows and walls, increasing the internal load, and by decreasing the window size. The lowest total energy use (heating, cooling and electricity) is achieved by small superwindows with low internal loads.

7. **Optimizing Energy Consumption in Offices as a Function of Window Area and Room Size.** Enedir Ghisi and John Tinker, School of Civil Engineering, University of Leeds, England

This work sought to optimize the relationship between window size, space dimensions and daylight with respect to the energy consumption. The simulation model was based on a building 10 storeys high. Models comprising of different room ratios and different room sizes were simulated using Visual DOE. The glazed areas of the rooms ranged from zero to 100% of the façade area. Energy consumption as a function of window area and room size was predicted for each model. Seven cities in Brazil and one in the UK were simulated to show the effect of climatic conditions on daylight provision and energy consumption. Resulting from the work, Ideal Window Areas for optimum energy efficiency were predicted.

The conclusions made in the study are as follows

1. Room ratios with a small façade have lower energy consumptions. This shows that narrow rooms, as recommended in daylight guides, may experience higher daylight levels, but may not have the lowest energy consumption.

2. The larger the room, the lower the energy consumption per floor area.

3. The ratio of the façade area to the space volume can be used as an index to compare the energy consumption of different room sizes.

4. The Ideal Window Area tends to be larger on the orientations whose energy consumption is lower due to the reduced solar radiation reaching them.

5. The larger the room and the smaller its façade, the larger its Ideal Window Area.

6. The Ideal Window Areas presented can be used as a guideline to improving energy efficiency in buildings.

8. **Daylighting in Schools: Improving Student Performance and Health at a Price Schools Can Afford.** Patricia Plympton, Susan Conway, Kyra Epstein Presented at the American Solar Energy Society Conference, Madison, Wisconsin 2000 National Renewable Energy Laboratory, Operated by Midwest Research Institute

This paper discusses the evidence regarding daylighting and student performance and development, and presents four case studies of schools that have cost effectively implemented daylighting into their buildings. With most studies daylighting was found to have 7% to18% positive correlation with higher scores. Another study compared test scores for students in three daylit schools in North Carolina to scores in the county school system as a whole, and other new schools within the county. Test scores for over 1,200 students in daylit schools were compared to scores for the students in the county. The study showed that students who attended daylit schools outperformed the students in non-daylit schools by 5% to14%. The two studies suggest that daylighting in classrooms can promote overall health and physical development. In a study of 90 Swedish elementary school students, researchers tracked behavior, health, and cortisol (a stress hormone) levels over the course of a year in four classrooms with varying daylighting levels.

2.2.2 Classroom of the 21st Century

Technology has transformed learning; the enormous access to information has changed the way students learn and teachers teach. The changing practice of education is in large part driven by evolving and changing styles in pedagogy.

Today there is an attempt to increase the rigor and relevance of core academics taught in schools. A goal is to create an inquiry based on a collaborative environment that encourages critical thinking and a problem solving mindset among students. All of this can be possible if the pedagogical patterns support a diversity of learners with different learning styles, in order to ensure every student has the opportunity to succeed. This shift in pedagogy is shown by changing patterns for student – teacher interaction. Students are often taught, while keeping in mind their individual learning styles, levels of intelligence, socio-cultural backgrounds, needs and proficiencies. An integral part of teaching is now seen as to be able to encourage and harness collaboration within the classroom and beyond.

The schools and classrooms of the future need to embrace the far reaching potential that technology can have in support of these new pedagogical models and for that they need to be designed keeping in mind the role that technology will play in shaping the high performance learning environment.

Pedagogical issues –the effects of Technology

Schools of the future will use a wide range of technologies within the classroom such as laptop computers, networked printers and library file servers, video communication systems via tape or broadband and videos all of which place new demands on the lighting and daylighting systems. The presence of this technology within classrooms has affected the way classrooms and schools as a whole are designed.

Some of the effects of the introduction of new technology on the design of classroom are:

- A greater cooling load on the HVAC system

- Additional space requirements for computers and other equipment within the classroom
- Additional electrical requirements – approx 15 – 20 sq. ft. per station, wall or ceiling mounted projection systems.
- Adaptability in the lighting requirements and control of lighting within the classroom, a requirement to be able to darken the room and eliminate glare on computer screens.
- An increase in the security systems of a school

Schools of the future -High performance school buildings

The design of high performance school buildings needs an understanding the roles technology can play in support of emerging learning methods. The schools of the future should to be high performance buildings which will integrate emerging technology not only in the way students are taught but also in its built character. The schools of the future will be shaped by physical factors, curriculum, instruction, relationships and flexibility. A high performance school building takes into consideration environmental, economic and social objectives; it is designed to meet the energy and environmental performance criteria.

Requirements of the new age classrooms

Along with new technologies, classrooms in themselves vary and must support different teaching styles such as individual study, one-on-one discussions (with a teacher or another student), small group work and large group work, teacher-directed instruction or lecture. A classroom may be used by a single teacher or by several teachers throughout the day, or may be even reconfigured through moving walls to allow for team-teaching or multi-class projects. Often the key issue for classroom spaces is the varied requirements of different age groups which suggests need to accommodate a wide range of activities.

The integration of design features such as daylight into classrooms filled with new learning technologies can become a challenge when considering the visual comfort and energy demands. For students in classrooms; their behavior maybe influenced by the shape of the classroom, and furniture arrangements. All of this indicates that, the daylit classroom should be designed more holistically. A number of studies have been performed to better understand and effectively design the classroom for the 21^{st} century, with the objective to develop and design flexible classroom spaces with integrated technology.

Classrooms are broadly classified into four types.

1. **Basic Classrooms**

   General Purpose Classrooms

   Seminar Rooms
2. **Multimedia Classrooms**
3. **Lecture Halls**
4. **Other Types of Technology-Enhanced Classrooms**

   Studio Classrooms

   Hands-on Classrooms

   Laptop-enabled Classrooms

   Tele-classrooms

Today rectangular classrooms are almost universal; with the exception of some open classrooms and certain experimental cases.

The design standards for classrooms prescribed by the University of North Carolina-Chancellor's Classroom Improvement Initiative (June 1997) states the following.

1. The room as a whole - The length-to-width ratio of a classroom should be no greater than three-to-two (3:2).
2. Ceiling heights should be a minimum of nine feet, preferably ten or more.
3. Classrooms must be able to accommodate seating arrangements as varied as rows, small group clusters, or U-shapes.
4. Factors such as lighting, furniture, computer workstation(s), display and storage area(s), teacher's work spaces all have to be taken into greater consideration with the introduction of new technology within the classroom.

The overall design objective being to create a classroom space that helps to create a sense of identity and belonging. Being able to provide opportunities to move around, engage in group activities, have a variety of seating arrangements where individual students and small groups can choose from alternative learning activities and work independently on projects and assignments.

2.2.3 Standards and design guidelines

A number of standards and studies on classrooms for the 21st century provide insight into the proper design of classroom spaces. Standards such as Neuferts and studies like Labplan have been used to in this study along with case studies to determine the characteristics of a typical classroom for evaluation. Reference for the classroom module has been taken from the following standard guide books.

Neuferts - Standards for classrooms

The Neuferts architects data is the standard guide book used by architects and designers for information needed to form a framework for the detailed planning of any building project. It provides data on spatial requirements and also covers planning criteria and considerations of function and siting.

Open plan

- Space per pupil – 37 – 43 sq ft
- Grid of 4 ft x 4 ft and 10 ft height
- Max 25-26 students for ideal learning groups

Elementary school classroom

700 -950 sq-ft to 1200 sq-ft spaces

Secondary schools – classroom size- 700 – 750 sq-ft

Space requirements for traditional teaching – 32.0 sq-ft/ pupil

For open plan teaching – 49 sq-ft / pupil

Standard room shape – rectangular or square

40 ft x 65 ft, 40 ft x 52 ft, 40 ft x 40 ft, 40 ft x 32 ft are suggested.

(1:1.66, 1:33, 1:1, 1:1.2)

Max room depth 42.0 ft if windows are only on one sided.

Floor areas for – traditional classrooms:

20 – 22 sq-ft /pupil

Open plan

32- 54 sq-ft /pupil

Clear height should be 9 ft -11 ft

<u>Time Saver Standards</u>

The Time Saver Standards for Interior Design and Space Planning is a graphics standard for a design and planning. The standards are for planning and design details for different buildings types, including schools, and the book has been used as a base reference for determining the classroom layout for this research.

Pupil capacity: Most administrators and teachers prefer classrooms to not exceed 25 pupils per class. In some schools the standard is set to 27 pupils. From this standard the class size of 25 students and 32sq-ft / pupil is assumed resulting in a typical classroom size of 800 sq-ft. With a depth of not more than 42 ft as it is assumed to be a one sidelight classroom the dimensions of the room were determined to be 24ft x 33ft with height of 9 to 11 ft. The resulting ratio of the room is 1:1.33 which is consistent with the Neuferts Standard.

<u>The Modular classroom</u>

As an underlying strategy for applying the results of this research, a modular classroom construction approach will be assumed. Preliminary Evaluation of Energy-Efficiency - Improvements to Modular Classrooms

The baseline modular classroom building (Figures 1 and 2) is 28' x 64' and has the following energy-related specifications: walls R-11, floors R-11, roof R-30, (2) aluminum frame slider type windows U = 0.5, (2) insulated steel doors, 2' x 4' recessed four-tube fluorescent light fixtures -50 Fc and a 3-ton air conditioner with 10 kW of strip resistance heating.

By far most modular classrooms are double units with dimensions of twenty-four (24') to twenty-eight feet (28') in width and from fifty-six (56') to sixty-four (64') feet in length.

The study baseline unit is one half of a 28' x 64' two classroom unit with a restroom (see Figures 1 and 2). This unit is comprised of two 14' wide by 64' long modular sections.

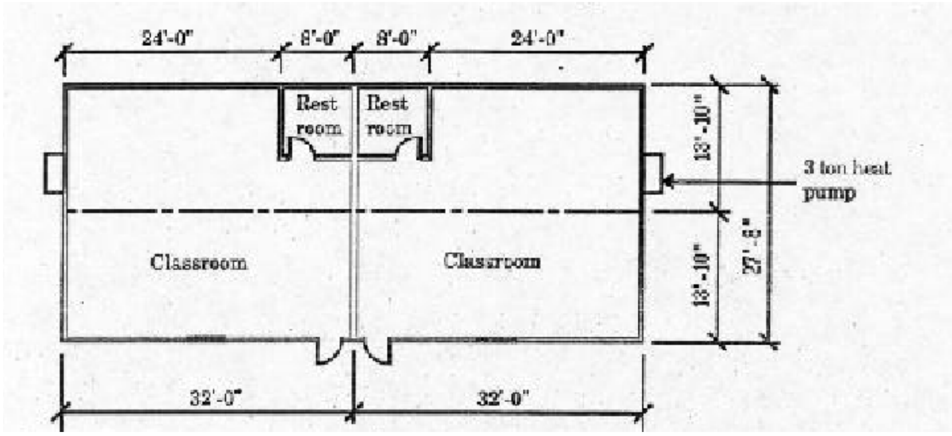


Figure 2.2 **Floor plan of the baseline modular classroom** (Source: Preliminary Evaluation of Energy-Efficiency Improvements to Modular Classrooms, Danny S. Parker and Philip W. Fairey Florida Solar Energy Center (FSEC*))*

Minimum Specifications for Relocatable Classrooms

Dimension Requirements

1. Floor to ceiling - 8’ 0” minimum

2. Exterior width - 24’ or 28’

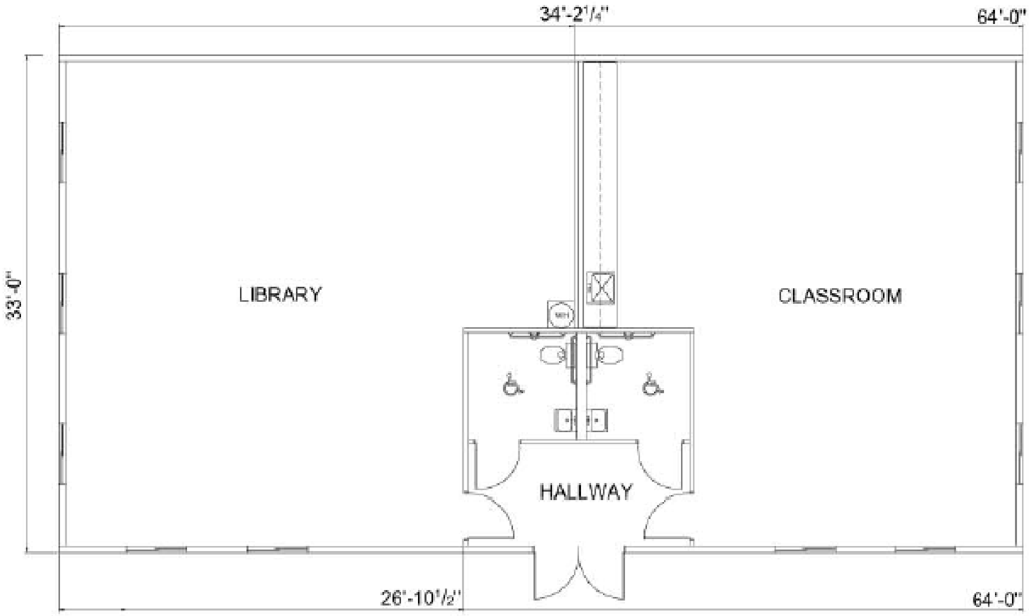


Figure 2.3 **Floor plan of the baseline modular classroom – Typology 1**(Source: Preliminary Evaluation of Energy-Efficiency Improvements to Modular Classrooms, Danny S. Parker and Philip W. Fairey Florida Solar Energy Center (FSEC*))*

<u>Labplan</u>

Another resource to help determine the preferred classroom layout as a base design for this research is Labplan. In an effort to improve high school science, math, and technology education teaching and learning, the National Science Foundation sponsored a planning study for science classrooms. The objective was to develop criteria, standards, and a process for programming and planning prototype laboratories and support spaces for secondary school instruction.

Science Classrooms

The science laboratory combines both science lab and class discussion models in one space. The number of students in each teaching mode is 24 and includes a wheelchair-accessible bench. There is sufficient space for students to have their own laptop computers as well as space for at least 6 desktop computer stations for specialized work. Also included are lab and demonstration fume hoods; storage; and a teacher's desk, demonstration bench, and audio-visual control station with demonstration computer. The optimum lab size, given the above assumptions, is 1,600 to 1,800 net assignable square feet (NASF).

Science 32-foot width – various options

Lab information: Layout: Double-sided island benches for four students with computer stations along walls.

Length: 32 feet

Width: 32 feet

NASF: 1024 SF

NASF/Station: 43

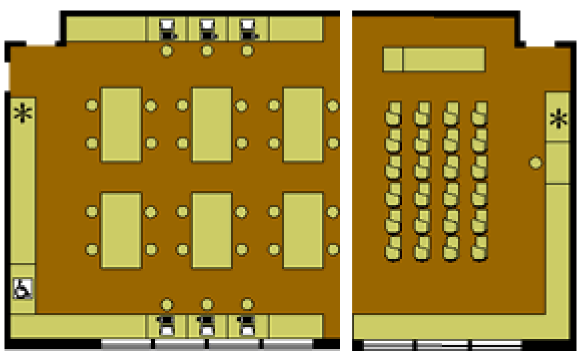


Figure 2.4 **Floor plan of the Science classroom** (ref: Lab Plan, http://www.nsf.gov/)

Layout

Small tablet arm chairs, 6 rows across by 4 rows.

Length: 21 feet

Width: 32 feet

NASF: 670 SF

NASF/Station: 28 sq ft

Math Teaching Laboratories

The math labs are developed using a room width of 32 feet. These spaces are sized for 24 students in two layouts– lecture or group work.

Math class room 32-foot width

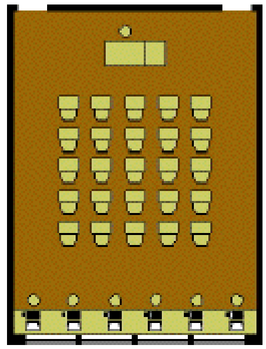


Figure 2.5 **Floor plan of the Math classroom** (ref: Lab Plan)

Layout:

Chair desks, 5 rows across by 5 rows, lecture format.

Length: 24 feet

Width: 32 feet

NASF: 768 SF

NASF/Station: 32 sq ft

Math classroom 32-foot width – type2

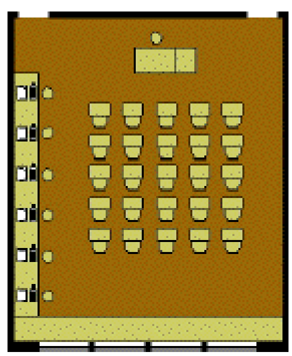


Figure 2.6 **Floor plan of the Math classroom** (ref: Lab Plan)

Layout

Chair desks, 5 rows across by 5 rows, lecture format.

Length: 26 feet

Width: 32 feet

NASF: 848 SF

NASF/Station: 35 sq ft

Technology Education Laboratories, Larger classrooms under consideration which are above 1000 sq ft. The number of students in this layout is assumed to be 24 for discussions and small projects, and 12 for computer work stations. The prototypical teaching spaces are developed using a 32-foot bay width for the classroom lab in conjunction with a 36-foot wide high-bay lab.

<u>General Purpose Classrooms</u>

The standard rectangular classroom configuration remains the most common, although there have been attempts to change this by clustering it, adapting to technology based relationships, subdividing, reconfiguring and reshaping all have had some success, but the classroom for twenty five to thirty students is still rectangular or square.

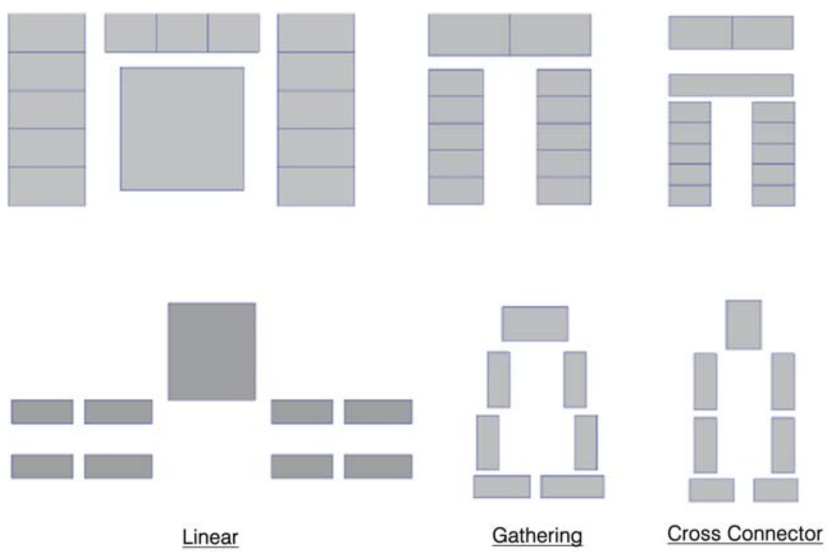


Figure 2.7 Types of Classroom arrangement (ref: Educational Objectives and the Classroom: Teacher Reactions to Classroom Prototypes- Ashraf Salama)

The following illustrate the different options for planning classrooms where learning spaces have been clustered in different configurations.

Refer to images from the book Planning and designing schools - Architecture for education by Perkins and will -C. William Brubaker, 1997. pg 44&45

1. Compact gridiron plan

Refer to images from the book Planning and designing schools - Architecture for education by Perkins and will -C. William Brubaker, 1997. pg 44&45

2. Organic plan

Refer to images from the book Planning and designing schools - Architecture for education by Perkins and will -C. William Brubaker, 1997. pg 44&45

3. Double loaded corridor with assigned classroom

Refer to images from the book Planning and designing schools - Architecture for education by Perkins and will -C. William Brubaker, 1997. pg 44&45

4. Double loaded corridor with generic classroom (left)

Refer to images from the book Planning and designing schools - Architecture for education by Perkins and will -C. William Brubaker, 1997. pg 44&45

5. Corridor pushed to one side for wider flexible space (right)

Refer to images from the book Planning and designing schools - Architecture for education by Perkins and will -C. William Brubaker, 1997. pg 44&45

6.Clustered five sided classrooms

Refer to images from the book Planning and designing schools - Architecture for education by Perkins and will -C. William Brubaker, 1997. pg 44&45

7.Hexagonal or octagonal classrooms

Refer to images from the book Planning and designing schools - Architecture for education by Perkins and will -C. William Brubaker, 1997. pg 44&45

8.Open plan classrooms

Figure 2.8 Planning and designing schools - Architecture for education by Perkins and will -C. William Brubaker, 1997. pg 44&45

Classrooms seating 20-75 students and having 350 sq ft of space. Dimensions: Classrooms to be designed so that the length is approximately one and one-half times the width of the room. Rooms that are wider than they are deep present unacceptable viewing angles for projected materials and for the chalkboard.

Table 2.8 Classroom seating Guidelines (Ref: Planning and designing schools - Architecture for education by Perkins and will -C. William Brubaker, 1997)

Room capacity	Flat Floor	Sloped or Tiered Floor
20-49 stations	12 feet clearance	Not recommended
50 – 75 stations	12 feet clearance	10 feet in rear, 12 feet in front

2.2.4 School case studies - from Literature

1. **Sunland Park, New Mexico – A prototype elementary School** (Planning and designing schools - Architecture for education by Perkins and Will -C. William Brubaker)

The building is organized into 3 functional subtypes - classrooms, library and administrative areas along with a multipurpose pavilion and cafeteria.

Key Features: Designed for 600 students, K-6 elementary children

H shaped plan, Classrooms at the four corners

Double loaded Classrooms, One sided windows

Rectangular classrooms

*Refer to images from the book Planning and designing schools - Arc*hitecture for education by *Perkins and will -C. William Brubaker, 1997. pg 56, 57& 58*

Figure 2.9 Plan and view of Sunland Park elementary school, New Mexico. Views of Double Loaded corridors and Rectangular Proportion classroom

2. **I m Birch School, Zurich, Switzerland – Primary and secondary school**

The school has been designed to overcome the traditional arrangement of isolated classrooms, three or four rooms have been arranged as a group or cluster. Glass and glass brick walls have been used in order to link rather than separate the classrooms.

Key Features:

Age of students 5 to 16 yrs

No. of students – 780

Total floor area per student 270 sq ft

Clustered classrooms

Rectangular proportion classrooms

Refer to project images from the book &\ also Hawkins \ brown, Hawkins/Brown Architects

Figure 2.10 Floor plan and external view, Im Birch Primary and Secondary School, Zurich, Switzerland

Refer to project images from the book &\ also Hawkins \ brown, Hawkins/Brown Architects

Figure 2.11 Detailed Plans of classroom spaces, Im Birch Primary and Secondary School, Zurich, Switzerland. Ref: &\ also Hawkins \ brown, Hawkins/Brown Architects

3. **Lachenzelg School, Hongg Switzerland – Secondary school**

The school has been designed as a two storey extension to an existing school. The various functions have been separated spatially. The corridor bordering the quadrangle links three unequal wings, the two storey hall in the north, the canteen and library in the south and special classrooms for crafts and the natural sciences to the west.

Key Features:

No. of classrooms 21, Age of students 12 to 16 yrs

No. of students – 420, Clustered classrooms

Rectangular proportion classrooms

Single loaded corridors with linear aligned classrooms

Refer to project images from the book &\ also Hawkins \ brown, Hawkins/Brown Architects

Figure 2.12 Internal, External view of classroom spaces Lachenzelg secondary School, Hongg Switzerland**,** Ref: &\ also Hawkins \ brown, Hawkins/Brown Architects

Refer to project images from the book &\ also Hawkins \ brown, Hawkins/Brown Architects

Figure 2.13 Detailed floor plan of classroom spaces Lachenzelg secondary School, Hongg Switzerland Ref: &\ also Hawkins \ brown, Hawkins/Brown Architects

4. Architecture for education – New school designs from the Chicago competition - Chicago north side winner (Konning Eizenberg)

The school is organized into five classroom clusters or neighborhoods made up of the pre-kindergarten, kindergarten, and elementary school. The higher grades are on the upper levels and the lower grade classes on the lower levels. The school has been designed like a neighborhood with the classroom spaces opening out onto front and back yards. The architects tried to maximize daylight for enhanced work performance, reduced energy use and delight of such a space. While a large amount of glass is used in the design to the north and south, the glazing area is reduced to the east and west.

Key Features: Rectangular proportioned classrooms oriented to face north and south. Age of students 5 – 15 yrs, No. of students – 400

Refer to project images from the book: Chicago competition Architecture for education, Clarke, Forman, 2003

Figure 2.14 Floor plans of classroom spaces, Chicago competition - Chicago north side winner Konning Eizenberg, Ref: Architecture for education, Clarke, Forman, 2003

Refer to project images from the book: Chicago competition Architecture for education, Clarke, Forman, 2003

Figure 2.15 Internal, External view, plan and section of classroom spaces, Chicago competition - Chicago north side winner Konning Eizenberg, Ref: Architecture for education, Clarke, Forman, 2003

5. Architecture for education – New school designs from the Chicago Competition - Chicago south side finalist (Borum, Daubmann, Hyde + Roddier)

The scheme is comprised of three types of spaces fully internal, semi- internal and external; this is achieved by the use of a double skin. The outer skin provides weather proofing, security and a degree of protection from the extremes of temperature that Chicago experiences. Classrooms have been grouped in three clusters. Each of these clusters includes a shared assembly space for the use by that school. Skylights are introduced in classrooms and common spaces. All classrooms have direct access to an external play area. The design scheme proposes the use of natural ventilation and passive solar gain in order to achieve comfortable and cost effective learning environments.

Refer to project images from the book: Chicago competition Architecture for education, Clarke, Forman, 2003

Figure 2.16 Floor plan, Double Loaded corridor, rectangular proportion of classroom Chicago competition - Chicago south side finalist Borum, Daubmann, Hyde + Roddier,

Refer to project images from the book: Chicago competition Architecture for education, Clarke, Forman, 2003

Figure 2.17 Detailed sections and views of classroom spaces. Chicago competition - Chicago south side finalist, Borum, Daubmann, Hyde + Roddier, Architecture for education, Clarke, Forman, 2003

4. Gesamtschule in der Hoh, Zurich Switzerland – Comprehensive School

The school designers worked on an innovative educational concept, children of all levels are taught in mixed age classes. Each classroom is shared by two classes and can be partitioned. Flexible classroom furniture arrangements with no particular front or back of the classrooms, the space is subdivided into a number of variously equipped working areas, groups of desks, computers, workspaces and work areas on the floor. At the centre of the building is a planted light well, which connects with the surrounding corridor linking the rooms. The buildings shell is subdivided to create a system of equally sized modular rooms, which can be combined partially or fully.

Key Features: Age of students 5 – 15 yrs

No. of students – 160, Total floor area per student 300 sq ft

Rectangular proportion classrooms, Multiuse classrooms

Conclusion

From the standards on classroom design and case studies the following set of recommendations are summarized:

- *Neuferts and Time savers standards* Recommended

Class size – 24 to 26 students per classroom

Space per pupil – 30 to 45 sq ft

Classroom proportion – 1:1.33

Height of classroom – 9 to 11 ft

- *Modular classrooms* Recommended

Class dimensions 24’ to 28’ x 56’ to 64’

Floor height – 8’ minimum

- *Lab Plan* Recommended

Class size – 24 students

Class width – 32 ft

Area per station – 28 sq ft

- *Case studies*

The case studies of various classroom spaces showed the following distinct characteristics : Rectangular Proportioned Classrooms

Single / Double Loaded corridor planning

Single long length window-wall in all classrooms.

<u>Summary</u>

The chapter presented an overview of lighting and daylighting research related to learning environments and also literature related to classroom design and layout. The review of the previous work done on daylighting does not focus on the classroom space in particular; the studies above have been used as a guiding factor in this research. The recommendations from standards and case studies have been used to set the classroom base model used in the simulation.

Chapter 3 Methodology

3.1 Introduction -Building Performance testing techniques

To make design decisions designers need to be able to predict and assess the performance of their ideas with respect to various criteria such as comfort, aesthetics, energy, environmental impact, economics etc. Designers have used techniques such as tests on full and scale models, field studies etc. for determining and gaining insight in to their decisions. For daylight physical models are often used to asses the performance of buildings using scale models in sky simulators. There however exists a degree of overestimation in the performance, usually expressed through work plane illuminance and daylight factor profiles, when compared to the real buildings. The reasons of discrepancies between buildings and scale models can be due to several sources of experimental errors such as modeling of building details, surface reflectance and glazing transmittance as well as photometer features.

Computer simulation techniques using mathematical models of lighting phenomena can be used to make informed decisions about building systems including envelope, glazing, lighting and HVAC. Simulation techniques also help to predict both construction and operating costs of proposed alternatives. Computer simulation can be space and time efficient when compared to physical modeling techniques.

The following study uses the simulation tool eQUEST as a means of analyzing energy consumption in classroom spaces. The simulation technique has been chosen in order to reduce discrepancies associated with scale models, to be able to simulate different variables and analyze for different locations, climatic zones and orientations.

3.2 The simulation tool eQUEST

High performance buildings are designed in order to optimize the trade off between heat loss, passive heat gains, daylighting, cooling requirements and natural ventilation. When considering these trade offs it is vital to use computer simulation tools to evaluate different systems and materials, in order to minimize the energy use for a given climate, site, building function and occupancy. Simulation tools provide performance information such as energy consumption that is critical to the "whole-systems" building design process. In the U.S DOE-2 is the most widely recognized and respected building energy analysis program in use today.

3.2.1 eQUEST modelling approach

The simulation "engine" within eQUEST is derived from the DOE-2 program. The eQUEST calculation engine extends and expands DOE-2's capabilities in several ways, including: interactive operation, dynamic/intelligent defaults, and other building system improvements. Also DOE-2 is often been too difficult and time consuming to use for most projects, due to the time involved in describing the building. The eQUEST simulation engine takes the designer through the creation of a detailed building model, allowing for parametric simulations of the design alternatives and providing intuitive graphics that compare the performance of the design and its alternatives.

eQUEST energy calculation method

eQUEST calculates hour-by-hour building energy consumption over an entire year (8760 hours) using hourly weather data for the location under consideration. Input to the program consists of a detailed description of the building being analyzed, including hourly scheduling of occupants, lighting, equipment, and thermostat settings. eQUEST also contains a dynamic daylighting model to assess the effect of natural lighting on thermal and lighting demands. eQUEST provides accurate simulation of building features such as shading, fenestration, interior building mass, envelope building mass, and the dynamic response of differing heating and air conditioning system types and controls.

eQUEST building site information and weather data

Important building site inputs include latitude, longitude and elevation, plus information about adjacent structures or landscape forms capable of casting significant shadows on the proposed (or existing) building. The eQUEST engine comes with long-term average weather data (~30-year average) for the sixteen standard climate zones in California. For areas outside of California, over 650 weather files are available. Some international locations are also available.

Building shell, structure, materials and shades

eQUEST takes into account the walls, roof, and floor of the proposed building in relation to their thermal properties, and their material properties with regard to heat transfer. It also takes into account the geometry and orientation of the building. This will include glass properties of windows and the dimensions of any window shades (e.g., overhangs and fins).

Heating and cooling load calculation

Heat gain from internal sources (e.g., people, lights, and equipment) can constitute a significant portion of the energy consumption in large buildings such as schools, both from their direct power requirements and the indirect effect they have on cooling and heating requirements. Internal loads frequently make large buildings relatively insensitive to weather. The performance of almost all energy-efficient design alternatives is impacted either directly or indirectly by the amount of internal load within a building. eQUEST contains reasonable defaults by building type, the standard source for these data is the ASHRAE *Handbook of Fundamentals* (published every four years). eQUEST like Doe2 works through the 4 main categories of loads, systems, plant and economics while modeling the given building

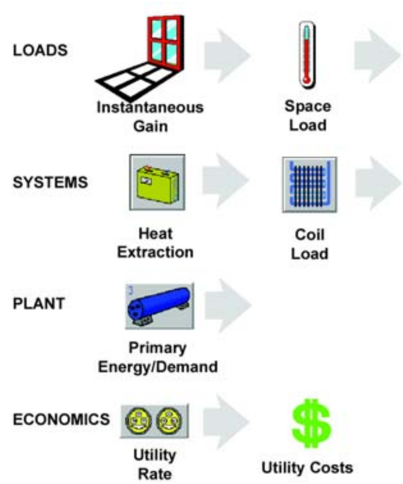


Figure 3.1 eQUEST – Main categories of Loads, (Source: eQUEST Tutorial)

Heat transfer calculation in eQUEST

Like DOE-2 eQUEST allows for four types of heat transfer surfaces from its "palette", these include:

1. Light-transmitting surfaces, e.g., windows, glass block walls, sliding glass doors, skylights, etc. DOE-2 / eQUEST treats of all of these as the same type of heat transfer surface, i.e., a WINDOW.

2. Exterior surfaces, e.g., opaque exterior surfaces such as exterior walls, roofs, and floors, etc. DOE-2 / eQUEST treats of all of these as an EXTERIOR-WALL.

3. Interior surfaces, e.g., opaque interior surfaces such as interior walls, interior floors, and interior ceilings, etc. DOE-2 / eQUEST treats of all of these as, an INTERIOR-WALL.

4. Underground surfaces, e.g., underground surfaces such as basement floors and walls, and slab-on-grade DOE-2 / eQUEST treats all of these as an UNDERGROUND-WALL.

Internal load calculation in eQUEST

There are three broadly different categories of internal loads that eQUEST allows users to model, these include:

1) Loads seen by BOTH a thermostat and the utility meter — examples include: receptacle or "plug" loads (e.g., electric and electronic office equipment), task and, ambient lighting) etc.

2) Loads seen ONLY by a thermostat, not by the utility meter — examples include: occupants, process loads, propane-powered fork lifts in a warehouse, etc.

3) Loads seen ONLY by the utility meter, not by any thermostat — examples include: outdoor parking lot or sign lighting, lights and plug loads in exhausted spaces

<u>Data requirements</u>

The descriptive input data required and information sources for modeling the building in eQUEST.

Table 3.1 E Quest Data requirement at different stages of work, Source – eQUEST Tutorial

Item	*Source*	*Schematic*	*Design Development*	*Construction Documents*
Architectural				
building and zone areas	plan sheets	x	x	x
envelope construction materials	wall sections		x	x
surface areas (by orientation)	building elevations	x	x	x
fenestration areas (by orientation)	building elevations	x	x	x
fenestration u-value & SC	window schedule			x
	or specifications			x
Mechanical				
HVAC zoning	HVAC plans		x	x
design flow rates	HVAC plans		x	x
equipment descriptions	equipment schedules			x
	or specifications			x
control sequences	control diagrams			x
	or specifications			x
Electrical				
lighting equipment	lighting layout		x	x
	or lighting schedule			x
Internal Loads				
peak occupancy (by zone)	owner, operator	x	x	x
peak lighting (by zone)	lighting plans		x	x
peak equipment (by zone)	mech or owner		x	x
Operations				
per zone:				
occ, lights, equip schedules	owner or operator	x	x	x
thermostat schedules	owner or operator	x	x	x
per terminal system:				
outside air operations	HVAC equip schedule			x
hot & cold deck temperatures	HVAC equip schedule			x
fan schedules	owner or operator	x	x	x
fan kW	HVAC equip schedule		x	x
per primary system:				
lock-out schedules	control sequences			x
Economic				
utility schedules (all fuels)	utility representative	x	x	x
equipment costs	designer or manufacturer		x	x
life-cycle cost parameters	owner	x	x	x

Modelling information required

The following table describes information needed to model the physical and operational conditions in the building.

Table 3.2 eQUEST Modeling Information Request, Source – eQUEST Tutorial

Modeling Information Request
Project Name / Date

assignment

DATES: *date1*	*date2*	*date3*	INFORMATION	
			ARCHITECTURAL	
☐			floor plans	space layout/areas, surface orientations
☐			elevations	surface areas (windows, doors)
	☐		building/wall/roof sections	materials composition
☐			site plans	adjacent structures and landscape
	☐		roof plans	skylights and overhangs
☐			gross area & net (conditioned area)	
			ENVELOPE MATERIALS	
	☐		glazing shading coefficient, u-value, frame type, interior shading	
	☐		u-values: wall, roof, ceiling, skylight, slab & spandral	
			MECHANICAL	
	☐		HVAC plans	approximate HVAC zoning layout
☐			equipment types	
	☐		approx equipment sizes, design conditions, & efficiencies	
	☐		anticipated control sequences	
			ELECTRICAL / INTERNAL LOADS	
	☐		lighting plans	
	☐		lighting power density (by HVAC zone)	
	☐		design illuminance (by HVAC zone)	
	☐		peak occupancy (by HVAC zone)	
	☐		peak equipment (by HVAC zone)	
			OPERATIONS	
			per HVAC zone	
	☐		occupancy, lights & equipment schedules	
	☐		thermostat settings and schedules	
			per air handler	
	☐		anticipated coil leaving air temperatures	
	☐		minimum outside air	
	☐		fan schedules	
	☐		anticipated fan static & efficiency	
			central plant (if applicable)	
	☐		chilled & hot water temperatures	
	☐		equipment control sequences	
			ECONOMIC	
		☐	base case first costs (for equipment & systems affected by ECM's)	
		☐	ECM first costs	
☐			applicable & optional utility rates	
			POTENTIAL ECM's	
☐			envelope	
☐			lighting	
☐			mechanical	

Limitations of eQUEST

One of the limitations of eQUEST is that it is a generic tool and often unable to deal with the specific parameters of a given project. The suppliers of the program also acknowledge limitations of the tool with regards to the selected footprint shape which applies to all floors in the project.

