AN ANALYSIS OF ENERGY REDUCTIONS FROM THE USE OF DAYLIGHTING IN LOW-COST HOUSING

A Thesis

by

NAYARAT RUNGCHAREONRAT

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

August 2003

Major Subject: Architecture

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Approved as to style and content by:

Jeff S. Haberl (Chair of Committee)	Keith E. Sylvester (Member)
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ABSTRACT

An Analysis of Energy Reductions from the Use of Daylighting in Low-cost Housing. (August 2003)

Nayarat Rungchareonrat, B.Arch., Chulalongkorn University

Chair of Advisory Committee: Dr. Jeff S. Haberl

This research focuses on energy reductions from the use of daylighting in residential buildings located in hot and humid climates. The proposed research studied the effectiveness of different daylighting strategies and assessed their performance in enhancing natural lighting in the space without causing excessive heat gain problems in the building. The goal of using effective daylighting strategies is to protect the interior from direct sunlight during the cooling season, and deliver indirect light into the building interior to reduce the need for supplemental lighting. The concern about using daylighting is that, while reducing the solar heat gains, it also reduces the amount of daylight needed to supplement interior lighting. Therefore, the objective of this study is to explore the effectiveness of daylighting strategies that balance the solar heat gain reduction and daylight utilization and result in electrical energy savings in building.

The study was performed using a physical scale model for the Daylight Factor studies and the DOE-2 energy simulation computer program for simulating models of a case study Habitat for Humanity house with and without applied daylighting. The case study building was used to represent the typical energy end-use patterns in the single-family residence in hot and humid climates. Illuminance data was measured at different points in the model under actual overcast sky conditions to obtain the Daylight Factors of the proposed daylighting models, which were then compared to the basecase building. The annual energy analysis was conducted using the DOE-2 energy simulation program. Results are reported in terms of the annual heating, cooling, and electrical energy uses with each device in place, as compared to the baseline building.

DEDICATION

To my father,

who has been inspiring, encouraging, and comforting me from afar

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From working on this thesis, I have learnt many things other than the research techniques. Those things include organizing my thoughts, managing my time, solving problems that might arise, as well as dealing with the unexpected. I do believe that this experience will also prove very valuable for both my career and personal life in the future.

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CHAPTER I

INTRODUCTION

1.1. BACKGROUND

In the past few years, increasing concerns about the world's increasing energy consumption and available energy sources have increased. The world's increasing energy use is driven by the increase of population. From reports of the Energy Information Administration (EIA 2001), the world population increased from 5,253 million in 1990 to 5,996 million in 1999, which amounts to a 1.48 percent average annual growth rate. The report also shows the increase of the world's energy use from 346 quadrillion (10^{15}) Btu in 1990 to 382 quadrillion Btu in 1999, an average annual gain of 1.11 percent. This amounts to a per capita energy use of 65.86 million Btu in 1990, which decreased to 63.71 million Btu per capita in 1999, resulting in a 0.36% average annual decrease. Since the world population continues to grow while there are limited supplies of energy, it is important to consider the efficient use of energy, as well as the preservation of natural resources.

From the EIA report, the United States population increased from 250 million in 1990 to 273 million in 1999, a 0.98 percent average annual growth rate. In the same period, the energy consumption in the U.S. increased on average by 1.61 percent annually, rising from 84 quadrillion Btu in 1990 to 97 quadrillion Btu in 1999. This amounts to a 1990 energy use per person of 336 million Btu. In 1999, the energy use per person increased to 355 million Btu, accounting for 0.61% average annual growth. The U.S. energy consumption has been categorized into 4 sectors: residential, commercial, industrial, and transportation. The total energy consumption in the residential sector increased from 17 quads in 1990 to 19 quads in 1999, representing 1.24% average annual increase. Energy consumption also increased significantly in the commercial sector, from 13 quads in 1990 to 16 quads in 1999, which amounted to 2.33% average annual increase. Considering the industrial sector, energy use increased from 32 quads in

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1990 to 35.5 quads in 1999, accounting for 1.16% average annual growth. In the transportation sector, energy use increased from 22.5 quads in 1990 to 26 quads in 1999, representing an average annual increase of 1.62%. Although energy use in the residential sector remains at about 20 percent of all U.S. energy consumption, it continues to grow at a rate that is higher than the population growth rate. Therefore, it is important to make efficiency improvements in residential housing in the U.S.