This is because the building geometry is limited to a fairly small set of typical orthogonal floor plans. Building geometries that are not represented by this floor plan set may not be modeled accurately. Fortunately for this research a typical rectilinear classroom building is among the base building types available in the library.

eQUEST is an energy simulation software which caters to whole building analysis in terms of energy use and is not specific only to lighting or any one component. Simulation approaches such as ‘Radiance’ specifically support modeling of lighting and daylighting analysis. Because the present study is focused on the interactions between lighting, daylighting and heating and cooling loads, eQUEST, with its radiance modeling algorithms is assumed to be appropriate.

eQUEST -Screen shots Example Input screens are shown in figures 3.2.1 to 3.2.6

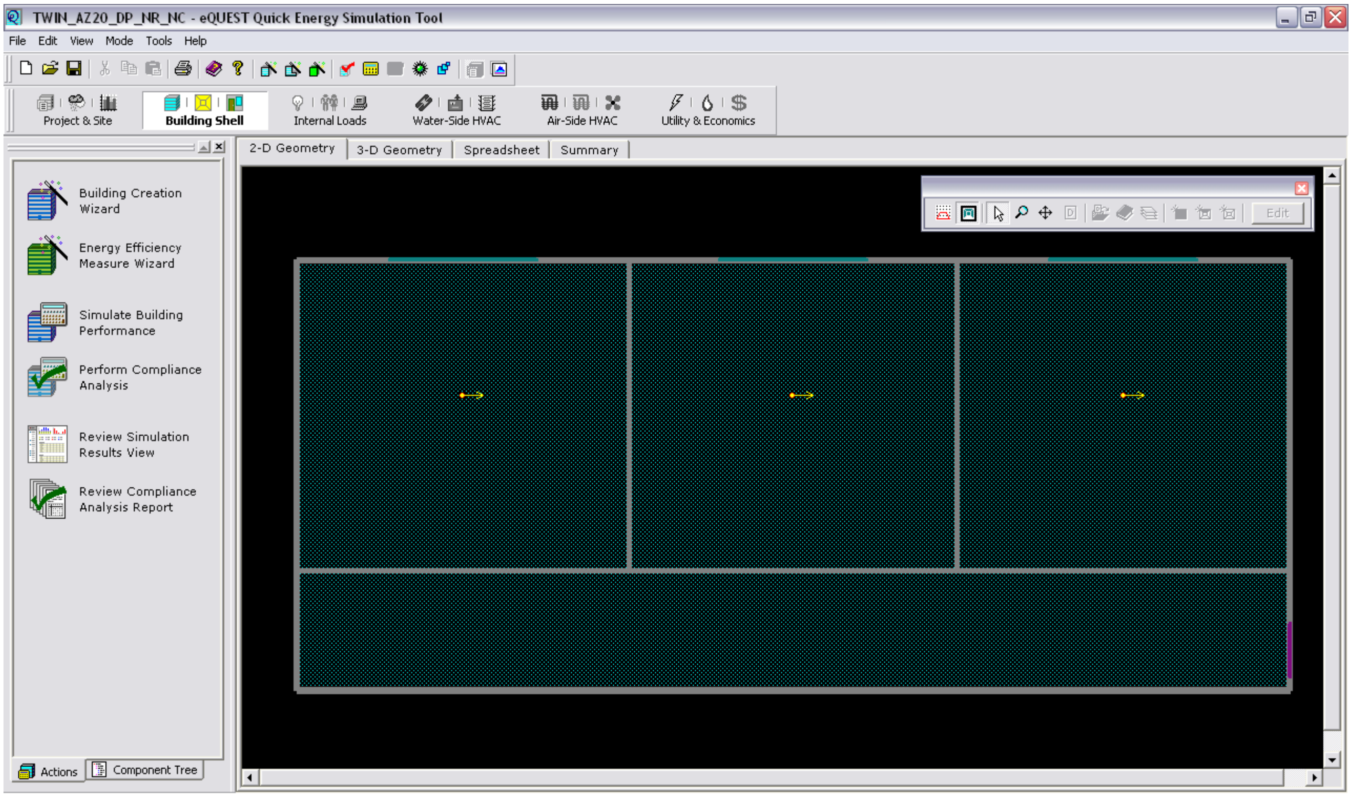


Figure 3.2.1 eQUEST screen shots – 2D Plan

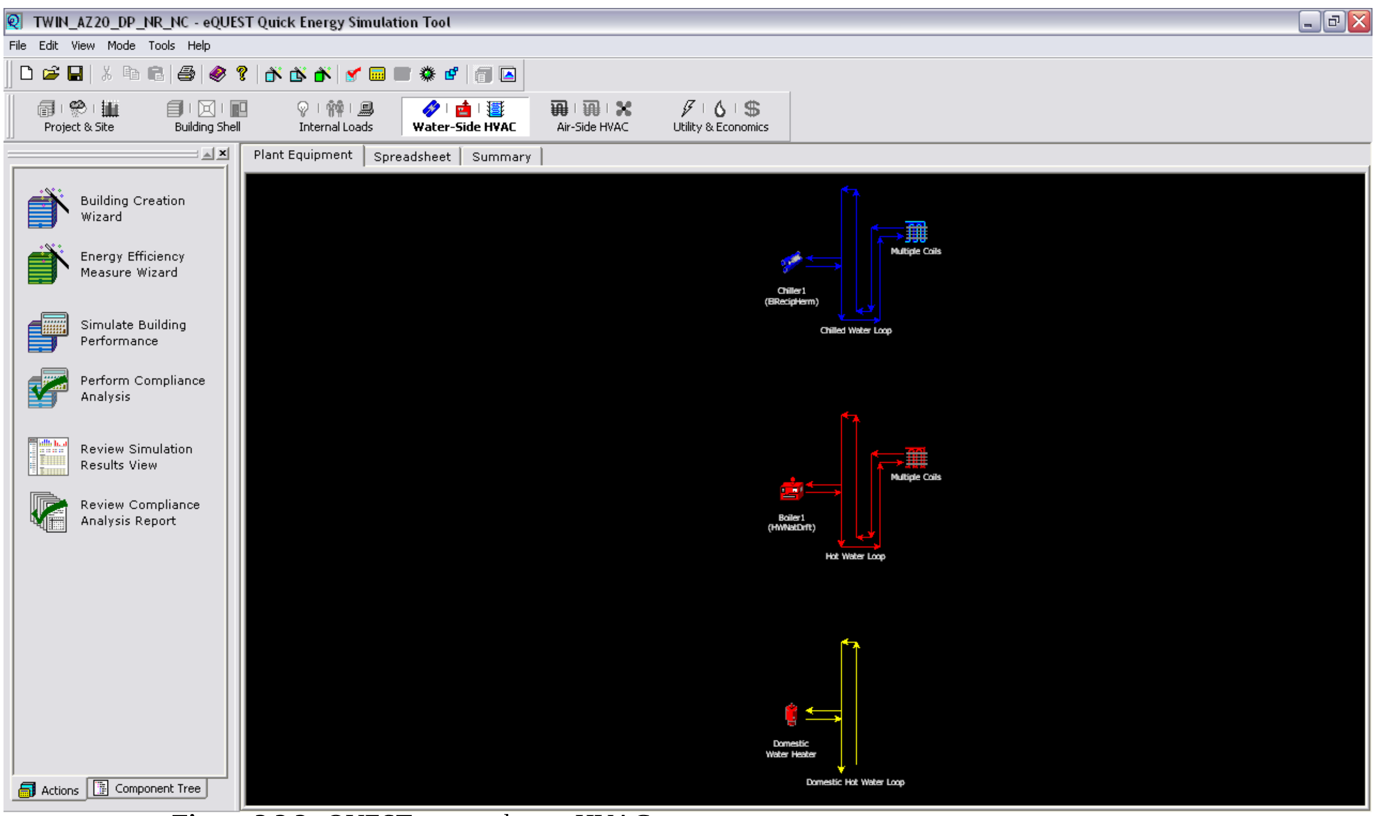


Figure 3.2.2 eQUEST screen shots – HVAC system

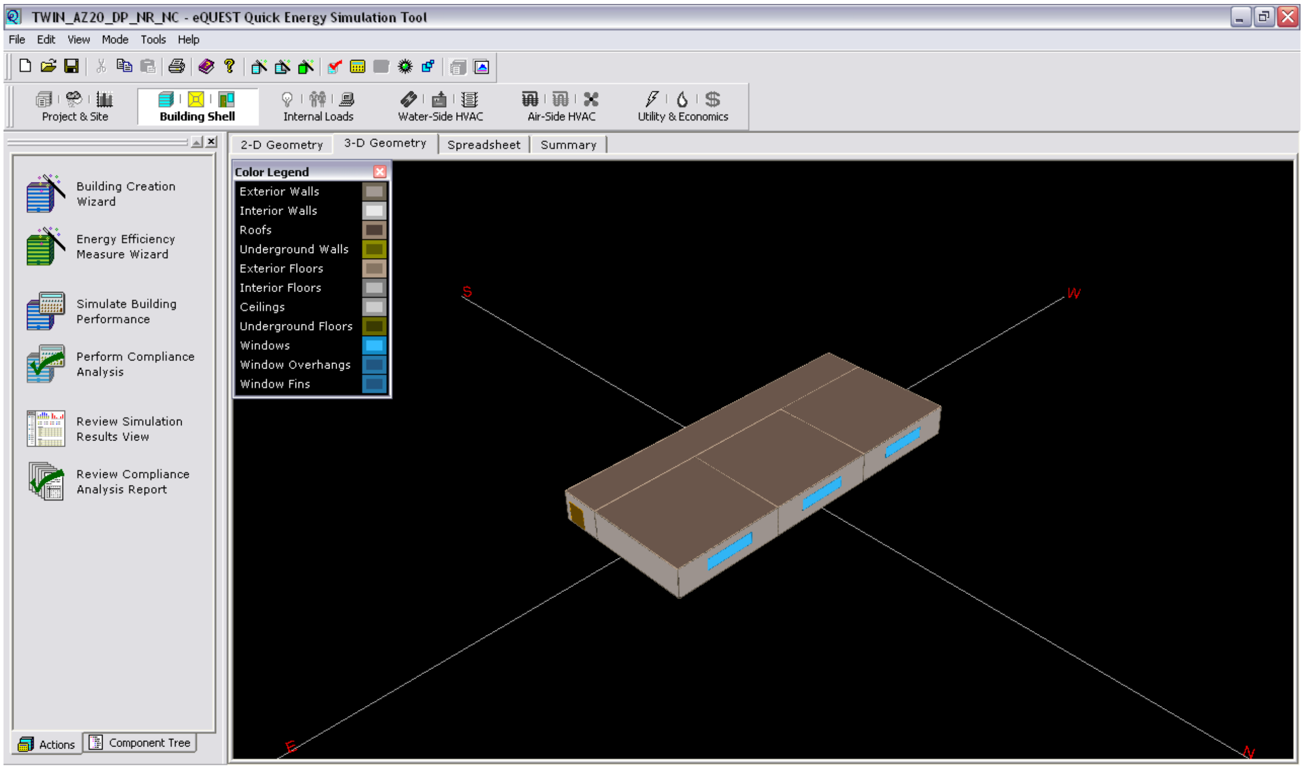


Figure 3.2.3 eQUEST screen shots – 3D View

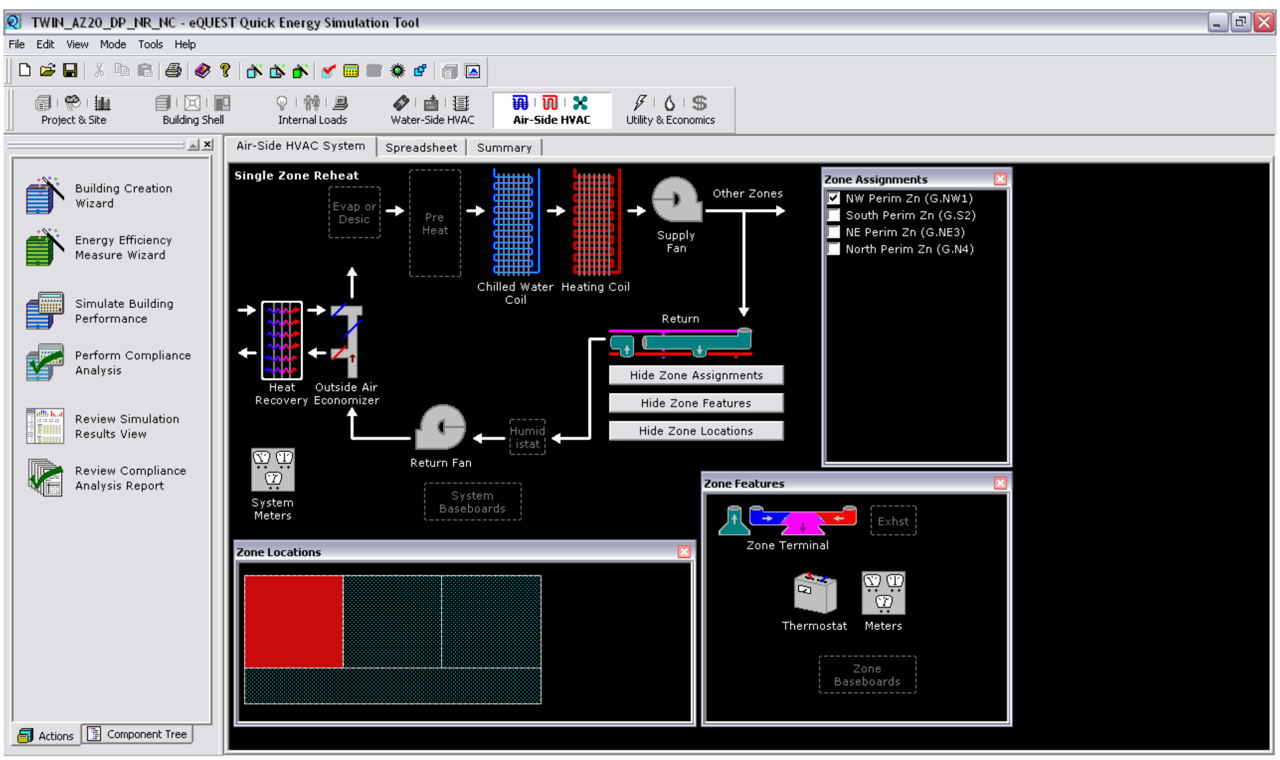


Figure 3.2.4 eQUEST screen shots – System zoning

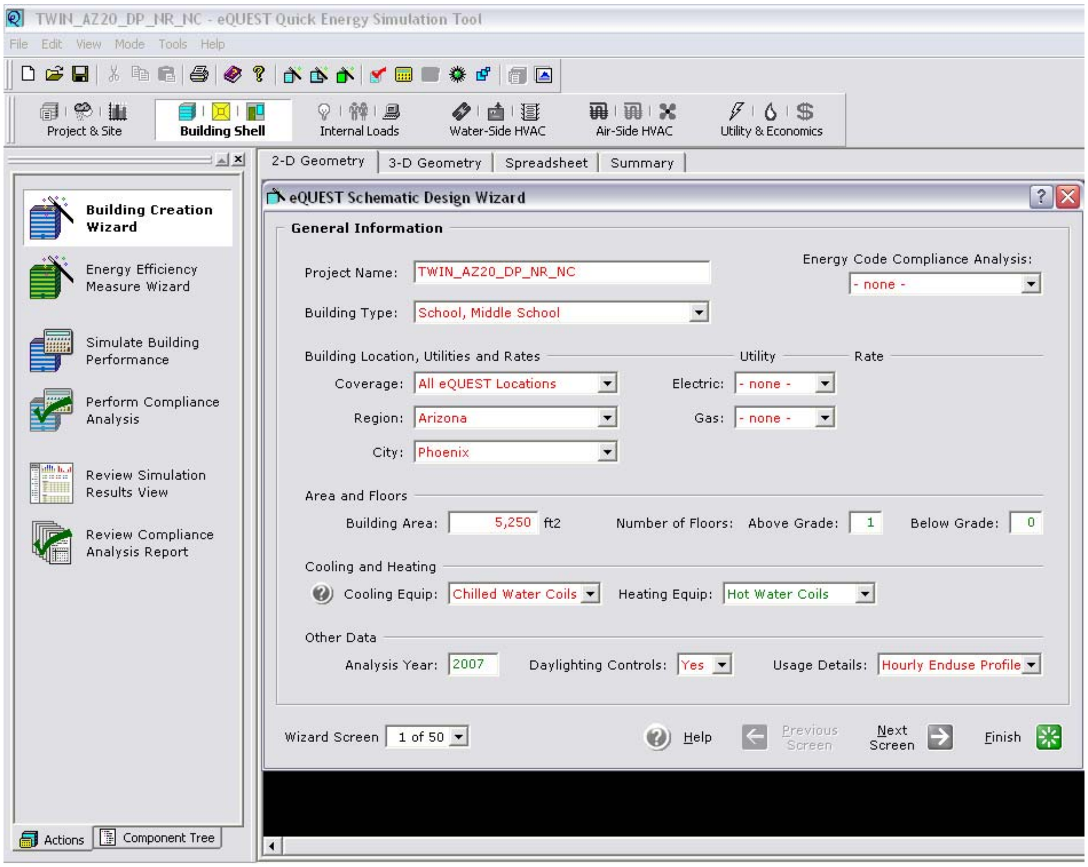


Figure 3.2.5 eQUEST screen shots – Data input screen, Building Information

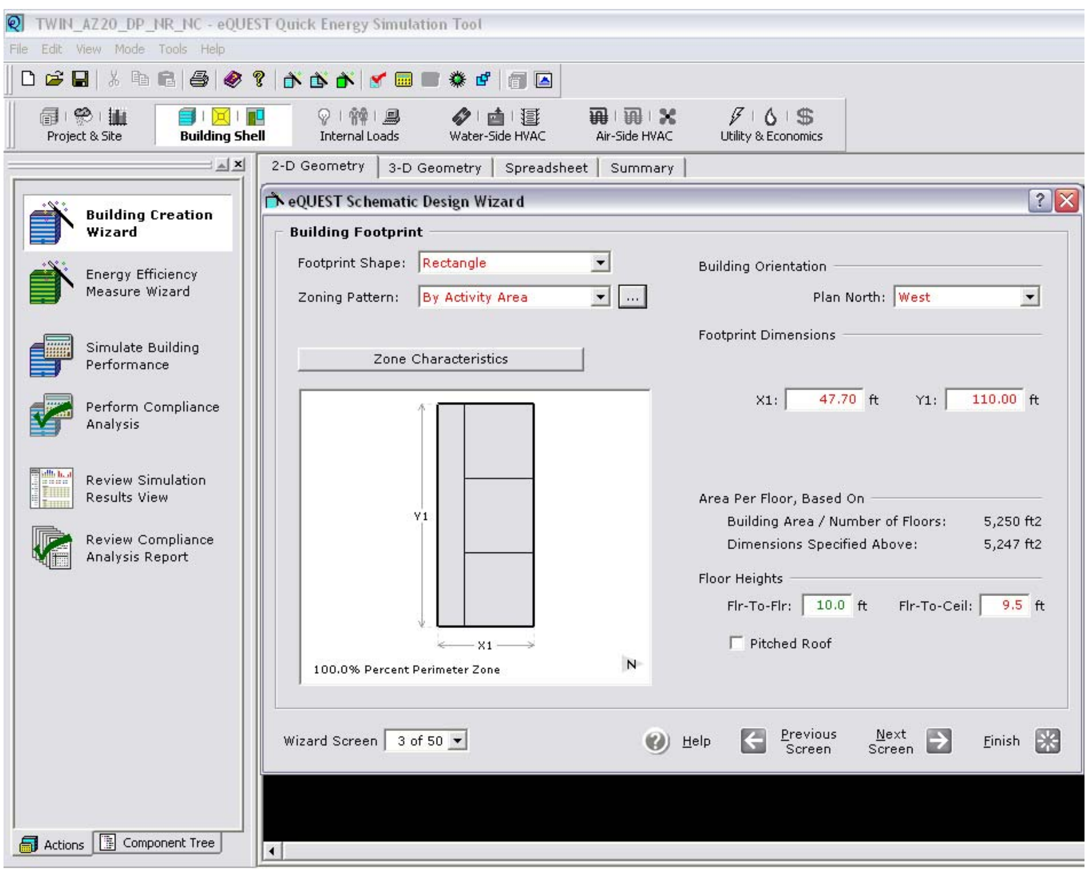


Figure 3.2.6 eQUEST screen shots – Data input screen, Building footprint

3.3 The Base Model

A building is a complex set of energy systems with a number of factors influencing the total energy demand. Energy simulation for determining the amount and influence of incoming solar energy through the fenestration is influenced by a number of factors. It is often difficult to isolate each factor to evaluate its impact on loads and total performance. For example how the window area and glazing type should be chosen and the influence of the window area and type on the energy balance of the building are important issues for whole building performance particularly for a school. Some of the key factors to take into account when performing energy simulations in relation to fenestration are building use, building size orientation, building occupancy, climate, building material, glazing type and glazing percentage.

When considering daylight and solar gains through windows, beyond a point, larger windows do allow more daylight into the space by which we can reduce the need for artificial lighting, however large glazed areas also allow large amounts of heat gain and loss into the space, which increases the heating and cooling loads and therefore the energy consumption. Conversely smaller windows reduce heat loss and gain from the space but they are unable to bring in enough daylight and do not help in offsetting the electric lighting requirements of a space. An optimum glazing area helps to balance the lighting requirements and the energy consumption of the space.

Variables considered for the simulation model

This study takes a number of factors into consideration. Factors such as, location, orientation, glazing percentage, glazing type, and presence of clerestory are considered as variables and all the other factors are fixed in this study. This limits the simulation matrix to a manageable set.

Fixed factors: Ventilation, Daylight Utilization, Internal Load, Climate, Wall Insulation
Variables: Location, Orientation, Glazing percentage, Glazing type, clerestory, non clerestory.

Location

Location is an important variable as climatic characteristics influence solar radiation; temperature patterns and altitude, which in turn affects the heating and cooling loads in buildings. The aim of the simulation being to determine how this would influence the type and percentage of glazing used in classrooms

The United States maybe divided into five climatically distinct areas (climate zones) that are defined by long-term weather conditions. The zones are based on the 45-year average annual number of degree-days (with a 65 degree Fahrenheit base). The cities taken representing these climatic zones for this study were Arizona(hot arid), Chicago(cold), New York (temperate), Raleigh (hot and humid), and Sacramento(costal temperature)

Orientation

The orientation of a sidelighting aperture strongly affects the quantity, quality, and distribution of daylight. A number of studies indicate that orientation has an effect on the heating and cooling demands of a building. Studies have also indicated that there exist large differences in the heating and cooling demands between northern and southern oriented buildings. And the effect of orientation can be significant for the differential energy savings both for cooling and heating. For the purpose of this study the classroom was modeled with north and south facing glazing.

Type of glazing

Glazing is the component of the building which transmits visible light. Glass is the most commonly used glazing material. During the last two decades a number of new glazing types have been introduced in the market. Informed decisions regarding glazing based on initial glazing cost, annual electric bill, light to heat ratio, view and aesthetic quality help in achieving a more efficient and higher quality building. Three different types of commonly used glazing in schools has be tested in this study, in order to understand the influence of glazing type, its effect on the heating cooling and lighting demands in relation to the overall energy consumption of the space.

With advancements in glazing technology and manufacturing methods a vast array of window assemblies and types of glass are now available. Some of the main types of glazing systems available to increases the overall performance of the glazing unit are: Low-E Glass, Laminated Glass, Tempered Glass, Tinted Glass, Reflective Glass, Heat Mirror and Obscure Glass. The three different and commonly used glazing types used in schools simulated in this study are: Double pane glazing, double pane Low - e glazing, and Special glazing (Azurite)

Glazing characteristics:

The NFRC National Fenestration Rating Council (NFRC) organization administers independent rating and labeling system approaches for the energy performance of windows, doors, skylights, and attachment products. The NFRC has set certain parameters and standards for the glazing used in different types of spaces in different locations.

The NFRC recommends the max value for U - value, shading coefficient and solar heat gain based on local climate (heating and cooling degree days) and building orientation.
The key representative window characteristics being

1. The glass thickness
2. Visible transmittance (% daylight)
3. U - value
4. Shading coefficient
5. Solar heat gain coefficient

Key properties

U- value– The rate of heat transfer due to conduction though the glass. The U value represents the overall conduction value. Also know as the insulating value, the suggested rating can fall between 0.20 and 1.20 Btu / sqft°Fh.

Solar Heat Gain Coefficient – Fraction of Incident solar radiation admitted through a window expressed as a number between 0 and 1. The lower a windows solar heat gain coefficient, the less solar heat is transmitted.

Visible Transmittance – Is the value of how much visible light comes through a product. It's expressed as a number between 0 and 1. Higher the value – more visible light is transmitted.

Air leakage – Air leakage rating expressed as the equivalent cubic feet of air passing through a square foot of window area.

Condensation Resistance (CR) - To resist the formation of condensation on the interior of the product surface. The higher the CR rating the better the product is at resisting condensation. It is expressed as a number between 0 and 100.

The total glazing performance can be calculated as

(Net performance of the glazing,
glazing contribution) = Solar gains + Conductive thermal gains + Conductive thermal losses + Daylight Contribution + Human factors + Environmental factors

Where

1. Glazing contribution = the net performance of the glazing
2. Solar gains = the solar heat gains
3. Thermal gains = are the gains and losses due to conduction
4. Daylight contribution = both quantitative and qualitative performance
5. Human factors = primarily related to thermal and visual comfort, psychological benefits and productivity
6. Environmental factors = energy use and environmental life cycle.

Table 3.3 Glazing Properties, Ref: NFRC

Glass type	**U factor**	**SHGC**	**VT**	**Thickness**
Single glazed clear	1.09	0.81	0.89	0.25”
Single glazed tinted	1.04	0.73	0.68	“
Single glazed reflective	0.29	0.25	0.15	“
Single electrochromic			0.85 – 0.13	“
Double Clear	0.5	0.76	0.81	“
Double tinted	0.5	0.63	0.61	“
Double reflective	0.48	0.22	0.18	“
Double –low e high SG	0.29	0.71	0.75	“
Moderate SG	0.27	0.39	0.70	“
Double low-e Low SG	0.25	0.39	0.70	“
Double electrochromic				“
Triple pane –clear glass	0.36	0.67	0.74	“
Triple glazed low e-moderate solar heat gain	0.15	0.51	0.65	“
Quad glass -clear	0.134	0.27	0.47	“

Percentage of glazing

The classroom simulation model is based on the Glass Wall Area Ratio (GWAR) from the range 0 – 40% of the façade area. The five cases being window walls with: 0 %, 10%, 20%, 30% and 40% glazing. For the purpose of this study the window wall is only the external wall.

Clerestory and non clerestory spaces

The introduction of skylights helps to bring in daylight and in balancing the ambient light throughout a space. When designing skylights in combination with sidelighting it is very important to consider factors relating to how much of the time will daylight levels meet or exceed the desired illuminance levels, and what will be the optimum skylight percentage to reduce energy consumption and cost, and to provide good lighting quality.

For the design of skylights the key factors that should be taken into consideration are:

- Uniform light distribution
- Low glare
- View
- Reduced energy cost
- Low first cost
- Cost effectiveness
- Safety and security concerns
- Maintenance

The typical objective for optimum energy performance is to balance daylight utilization with the impact on cooling and heating loads. The National Fenestration Rating Council recommends the following principles for skylights.

1. Space skylights at 1- 1.5 times ceiling height center to center in both directions
2. Light wells should be shallow and splayed light reflective surfaces of the light well are preferred.
3. For high ceiling heights skylights can be placed further apart.

The types of skylights used in buildings are basically of six types, they being:

1. Centered and patterned top lighting
2. Linear top light
3. Tubular skylights
4. High sidelights
5. Wall wash top lights
6. View windows

For the purpose of the simulation model linear top skylights at 1/4th the roof distance from the window wall from the north end have been introduced, which are commonly used within single story classroom spaces. The classroom model has been simulated for conditions with skylights. The study however has been limited to the extent of having the skylights restricted only to the north end of the classroom module.

The base case classroom is developed with the following inputs

- Climatic zones/ locations considered: Arizona, Chicago, New York, Raleigh, and Sacramento
- Orientation: North and South facing glazing
- Type of glazing: Double plane, double low - e, Super glazing – Azurite
- Percentage of glazing: 0%, 10%, 20%, 30% and 40%
- Clerestory and non clerestory spaces.

Base model specifications

The specification for the classroom module used in the simulation is based on the standards such as ASHRAE, CHPS and the California nonresidential efficiency standards. The key factors of the model such as the building shell, roofing system, lighting, internal loads, mechanical and ventilation systems are discussed below

Classroom construction

The designing of the school building enclosure has a great effect on the acoustic performance, thermal comfort and air infiltration and consequently the overall energy consumption of the space. The building material used for school spaces needs to be durable, resistant to vandalism, easy to clean as well as inexpensive. The building enclosure must meet the goals for energy efficiency and sustainability. The important characteristics of the building envelope are – U- value, R- value, thermal mass- HC, indoor air quality, moisture, reflective qualities and acoustic performance. The technical guidelines for school buildings have standards according to climatic regions for wall insulation, roof insulation, slab on grade insulation and fenestration performance. The California nonresidential energy efficiency standards (Title 24) apply to schools and these standards require that roofs, walls and floors have a minimum level of insulation. The requirements vary according to climate and region and are summarized below.

Table 3.4 Standards for building envelope, Source: California 2005 Nonresidential Energy Efficiency Standards – title 24

Refer to table from the book: California 2005 Nonresidential Energy Efficiency Standards – title 24

Building shell

Exterior wall construction has a great impact on comfort, operating costs, acoustics and ultimately affecting the size and capacity of the heating and cooling systems required for the building. The CHIPS recommends the following wall construction and assembly according to climate and region:

Table 3.5 Standards wall construction insulation recommendations ,Ref: CHPS best practices manual 2006.

Class of wall	South Coast, North Coast Climates	Central Valley, Desert Mountain
Wood framed walls	Insulate 2x4 wood – framed walls with R-13 fiberglass batt insulation or use other insulating materials with a similar thermal resistance. When 2x6 wood framing is needed for structural (or other) reasons, insulate with at least R -19 fiberglass insulation.	Use 2x6 wood studs and advance framing techniques to increase the percent of insulated cavity in walls. Insulate the cavities with R-19 batt insulation or other materials with a similar thermal resistance.
Steel framed walls	Insulate 2x4 steel – framed walls with R-13 fiberglass batt insulation or use other insulating materials with a similar thermal resistance. When 2x6 framing is needed for structural (or other) reasons, insulate with at least R -19 fiberglass insulation.	Provide a continuous thermal barrier by installing a layer of continuous insulation on either the exterior or interior surface of the wall. Protect the insulation from physical damage and from moisture penetration.
Mass walls	Shade mass walls from exposure to direct sun. Insulation is marginally cost effective in costal climates.	Insulate mass walls either by furring on the interior surface. With an exterior insulation finish system (EIFS) or with an integral insulation system.

The following 3 basic wall technologies are commonly used for school buildings with a general STC of 50:

Table 3.6 Standards wall construction insulation recommendations, Ref: CHPS best practices manual 2006.

1.	2 x 4-in. wood studs spaced 16 inches on center with R-11 Batt insulation, sheathed with 1/2-in. thick gypsum board and 1/2-in. thick plywood.
2.	3-1/2 x 1-5/8-in. 18GA metal studs spaced 16 inches on center with mineral-fiber insulation (R = 3.45 hft^2F/Btu per inch), sheathed with 1/2-in. thick gypsum board, 1/2-in. thick plywood, and 1/2-in. thick clapboard siding.
3.	12-in. two-core concrete masonry unit(CMU) produced with 120 lbs/ft^3 concrete with empty cores. The effects of mortar joints were not included in the modeling.

Roof system and classroom ceiling

Roofing systems are designed keeping in mind factors such as wind, rain / snow, temperature, solar radiation and noise. Decisions related to all these factors are influenced by the location and climatic region of the building. The types of roofs are classified according to its shape such as flat roof and gable and on the basis of the material used such as metal roof or a membrane.

The key components of a roofing system being: deck, barrier, insulation, membrane and attachment systems. The components of the roofing system being: *The deck:* Steel, wood, concrete, fiber and composite boards. *Barriers:* Vapor barrier, air barrier and fire barrier. *Insulation:* Extruded or expanded polystyrene, urethanes, polyisocyanurate, phenolics, glass and mineral fiber. *Membrane:* EPDM, PVC, TPE, TPO, Hypalon, reinforced varieties, neoprene and modified bituminous. *Attachment systems:* Spot fasteners, bar strap and anchors, adhesive, stone, heavy-weight pavers, light-weight interlocking pavers, ballast, concrete tiles with ship laps. The CHPS guidelines have recommended insulation values according to the climatic region and location and class of construction:

Table 3.7 Recommended roof Insulation values, Ref: CHPS best practices manual 2006

.Roof Class	South Coast, North Coast	Central Valley, Desert, Mountain
Insulation above deck Including mass	Provide a continuous layer of R-13 rigid insulation over the structural deck and protect this with a durable weather proof membrane.	Provide a continuous layer of R-19 rigid insulation over the structural deck and protect this with a durable weatherproof membrane.
Wood framed, attics and other	Install R-30 blown in insulation in ventilated attics. Use R-30 batt insulation in other framed cavities.	Install R-38 blown in insulation in ventilated attics. Use R-38 batt insulation in other framed cavities.

For classroom ceilings nonsagging (humidity resistant) lay-in acoustical tiles are recommended by the CHPS best practices manual. For new construction the recommended ceiling height at the instructional end of the classroom taking projectors and screens into consideration for up to 75 students is 11' minimum clear height, 75 to 150 students would require greater than 13' and for 150 & over students greater than 15' should be maintained.

Lighting

The advancement in, energy efficient lighting in classrooms helps to create a productive, comfortable and adaptable learning environment along with opportunities to lower energy consumption. Most classrooms require a range of lighting levels, for activities ranging from comfortable reading and seeing the chalkboard to sufficient light at the desk space, as well as darkening the projection screen area while still permitting enough light in the seating area for note taking. Two most important factors to consider when designing for lighting of a space is the quantity and quality of light.

The quantity of light is measured in footcandles, taken in the horizontal plane at the task. The IESNA has recommended light levels for horizontal illuminance in classroom spaces. For most typical classroom and office reading tasks, the current recommended light level is 30 footcandles, certain standards however recommend 50 footcandles, an average level between 30 to 50 footcandles is considered ideal. Exceptions include art classrooms, shops, laboratories, and other spaces where tasks require higher illumination levels. Computer labs and similar spaces are the exception – high daylight levels cause visual difficulties, so daylight, if introduced at all, should be done carefully and at very low light levels. For note taking during screen projection, lighting level of 5 - 10 foot-candles over the seating and complete darkness from the projection area is required. Lower lighting levels of 15 to 30 footcandles are suggested for computer classrooms. Providing a low ambient light level 5 to 10 footcandles and task lighting is recommended for computer spaces.

Table 3.7.1 Recommended illumination levels for classroom spaces, Source: IESNA hand book

Activity	**Recommended lighting Levels -IESNA**
Note taking during screen projection	5 - 10 footcandles – over seating 0 footcandles – over projection area
Computer classrooms	15 to 30 footcandles / 5 to 10 footcandles with task lighting

Illumination criteria for a daylight classroom

For common visual tasks – recommended illuminance (FC) is 30 – 50 FC

Table 3.8 Recommended illumination levels for a daylit classroom, Source: IESNA hand book

Activity	Task light level @ desk	Acceptable variation of task light level	Other considerations
Reading, Artwork, Social time	45 FC	30- 250FC	Daylight glare control required
Normal lecture chalkboard or whiteboard	45FC	30 – 250FC	Additional vertical surface lighting for board should be considered

Screen lecture	15FC	Dim lower levels is permissible higher levels should not be used	Max of 5 vertical FC ant any point on the screen. Room use shades required.

Lighting Quality: The quality of lighting in the space is as important as the quantity of light to achieve a good visual environment. The key issues of the quality of light are vertical illumination, glare control, uniformity and color rendering. Factors such as color appearance, daylighting integration, control, luminance of room surfaces should also be considered in lighting design.

Vertical Illumination: Vertical illumination is a critical design issue in school lighting. With the exception of desktop reading, most of the classroom visual tasks involve “heads-up” activities which require proper vertical illumination of chalkboards and other displays.

Glare Control. Light sources that are too bright create uncomfortable glare. Direct or reflected glare can also impair visual performance by reducing task visibility. In such a case, fatigue results from the eye having to work much harder to perform. All sources of light, including daylight, have to be carefully designed to avoid causing discomfort or disabling glare. Common glare problems in classrooms include uncomfortable overhead glare from direct distribution luminaries, reflected luminary imaging on VDTs and whiteboards, and direct glare from uncontrolled windows or skylights.

Uniformity: Classroom spaces should be uniformly illuminated, avoiding shadows or sharp patterns of light and dark. For classrooms, luminance contrast ratios between the visual task and its immediate surround should not exceed 3:1, and contrast between the brightest surfaces in the visual field and the visual task should not exceed 10:1. Higher ratios contribute to fatigue because the eye is constantly adapting to differing light levels.

Color Rendering: Light sources that render color well enhance the visual environment. Light sources should have a minimum color-rendering index (CRI) of 80 for most interior spaces.

Internal loads - Equipment plug loads

The electrical needs of schools have changed dramatically in the past 10 years. With the explosion of the use of computers in the classrooms in the late eighties through today, electrical outlets are now placed everywhere in the classroom. This has led to the proliferation of devices and appliances in classrooms and the resulting increase in electrical use. With the introduction of laptops within the classrooms the energy use and cooling loads of the classroom have increased significantly, now plug loads account for up to 25 % of the electrical energy consumed within an educational facility. Plug loads include educational tools and delivery systems like TV's, VCR's/DVD players, computers, printers, scanners, projectors, and office equipment, but also include personal items brought into the classroom/school like coffee makers, microwaves, personal refrigerators, heaters, popcorn poppers, toaster ovens and task lighting. Phantom energy loads account for a around 1.25watts /hr per sq ft contributing further to the energy used in the classroom.

Table 3.9 Equipment Plug Loads, Ref: Managing Plug loads and phantoms in the school, Author: Lorenz. V. Schoff.

DEVICE	**No.**	**Plug Load / Device**	**Total**	**Plug Load when not in use**	**Total**
Laptops	25	45 watts	1125	1 watt	25
Desktop computer	1	150 watts	150	2 watt	1
VCRs	1	25 watts	25	1 watt	1
Overhead /LCD projectors	1	600 watts	600	1 watt	1
DVD Player	1	30 watts	30	1 watt	1
Sound systems	1	30 watts	30	1 watt	1
Printers	1	250 watts	250	1 watt	1
scanners	1	100 watts	100	1 watt	1
TV	1	100 watts	100	1 watt	1
Total			**2410**		**33**

Mechanical ventilation -Systems / HVAC systems

According to the ASHRAE standards a typical classroom with 30 people requires a minimum of 15 cfm/person x 30 or 450 cfm. Other spaces in schools require differing levels of outside air ventilation, based on the expected occupant density of the space and the recommended ventilation rate of 15 cfm/occupant. If outside air is provided through a mechanical system, then at least 15 cubic feet per minute (cfm) of outside air must be provided for each occupant. Systems also need to be designed to provide at least three air changes per hour, or the required ventilation rate indicated above for the hour prior to normal occupancy of the building.

The important considerations while specifying HVAC systems for any space are: noise and vibration, IAQ ventilation performance, thermal comfort performance, operating costs, energy efficiency, maintenance access, costs, HVAC equipment space requirements (in the classroom, on the roof, in mechanical rooms) durability and longevity, ability to provide individual control for classrooms and other spaces, type of refrigerant used and the ozone-depleting potential.

The established system types for classroom spaces are:

Variable-air-volume (VAV) systems: VAV systems save energy by slowing down the fan in response to dynamic heating and cooling demands. When the rooms need full cooling, the fan is at full speed; when the rooms require heat, the fan slows down. Variable-air-volume (VAV) systems are ideal for warmer climates as its cooling effectiveness is best.

Heat pumps: use a refrigeration cycle to generate heat from a tepid source. Water-loop heat pumps provide heating and cooling by cycling the water through the earth are considered among the most efficient HVAC systems available. In those systems, the only energy used to reject or add heat from the loop is pump energy; there is typically not a boiler or chiller involved. Heat pumps are ideal in cooler climates as its heating effectiveness is best. The HVAC system for the simulation model has been specified as a heat pump system with the assumption that each classroom holds 25 students and 1 teacher (26 people total) that generate 240 Btu/hr/person of latent heat and 100 Btu/hr/person of sensible heat into the space. The system is specified as per the eQUEST outline specifying fan speeds and energy consumption.

Classroom Module

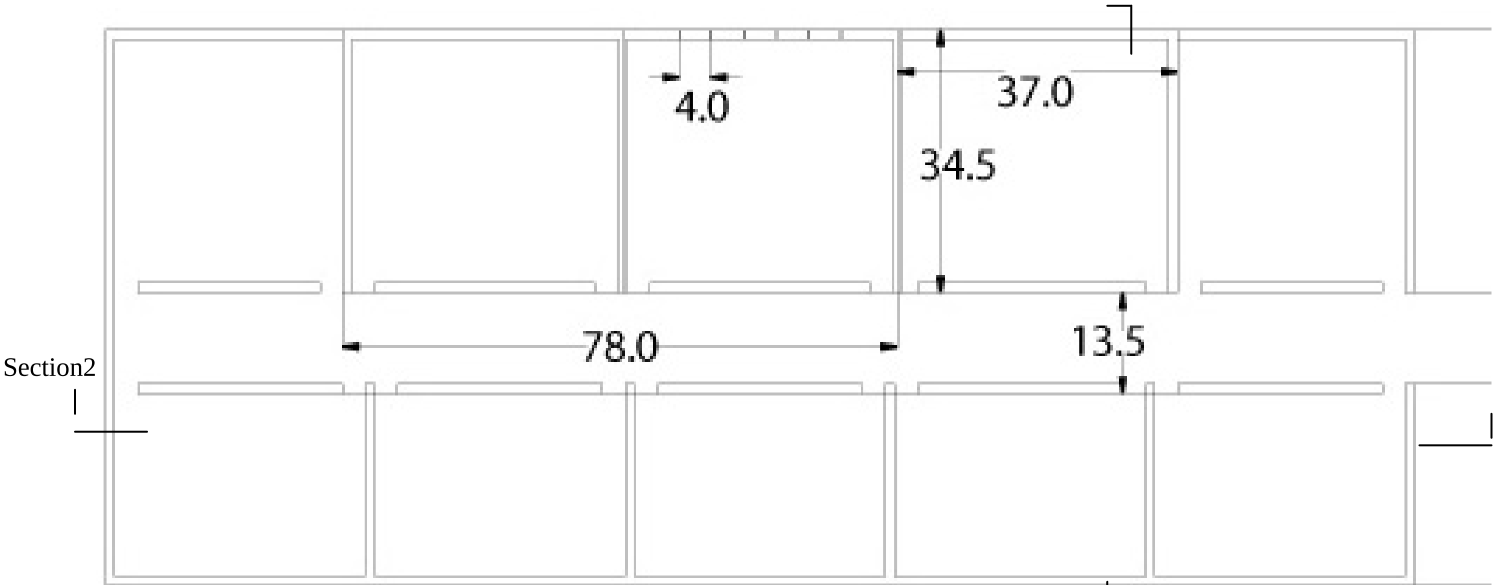


Figure 3.3.1 Building Module Classroom Module Plan Section1

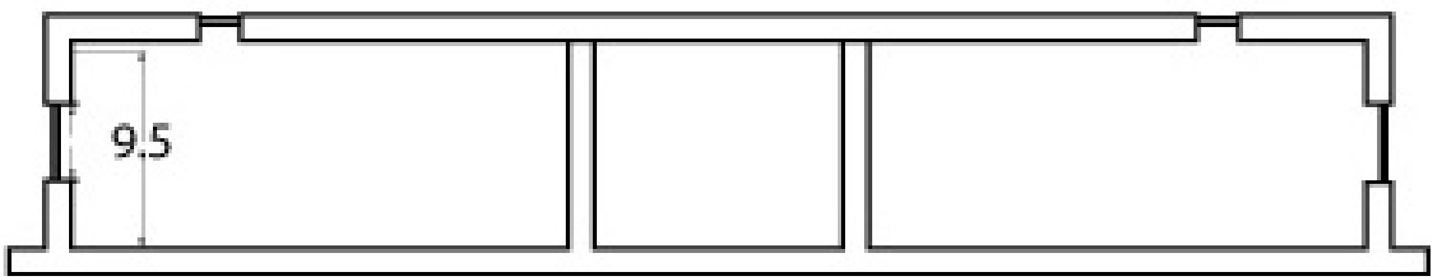


Figure 3.3.2 Building Module Classroom Module Section 1

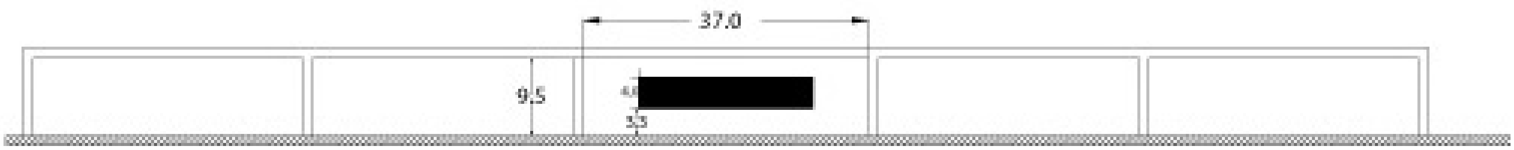


Figure 3.3.3 Building Module Classroom Module Section 2

E- Quest simulation model inputs

The following is a summary of the data input for the eQUEST model used for the study. A number of parameters not shown here have been assigned eQUEST default values. These parameters are derived from codes and standards and adjusted for building type and location.

Building Description

- Building Type – Middle School
- Building Area – 5250 sq ft
- No of Floors – Above Grade: 1 Below Grade: 0
- Cooling Equipment - Chilled Water Coils
- Heating Equipment – Hot water Coils
- Analysis year – 2007
- Daylighting Controls – yes
- Foot Print shape – Rectangular
- Zoning Pattern – By activity area (Conditioned)
- Floor to Floor height - 10ft
- Floor to Ceiling height – 9.5ft

Building Envelope Construction

- Roof Surface

Construction: Metal Frame@ >24in oc

Ext Finish / Color: Built up roof

Exterior Insulation: 3in polyurethane (R-18)

- Above Grade Walls

Construction: 12in CMU

Ext Finish / Color – Stucco

Exterior Insulation – No Board Insulation

Additional Insulation – Solid Grouted

Interior Insulation – R13 Furred insulation

- Ground Floor

Exposure: Earth Contact

Construction: 6in Concrete

Ext / Cavity Insulation: No Perimeter Insulation

Interior finish – Vinyl tile

- Interior Construction

Ceilings: Lay in acoustic tile

Vertical walls: Wall type – Frame

Batt insulation – R-11batt

- Exterior Door

Door type: Opaque

No. 1

Ht – 7ft

Wd – 6ft

Construction – Steel, Urethane foam core w/o Brk

- Exterior Windows

Window area specification method – Percent of net wall area (floor to ceiling)

Types of glass used:

1. Double Clear ¼ in, ½ in air (2004)
2. Single Low e (ez = 0.4) Clear 1/8th in (1600)
3. Azurlite

Frame Type – Reinforced Vinyl, Fixed Insulated Spacer

Frame wd (in) 1.30

Activity Areas Allocation

Table 3.10 E Quest Simulation Model Inputs

Area Type	**Percent Area%**	**Design max Occ. (sq ft/per)**	**Design Ventilation (cfm/per)**
Classroom/ lecture	24.1	75	15.0
Corridor	27.9	1000.0	50.0
Classroom/lecture	24.2	75	15
Classroom / lecture	23.8	75	15

Interior Lighting Loads and Profiles

Table 3.11 E Quest Simulation Model Inputs

Area Type	**Percent area %**	**Lighting (w/sqft)**	**Task light (w/ sqft)**
Classroom/lecture	24.1	1.45	0.00
Corridor	27.9	0.57	0.00
Classroom/lecture	24.2	1.45	0.00
Classroom/lecture	23.8	1.45	0.00

Office equipment loads and profile

Table 3.12 E Quest Simulation Model Inputs

Area Type	**Percent Area %**	**Office Equipment (w/sq ft)**
Classroom/lecture	24.1	1.10
Corridor	27.9	0.0
Classroom/lecture	24.2	1.10
Classroom/lecture	23.8	1.10

Miscellaneous Loads and profiles

Table 3.13 E Quest Simulation Model Inputs

Area Type	**% Area**	**Electric**		**Natural Gas**	
		Load(w/sqft)	**Sensible heat (frac)**	**Load(w/sqft)**	**Sensible heat (frac)**
Classroom/lecture	24.1	0.50	1.0	0.00	1.00
Corridor	27.9	0.00	1.0	0.00	1.00
Classroom/lecture	24.2	0.50	1.0	0.00	1.00
Classroom/lecture	23.8	0.50	1.0	0.00	1.00

HVAC System

Cooling Source – Chilled water coils

Heating Source – Hot water coils

Hot water Source – Hot water loop

System type – Single zone air handlers with HW heat

Return air path – Ducted

Temperatures and Airflow

Seasonal Thermostat Set points

Table 3.14 E Quest Simulation Model Inputs

	Occupied (deg F)		**Unoccupied (deg F)**	
	Cool	**Heat**	**Cool**	**Heat**
Breaks (winter, Spring)	76.0	70.0	82.0	64.0
School in session	76.0	70.0	82.0	64.0
School in session #2	76.0	70.0	82.0	64.0

Design Temperatures	**Indoor**	**Supply**
Cooling Design Temp	75.0 deg F	55.0 deg F
Heating design	72.0 deg F	95.0 deg F

Air Flows : Minimum Design Flow - 0.50 Cfm / sq ft, VAV Maximum flow 100%

Chapter 4 Results

4.1 Introduction

The following chapter presents the results from the simulations and discusses how the glazed area influences the energy balance of the classroom space in relation to factors such as glazing percentage, glazing type orientation and location.

A building is a complex energy system and it is difficult to isolate the influence of one particular factor towards the energy consumption of the space.The results therefore are only an overview and a deeper study of the various factors is required to understand the complete influence of the variables considered.

4.2 Simulation Results

The simulation results for the five different locations are plotted as data graphs and are categorized based on the following:

Space Cooling

Space heating

Area Lights

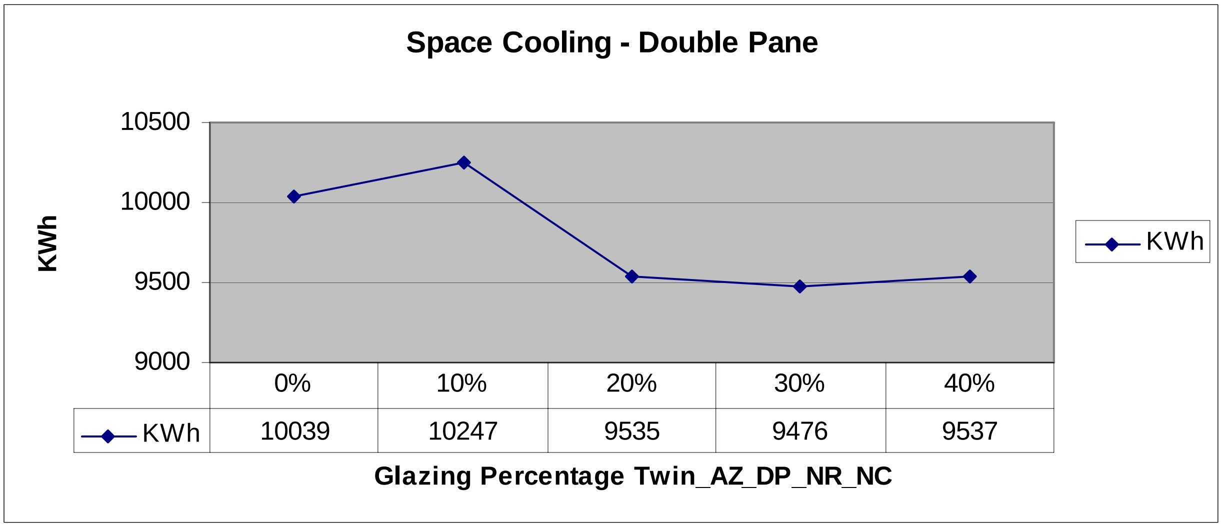
Total Electric consumption

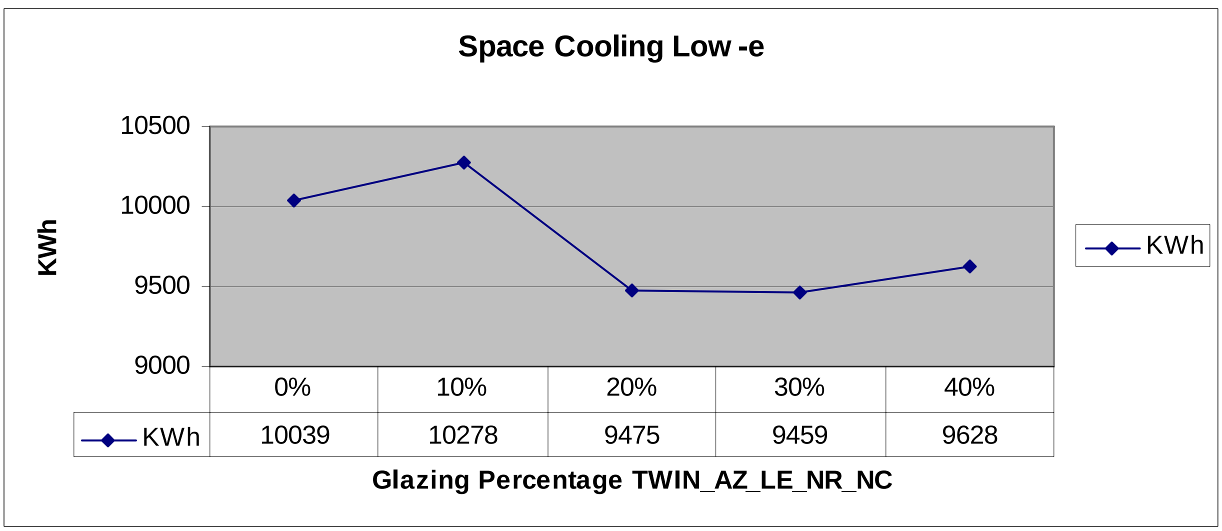
Total Natural Gas consumption

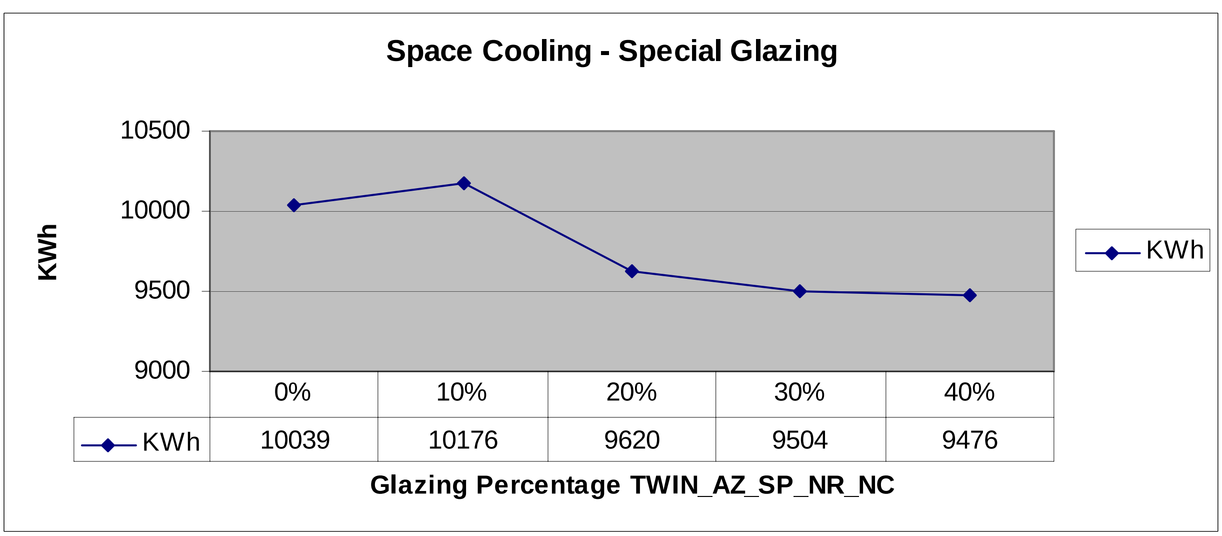
Arizona Data Graphs

North, Non Clerestory

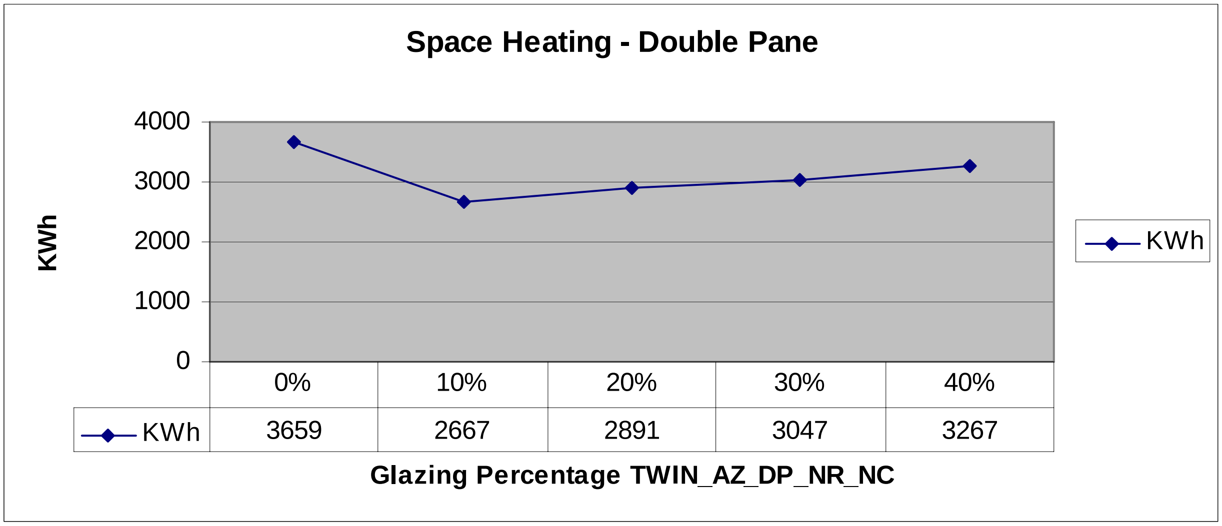
Results for the three different glazing types – Space Cooling

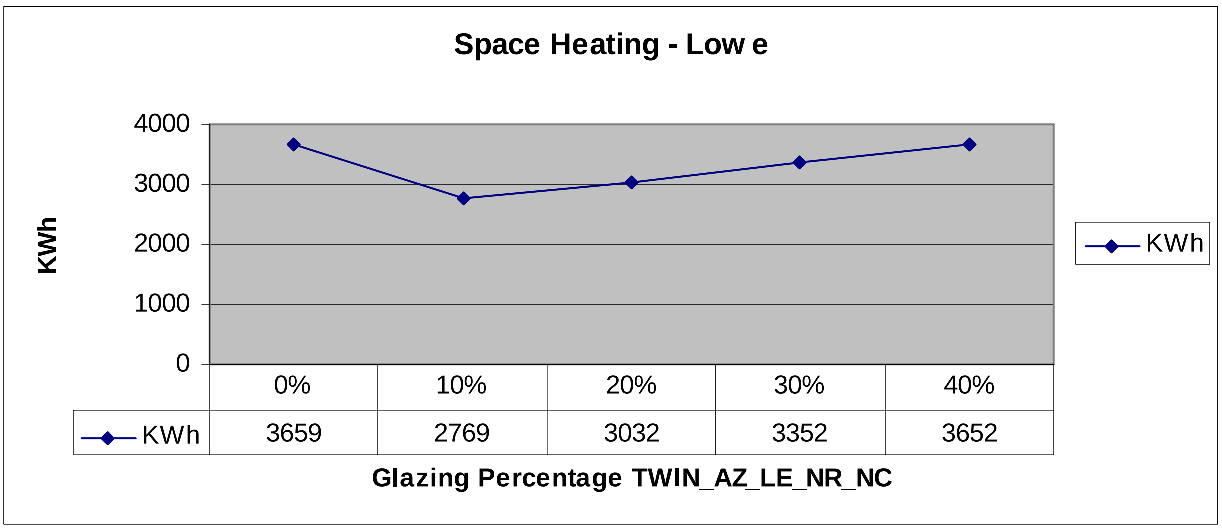


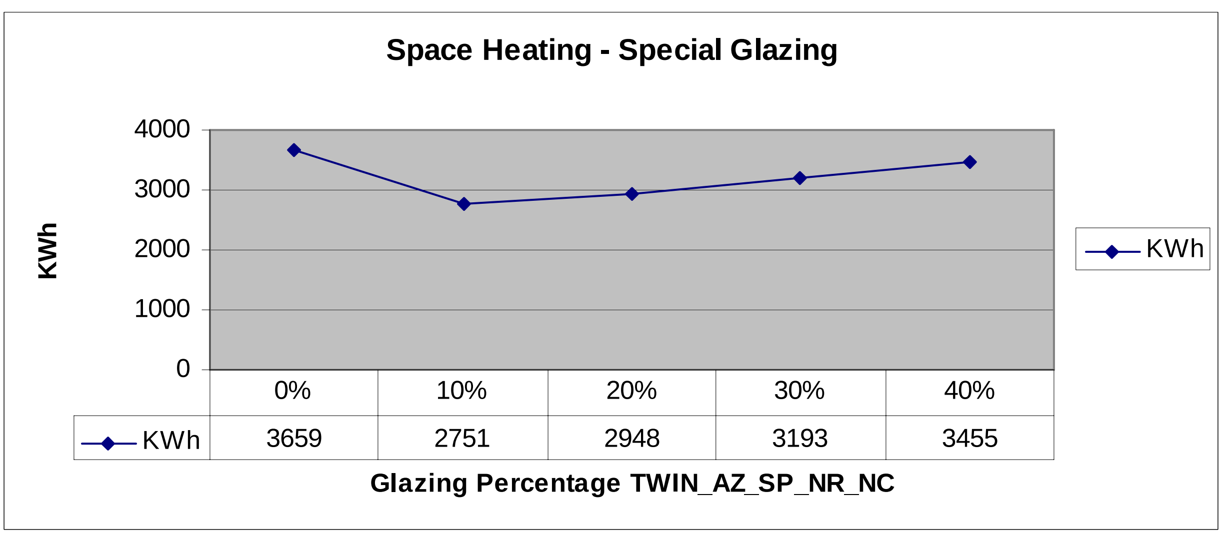




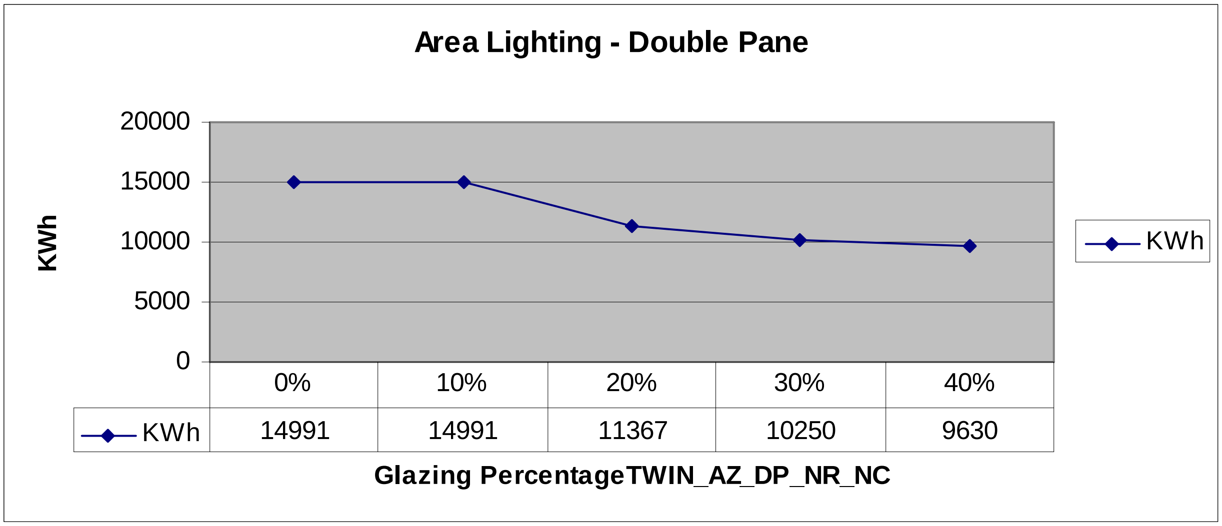
Results for the three different glazing types – Space Heating