From the Residential Energy Consumption Survey (RECS 1997), the number of households in the U.S. has increased by 33 percent from 76.6 million in 1978 to 101.5 million in 1997, or a 1.5% average annual growth rate. According to the RECS Survey, the energy consumption in the U.S. housing units is mostly driven by space heating. However, the heating energy decreased from 7 quads (66 percent of all Btu) in 1978 to 5.2 quads (51 percent) in 1997. These data most likely indicated that during this period, there were significant improvements in building insulation and equipment efficiency. Over the 1978-1997 period, the water heating energy increased 25% from 1.5 quads to 1.9 quads (from 15 to 18 percent of all Btu), and the cooling energy increased 33% from 0.3 quads to 0.4 quads (3 percent to 5 percent of the total Btu). The increase in cooling energy indicated an increased use of air-conditioning equipment in residential buildings.

Over the same 19-year period, the energy consumption for appliances and lighting increased by 66 percent from 1.8 quads to 3.0 quads (17 percent to 29 percent of the total residential Btu), which was twice the rate of the increase of housing. Data from the 1997 RECS also showed that the total lighting energy was 0.33 quads, which accounts for 3 percent of the total residential Btu. For the next 23 years, the number of U.S. households is predicted to increase by 24 percent to 127 million in 2020. Likewise, the energy consumption in the U.S. residential lighting is predicted to increase by 58 percent from 0.33 quads in 1997 to 0.52 quads in 2020. Even though the lighting energy portion is small, compared to the total energy use, it increases more than twice the rate of the number of housing. Hence, it is important to consider energy-efficient lighting in residential buildings. Energy savings in lighting can be accomplished by the use of more efficient lights, or by using daylighting, or both.

Daylighting can make a significant contribution to overall energy consumption. The principle of daylighting design is to maximize the use of available outdoor illuminance without imposing excessive cooling loads or causing glare (Lam and Li 1998). Effective daylighting strategies should protect the interior space from direct sunlight during the cooling season and project daylight into a space to increase room brightness (Ander 1995). This important consideration can contribute to preserving natural resources and contribute to a solution for the world's energy shortage problem.

1.2. OBJECTIVES

The primary objective of this research is to evaluate the effectiveness of several daylighting design strategies applied to low-cost housing. To achieve the objective, the following tasks have been defined:

1) Research and define the effective daylighting strategies to be applied to residential fenestrations.
2) Investigate the energy use and the interior illumination levels of a case study, low-income house.
3) Develop a daylighting model of the case study house to measure the interior illuminance under overcast sky conditions.
4) Use the DOE-2 energy simulation program to simulate the energy use and daylighting of the base case building and the new designs with and without daylighting.
5) Evaluate the effectiveness of proposed daylighting design strategy in terms of daylight utilization and energy savings.

1.3. PROPOSED RESEARCH

The objective of this study is to assess the effectiveness of daylighting strategies considering the illuminance, and cooling energy requirements. The study will be performed on a simulated model of a case study house with applied shading devices, which provide varying amounts of daylighting. The study will utilize data gathered from the case study house, the testing of physical model, and simulations from the DOE-2 program. The research will be based on the following assumptions:

1) An appropriate daylighting strategy for hot-humid climates should minimize the amount of direct sunlight into the building interior, which contributes to heat gain during the cooling season.

2) The most effective daylighting strategies redirect any direct sunlight onto a ceiling to enhance the distribution of light into space.
3) An effective daylighting design should contribute to visual comfort in the building and minimize glare problems.
4) The proposed strategies should be cost-effective, so they can be implemented in low-cost housing.

To accomplish the objectives of the research, four major tasks are proposed: 1) Model building and testing, 2) Field measurements, 3) Simulation using the DOE-2 energy simulation program, 4) Analysis and evaluation.

1) Model building and testing

The physical model used for this research will be constructed to represent the geometry of a case study house with the scale 1 inch = 1 foot. Model testing will be conducted in the daylighting laboratory, and under overcast sky conditions. Measurement of illuminance levels will be conducted for each daylighting strategy applied to the model to find the most effective daylighting design. Results from the model measurements will then be compared with the simulations from the DOE-2 program and the measurements from the case study site.

2) Field measurements

Illuminance levels will be measured in the case study house on the overcast days. Data gathered will be compared to the data from model testing, and from DOE-2 simulation. Other necessary data such as occupancy profiles, building activity schedules, and electricity use will be collected for the analysis and simulations.

3) Simulation using the DOE-2 energy simulation program

The DOE-2.1e (version 119) program will be used to evaluate the energy uses of a case study house with and without daylighting features. Actual measured data, such as occupancy profiles, building schedules, electricity use, and measured temperatures will be input into the DOE-2 input files for calibrating the simulations.