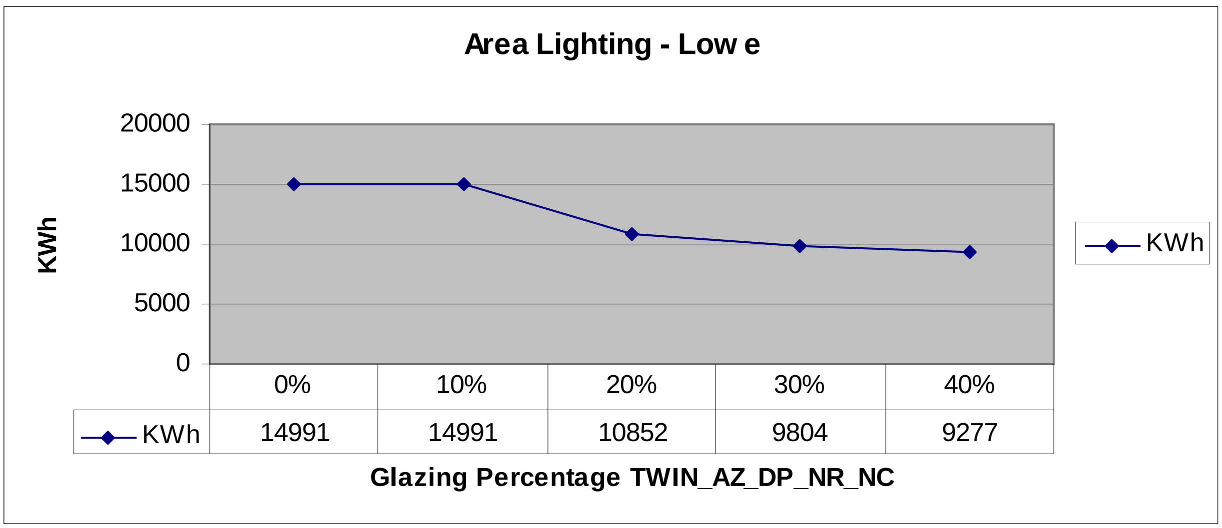


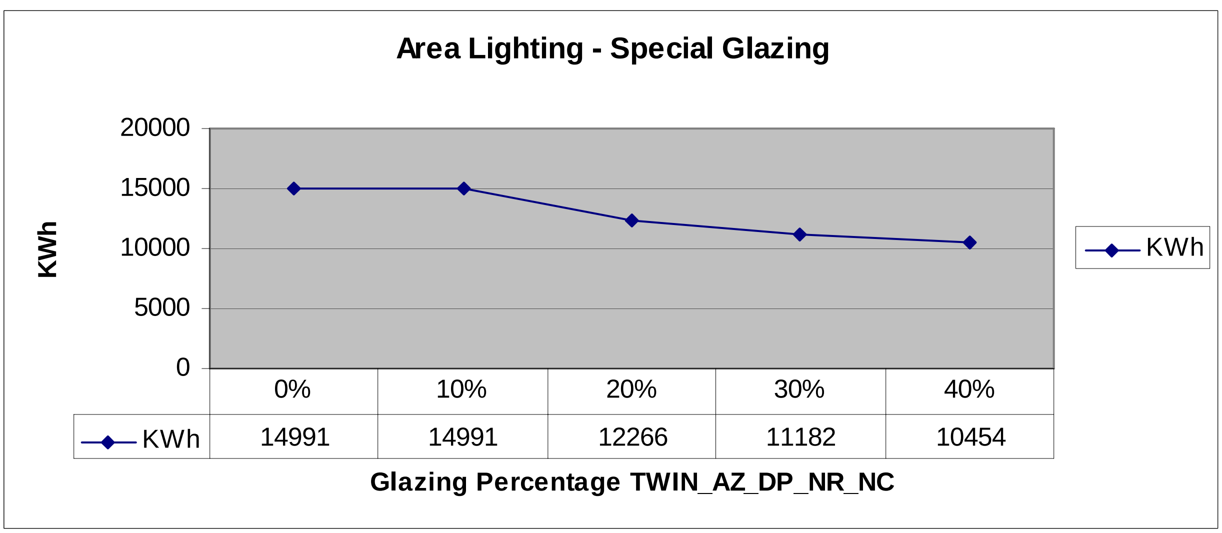




Results for the three different glazing types – Area Lighting

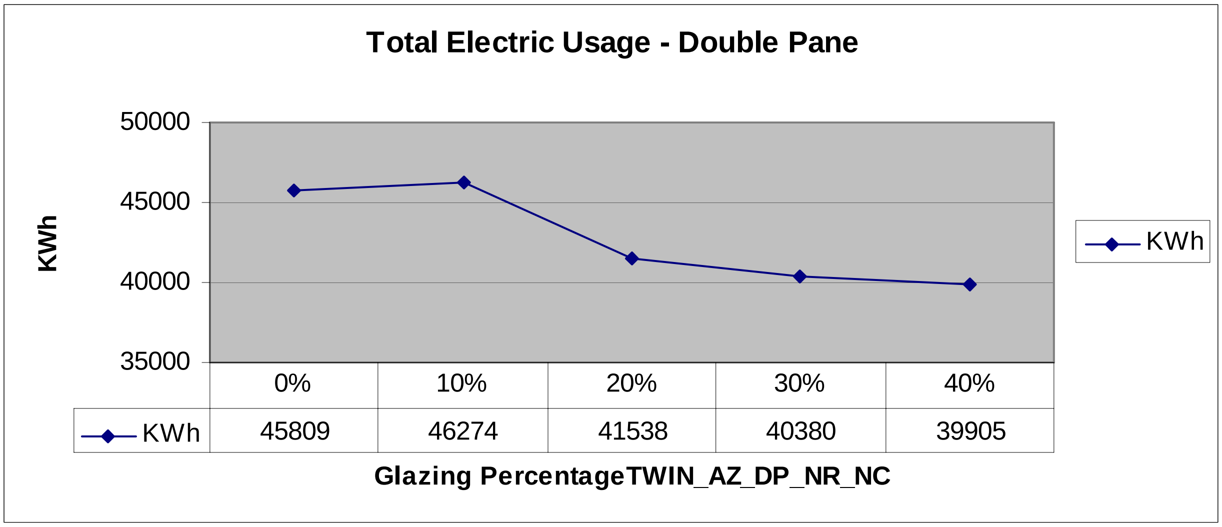


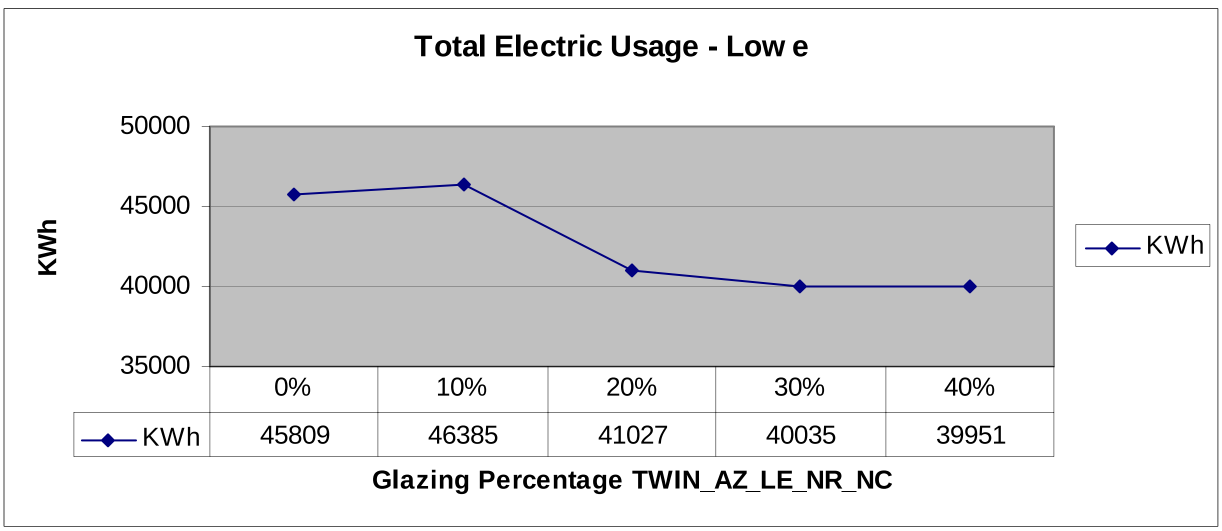


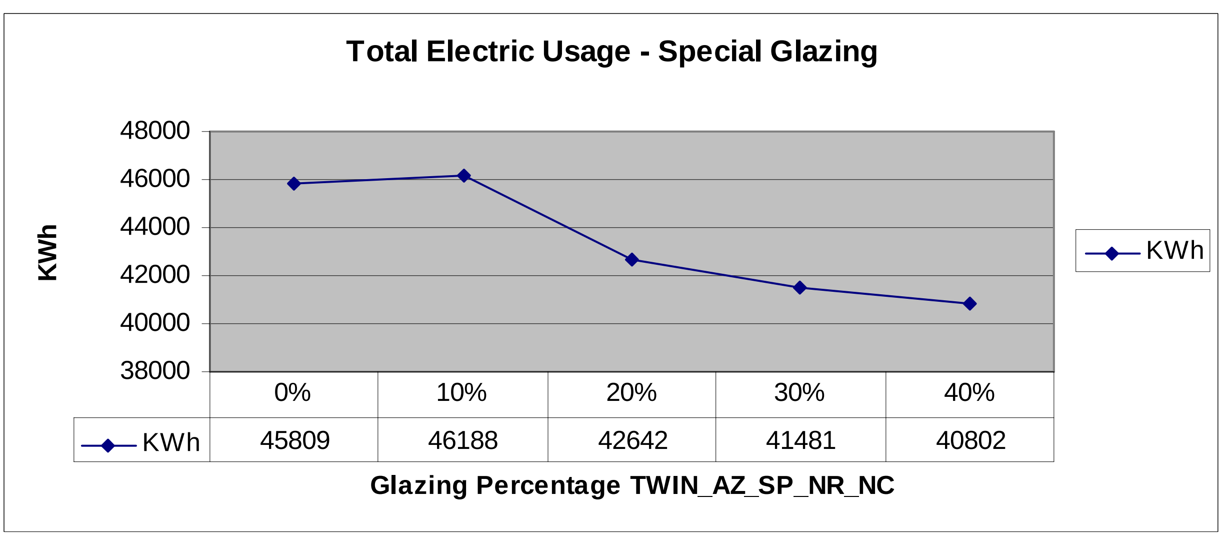


Total electric use

Results for the three different glazing types Total Electric Usage

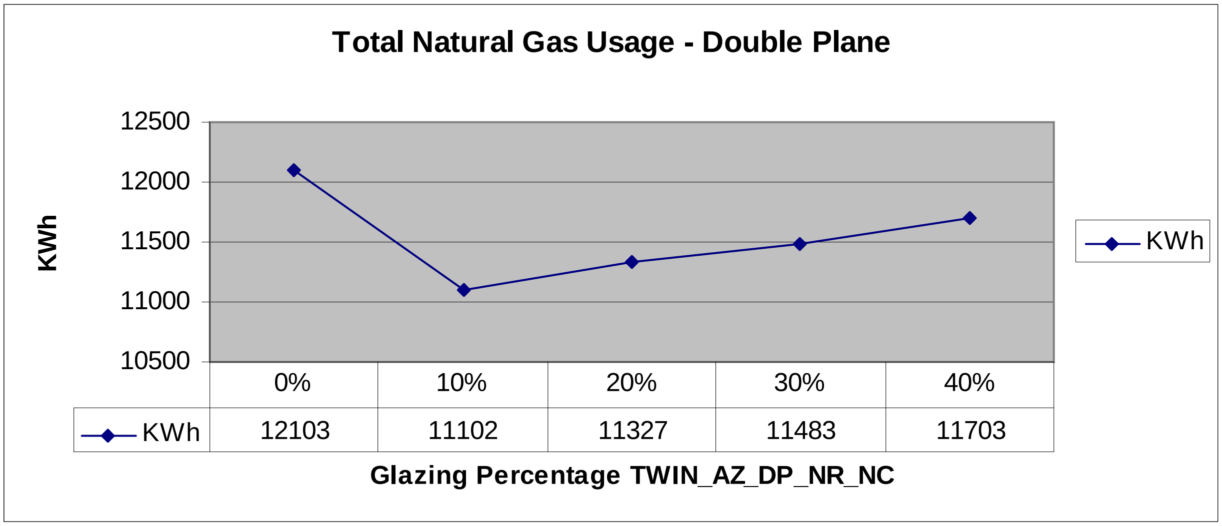


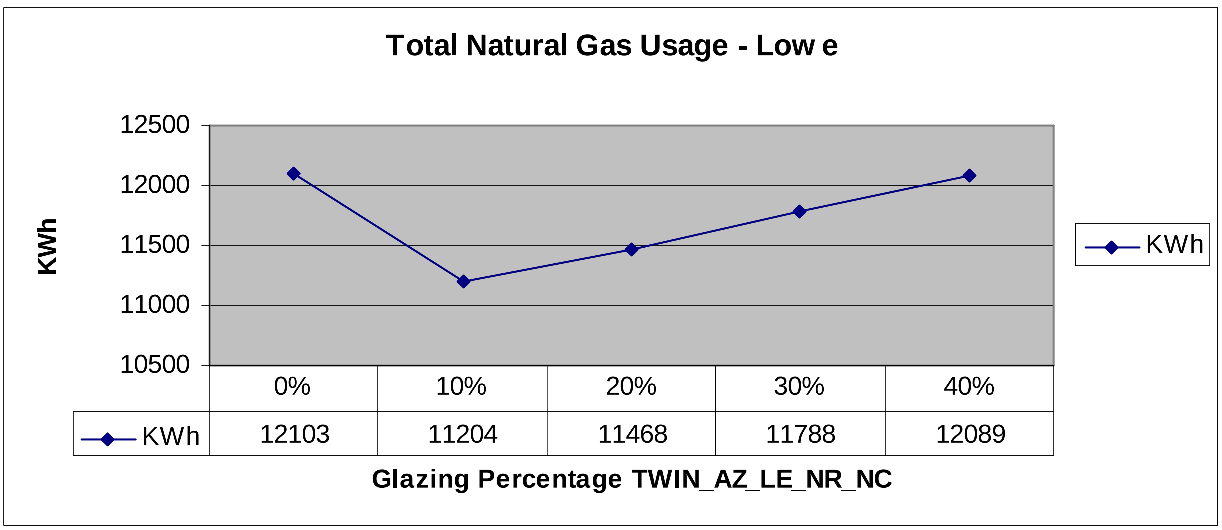


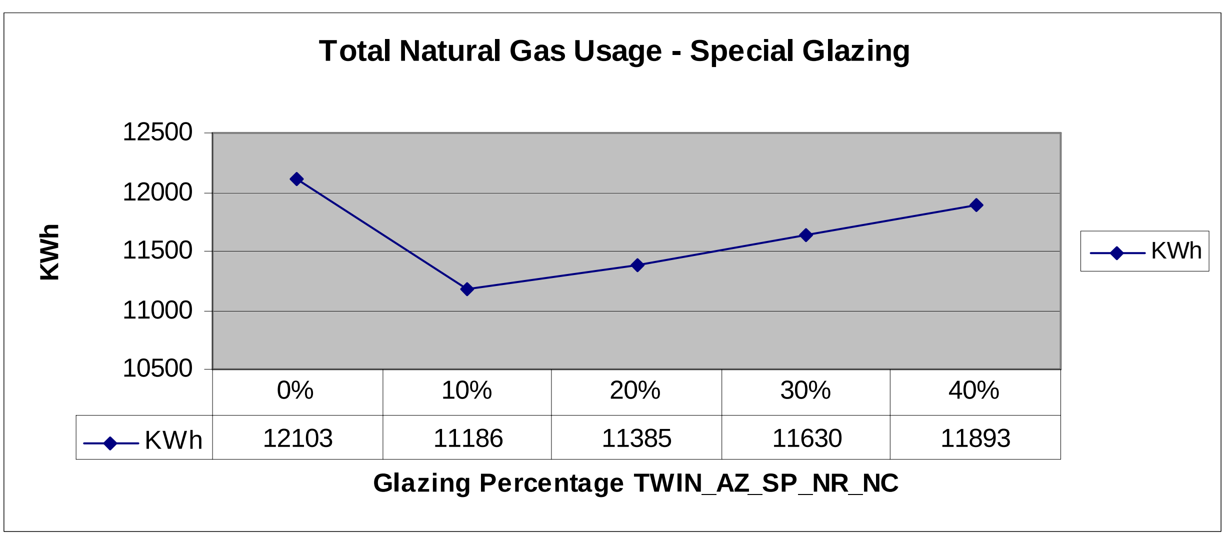


Total natural gas use

Results for the three different glazing types Total Natural Gas Usage



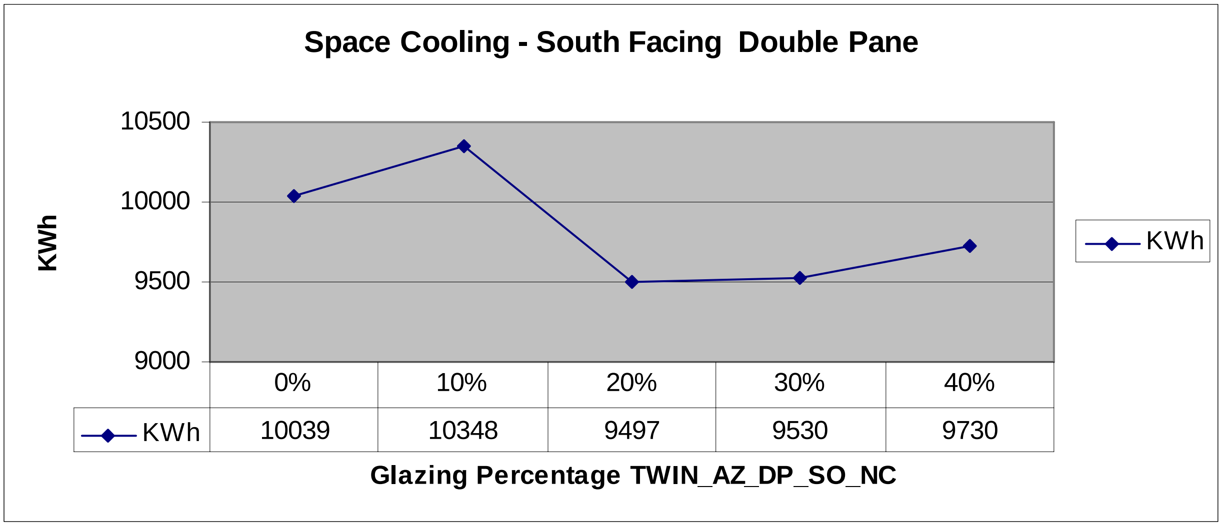




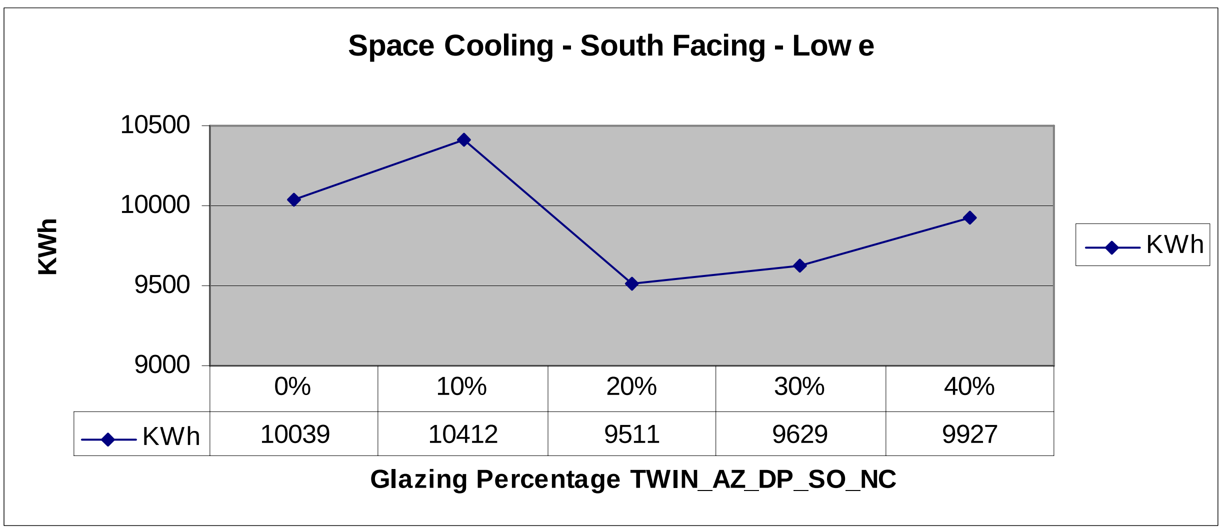
Arizona – space cooling

South, Non Clerestory

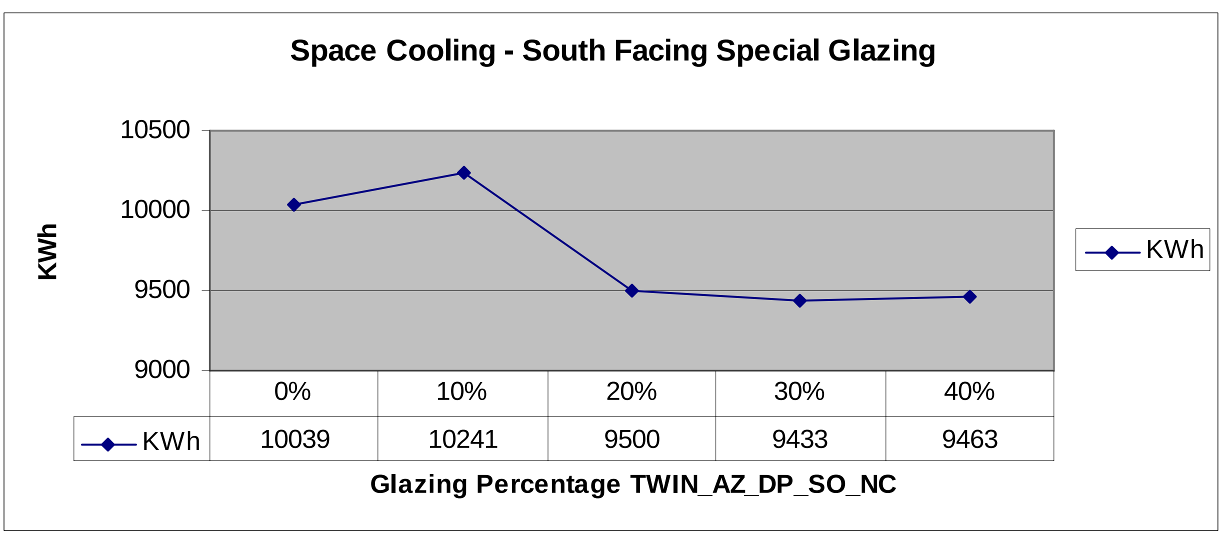
Results for the three different glazing types – Space Cooling



	0%	10%	20%	30%	40%
KWh	10039	10348	9497	9530	9730

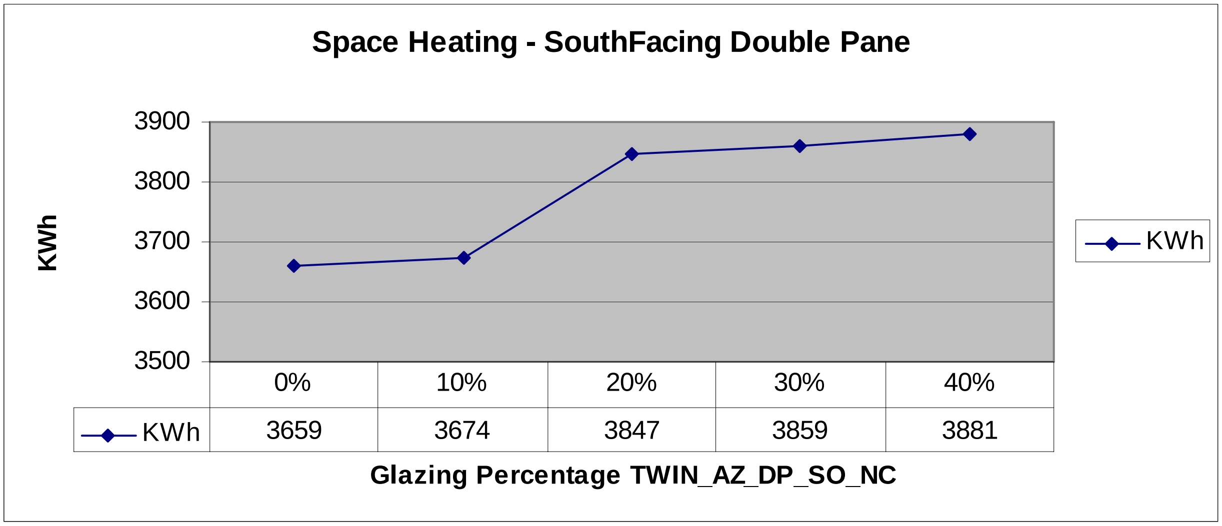


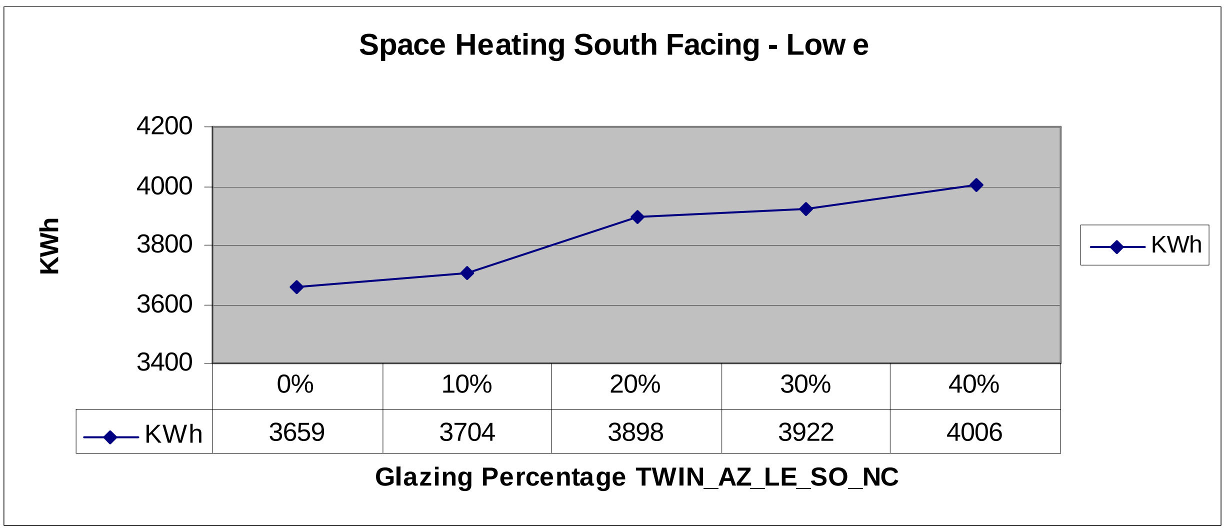
	0%	10%	20%	30%	40%
KWh	10039	10412	9511	9629	9927

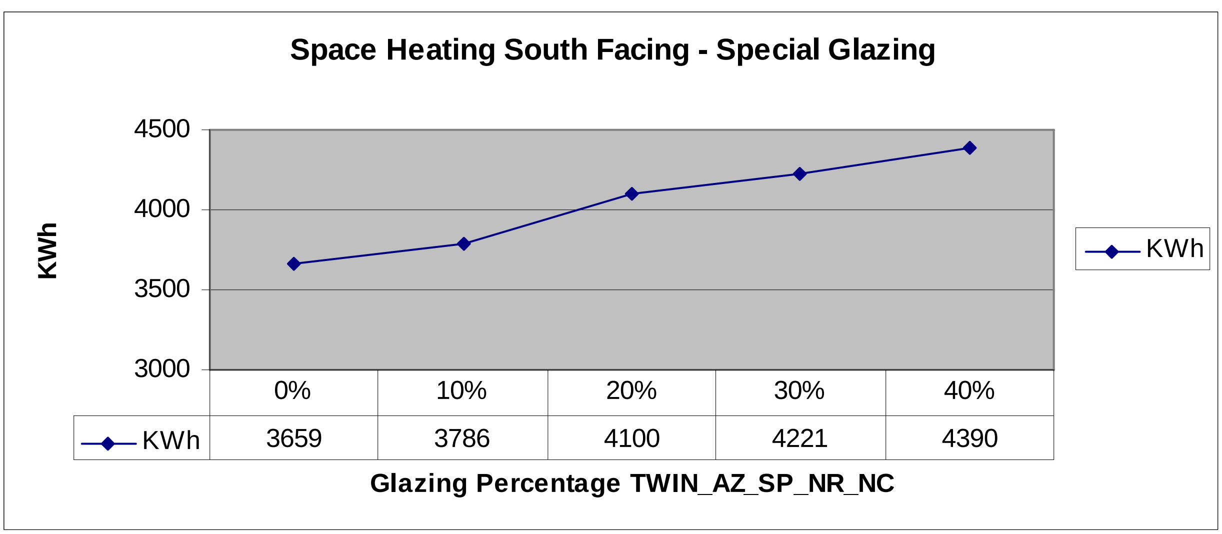


	0%	10%	20%	30%	40%
KWh	10039	10241	9500	9433	9463

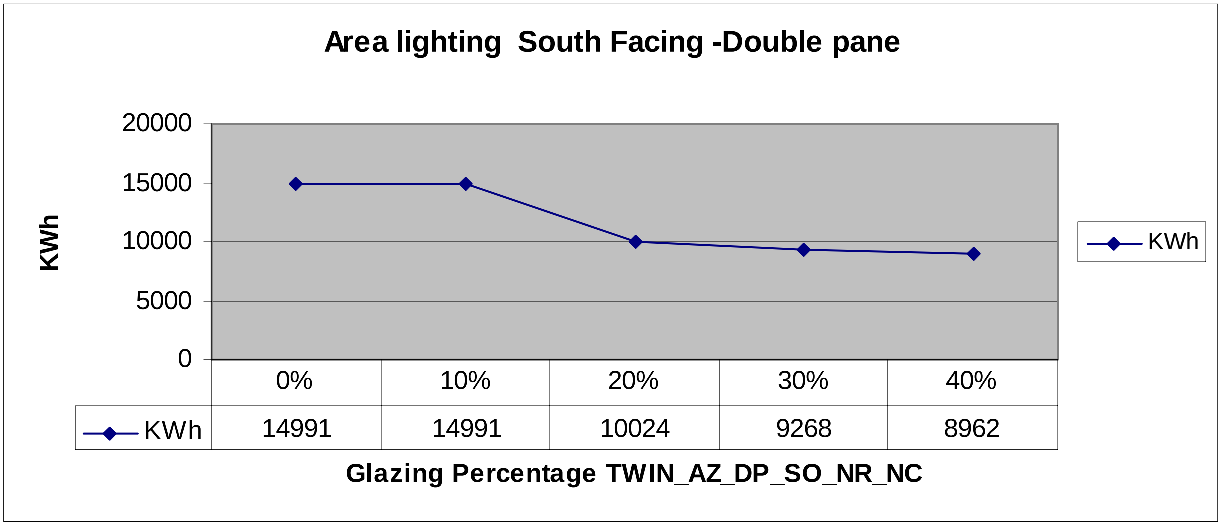
Results for the three different glazing types –Space Heating



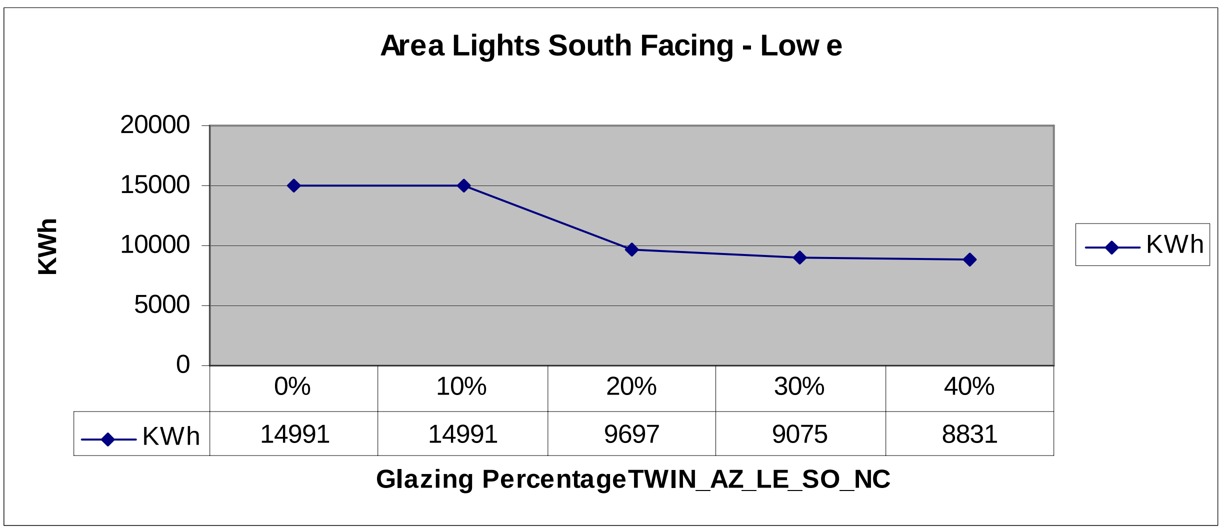




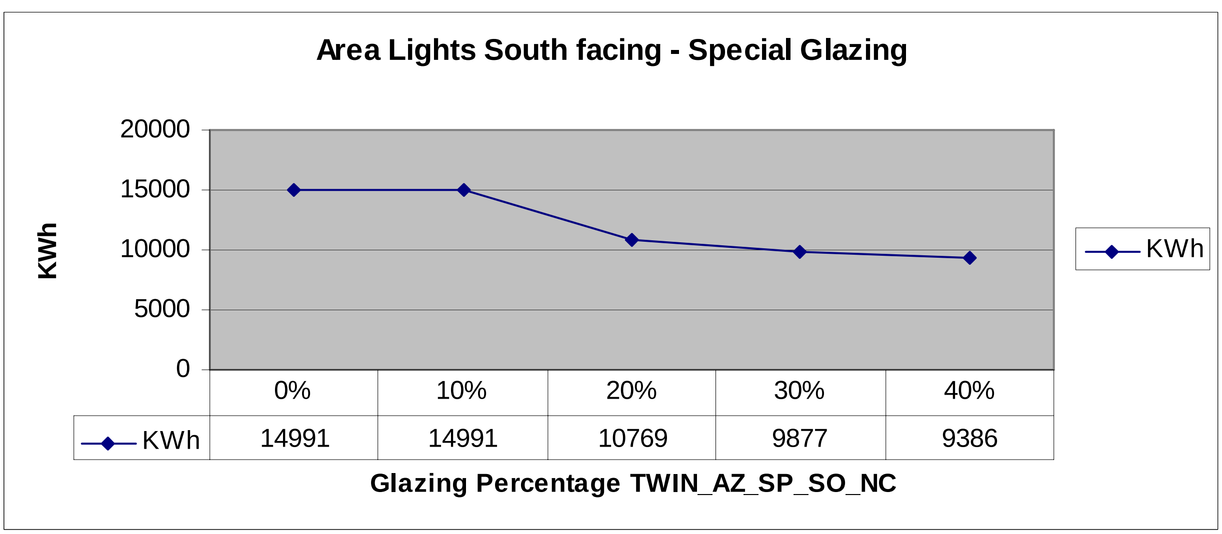
Results for the three different glazing types – Area Lighting



	0%	10%	20%	30%	40%
KWh	14991	14991	10024	9268	8962



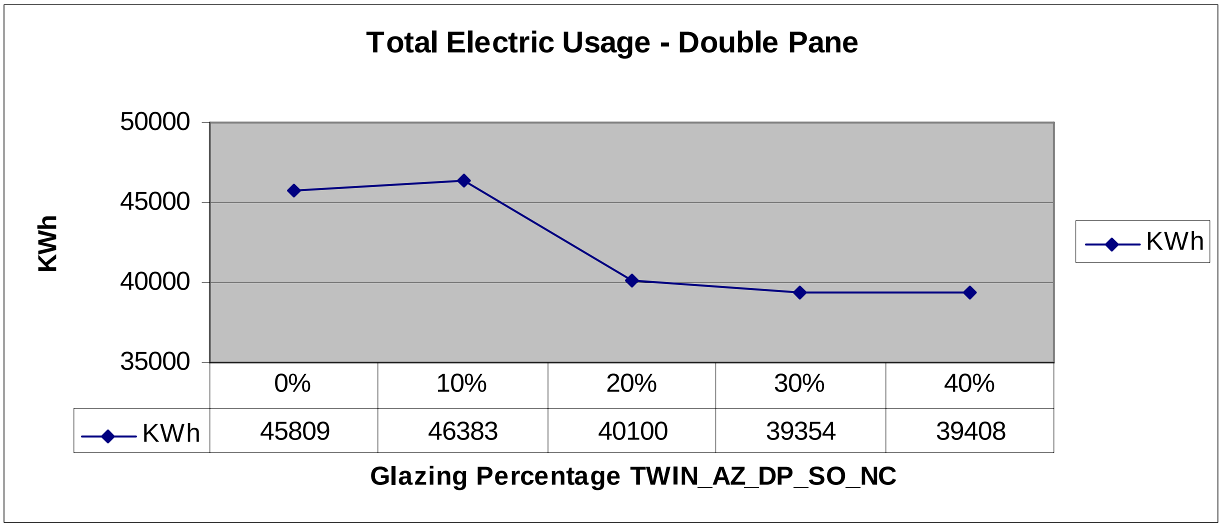
	0%	10%	20%	30%	40%
KWh	14991	14991	9697	9075	8831

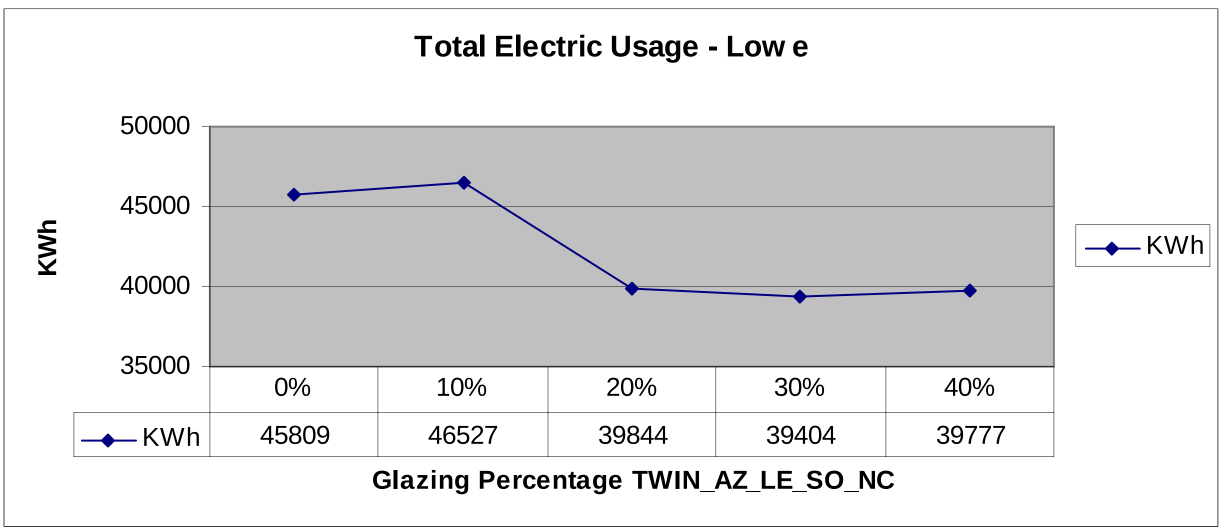


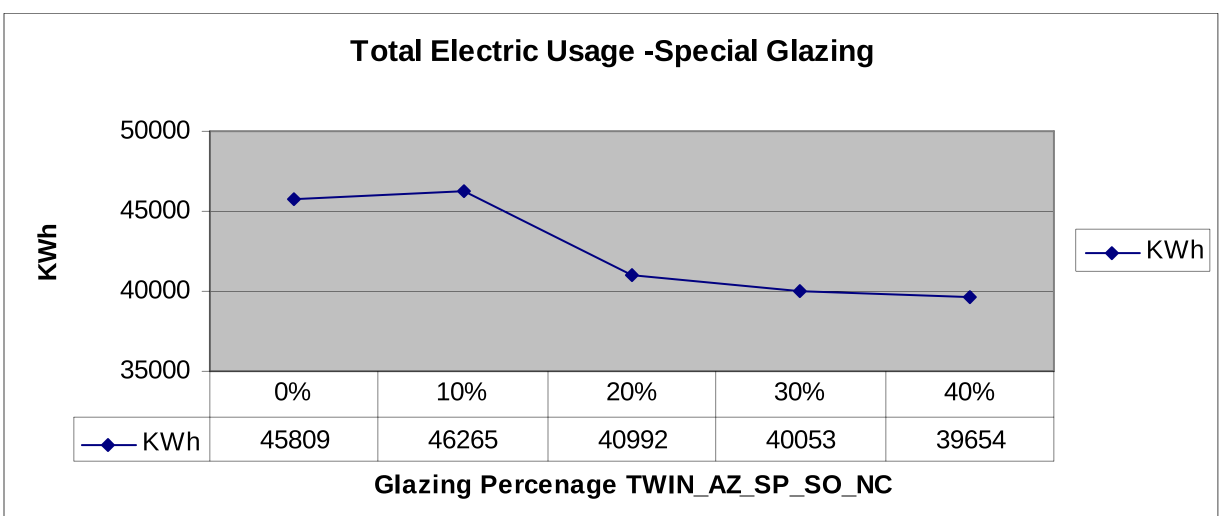
	0%	10%	20%	30%	40%
KWh	14991	14991	10769	9877	9386

Arizona – total electric use

Results for the three different glazing types – Total Electric Usage

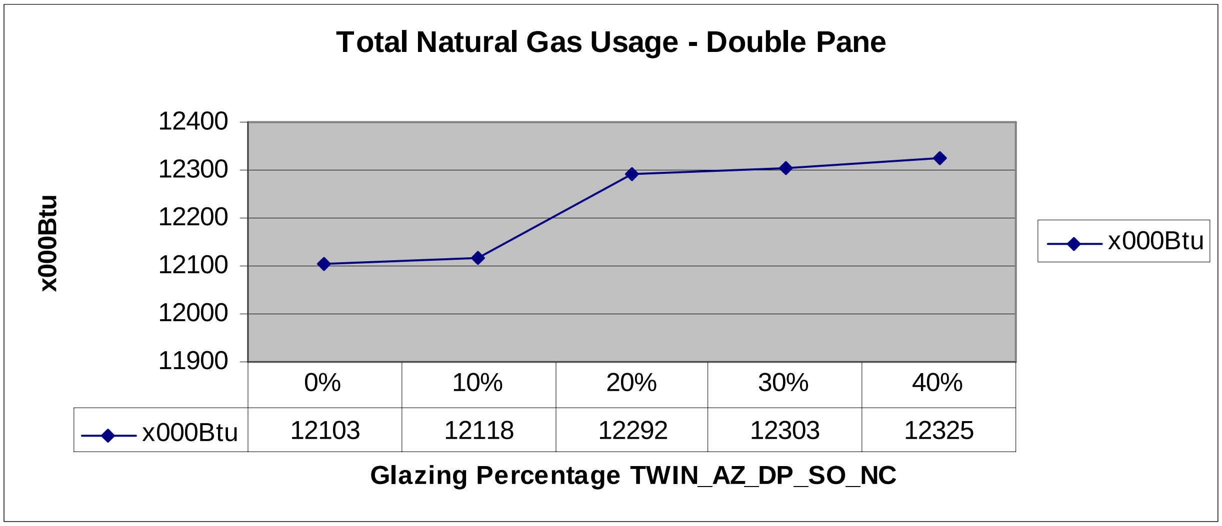




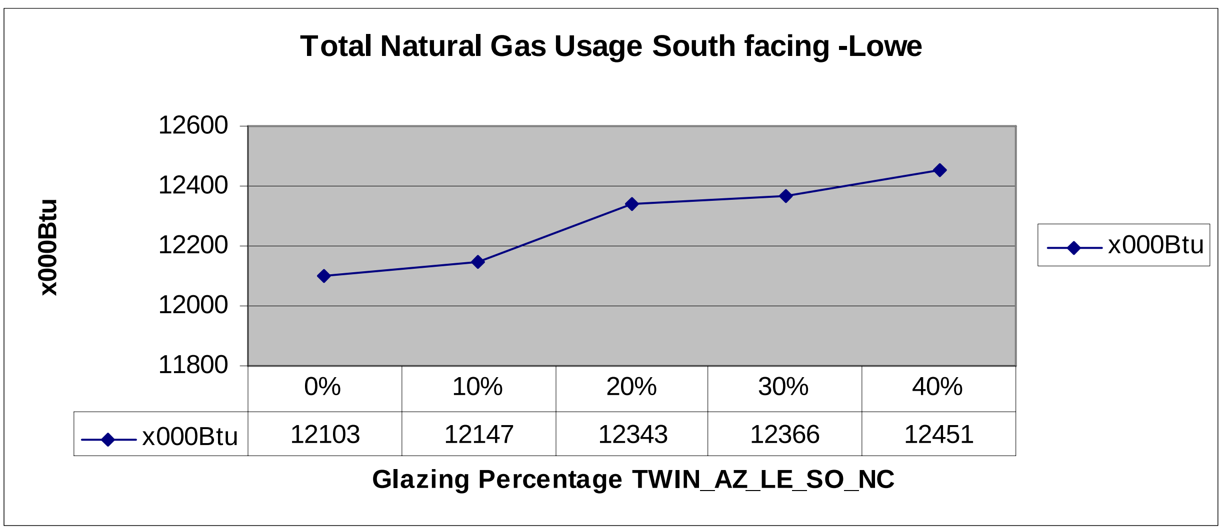


Arizona – total natural gas use

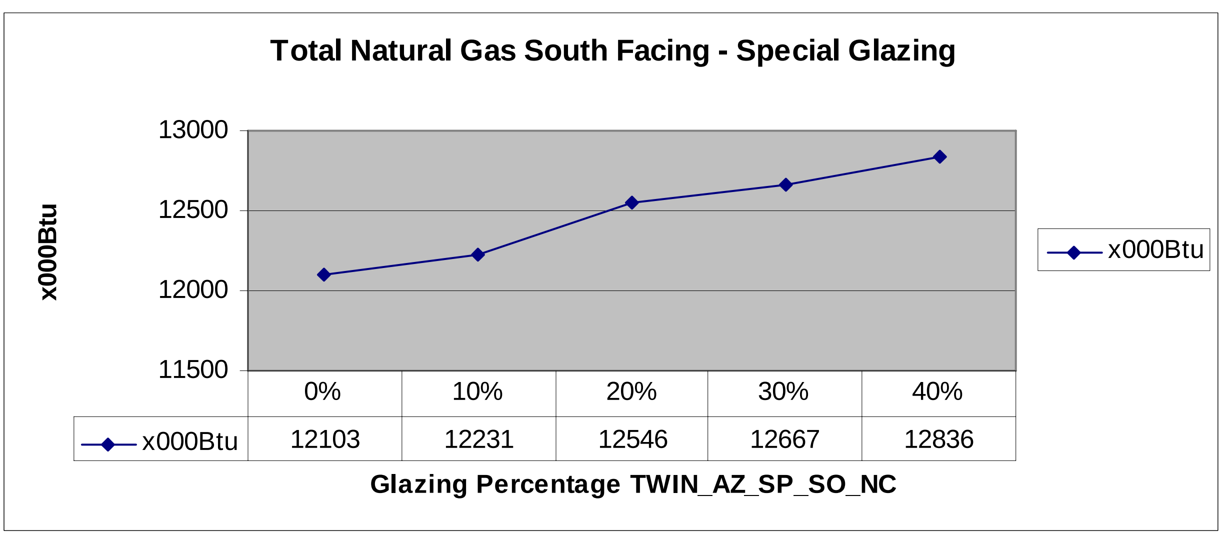
Results for the three different glazing types – Total Natural Gas Usage



	0%	10%	20%	30%	40%
x000Btu	12103	12118	12292	12303	12325



	0%	10%	20%	30%	40%
x000Btu	12103	12147	12343	12366	12451

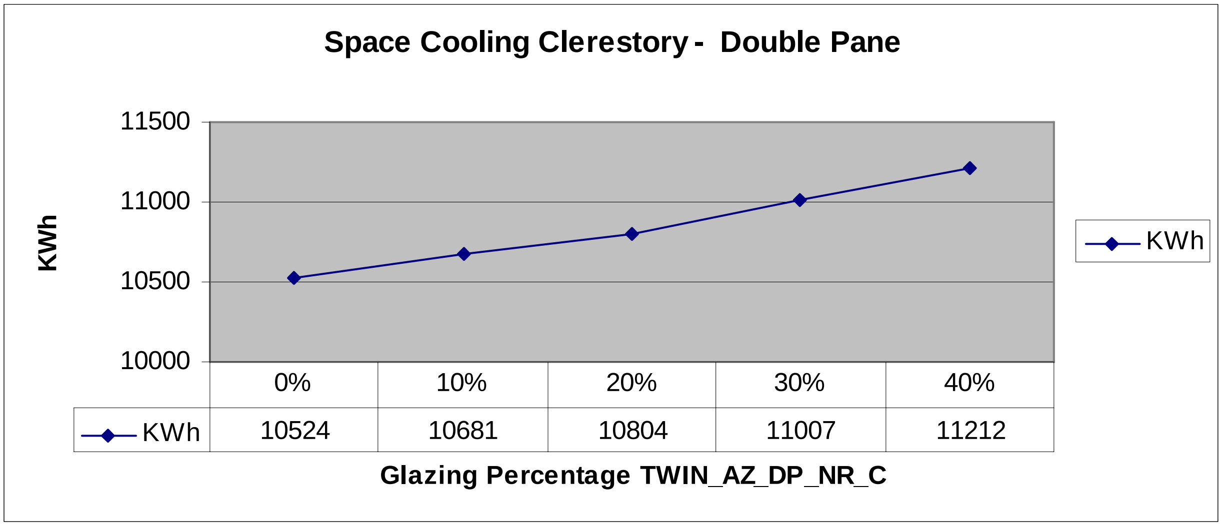


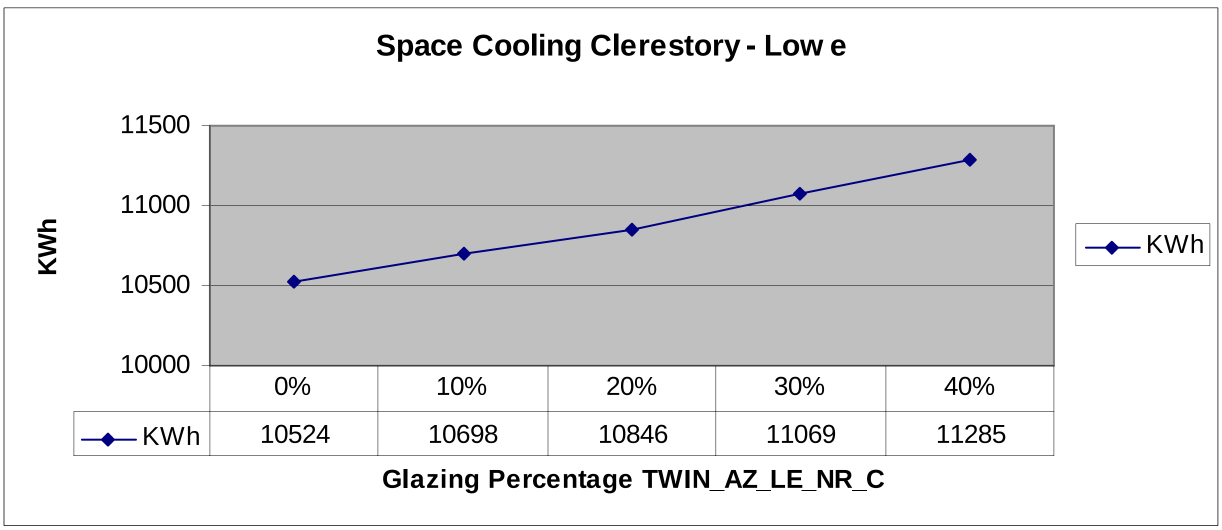
	0%	10%	20%	30%	40%
x000Btu	12103	12231	12546	12667	12836

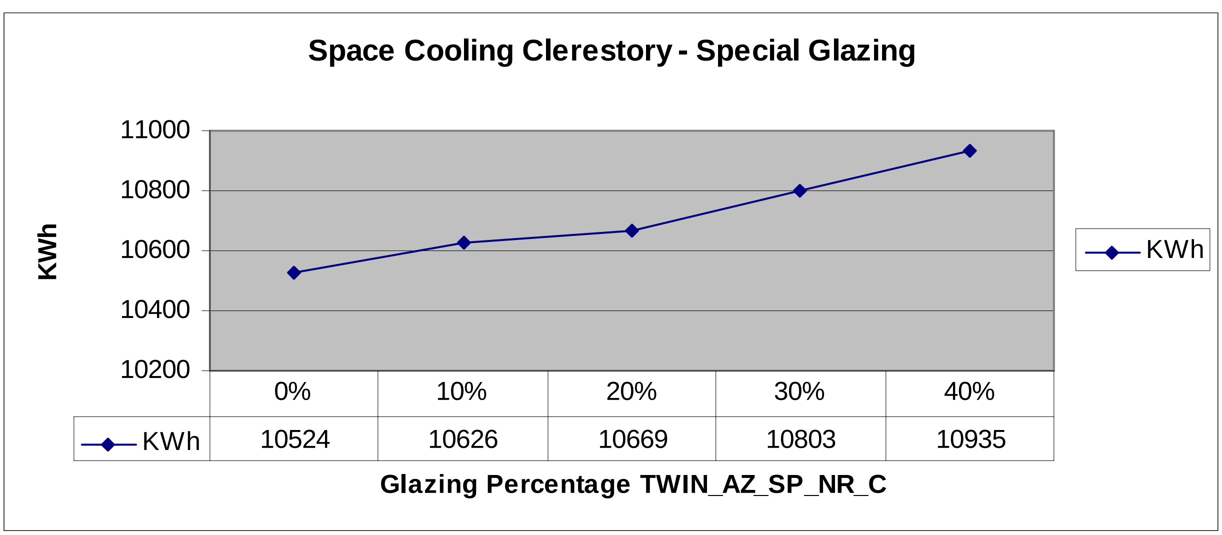
Arizona – space cooling

North, Clerestory

Results for the three different glazing types Space Cooling

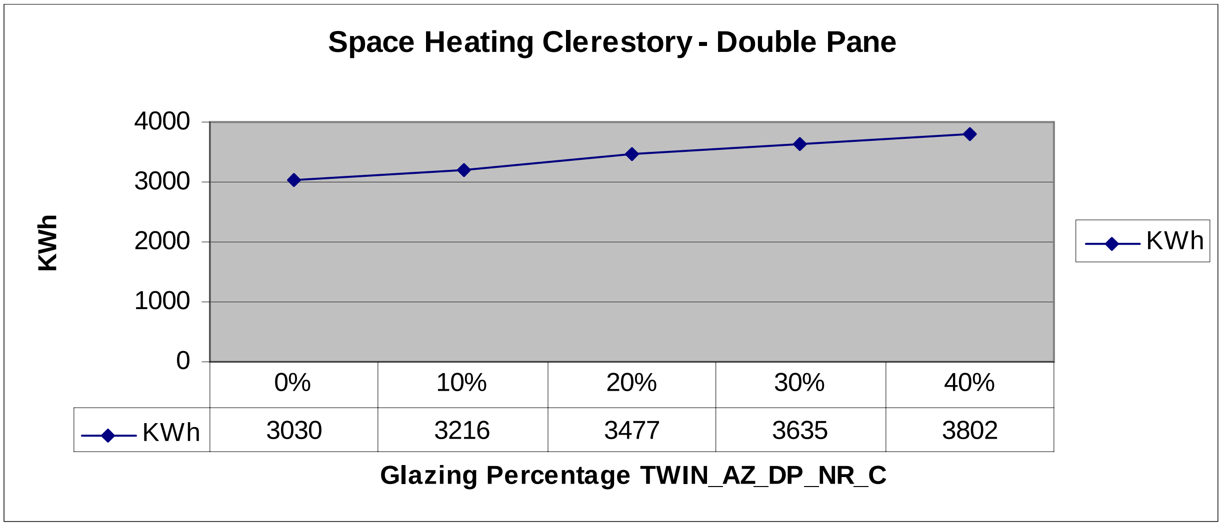


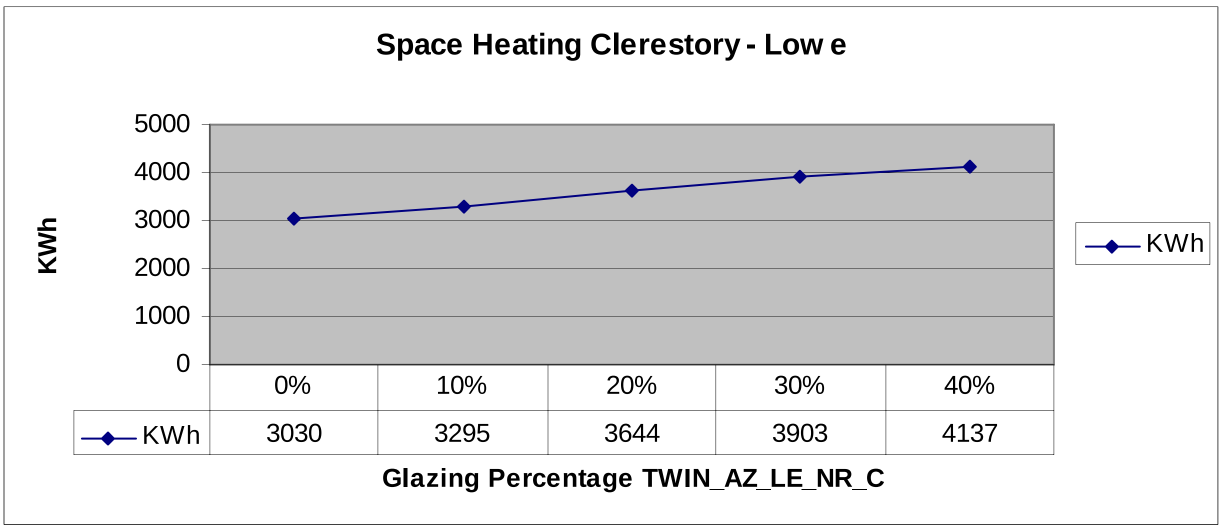


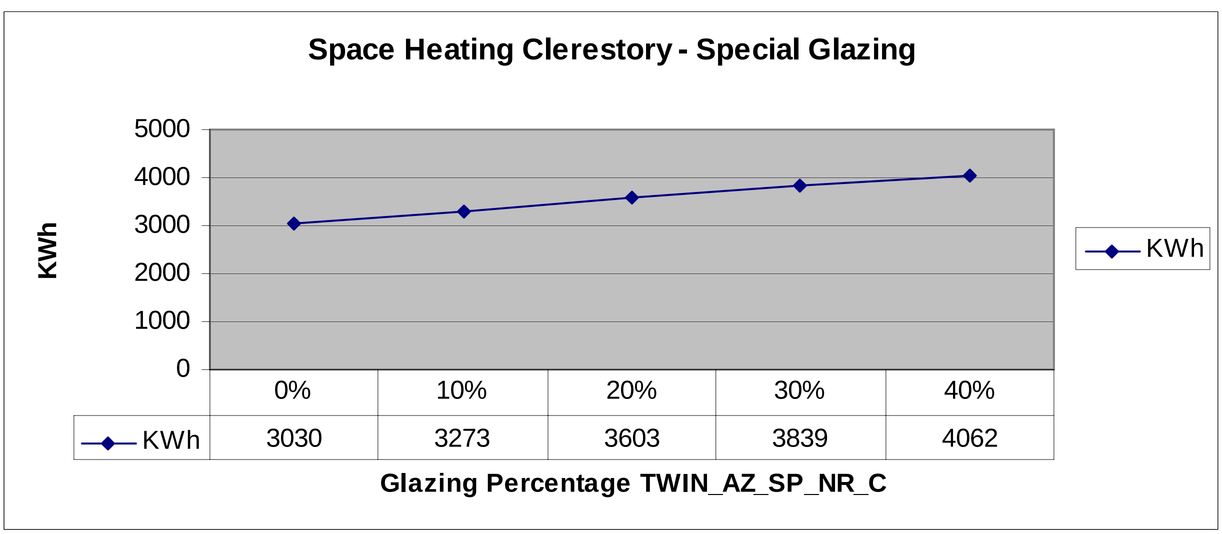


Arizona – space heating

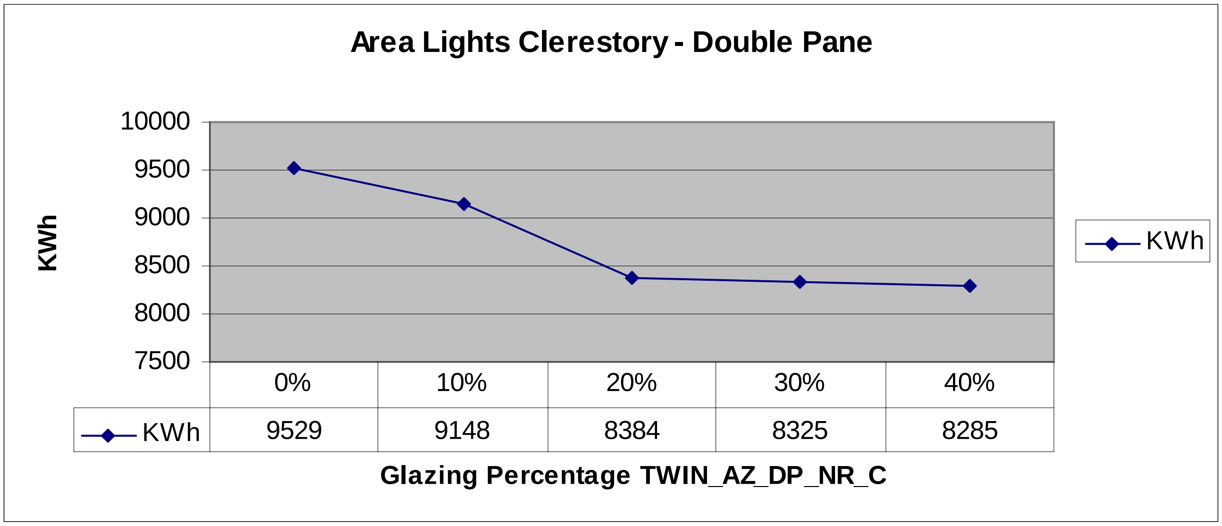
Results for the three different glazing types – Space Heating

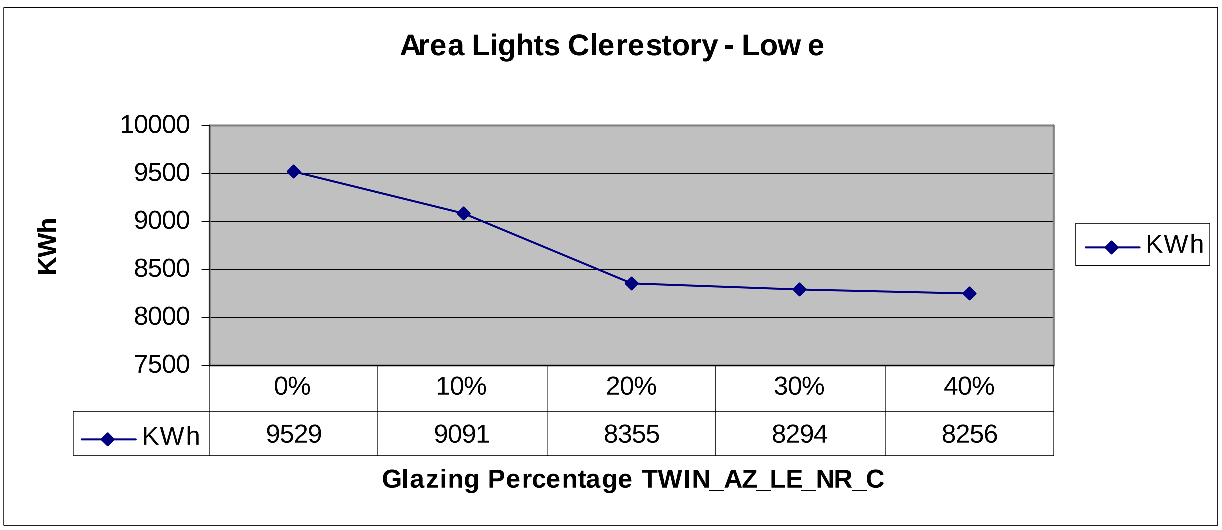


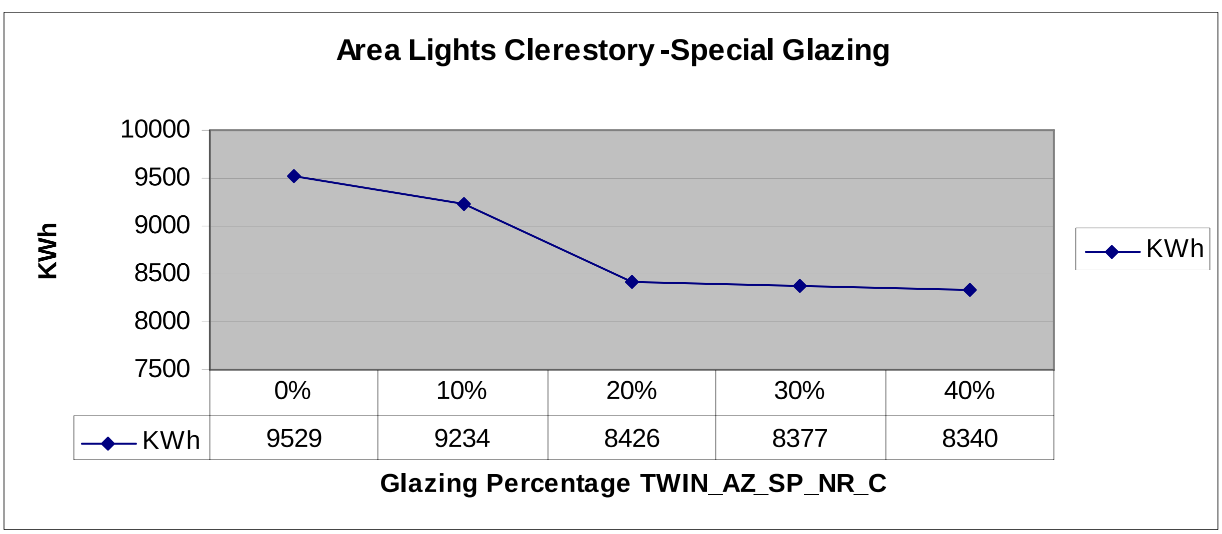




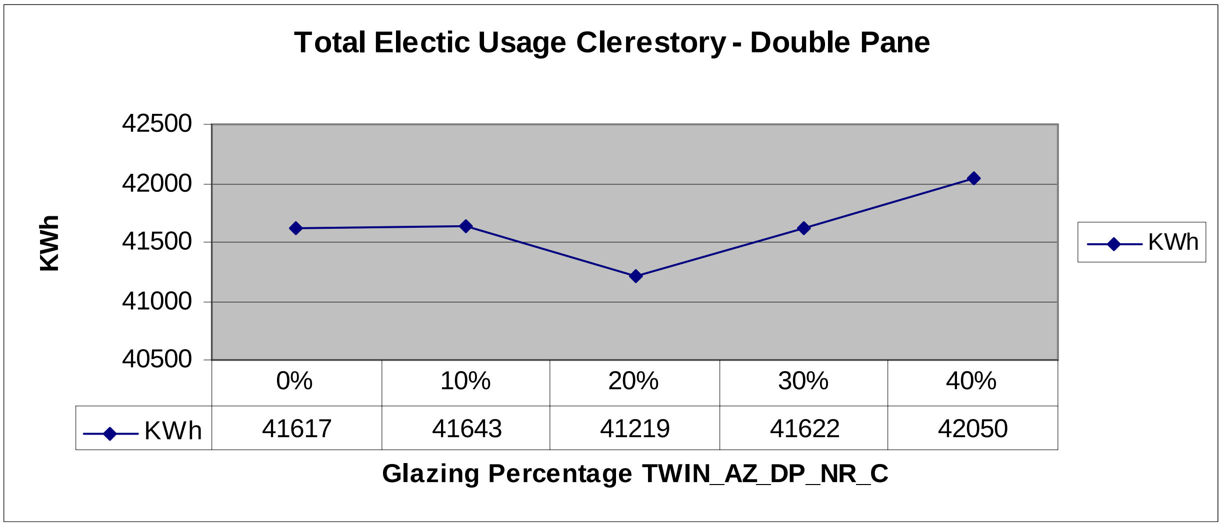
Results for the three different glazing types – Area Lights

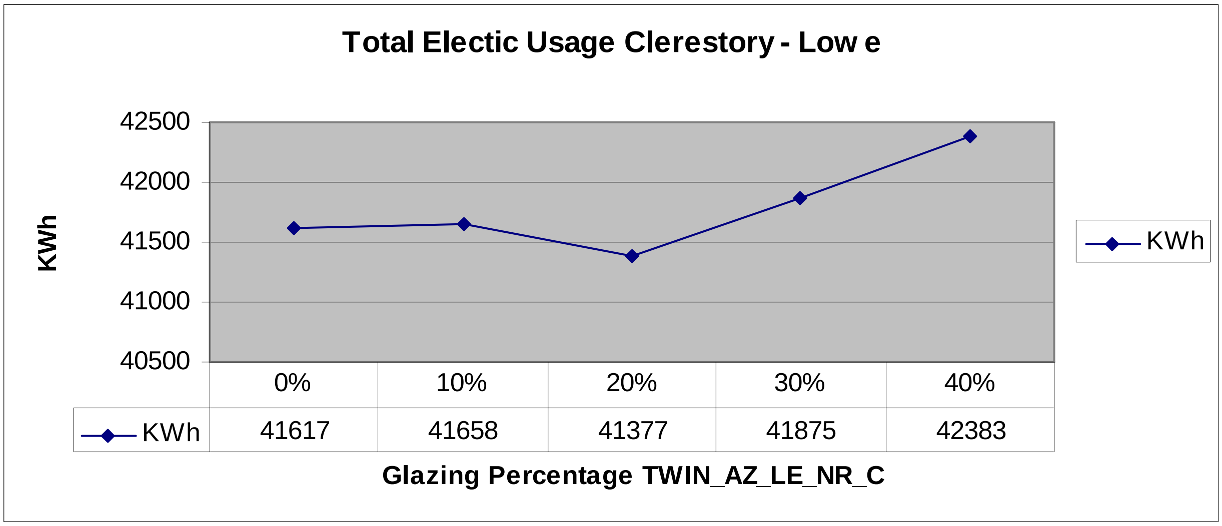


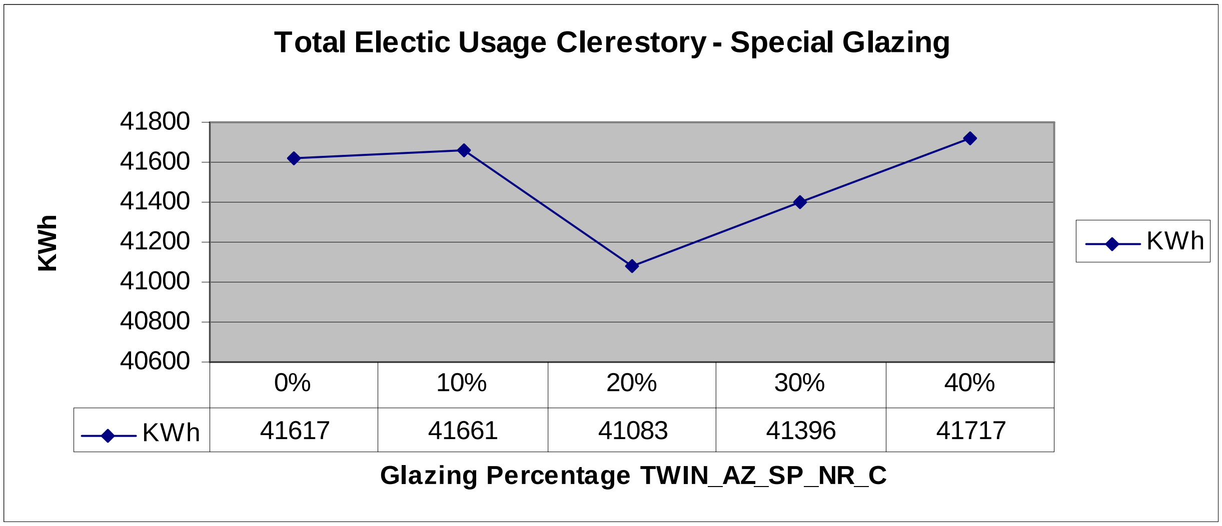




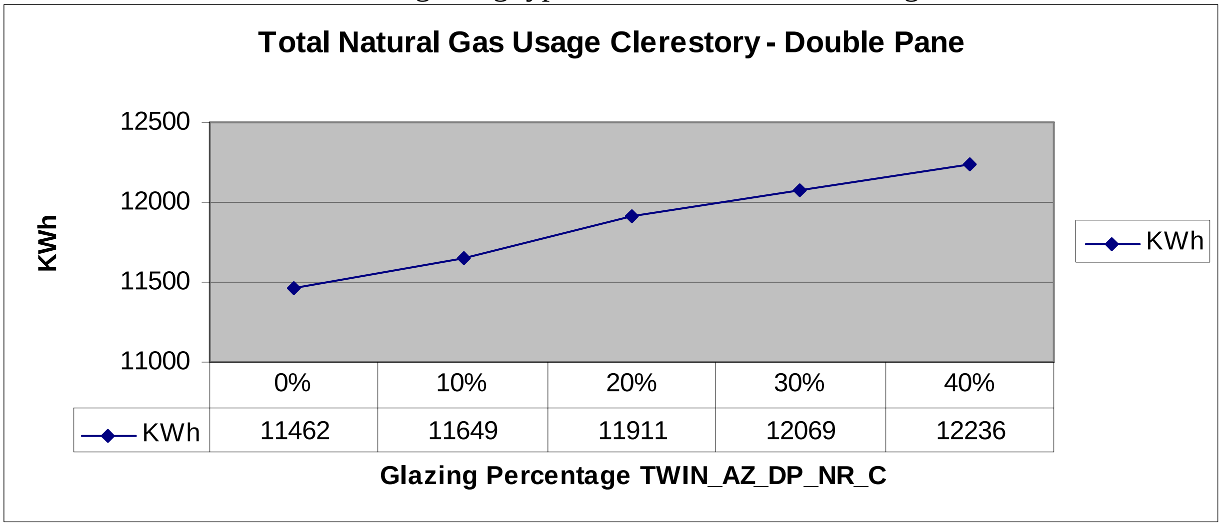
Results for the three different glazing types – Total Electric Usage



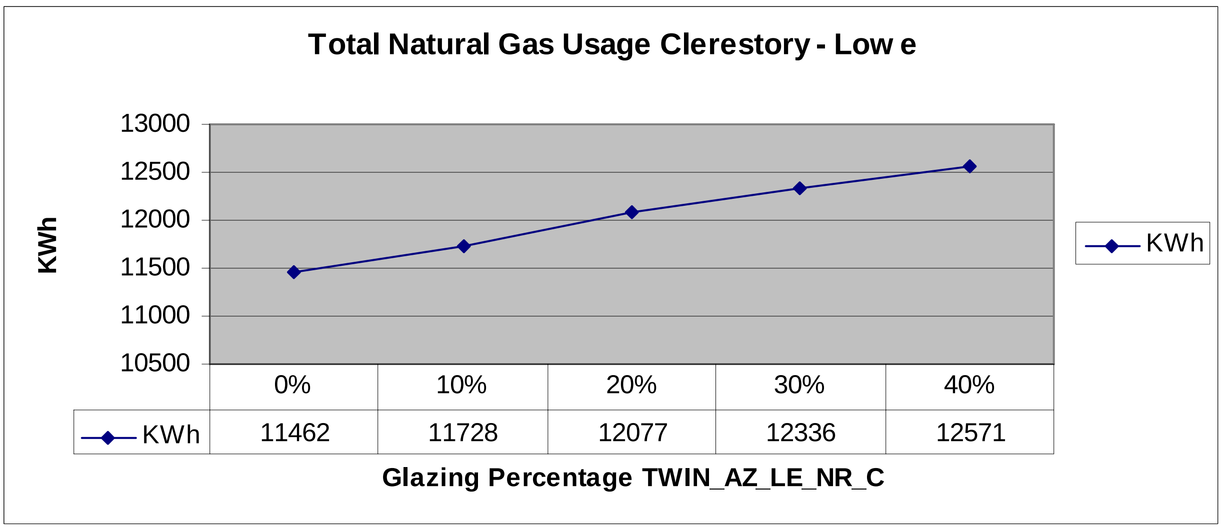




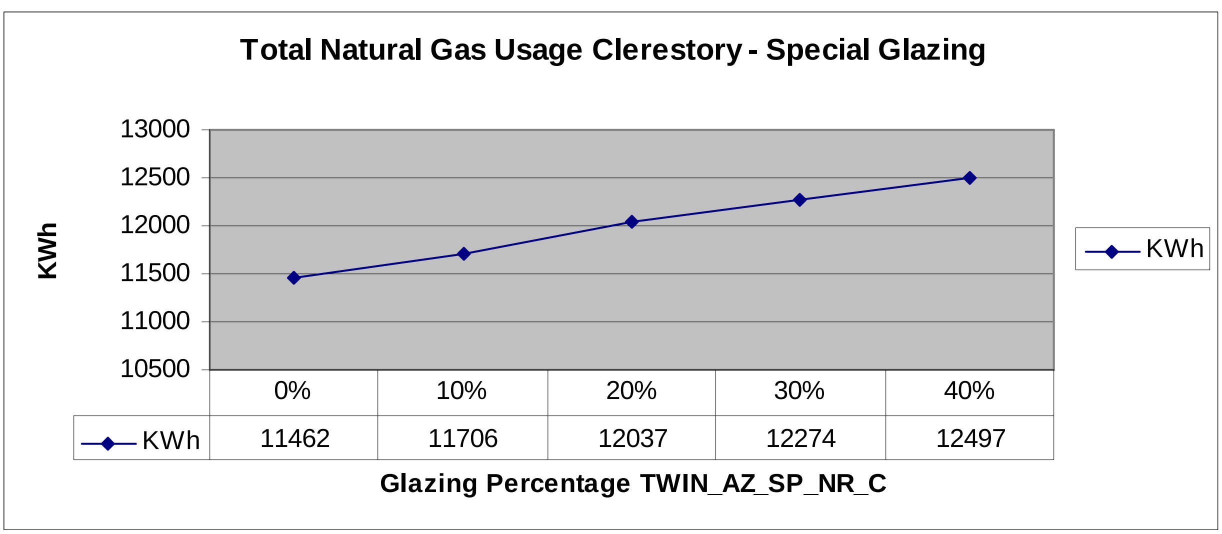
Results for the three different glazing types – Total Natural Gas Usage



	0%	10%	20%	30%	40%
KWh	11462	11649	11911	12069	12236



	0%	10%	20%	30%	40%
KWh	11462	11728	12077	12336	12571



	0%	10%	20%	30%	40%
KWh	11462	11706	12037	12274	12497

4.2.1 Results summary The following tables give a summary of the results in brief. The tables present an analysis of the simulation results. The analysis is categorized according to orientation (North, South) and Clerestory glazing and also with respect to the types of glazing tested. (Double pane, Low - e, Special Glazing)

Arizona			
	North _ Non Clerestory		
Double Pane	Window % with Lowest Energy Consumption	Window % withHighest Energy Consumption	
Space Cooling (KWh)	30%	10%	
Space Heating (x000Btu)	10%	0%	
Area Lights (KWh)	40%	0-10%	
Total Electric Usage	40%	10%	
Total Natural Gas Usage (x000Btu)	10%	0%	
Conclusion: The effective percentage ideal for this situation lies between 30 - 40 %			
	North _ Non Clerestory		
Low e	Window % with Lowest Energy Consumption	Window % withHighest Energy Consumption	
Space Cooling (KWh)	30%	10%	
Space Heating (x000Btu)	10%	0%	
Area Lights (KWh)	40%	0-10%	
Total Electric Usage	40%	10%	
Total Natural Gas Usage (x000Btu)	10%	0%	
Conclusion: The effective percentage ideal for this situation lies between 30-40%			
	North _ Non Clerestory		
Special Glazing	Window % with Lowest Energy Consumption	Window % withHighest Energy Consumption	
Space Cooling (KWh)	40%	10%	
Space Heating (x000Btu)	10%	0%	
Area Lights (KWh)	40%	0-10%	
Total Electric Usage	40%	10%	
Total Natural Gas Usage (x000Btu)	10%	0%	
Conclusion: The effective percentage ideal for this situation lies between 40%			
Comparison	Total Electic Consumption	Total Natural Gas Consumption	
Double pane	39905	11483	
Low e	39951	11788	
Special Glazing	40802	11630	
Optimum Energy consumption will be achived for this situation 30 - 40 % Double Pane Glass			

Arizona	South _ Non Clerestory		
Double Pane	Window % with Lowest Energy Consumption	Window % withHighest Energy Consumption	
Space Cooling (KWh)	20%	10%	
Space Heating (x000Btu)	0%	40%	
Area Lights (KWh)	40%	0-10%	
Total Electric Usage	30%	10%	
Total Natural Gas Usage (x000Btu)	0%	40%	
Conclusion: The effective percentage ideal for this situation lies between 0 - 30%			
	South _ Non Clerestory		
Low e	Window % with Lowest Energy Consumption	Window % withHighest Energy Consumption	
Space Cooling (KWh)	20%	10%	
Space Heating (x000Btu)	0%	40%	
Area Lights (KWh)	40%	0-10%	
Total Electric Usage	30%	10%	
Total Natural Gas Usage (x000Btu)	0%	40%	
Conclusion: The effective percentage ideal for this situation lies between 0 - 30 %			
	South _ Non Clerestory		
Special Glazing	Window % with Lowest Energy Consumption	Window % withHighest Energy Consumption	
Space Cooling (KWh)	30%	10%	
Space Heating (x000Btu)	0%	40%	
Area Lights (KWh)	40%	0-10%	
Total Electric Usage	40%	10%	
Total Natural Gas Usage (x000Btu)	0%	40%	
Conclusion: The effective percentage ideal for this situation lies between 30 - 40%			
Comparison	Total Electic Consumption	Total Natural Gas Consumption	
Double pane	39354	12303	
Low e	39844	12103	
Special Glazing	39654	12667	
Optimum Energy consumption will be achived for this situation with 30% Double pane glass or 30% Low e glass			

Arizona	North _Clerestory	
Double Pane	Window % with Lowest Energy Consumption	Window % withHighest Energy Consumption
Space Cooling (KWh)	0%	40%
Space Heating (x000Btu)	0%	40%
Area Lights (KWh)	40%	0%
Total Electric Usage	20%	40%
Total Natural Gas Usage (x000Btu)	0%	40%

Conclusion: The effective percentage ideal for this situation lies between 0 - 20%

	North _Clerestory	
Low e	Window % with Lowest Energy Consumption	Window % withHighest Energy Consumption
Space Cooling (KWh)	0%	40%
Space Heating (x000Btu)	0%	40%
Area Lights (KWh)	40%	0%
Total Electric Usage	20%	40%
Total Natural Gas Usage (x000Btu)	0%	40%

Conclusion: The effective percentage ideal for this situation lies between 0 - 20%

	North _Clerestory	
Special Glazing	Window % with Lowest Energy Consumption	Window % withHighest Energy Consumption
Space Cooling (KWh)	0%	40%
Space Heating (x000Btu)	0%	40%
Area Lights (KWh)	40%	0%
Total Electric Usage	20%	40%
Total Natural Gas Usage (x000Btu)	0%	40%

Conclusion: The effective percentage ideal for this situation lies between 0 - 20%

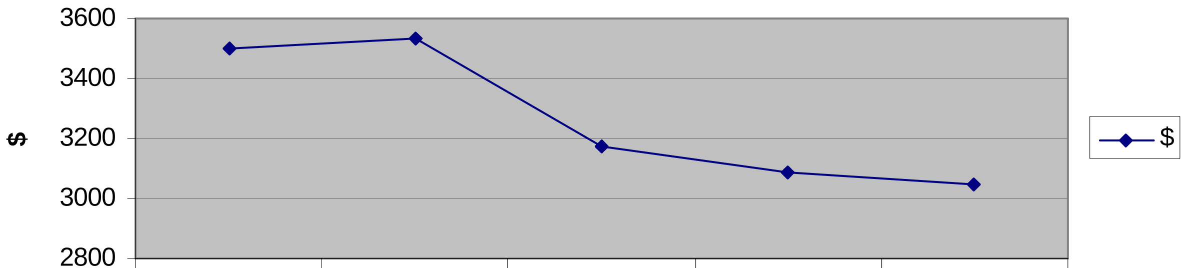
Comparison	Total Electic Consumptic	Total Natural Gas Consumption
Double pane	41219	11911
Low e	41377	12077
Special Glazing	41083	12037

Optimum Energy consumption will be achived for this situation with 20%Special Glazing or 20% Double Pane

<u>**Total Electric Cost Data Graphs (Arizona)**</u>

The total cost of using different types of glazing and percentages are plotted below
Results for the three different glazing types which are north oriented and non clerestory

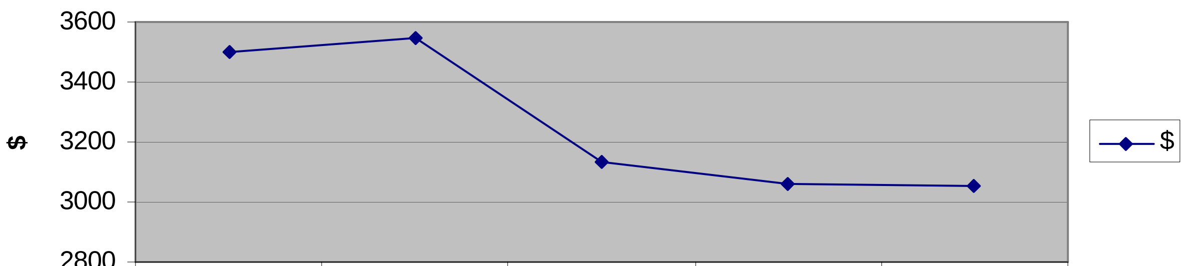
Total Electric Cost



	0%	10%	20%	30%	40%
$	3499.8076	3535.3336	3173.5032	3085.032	3048.742

Glazing Percentage TWIN_AZ_DP_NR_NC

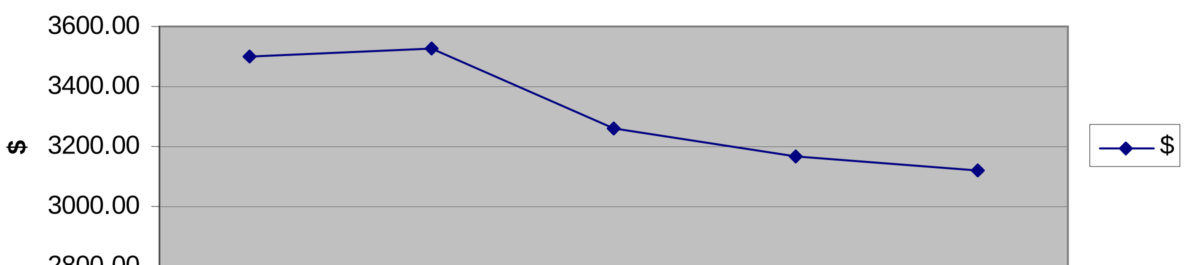
Total Electic Cost



	0%	10%	20%	30%	40%
$	3499.8076	3543.814	3134.4628	3058.674	3052.2564

Glazing Percentage TWIN_AZ_LE_NR_NC

Total Electric Cost

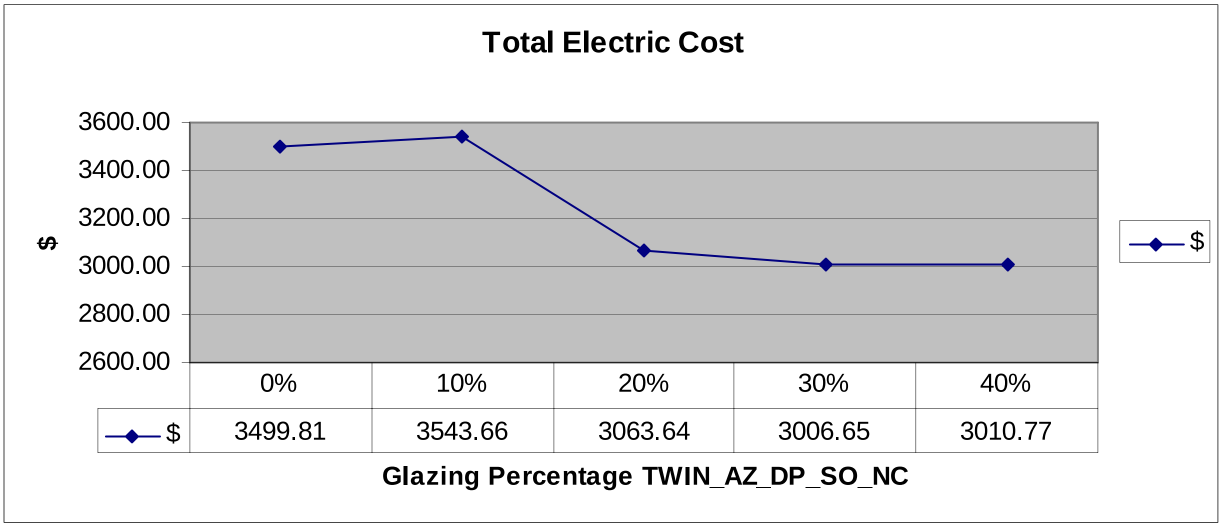


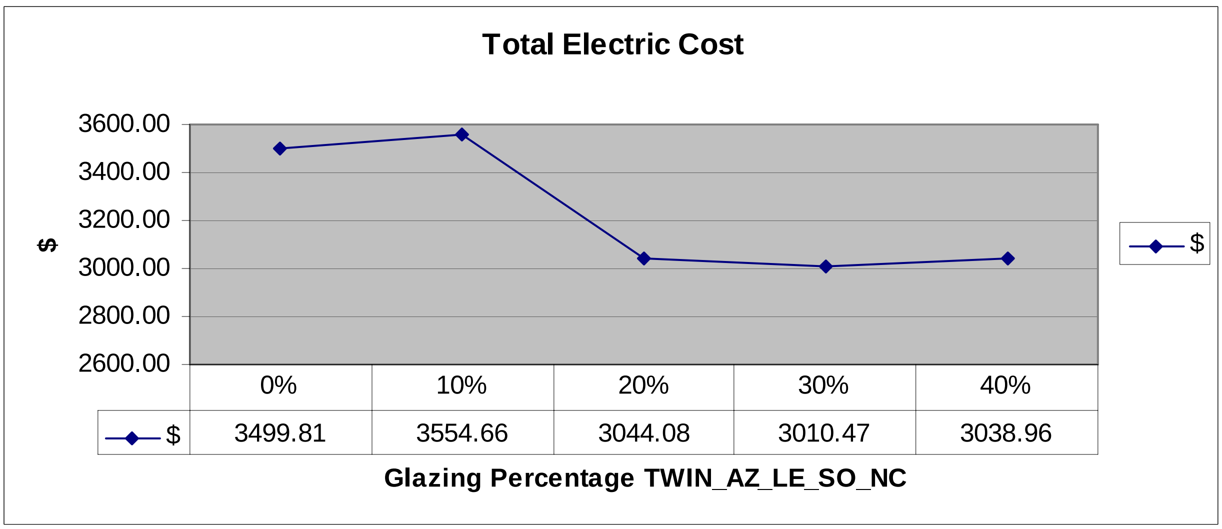
	0%	10%	20%	30%	40%
$	3499.81	3528.76	3257.85	3169.15	3117.27

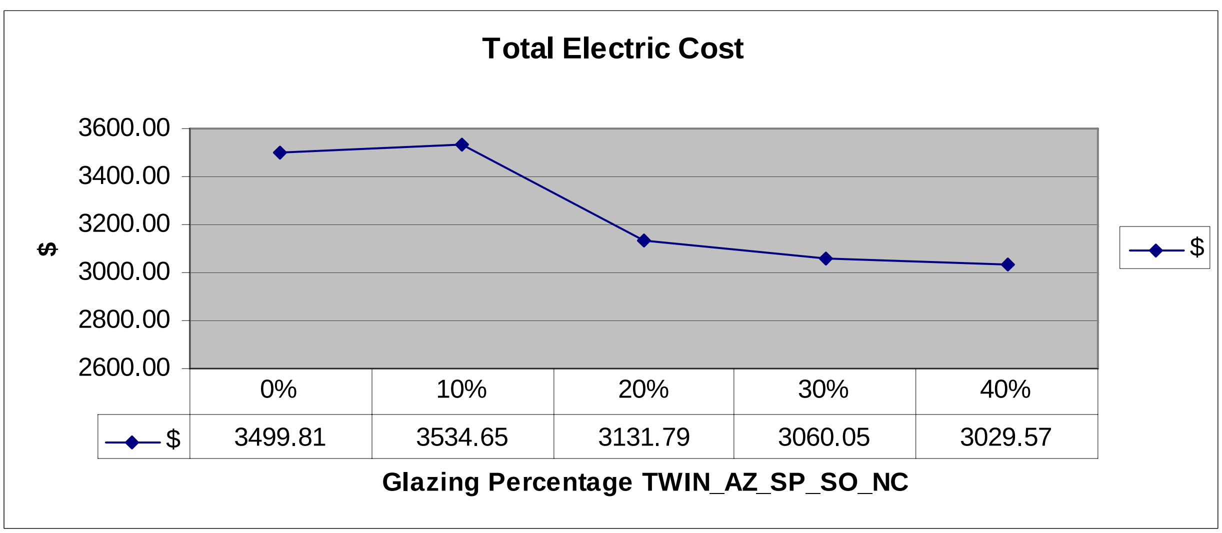
Glazing Percentage TWIN_AZ_SP_NR_NC

Arizona – total electric cost

Results for the three different glazing types which are south oriented and non clerestory

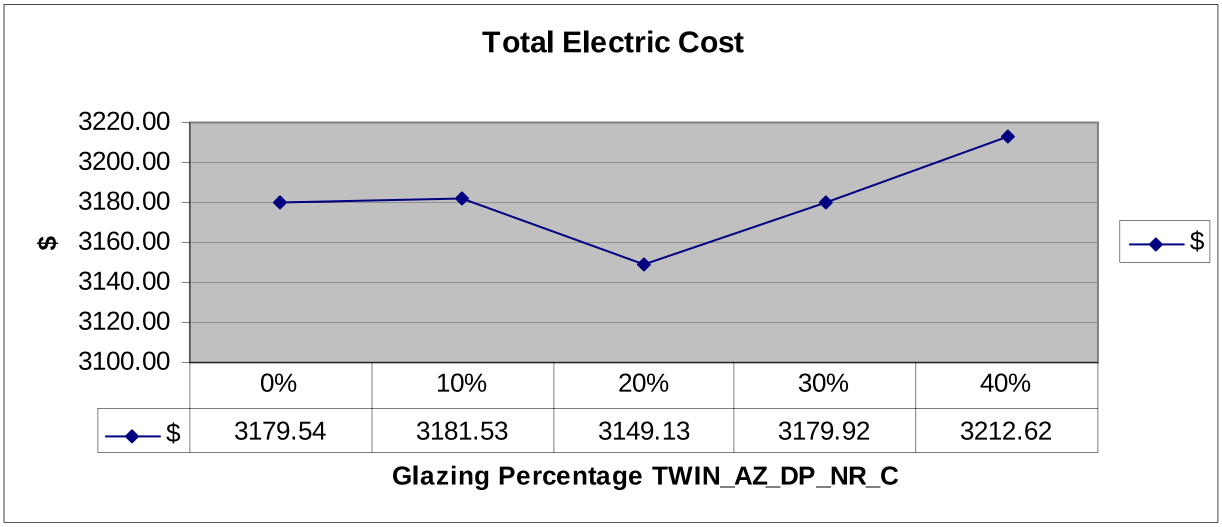




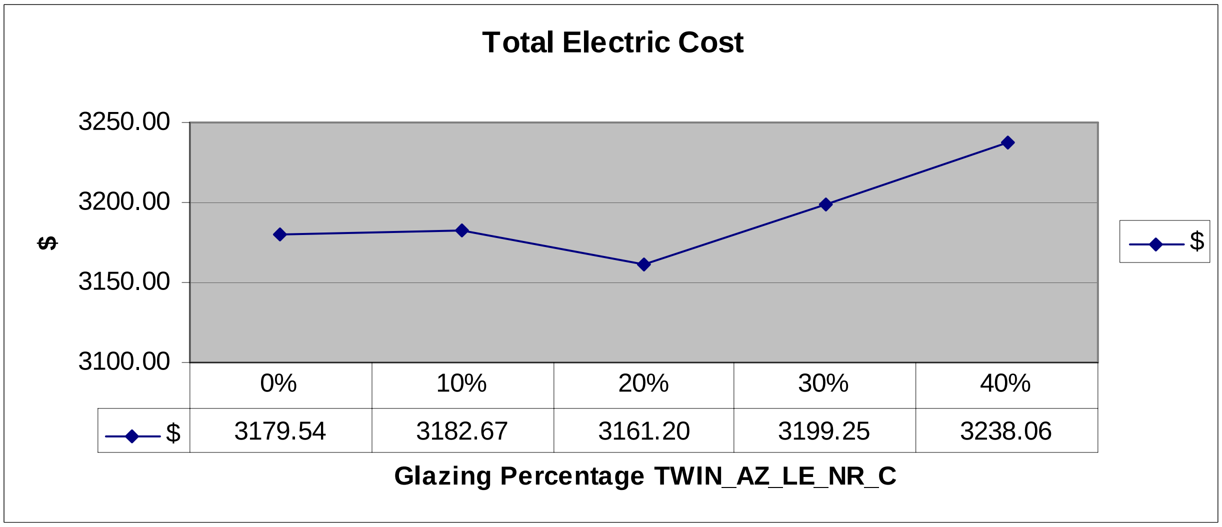


Arizona – total electric cost

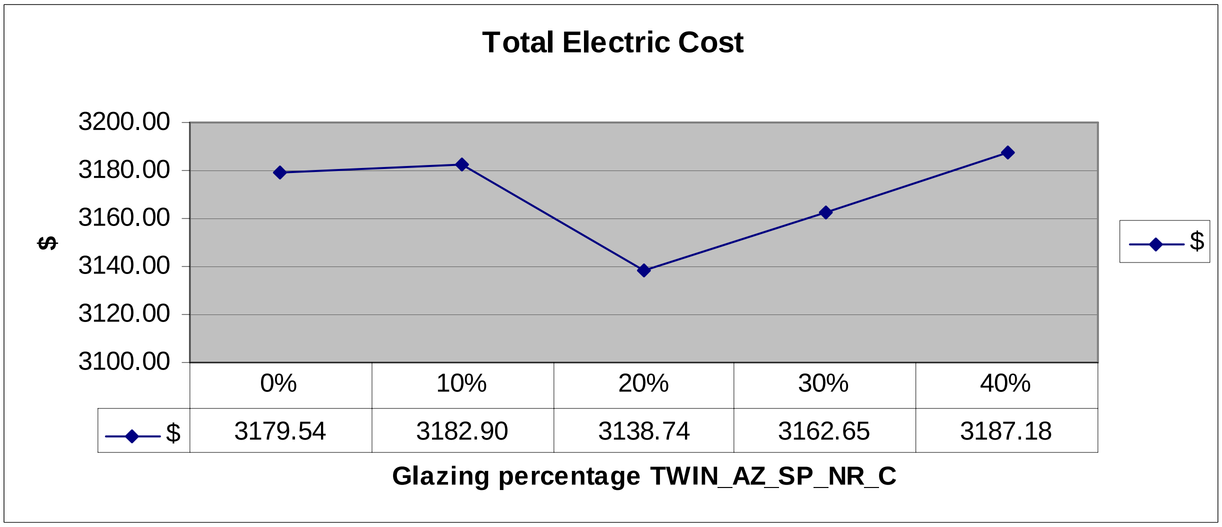
Results for the three different glazing types which are north oriented and clerestory



	0%	10%	20%	30%	40%
$	3179.54	3181.53	3149.13	3179.92	3212.62



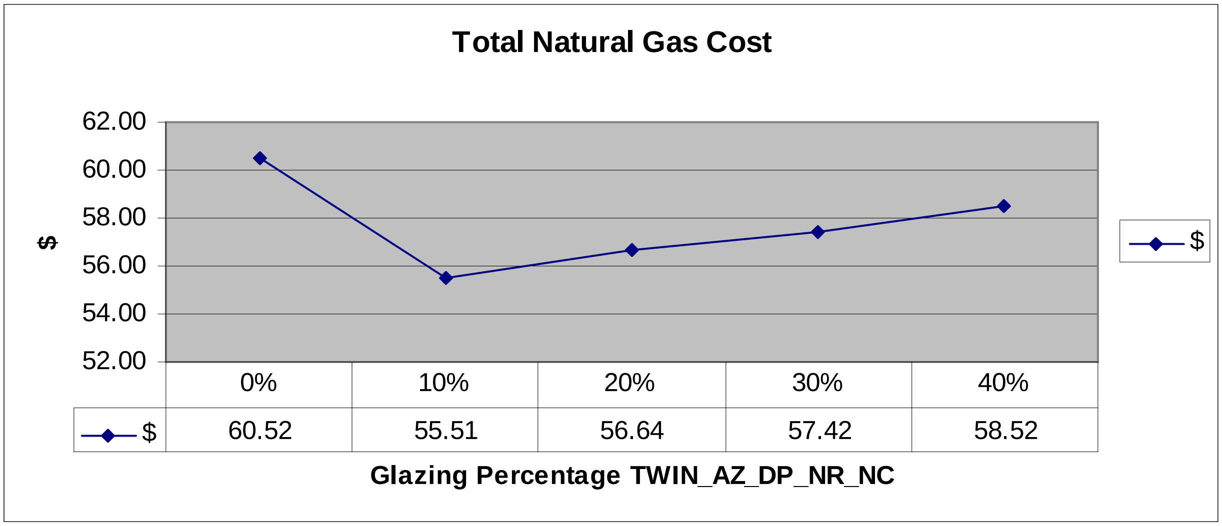
	0%	10%	20%	30%	40%
$	3179.54	3182.67	3161.20	3199.25	3238.06

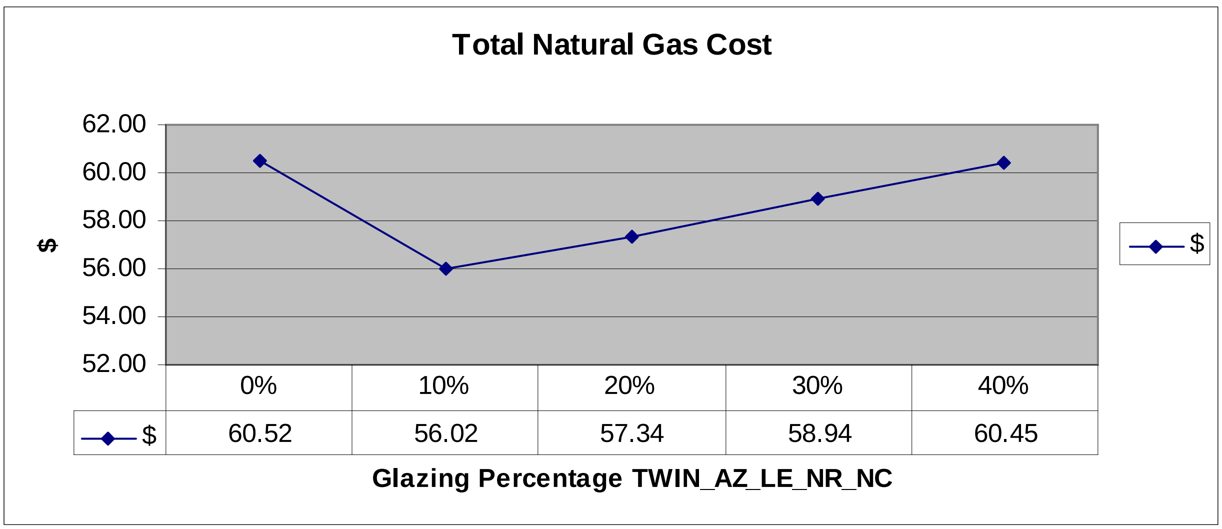


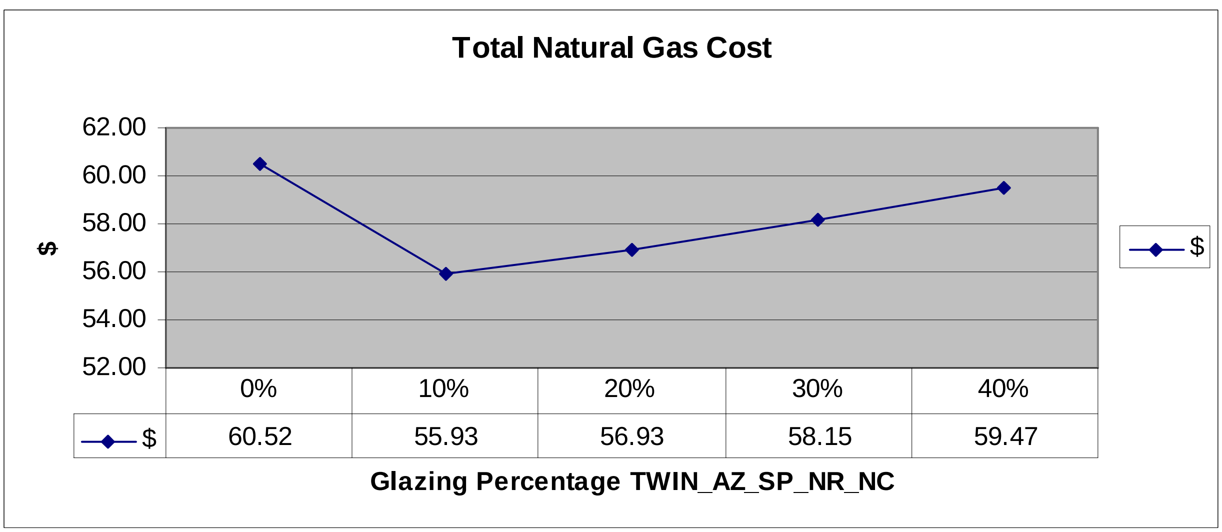
	0%	10%	20%	30%	40%
$	3179.54	3182.90	3138.74	3162.65	3187.18

Total Natural Gas Cost Data Graphs (Arizona)

Results for the three different glazing types which are north oriented and non clerestory

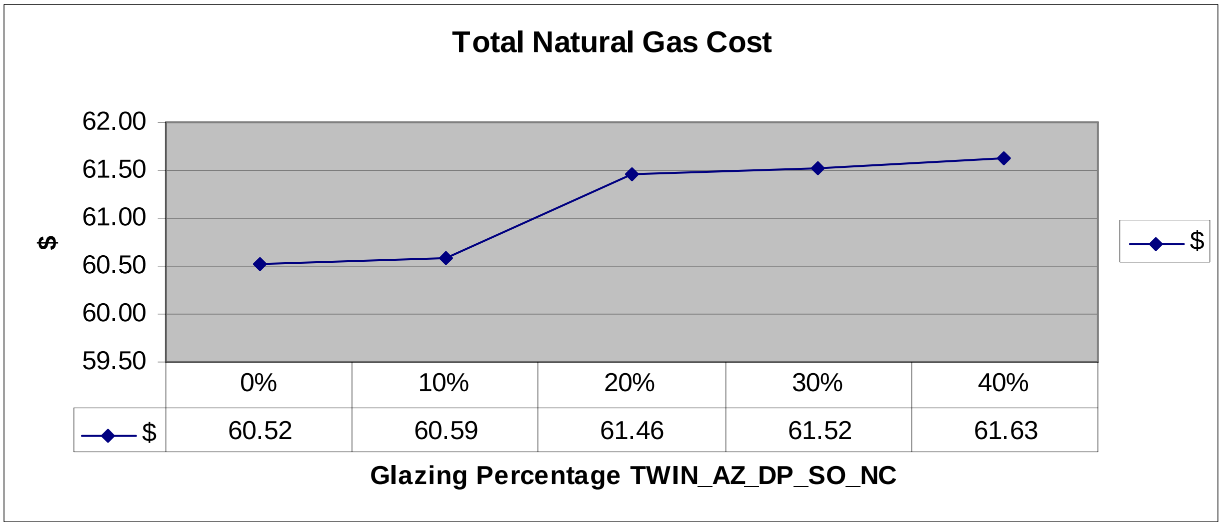


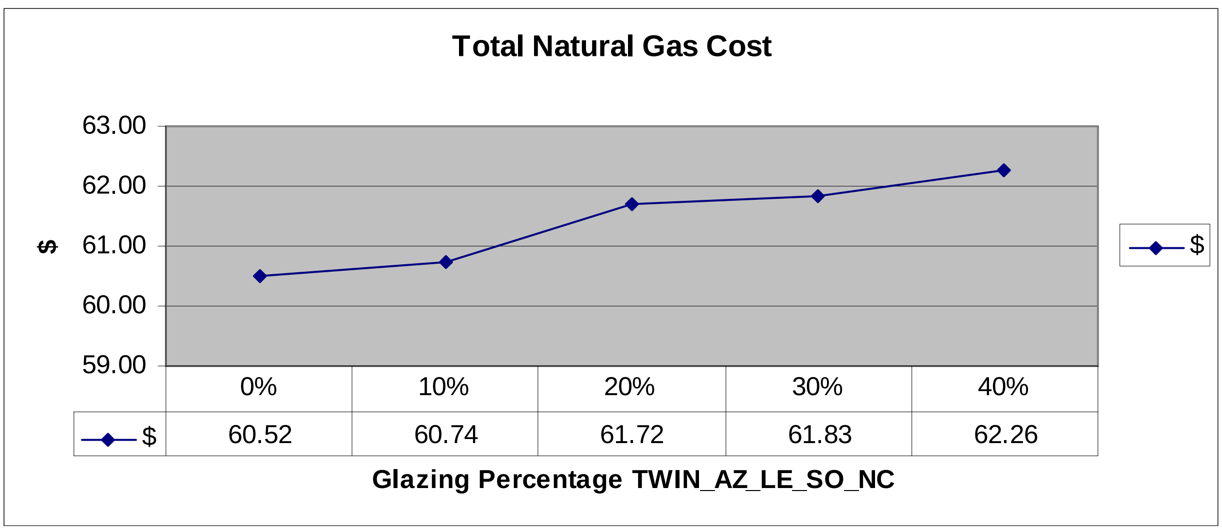


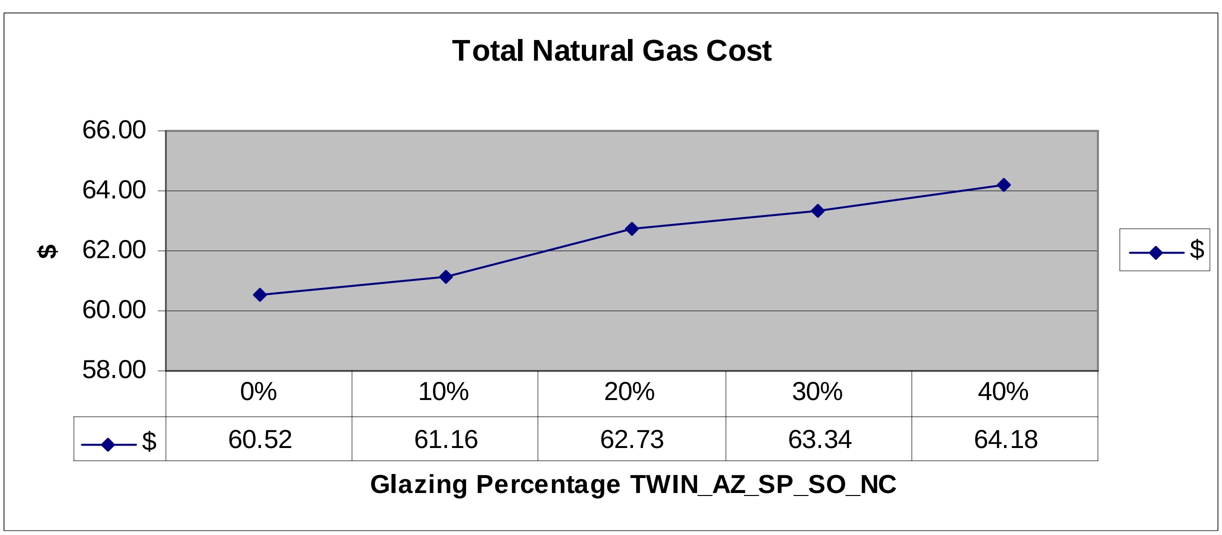


Arizona – total natural gas cost

Results for the three different glazing types which are south oriented and non clerestory

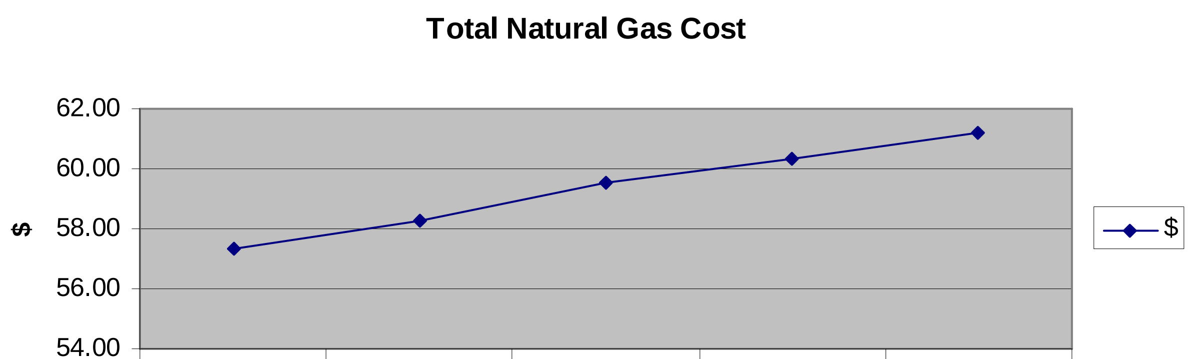






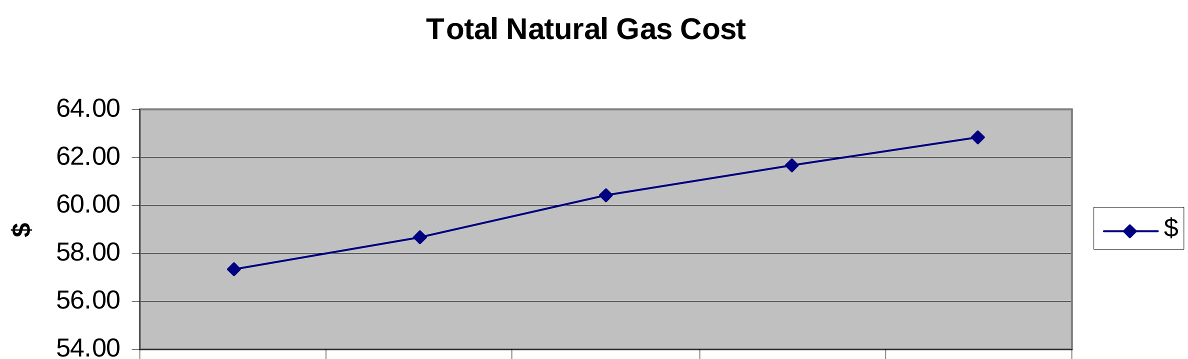
Arizona – total natural gas cost

Results for the three different glazing types which are north oriented and clerestory



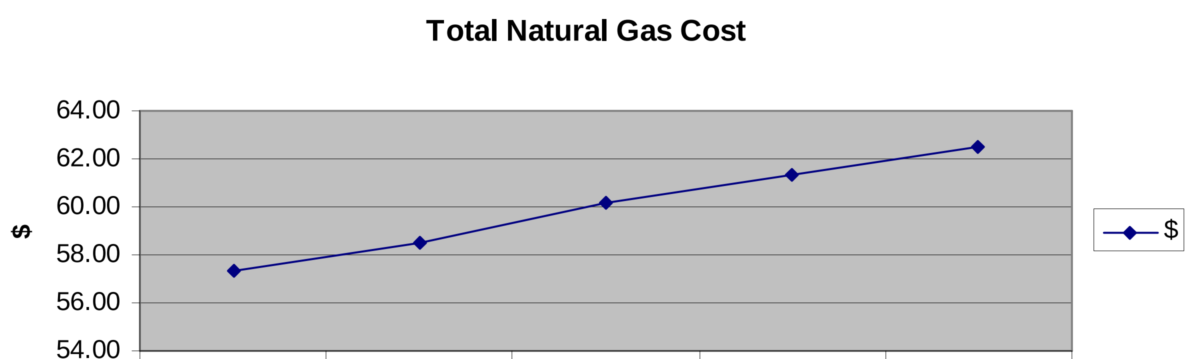
	0%	10%	20%	30%	40%
$	57.31	58.25	59.56	60.35	61.18

Glazing Percentage TWIN_AZ_DP_NR_C



	0%	10%	20%	30%	40%
$	57.31	58.64	60.39	61.68	62.86

Glazing Percentage TWIN_AZ_LE_NR_C



	0%	10%	20%	30%	40%
$	57.31	58.53	60.19	61.37	62.49

Glazing Percentage TWIN_AZ_SP_NR_C

Analysis

Annual Total electricity cost observed for – Arizona

- The total annual electric cost decreases as the percentage of glazing is increased, with noticeable benefit at and beyond 0.20 GWAR (glazing to wall area ratio)
- The double pane glazing alternative has the lowest total annual electric cost and when clerestory windows are introduced special glazing shows better performance.
- The total annual electric cost is noticeably influenced by orienting the glazed area to the south. The south orientation shows a lower consumption of electricity than the north orientation.
- Introduction of clerestory in the space with north facing windows decreases the total annual electric demand at 0.20 GWAR Increasing the window area beyond 0.20 GWAR however causes overheating problems and an increase in the total annual electric cost / consumption.

Annual Total Natural Gas cost observed for – Arizona

- The total annual natural gas cost decreases as the percentage of glazing is increased, with greatest benefit at 0.20 double pane GWAR (glazing to wall area ratio) for the north orientation with double pane glass.
- The total annual natural gas cost for the south orientation and with clerestory increases with the increase in the glazing percentage and no solar benefit is noticeable for either of the conditions.

Simulation Results for Chicago, New York, Raleigh, Sacramento

Similar graphs have been plotted for all the remaining four locations, the results and observations are as below. The graphs for the four cities have been attached in the appendix for reference.

Chicago

Chicago	**North _ Non Clerestory**		
Double Pane	Window % with Lowest Energy Consumption	Window % withHighest Energy Consumption	
Space Cooling (KWh)	30%	10%	
Space Heating (x000Btu)	0%	40%	
Area Lights (KWh)	40%	0-10%	
Total Electric Usage	40%	10%	
Total Natural Gas Usage (x000Btu)			
Conclusion: The effective percentage ideal for this situation lies between 30 - 40%			
	North _ Non Clerestory		
Low e	Window % with Lowest Energy Consumption	Window % withHighest Energy Consumption	
Space Cooling (KWh)	30%	10%	
Space Heating (x000Btu)	0%	40%	
Area Lights (KWh)	40%	0-10%	
Total Electric Usage	40%	10%	
Total Natural Gas Usage (x000Btu)			
Conclusion: The effective percentage ideal for this situation lies between 30 - 40%			
	North _ Non Clerestory		
Special Glazing	Window % with Lowest Energy Consumption	Window % withHighest Energy Consumption	
Space Cooling (KWh)	40%	10%	
Space Heating (x000Btu)	0%	40%	
Area Lights (KWh)	40%	0-10%	
Total Electric Usage	40%	10%	
Total Natural Gas Usage (x000Btu)			
Conclusion: The effective percentage ideal for this situation lies between 30 - 40 %			
Comparison	Total Electic Consumptio	Total Natural Gas Consumption	
Double pane	33482		
Low e	33049		
Special Glazing	34318		
Optimum Energy consumption will be achived for this situation with 40 % Low e glazing			

Chicago	South _ Non Clerestory		
Double Pane	Window % with Lowest Energy Consumption	Window % withHighest Energy Consumption	
Space Cooling (KWh)	30%	10%	
Space Heating (x000Btu)	0%	40%	
Area Lights (KWh)	40%	0-10%	
Total Electric Usage	40%	10%	
Total Natural Gas Usage (x000Btu)			
Conclusion: The effective percentage ideal for this situation lies between 30 - 40 %			

	South _ Non Clerestory		
Low e	Window % with Lowest Energy Consumption	Window % withHighest Energy Consumption	
Space Cooling (KWh)	30%	10%	
Space Heating (x000Btu)	0%	40%	
Area Lights (KWh)	40%	0-10%	
Total Electric Usage	40%	10%	
Total Natural Gas Usage (x000Btu)			
Conclusion: The effective percentage ideal for this situation lies between 30 - 40 %			

	South _ Non Clerestory		
Special Glazing	Window % with Lowest Energy Consumption	Window % withHighest Energy Consumption	
Space Cooling (KWh)	40%	10%	
Space Heating (x000Btu)	0%	40%	
Area Lights (KWh)	40%	0-10%	
Total Electric Usage	40%	10%	
Total Natural Gas Usage (x000Btu)			
Conclusion: The effective percentage ideal for this situation lies between 30 - 40 %			

Comparison	Total Electic Consumptior	Total Natural Gas Consumption	
Double pane	32846		
Low e	32795		
Special Glazing	33191		
Optimum Energy consumption will be achived for this situation with 40 % Low e glazing			

Chicago	**North _Clerestory**		
Double Pane	Window % with Lowest Energy Consumption	Window % withHighest Energy Consumption	
Space Cooling (KWh)	0%	40%	
Space Heating (x000Btu)	0%	40%	
Area Lights (KWh)	40%	0%	
Total Electric Usage	20%	0%	
Total Natural Gas Usage (x000Btu)	0%	40%	
Conclusion: The effective percentage ideal for this situation lies between 20 - 40 %			
	North_ Clerestory		
Low e	Window % with Lowest Energy Consumption	Window % withHighest Energy Consumption	
Space Cooling (KWh)			
Space Heating (x000Btu)			
Area Lights (KWh)			
Total Electric Usage			
Total Natural Gas Usage (x000Btu)			
Conclusion: The effective percentage ideal for this situation lies between 20 - 40 %			
	North _ Clerestory		
Special Glazing	Window % with Lowest Energy Consumption	Window % withHighest Energy Consumption	
Space Cooling (KWh)			
Space Heating (x000Btu)			
Area Lights (KWh)			
Total Electric Usage			
Total Natural Gas Usage (x000Btu)			
Conclusion: The effective percentage ideal for this situation lies between 20 - 40 %			
Comparison	Total Electic Consumption	Total Natural Gas Consumption	
Double pane	32857	89472	
Low e	32890	91916	
Special Glazing	32737	91373	
Optimum Energy consumption will be achived for this situation with 20% Special Glazing			

Annual Total electricity cost observed for – Chicago

- The total annual electric cost decreases as the percentage of glazing is increased, with noticeable benefit at and beyond 0.20 GWAR (glazing to wall area ratio)
- The Low - e glazing alternative has the lowest total annual electric cost and when clerestory windows are introduced double pane glazing shows better performance.
- The total annual electric cost is noticeably influenced by orienting the glazed area to the south. The south orientation shows a lower consumption of electricity than the north orientation.
- Introduction of north facing clerestory windows in the space with north facing windows minimizes the total annual electric demand at 0.20 GWAR, Increasing the window area beyond 0.20 GWAR causes overheating problems and an increase in the total annual electric cost.

Annual Total Natural Gas cost observed for –Chicago

- The total annual natural gas cost increases as the percentage of glazing is increased, with no noticeable solar benefit for the north the orientation
- The south orientation is marginally more beneficial with slightly less total annual natural gas cost.
- The total annual natural gas cost with clerestory increases with the increase in the glazing percentage and no solar benefit is noticeable for this condition. Double Pane glazing shows the least total annual natural gas cost when combined with clerestory.

New York

New york	**North _ Non Clerestory**		
Double Pane	Window % with Lowest Energy Consumption	Window % withHighest Energy Consumption	
Space Cooling (KWh)	30%	10%	
Space Heating (x000Btu)	0%	40%	
Area Lights (KWh)	40%	0-10%	
Total Electric Usage	40%	10%	
Total Natural Gas Usage (x000Btu)	0%	40%	
Conclusion: The effective percentage ideal for this situation lies between 30 - 40 %			
	North _ Non Clerestory		
Low e	Window % with Lowest Energy Consumption	Window % withHighest Energy Consumption	
Space Cooling (KWh)	20%	10%	
Space Heating (x000Btu)	0%	40%	
Area Lights (KWh)	40%	0-10%	
Total Electric Usage	40%	10%	
Total Natural Gas Usage (x000Btu)	0%	40%	
Conclusion: The effective percentage ideal for this situation lies between 20 - 40 %			
	North _ Non Clerestory		
Special Glazing	Window % with Lowest Energy Consumption	Window % withHighest Energy Consumption	
Space Cooling (KWh)	40%	10%	
Space Heating (x000Btu)	0%	40%	
Area Lights (KWh)	40%	0-10%	
Total Electric Usage	40%	10%	
Total Natural Gas Usage (x000Btu)	0%	40%	
Conclusion: The effective percentage ideal for this situation lies between 30 - 40 %			
Comparison	Total Electic Consumption	Total Natural Gas Consumption	
Double pane	33066	70390	
Low e	32926	75512	
Special Glazing	33493	72909	
Optimum Energy consumption will be achived for this situation with 40% Low e or 40% Double pane Glazing			

New york	South _ Non Clerestory		
Double Pane	Window % with Lowest Energy Consumption	Window % withHighest Energy Consumption	
Space Cooling (KWh)	20%	10%	
Space Heating (x000Btu)	0%	40%	
Area Lights (KWh)	40%	0-10%	
Total Electric Usage	40%	10%	
Total Natural Gas Usage (x000Btu)	0%	40%	

Conclusion: The effective percentage ideal for this situation lies between 20 - 40%

	South _ Non Clerestory		
Low e	Window % with Lowest Energy Consumption	Window % withHighest Energy Consumption	
Space Cooling (KWh)	20%	10%	
Space Heating (x000Btu)	0%	40%	
Area Lights (KWh)	40%	0-10%	
Total Electric Usage	30%	10%	
Total Natural Gas Usage (x000Btu)	0%	40%	

Conclusion: The effective percentage ideal for this situation lies between 20 - 40 %

	South _ Non Clerestory		
Special Glazing	Window % with Lowest Energy Consumption	Window % withHighest Energy Consumption	
Space Cooling (KWh)	40%	10%	
Space Heating (x000Btu)	0%	40%	
Area Lights (KWh)	40%	0-10%	
Total Electric Usage	40%	10%	
Total Natural Gas Usage (x000Btu)	0%	40%	

Conclusion: The effective percentage ideal for this situation lies between 30 - 40 %

Comparison	Total Electic Consumptio	Total Natural Gas Consumption
Double pane	32726	65944
Low e	32750	69038
Special Glazing	32894	71553

Optimum Energy consumption will be achived for this situation with 40% Double Pane

New york	North _Clerestory		
Double Pane	Window % with Lowest Energy Consumption	Window % withHighest Energy Consumption	
Space Cooling (KWh)	0%	40%	
Space Heating (x000Btu)	0%	40%	
Area Lights (KWh)	20-40%	0%	
Total Electric Usage	20%	0%	
Total Natural Gas Usage (x000Btu)	0%	40%	

Conclusion: The effective percentage ideal for this situation lies between 20 - 40 %

	North _ Clerestory		
Low e	Window % with Lowest Energy Consumption	Window % withHighest Energy Consumption	
Space Cooling (KWh)	0%	40%	
Space Heating (x000Btu)	0%	40%	
Area Lights (KWh)	20 - 40%	0%	
Total Electric Usage	20%	0%	
Total Natural Gas Usage (x000Btu)	0%	40%	

Conclusion: The effective percentage ideal for this situation lies between 20 - 40 %

	North _ Clerestory		
Special Glazing	Window % with Lowest Energy Consumption	Window % withHighest Energy Consumption	
Space Cooling (KWh)	0%	40%	
Space Heating (x000Btu)	0%	40%	
Area Lights (KWh)	20-40%	0%	
Total Electric Usage	20%	0%	
Total Natural Gas Usage (x000Btu)	0%	40%	

Conclusion: The effective percentage ideal for this situation lies between 20 - 40 %

Comparison	Total Electic Consumption	Total Natural Gas Consumption
Double pane	32976	73821
Low e	33044	76026
Special Glazing	32835	75594

Optimum Energy consumption will be achived for this situation with 20% Special Glazing or 20% Double pane Glazing

Annual Total electricity cost observed for – New York

- The total annual electric cost reduces as the percentage of glazing is increased, with noticeable benefit at and beyond 0.20 GWAR (glazing to wall area ratio)
- The Low - e glazing alternative has the lowest total annual electric cost without clerestory windows and when clerestory windows are introduced special glazing shows better performance.
- The total annual electric cost is noticeably influenced by orienting the glazed area to the south. The south orientation shows a lower consumption of electricity than the north orientation.
- Introduction of clerestory windows in the space with north facing windows decreases the total annual electric demand at 0.20 GWAR. Increasing the window area beyond 0.20 GWAR however causes overheating problems and an increase in the total annual electric cost / consumption.

Annual Total Natural Gas cost observed for –New York

- The total annual natural gas cost increases as the percentage of glazing is increased, with no noticeable solar benefit for the north orientation
- The south orientation is marginally more beneficial with slightly less total annual natural gas cost.
- The total annual natural gas cost with clerestory windows increases with the increase in the glazing percentage and no solar benefit is noticeable for this condition.

Raleigh

Raleigh	North _ Non Clerestory	
Double Pane	Window % with Lowest Energy Consumption	Window % withHighest Energy Consumption
Space Cooling (KWh)	30%	10%
Space Heating (x000Btu)	10%	40%
Area Lights (KWh)	40%	0-10%
Total Electric Usage	40%	10%
Total Natural Gas Usage (x000Btu)	0-10%	40%

Conclusion: The effective percentage ideal for this situation lies between 30-40%

	North _ Non Clerestory	
Low e	Window % with Lowest Energy Consumption	Window % withHighest Energy Consumption
Space Cooling (KWh)	30%	20%
Space Heating (x000Btu)	10%	40%
Area Lights (KWh)	40%	0-10%
Total Electric Usage	40%	20%
Total Natural Gas Usage (x000Btu)	10%	40%

Conclusion: The effective percentage ideal for this situation lies between 10-30%

	North _ Non Clerestory	
Special Glazing	Window % with Lowest Energy Consumption	Window % withHighest Energy Consumption
Space Cooling (KWh)	40%	10%
Space Heating (x000Btu)	0-10%	40%
Area Lights (KWh)	40%	0-10%
Total Electric Usage	40%	10%
Total Natural Gas Usage (x000Btu)	10%	40%

Conclusion: The effective percentage ideal for this situation lies between 20-30%

Comparison	Total Electic Consumption	Total Natural Gas Consumption
Double pane	34670	32931
Low e	34524	33557
Special Glazing	35011	33433

Optimum Energy consumption will be achived for this situation with 30-40% Low e Glazing

Raleigh **South _ Non Clerestory**

Double Pane	Window % with Lowest Energy Consumption	Window % withHighest Energy Consumption
Space Cooling (KWh)	30%	20%
Space Heating (x000Btu)	10%	40%
Area Lights (KWh)	40%	0-10%
Total Electric Usage	40%	20%
Total Natural Gas Usage (x000Btu)	10%	40%

Conclusion: The effective percentage ideal for this situation lies between 30 - 40%

South _ Non Clerestory

Low e	Window % with Lowest Energy Consumption	Window % withHighest Energy Consumption
Space Cooling (KWh)	30%	10%
Space Heating (x000Btu)	10%	40%
Area Lights (KWh)	40%	10%
Total Electric Usage	30%	10%
Total Natural Gas Usage (x000Btu)	10%	40%

Conclusion: The effective percentage ideal for this situation lies between 10-30%

South _ Non Clerestory

Special Glazing	Window % with Lowest Energy Consumption	Window % withHighest Energy Consumption
Space Cooling (KWh)	40%	10%
Space Heating (x000Btu)	10%	40%
Area Lights (KWh)	40%	0-10%
Total Electric Usage	40%	10%
Total Natural Gas Usage (x000Btu)	10%	40%

Conclusion: The effective percentage ideal for this situation lies between 30 - 40 %

Comparison	Total Electic Consumption	Total Natural Gas Consumption
Double pane	34283	33032
Low e	34260	33334
Special Glazing	34311	32090

Optimum Energy consumption will be achived for this situation with 30% Low-e Glazing

Raleigh **North _Clerestory**

Double Pane	Window % with Lowest Energy Consumption	Window % withHighest Energy Consumption
Space Cooling (KWh)	20%	40%
Space Heating (x000Btu)	10%	40%
Area Lights (KWh)	40%	0%
Total Electric Usage	20%	0%
Total Natural Gas Usage (x000Btu)	10%	40%

Conclusion: The effective percentage ideal for this situation lies between 20 - 30 %

North _ Clerestory

Low e	Window % with Lowest Energy Consumption	Window % withHighest Energy Consumption
Space Cooling (KWh)	20%	40%
Space Heating (x000Btu)	0-10%	40%
Area Lights (KWh)	40%	0%
Total Electric Usage	20%	0%
Total Natural Gas Usage (x000Btu)	0%	40%

Conclusion: The effective percentage ideal for this situation lies between 20 - 30 %

North _ Clerestory

Special Glazing	Window % with Lowest Energy Consumption	Window % withHighest Energy Consumption
Space Cooling (KWh)	20%	40%
Space Heating (x000Btu)	0%	40%
Area Lights (KWh)	40%	0%
Total Electric Usage	20%	0%
Total Natural Gas Usage (x000Btu)	20%	40%

Conclusion: The effective percentage ideal for this situation lies between 20 - 40 %

Comparison	Total Electic Consumptior	Total Natural Gas Consumption
Double pane	34731	37897
Low e	34778	41494
Special Glazing	34553	38310

Optimum Energy consumption will be achived for this situation with 20% Special Glazing

Annual Total electricity cost observed for – Raleigh NC

- The total annual electric cost decreases as the percentage of glazing is increased, with noticeable benefit at 0.20 – 0.30 GWAR (glazing to wall area ratio)
- The total annual electric cost is noticeably influenced by orienting the glazed area to the south. The south orientation shows a lower consumption of electricity when compared to the north orientation.
- Introduction of clerestory windows in the space with north facing windows decreases the total annual electric demand at 0.20 GWAR Increasing the window area beyond 0.20 GWAR however causes overheating problems and an increase in the total annual electric cost / consumption.

Annual Total Natural Gas cost observed for –Raleigh

- The total annual natural gas cost increases as the percentage of glazing is increased, with no noticeable solar benefit for the north orientation.
- The south orientation is marginally more beneficial with slightly less total annual natural gas cost.
- The total annual natural gas cost with clerestory windows increases with the increase in the glazing percentage and no solar benefit is noticeable for this condition. Low - e glazing shows the least total annual natural gas cost when combined with clerestory windows.

Sacramento	North _ Non Clerestory		
Double Pane	Window % with Lowest Energy Consumption	Window % withHighest Energy Consumption	
Space Cooling (KWh)	40%	10%	
Space Heating (x000Btu)	0%	40%	
Area Lights (KWh)	40%	0-10%	
Total Electric Usage	40%	10%	
Total Natural Gas Usage (x000Btu)	0%	40%	

Conclusion: The effective percentage ideal for this situation lies between 30 - 40 %

	North _ Non Clerestory		
Low e	Window % with Lowest Energy Consumption	Window % withHighest Energy Consumption	
Space Cooling (KWh)	40%	10%	
Space Heating (x000Btu)	0%	40%	
Area Lights (KWh)	40%	0-10%	
Total Electric Usage	40%	10%	
Total Natural Gas Usage (x000Btu)	0%	40%	

Conclusion: The effective percentage ideal for this situation lies between 30 - 40 %

	North _ Non Clerestory		
Special Glazing	Window % with Lowest Energy Consumption	Window % withHighest Energy Consumption	
Space Cooling (KWh)	40%	10%	
Space Heating (x000Btu)	0%	40%	
Area Lights (KWh)	40%	0-10%	
Total Electric Usage	40%	10%	
Total Natural Gas Usage (x000Btu)	0%	40%	

Conclusion: The effective percentage ideal for this situation lies between 30 - 40 %

Comparison	Total Electic Consumptior	Total Natural Gas Consumption
Double pane	32540	28806
Low e	32316	30633
Special Glazing	33461	29614

Optimum Energy consumption will be achived for this situation with 40% Low e Glazing

Sacramento	South _ Non Clerestory			
Double Pane	Window % with Lowest Energy Consumption	Window % withHighest Energy Consumption		
Space Cooling (KWh)	30%	10%		
Space Heating (x000Btu)	0%	40%		
Area Lights (KWh)	40%	0-10%		
Total Electric Usage	30%	10%		
Total Natural Gas Usage (x000Btu)	0%	40%		

Conclusion: The effective percentage ideal for this situation lies between 30 - 40%

	South _ Non Clerestory			
Low e	Window % with Lowest Energy Consumption	Window % withHighest Energy Consumption		
Space Cooling (KWh)	30%	10%		
Space Heating (x000Btu)	0%	40%		
Area Lights (KWh)	40%	0-10%		
Total Electric Usage	30%	10%		
Total Natural Gas Usage (x000Btu)	0%	40%		

Conclusion: The effective percentage ideal for this situation lies between 30 - 40%

	South _ Non Clerestory			
Special Glazing	Window % with Lowest Energy Consumption	Window % withHighest Energy Consumption		
Space Cooling (KWh)	40%	10%		
Space Heating (x000Btu)	0%	40%		
Area Lights (KWh)	40%	0-10%		
Total Electric Usage	40%	10%		
Total Natural Gas Usage (x000Btu)	0%	40%		

Conclusion: The effective percentage ideal for this situation lies between 30 - 40 %

Comparison	Total Electic Consumpti	Total Natural Gas Consumption		
Double pane	39354	12303		
Low e	39404	28591		
Special Glazing	39654	29290		

Optimum Energy consumption will be achived for this situation with 30% Double Pane Glazing

Sacramento	**North _Clerestory**		
Double Pane	Window % with Lowest Energy Consumption	Window % withHighest Energy Consumption	
Space Cooling (KWh)	0%	40%	
Space Heating (x000Btu)	0%	40%	
Area Lights (KWh)	40%	0%	
Total Electric Usage	20%	0%	
Total Natural Gas Usage (x000Btu)	0%	40%	
Conclusion: The effective percentage ideal for this situation lies between 20 - 40 %			
	North _ Clerestory		
Low e	Window % with Lowest Energy Consumption	Window % withHighest Energy Consumption	
Space Cooling (KWh)	0%	40%	
Space Heating (x000Btu)	0%	40%	
Area Lights (KWh)	40%	0%	
Total Electric Usage	20-30%	0%	
Total Natural Gas Usage (x000Btu)	0%	40%	
Conclusion: The effective percentage ideal for this situation lies between 20 - 30 %			
	North _ Clerestory		
Special Glazing	Window % with Lowest Energy Consumption	Window % withHighest Energy Consumption	
Space Cooling (KWh)	20%	40%	
Space Heating (x000Btu)	0%	40%	
Area Lights (KWh)	40%	0%	
Total Electric Usage	20%	0%	
Total Natural Gas Usage (x000Btu)	0%	40%	
Conclusion: The effective percentage ideal for this situation lies between 20 - 40 %			
Comparison	Total Electic Consumptic	Total Natural Gas Consumption	
Double pane	33214	29909	
Low e	33253	30671	
Special Glazing	33109	30588	
Optimum Energy consumption will be achived for this situation with 20% Special Glazing			

Annual Total electricity cost observed for – Sacramento CA

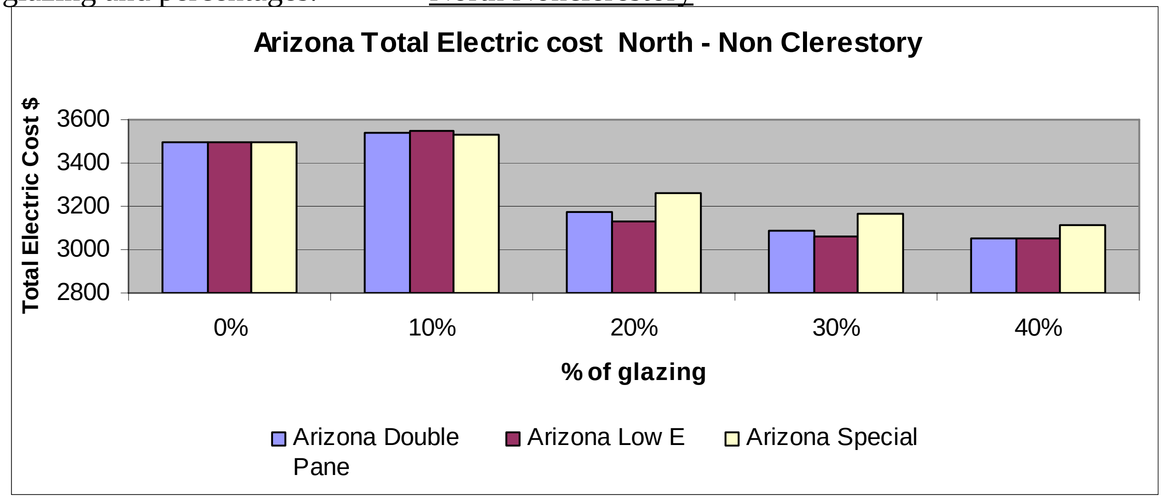
- The total annual electric cost reduces as the percentage of glazing is increased, with noticeable benefit at and beyond 0.20 GWAR (glazing to wall area ratio)
- The Low - e glazing alternative has the lowest total annual electric cost and when clerestory windows are introduced the special glazing alternative shows better performance.
- The total annual electric cost is noticeably influenced by orienting the glazed area to the north. The north orientation shows a lower consumption of electricity than the south orientation.
- Introduction of clerestory windows in the space with north facing windows decreases the total annual electric demand at 0.20 GWAR. Increasing the window area beyond 0.20 GWAR however causes overheating problems and an increase in the total annual electric cost / consumption.

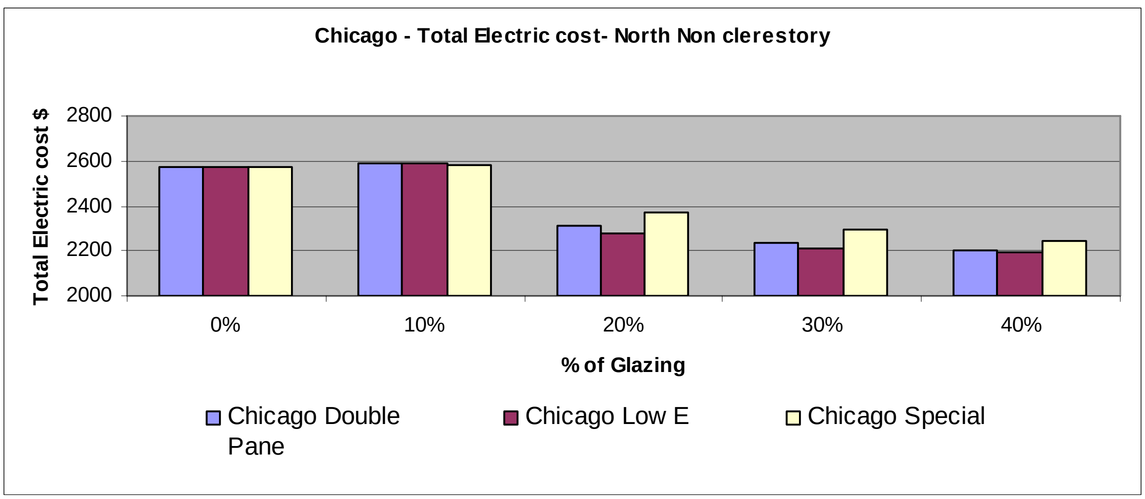
Annual Total Natural Gas cost observed for –Sacramento

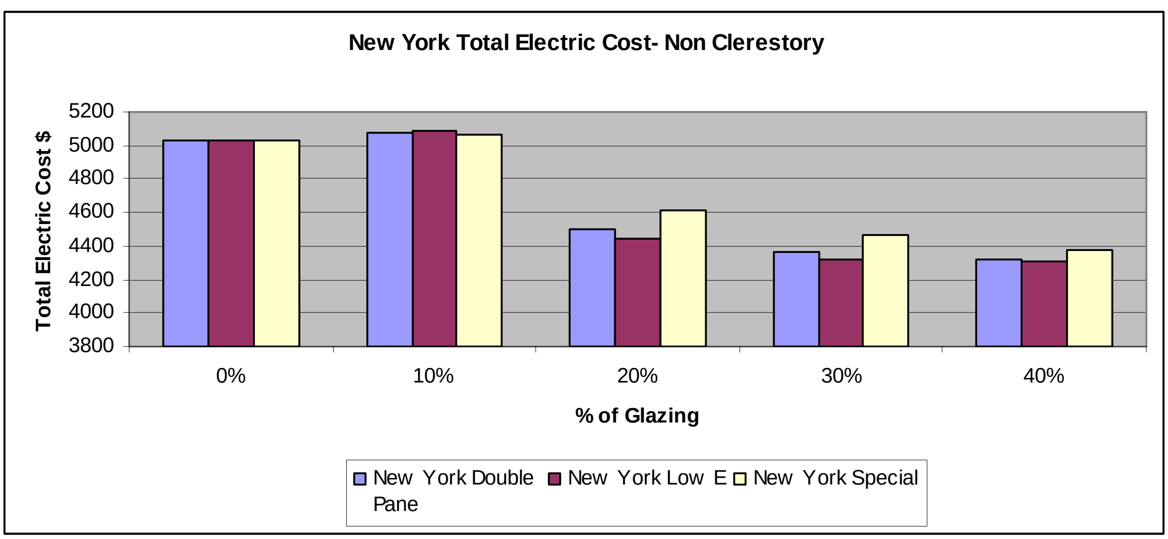
- The total annual natural gas cost increases as the percentage of glazing is increased, with no noticeable solar benefit for the north orientation
- No distinct benefit is observed with the change in orientation of the windows.
- The total annual natural gas cost with clerestory windows increases with the increase in the glazing percentage and no solar benefit is noticeable for this condition.

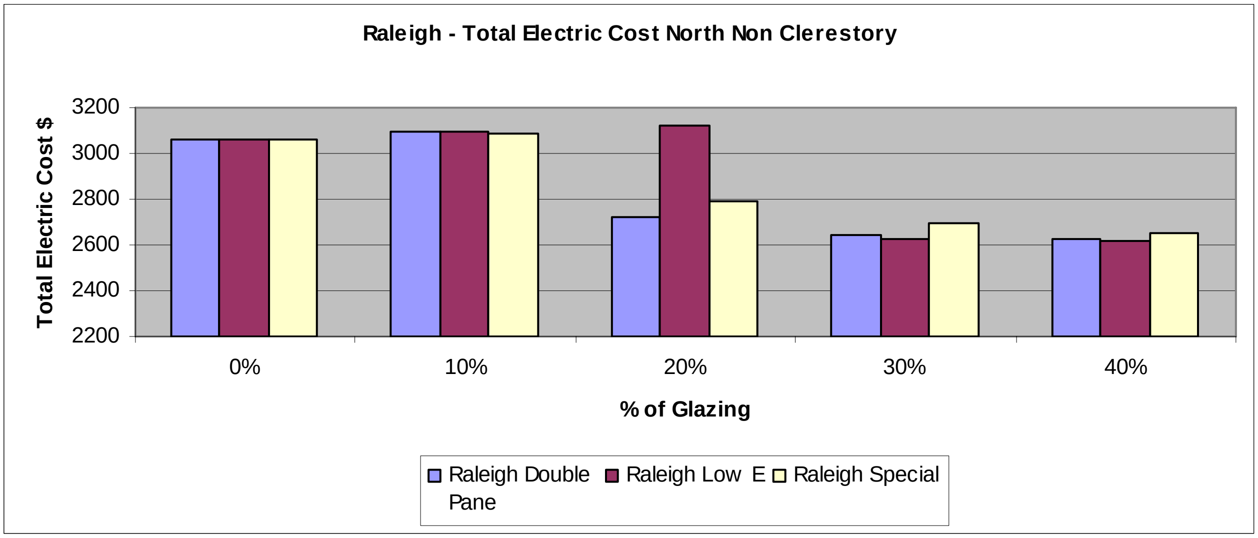
Total Electric cost comparison graphs.

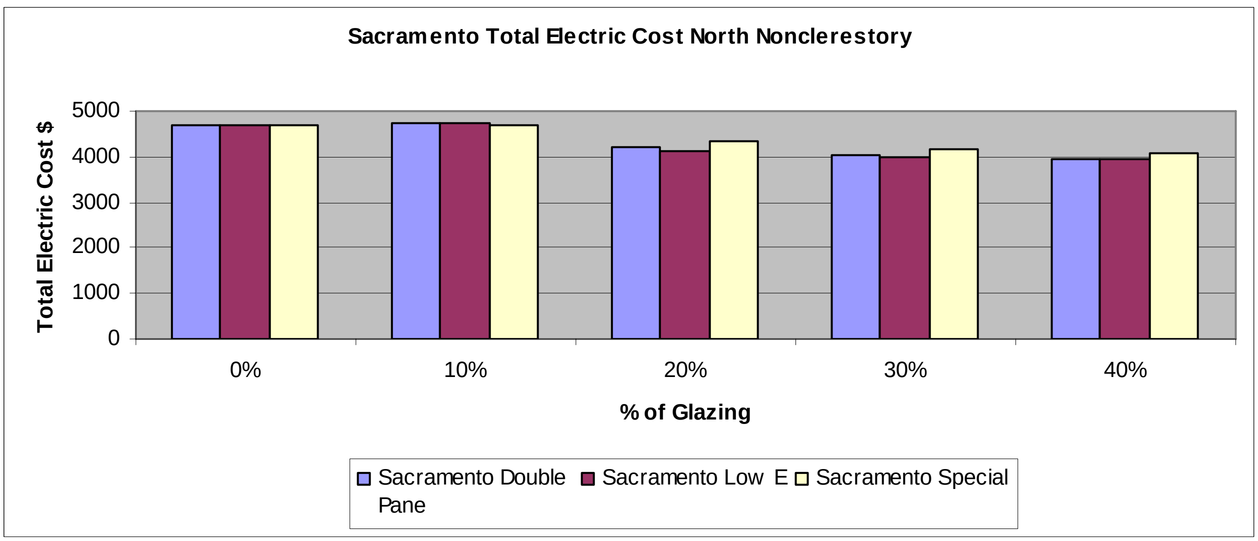
The total Electric cost for the five locations is compared with respect to the three types of glazing and percentages. North Nonclerestory





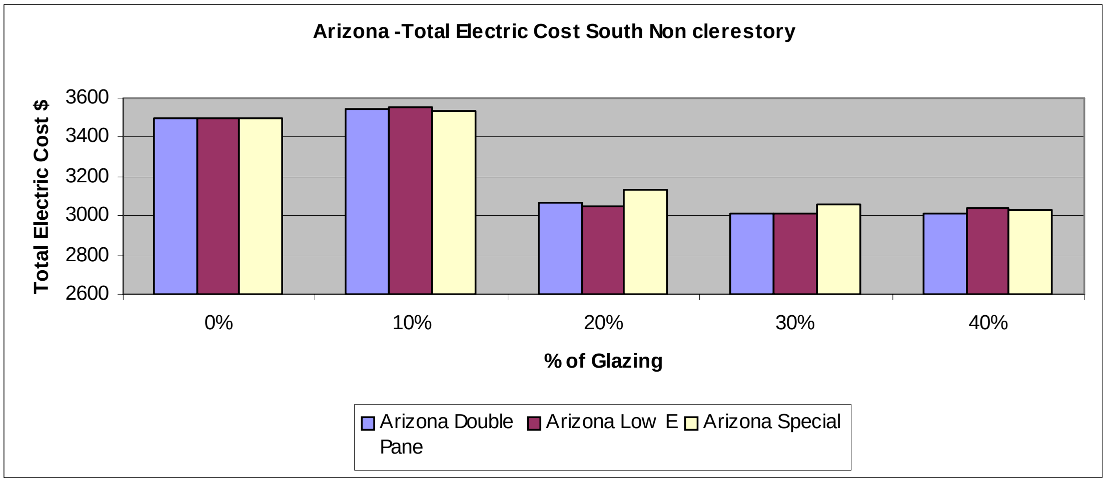


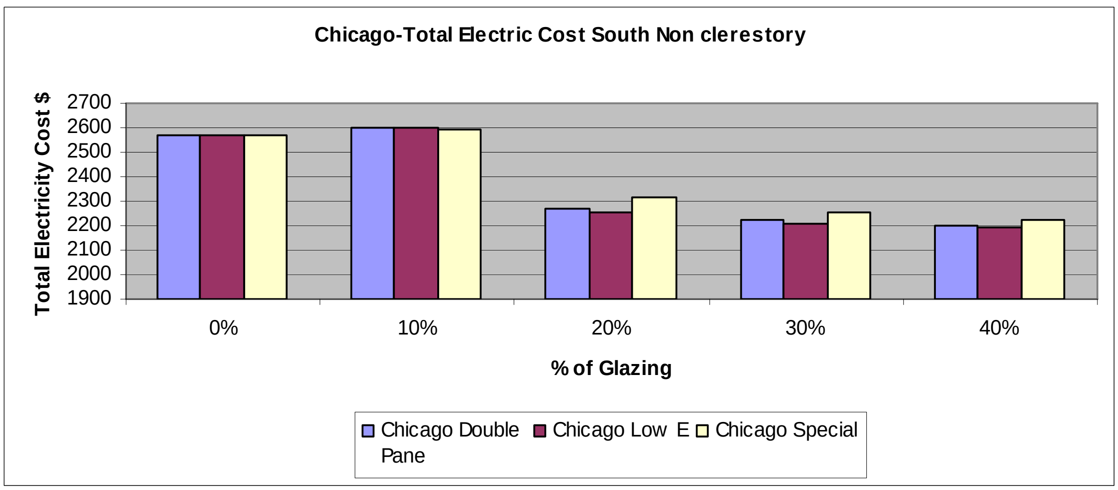

Raleigh - Total Electric Cost North Non Clerestory
Total Electric Cost $
3200
3000
2800
2600
2400
2200
0%
10%
20%
30%
40%
% of Glazing
Raleigh Double Pane
Raleigh Low E
Raleigh Special

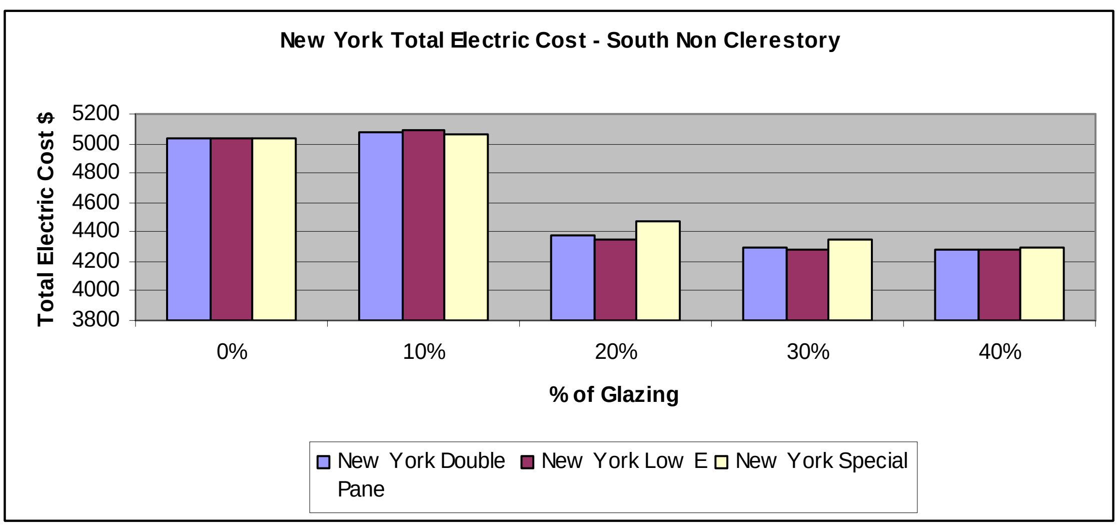

Sacramento Total Electric Cost North Nonclerestory
Total Electric Cost $
5000
4000
3000
2000
1000
0
0%
10%
20%
30%
40%
% of Glazing
Sacramento Double Pane
Sacramento Low E
Sacramento Special

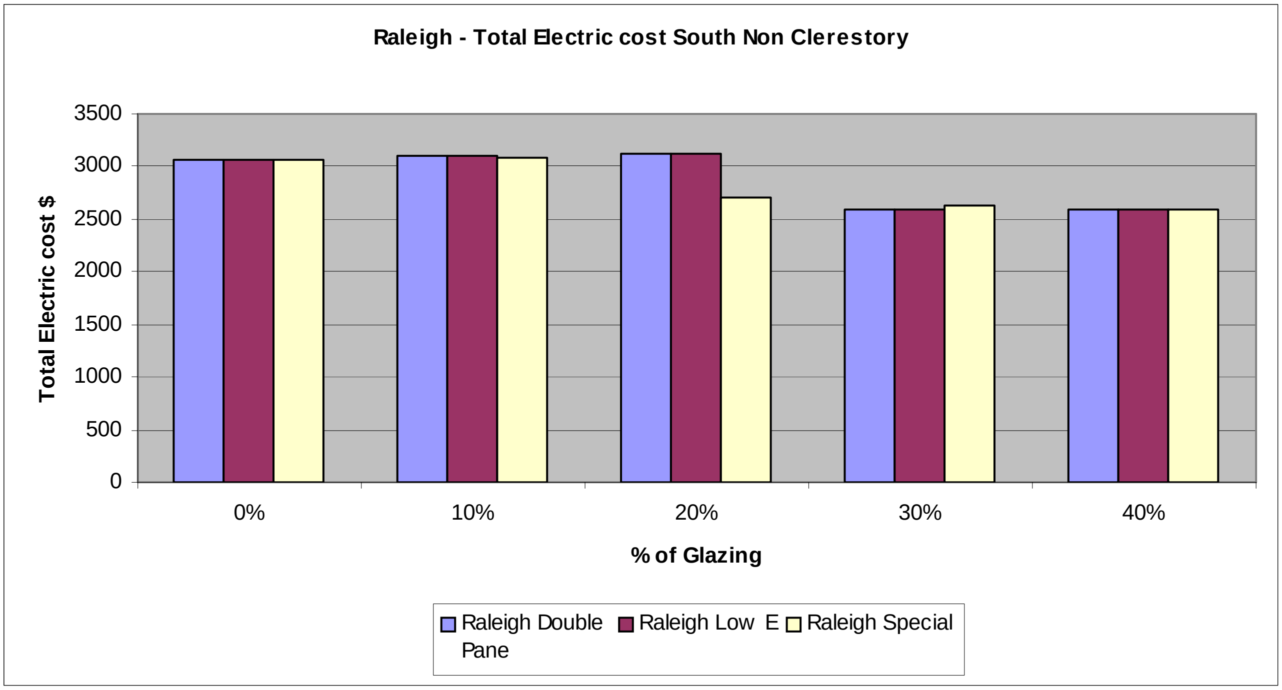
Total Electric cost comparison graphs.

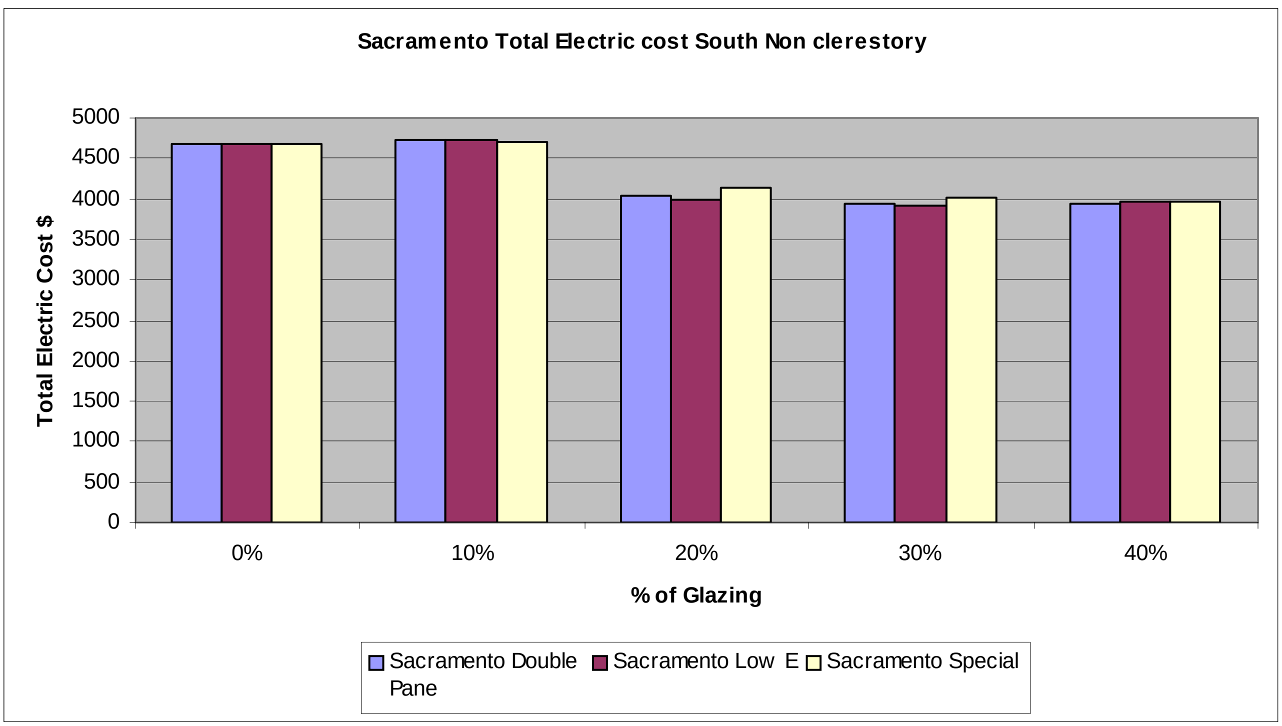
The total Electric cost for the five locations is compared with respect to the three types of glazing and percentages. South Nonclerestory





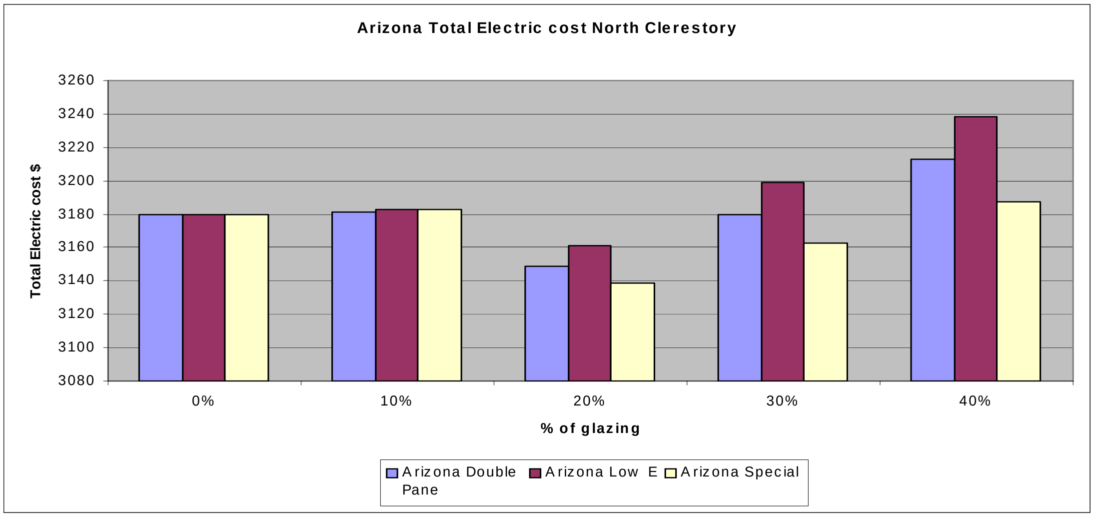


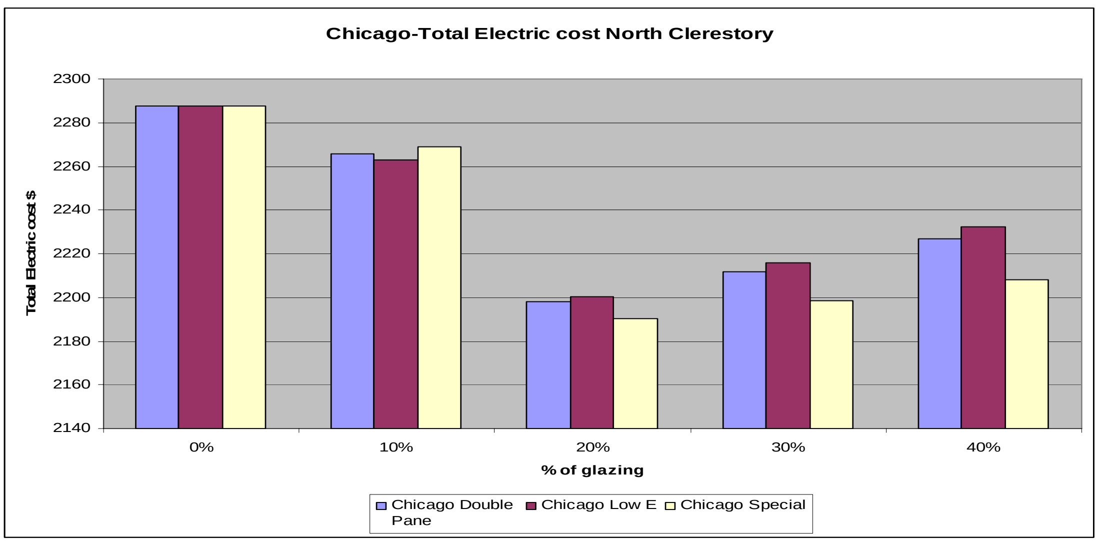

Raleigh - Total Electric cost South Non Clerestory
Total Electric cost $
3500
3000
2500
2000
1500
1000
500
0
0%
10%
20%
30%
40%
% of Glazing
Raleigh Double Pane
Raleigh Low E
Raleigh Special

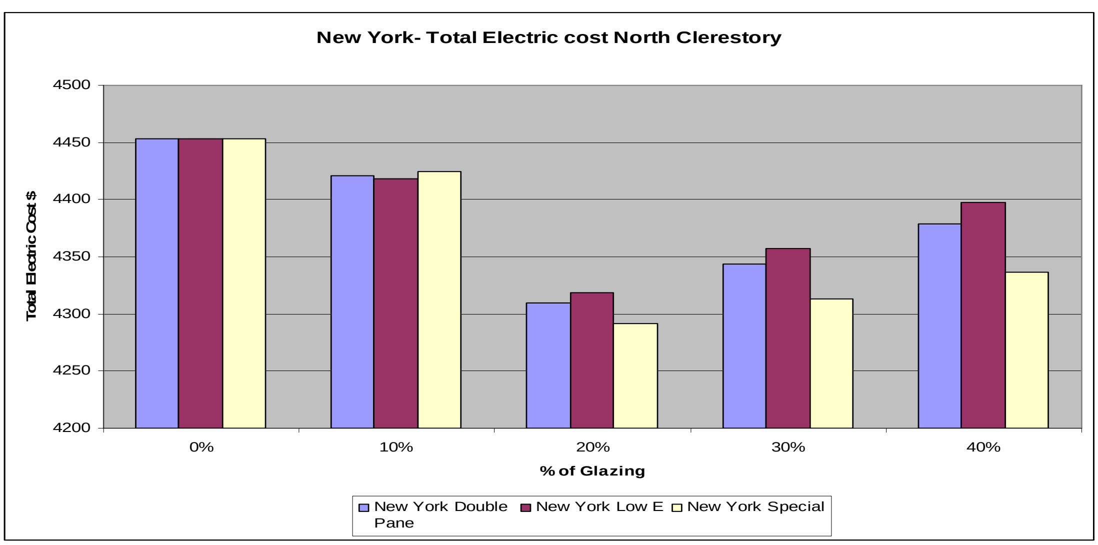

Sacramento Total Electric cost South Non clerestory
Total Electric Cost $
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
0%
10%
20%
30%
40%
% of Glazing
Sacramento Double Pane
Sacramento Low E
Sacramento Special

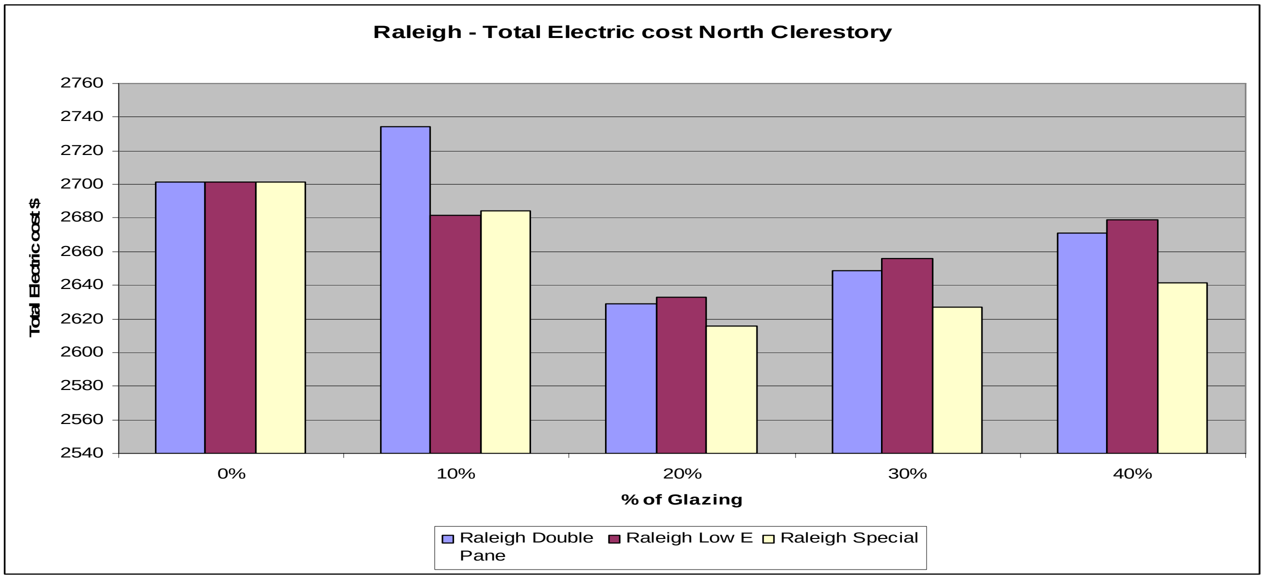
Total Electric cost comparison graphs.

The total Electric cost for the five locations is compared with respect to the three types of glazing and percentages. North Clerestory

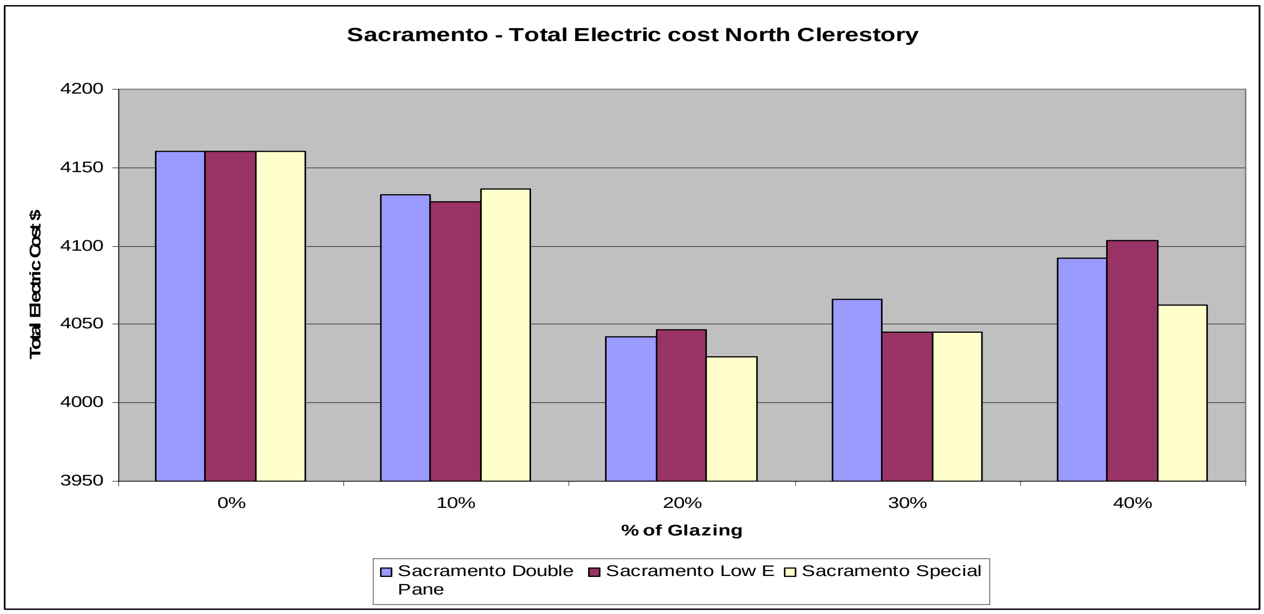








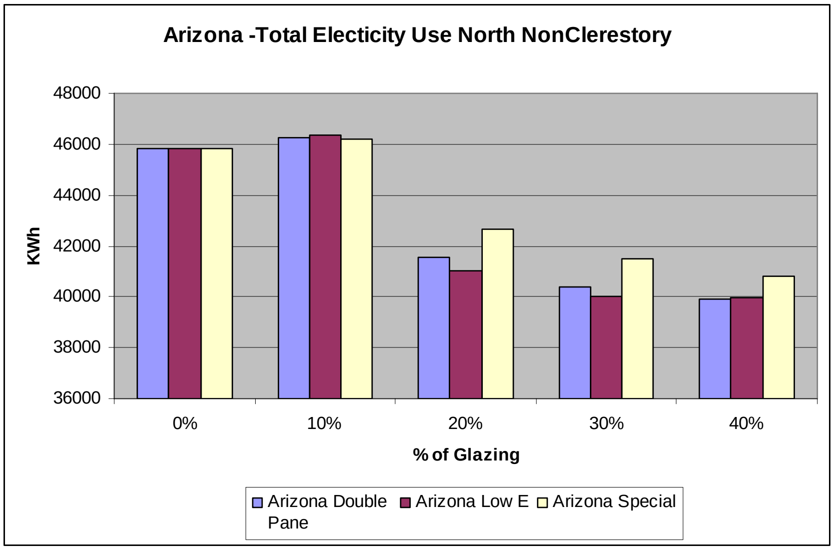
Raleigh - Total Electric cost North Clerestory
Total Electric cost $
2760
2740
2720
2700
2680
2660
2640
2620
2600
2580
2560
2540
0%
10%
20%
30%
40%
% of Glazing
Raleigh Double Pane
Raleigh Low E
Raleigh Special

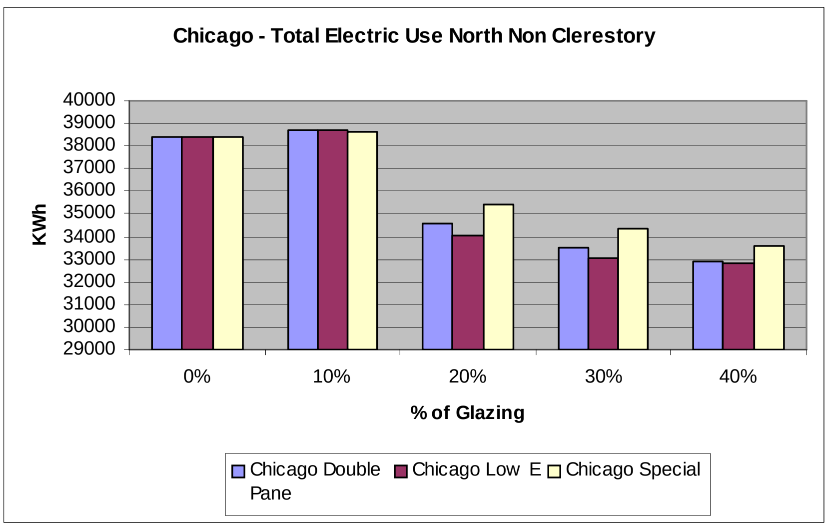


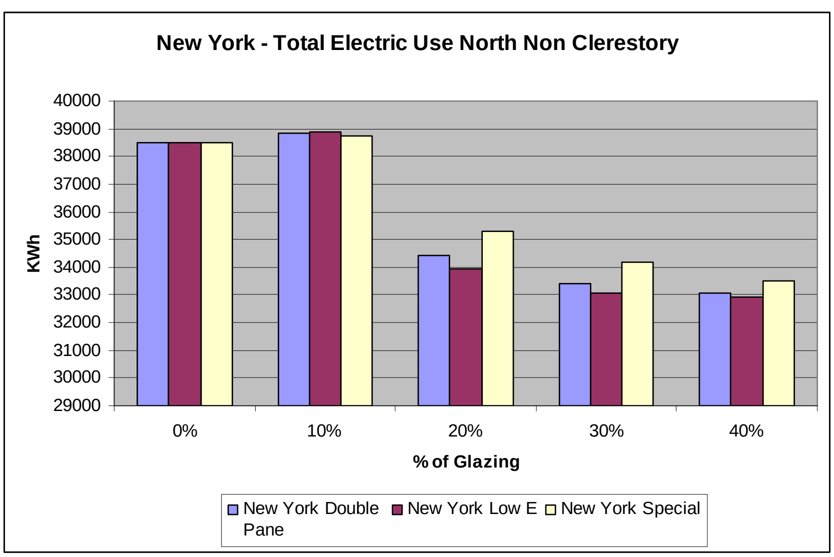
Sacramento - Total Electric cost North Clerestory
Total Electric Cost $
4200
4150
4100
4050
4000
3950
0%
10%
20%
30%
40%
% of Glazing
Sacramento Double Pane
Sacramento Low E
Sacramento Special

<u>Total Electric Use comparison graphs.</u>

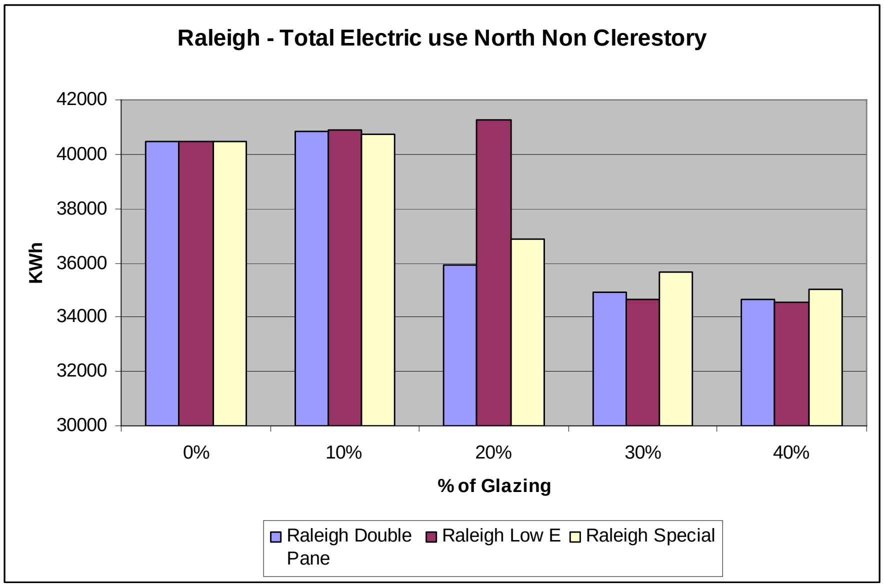
The total Electric use for the five locations is compared with respect to the three types of glazing and percentages. <u>North Non clerestory</u>

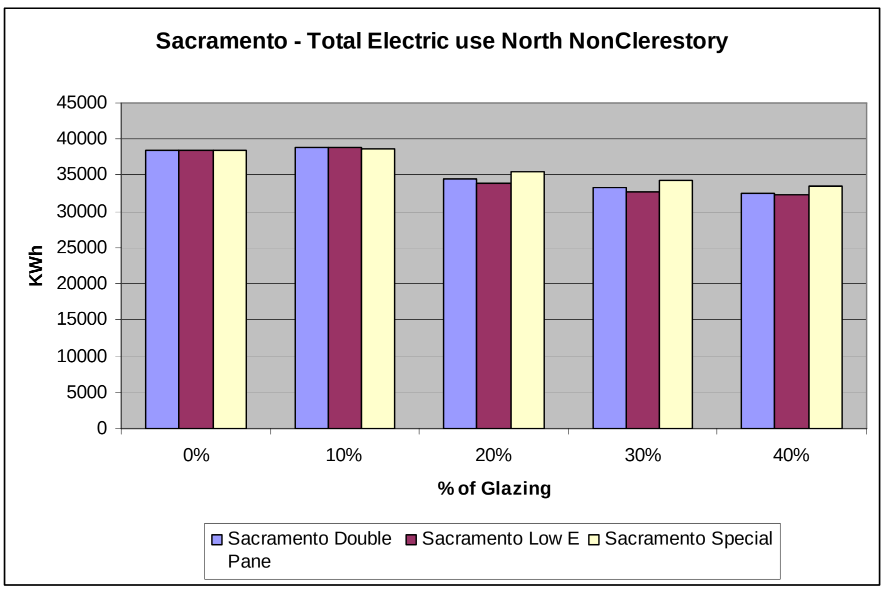




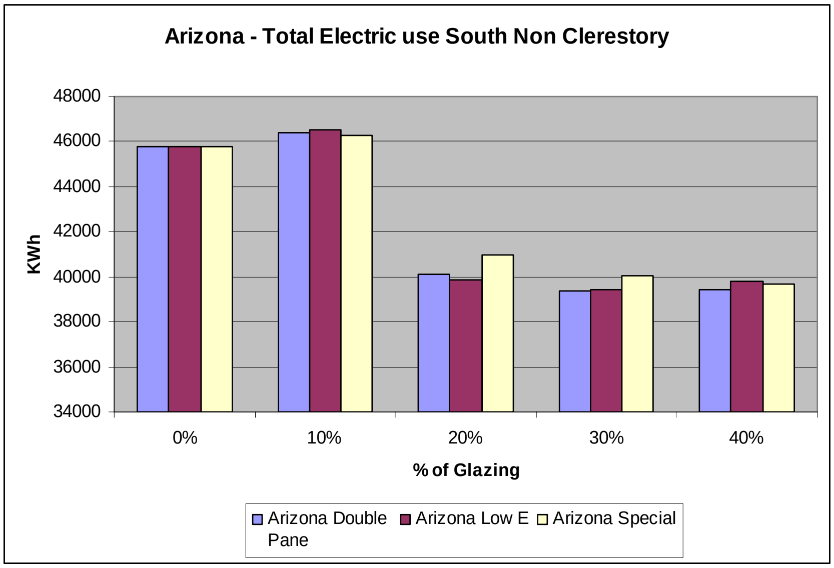


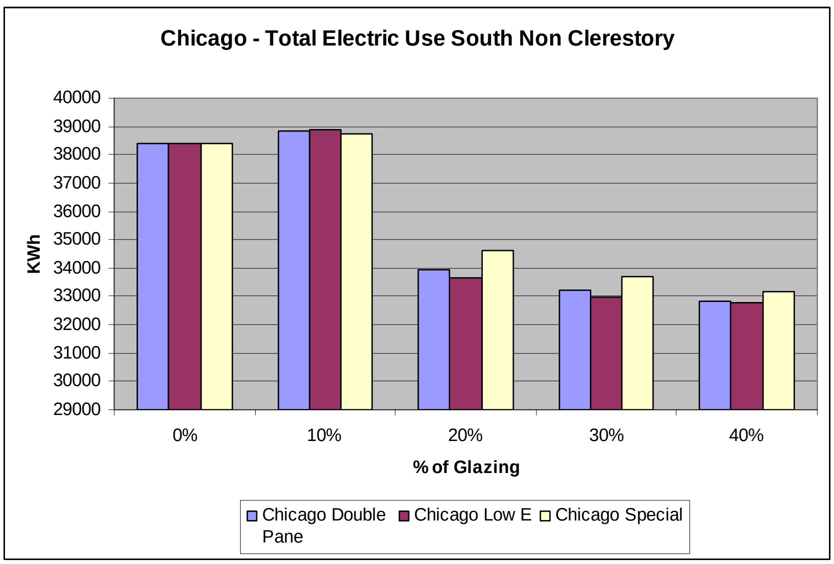
North Non clerestory

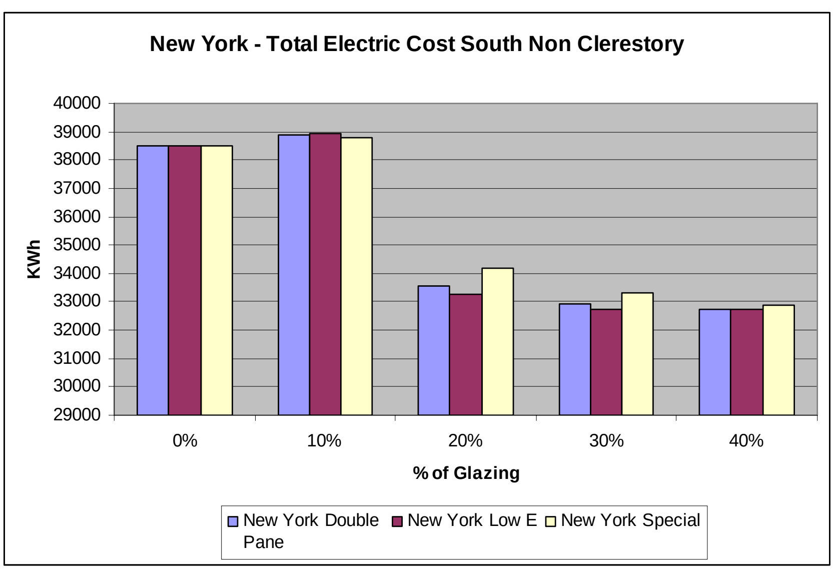




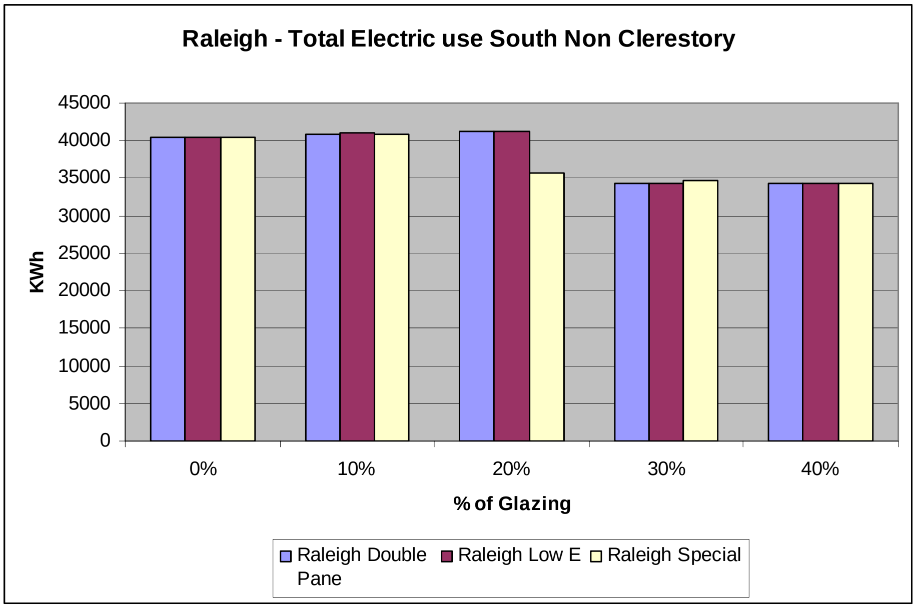
South Non clerestory

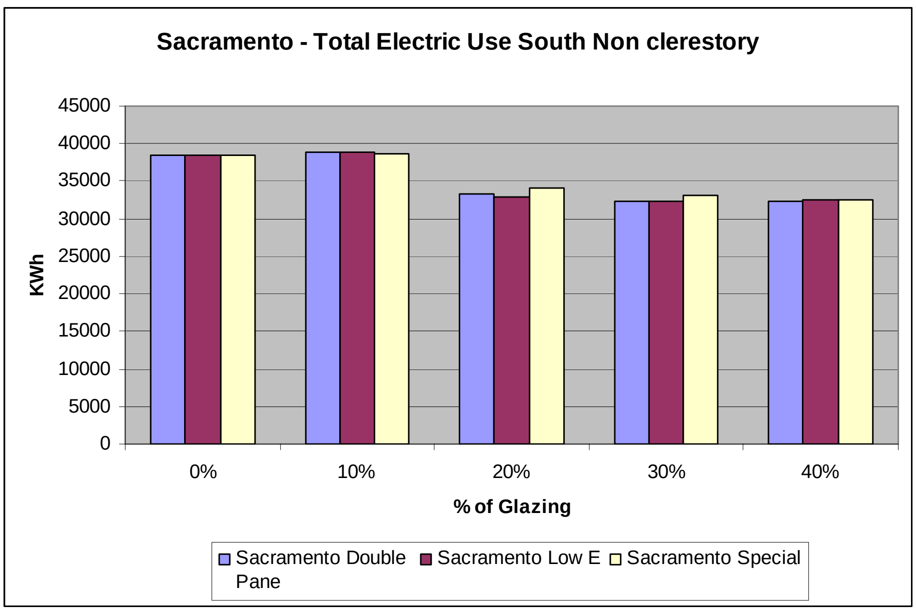




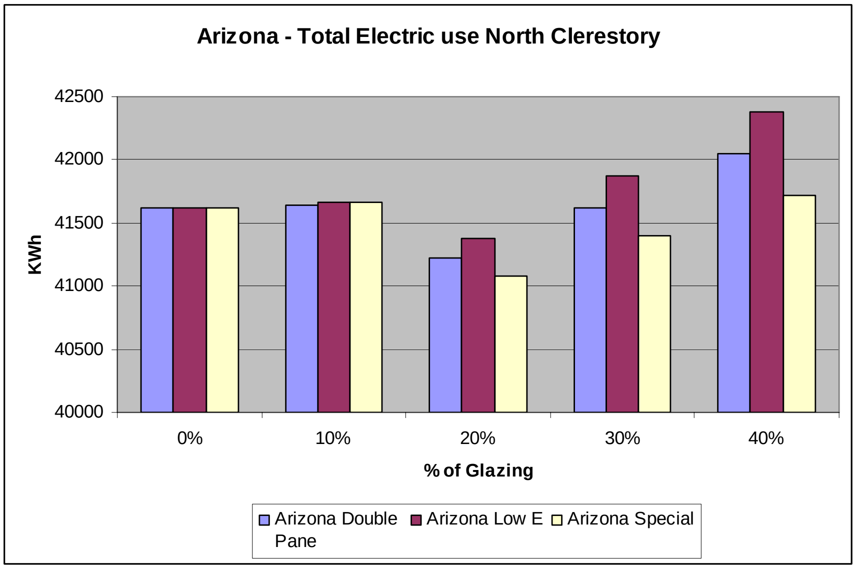


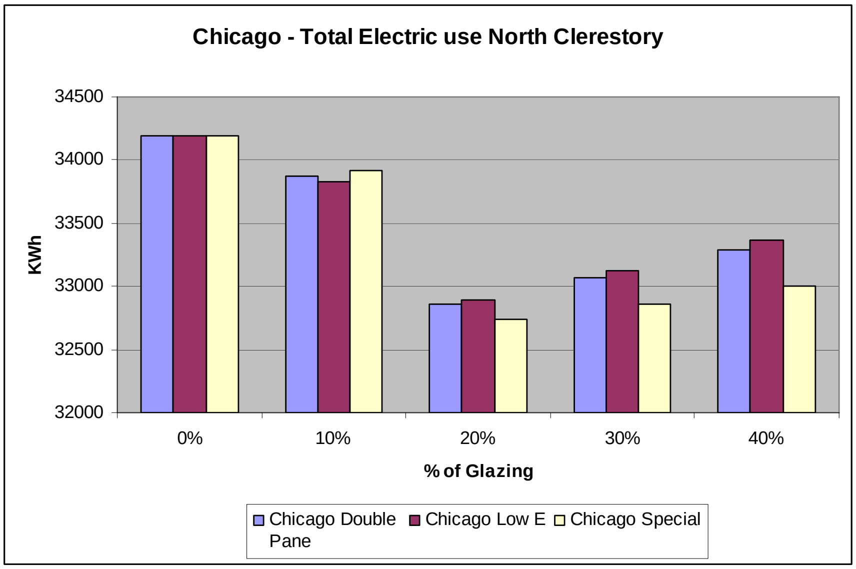
South Non clerestory

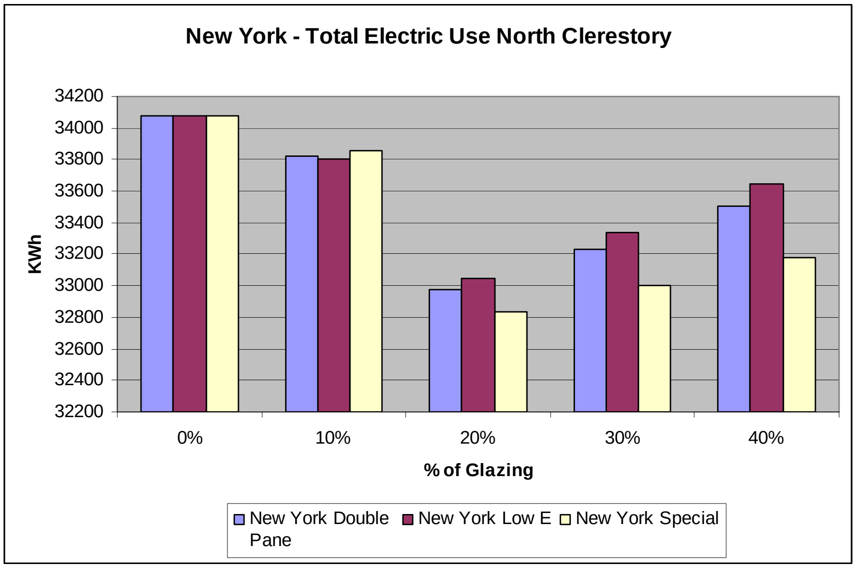




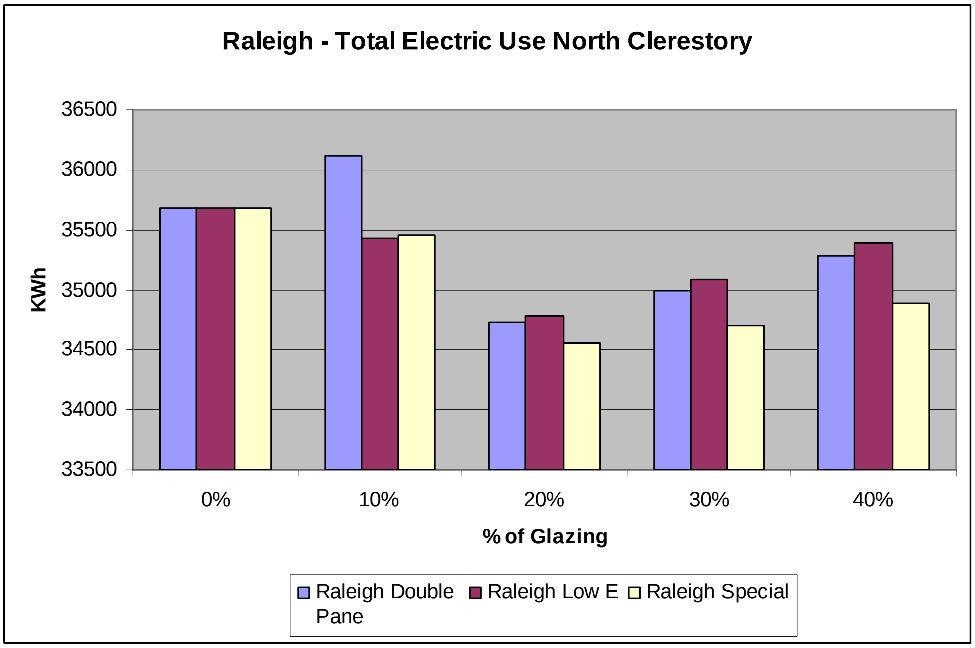
<u>North Clerestory</u>

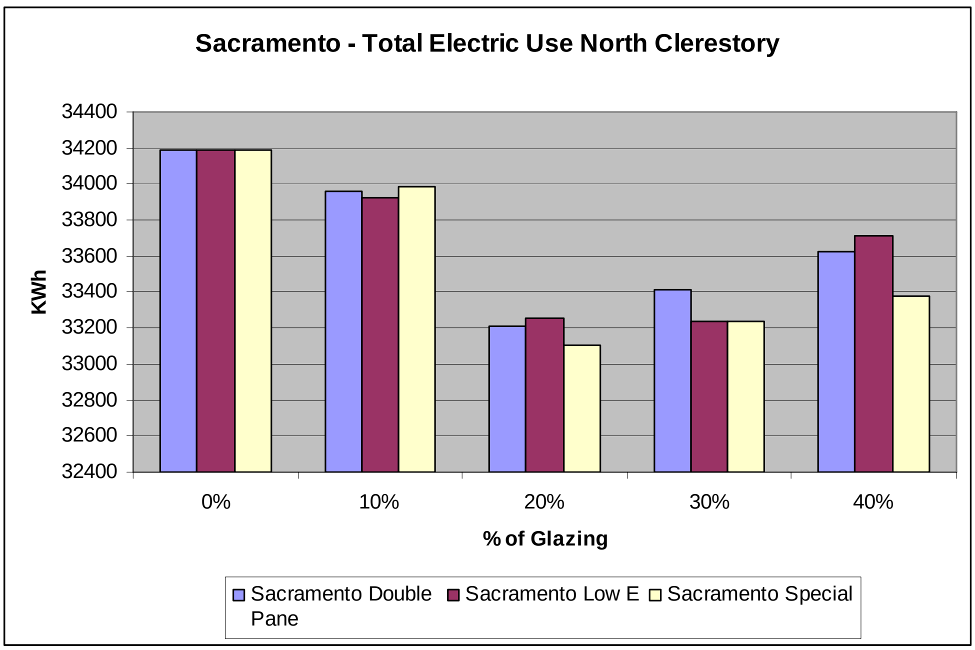






North Clerestory





Observations

1. For all Locations introducing only 0.10 GWAR shows an increase in electric consumption is suggesting no daylight benefit.
2. A distinct drop in electric costs is observed as the glazing percentage increases, the most benefit is seen at 0.2 -0.3 GWAR, with low - e glazing showing the least electric consumption, an exception is observed at Raleigh where Double pane glazing proving to be the most beneficial.
3. For a larger GWAR the double pane window electric consumption is shown to be nearly equivalent to the low e glazing.

4.3 Observations for the different variables

- Percentage of glazing

The total annual electric cost decreases as the percentage of glazing is increased with noticeable benefit at and beyond 0.2 GWAR

- Type of Glazing

Based on location the glazing type that proves to be the most beneficial were observed as follows:

Location	**Type of glazing**
Arizona	Double pane
Chicago	Low e
New York	Low e/ Double pane
Raleigh	Double Pane
Sacramento	Low e

Special glazing proved to be most beneficial when clerestory windows were introduced.

- Orientation

The total annual electric cost is noticeably influenced by orienting the glazed area to the south. The south orientation shows a lower consumption of electricity than the north orientation.

- Clerestory

Introduction of clerestory windows in the space with north facing view windows shows a decreases in the total annual electric demand at 0.2 GWAR. Above 0.2 GWAR causes an increase in the cooling demand, and a consequent increase in electric consumption and cost.

The results also show that improved glazing such as Low - e and Special glass (Azurite) which have a lower SHGC also have a lower visible transmission (VT) thus having an effect on the demand for area lighting. As the heating / cooling demand decreased the demand for area lighting increased simultaneously, indicating that the percentage of glazing used is vital in order to achieve a balance in energy consumption.

4.3.1 Conclusion and Recommendations

When we consider the total electric cost for the various cities the following are the observations:

1. A balance between the heating / cooling and lighting requirement of the classroom space can be achieved with 0.2 – 0.3 GWAR
2. For determining the percentage of glazing we should take into consideration factors such as climate, type of glazing, orientation, the demand for heating / cooling and lighting within the space, as it is observed these various factors and their influence is interdependent.

Bibliography

1. A Room With A View: A Review of The Effects of Windows on Work and Well-being ,Kelly M. J. Farley and Jennifer A. Veitch
   Institute for Research in Construction, National Research Council Canada, Ottawa, ON, K1A 0R6, Canada, 2001-August-15

2. CHPS Best Practices Manual 2006 CHPS Inc.

3. Daylighting in Schools A N e w Z e a l a n d P e r s p e c t i v e
   Master of Building Science, School of Architecture Victoria University of Wellington, Thesis, Quentin Jackson -2006

4. National Best Practices Manual For Building High Performance Schools,
   Office of Energy Efficiency and Renewable Energy, U.S. Department of Energy

5. GLAZING PERFORMANCE, James H. Wasley & Michael Utzinger
   Johnson Controls Institute, for Environmental Quality in Architecture, School of Architecture and Urban Planning, University of Wisconsin- Milwaukee

6. The future of daylight, Power point Presentation, Centennial conference IESNA 2006, Lisa Heschong, Architect LC principle, Heschong Mahone Group Inc.

7. How much energy do different toplighting strategies save? Moeck, Yoon, Bahnfleth, Mistrick, The Pennsylvania State University, Department of Architectural Engineering

8. How much energy do sidelighting strategies save? Moeck, Yoon, Bahnfleth, Mistrick, The Pennsylvania State University, Department of Architectural Engineering

9. Life Cycle Cost Optimization of Buildings with Regard to Energy Use, Thermal Indoor Environment and Daylight, June 2002, Toke R Nielsen Department of Civil Engineering, Technical University of Denmark, Lyngby, Denmark

10. Lighting for Schools, *National Clearinghouse for Educational Facilities*
    James R. Benya, PE Benya, Lighting Design December 2001

11. Windows of Opportunities, the Glazed Area and its Impact on the Energy Balance of Buildings, Mari –Louise Persson. Department of Science and Technology, Uppsala University.

12. The Cool Daylighting Design Approach Workbook: Volume 2 – Schools
    Steven E Ternoey, AIA, IES, Light Forms: Daylighting, Lighting, Energy & Training Consultants, Santa Barbara, CA.

13. Visual Comfort and Energy Saving, Mike Wilson, Low Energy Architecture Research Unit, School of Architecture and Interior Design, University of North London - London

14. “Mechanical Systems” 2003, Julian de Bullet HVAC Systems Manager, Mc-Quay International, High Performance Schools, Office of Energy Efficiency Rebuild America Oregon Department of Energy & Green Building Services

15. Classrooms for the Future By L. Michael Golden ,Deputy Secretary, Pennsylvania Department of Education

16. Educational Objectives and the Classroom: *Teacher Reactions to Classroom Prototypes* Ashraf Salama, Ph.D. Adams Group Consultants, LLC, *Charlotte, NC*

17. Classrooms of the future, innovative designs for schools classrooms
Department for education and skills, London

18. Future Schools as Future Schools as High Performance High Performance Learning Environments in a World of Learning Environments in a World of Continuous Computing Continuous Computing
Roy Pea Roy Pea , Stanford University Stanford University

19. Report from the National Summit on School Design – A resource for educators and designers. Convened by the American Architectural Foundation and Knowledge Works Foundation, Washington DC, 2005

20. Classroom Standards, The University of North Carolina at Chapel Hill, Chancellor's Classroom Improvement Initiative, June1997

References

[1] The Heschong Mahone study- "Daylighting in Schools - an investigation into the relationship between daylighting and human performance"

[2] Kuller R and C Lindsten "Health and Behavior of children in classrooms with and without windows" Journal of Environmental Psychology 12pp, 305-317, 1992.

[3] Hathaway W "Effects of school lighting on physical development and school performance." The journal of education research volume 88, no.4 p 228, March 1st 1995

[4] "Energy Performance of Daylit schools in North Carolina" 1996 Nicklas M and G Bailey.

[5] North Carolina State Board of education 1998