4) Analysis and evaluation

The simulated results will be compared with the measured data to evaluate the effectiveness of the proposed daylighting strategies in terms of improved lighting levels and decreased energy use. Recommendations will be proposed regarding the alternatives for energy-efficient fenestration design for low-cost ho using.

1.4. ORGANIZATION OF THE THESIS

This thesis is divided into 6 chapters. Chapter I includes the introduction, which provides the background of the research, the objectives, the significance of the work, and the proposed research. Chapter II contains the literature review. This chapter discusses the previous works related to the proposed study, which include a lighting analysis, daylighting strategies, and a summary of the literature review. In Chapter III, the research methodology is provided. The discussion covers the procedures used in this study, which include the use of the case study building, the use of physical model, and the use of the DOE-2 Energy simulation program.

Chapter IV contains the results and analysis. Discussions in this chapter include the results of using daylighting strategies in terms of light levels and energy use reductions. This chapter also includes the results of the DOE-2 basecase model calibration, the results of Daylight Factor measurements, and the results of the DOE-2 daylighting simulation. Chapter V contains the recommendations on future studies in conducting further research about daylighting and energy savings in buildings. Conclusions from the study are presented in Chapter VI, which summarizes the daylighting strategies for the energy-efficient designs. This chapter also provides conclusions about using daylighting to achieve lighting energy savings in low-cost housing, in hot-humid climates.

CHAPTER II

LITERATURE REVIEW

This chapter contains the relevant literature review for this study. The literature review includes lighting analysis, daylighting studies and evaluations, and daylighting strategies. It also includes previous work on the case study building. The following sources were consulted for this literature review: IESNA lighting handbook and IESNA journals, LBL research reports, ASHRAE Transactions, proceedings of the ACEEE on Energy Efficiency in Buildings, proceedings of the International Building Performance Simulation Association (IBPSA), proceedings of the symposium on improving Building Energy Efficiency in Hot and Humid Climates, proceedings of the International Daylighting Conference, and previous researches on daylighting and energy studies.

2.1. LIGHTING ANALYSIS

2.1.1. Lighting Definition and Design Concepts

“Light is defined as radiant energy that is capable of exciting the human retina and creates a visual sensation” (IESNA 1984, pp. 2-1). The quality of light is defined by the luminance ratio, visual ability and comfort, glare, and contrast between the work plane and the immediate surroundings. From Stein and Reynolds (1999), the goal of good lighting is to create an efficient and pleasing visual interior. Light can and should be used as a primary architectural feature, and should provide adequate lighting levels for the efficient viewing of the particular task. The entire lighting design should be accomplished efficiently in terms of capital and energy resources (Stein and Reynolds 1999)

2.1.2. Residential Lighting

“The objectives of residential lighting design are to provide illumination for the planned activity in the area being lit, whether it is a difficult viewing task or a casual entertainment” (IESNA 1987, pp. 10-1). The design factors that should be considered in residential lighting design include: the number and age of the occupants, the type of visual activities, the location and size of the task area, the frequency and duration of use, the architectural space and furnishings, the size and scale of the space, the desired mood to be created, the building and electrical code requirements, the structural constraints, and the power costs.

According to the *IESNA Lighting Handbook* (IESNA 1999), an individual's visual field is considered to consist of three major zones. The first is the task itself, the second is the area immediately surrounding the task, and the third is the general surroundings. Luminance ratios are recommended between all three zones to achieve visual comfort. Between the immediate surroundings and the visual task, the desirable ratio is 1:3, the minimum acceptable ratio is 1:5. Between the general surroundings and the visual task, the desirable ratio is 1:5, and the minimum acceptable ratio is 1:10. These values are based on typical task luminance range, of 4 to 12 footcandles.

The IESNA: Illuminating Engineering Society of North America (IESNA 1999) also recommends reflectance values (percent) for residential room surfaces. The recommended reflectance for ceilings is between 60 to 90 percent, for curtains and drapery treatments on large wall areas 45 to 85 percent is recommended, for walls 35 to 60 percent is recommended, and for floors it is 15 to 35 percent.

Finally, the IESNA recommends that residential lighting be planned on the basis of activities, not on the basis of rooms. Illuminance values for interiors of a building are derived from the IESNA tabulation: "currently recommended illuminance categories and values" (IESNA 1987). The weighting factors considered in selecting illuminance values are occupant ages that are under 40, room surface reflectance between 30 to 70 percent, and speed and/or accuracy somewhat important for any visual tasks. The targeted illuminance values considered for this case study building include 7.5 fc (footcandles) for the living area, 15 fc for the dining area, 75 fc for the kitchen area (critical tasks), 30 fc for non-critical kitchen tasks, 30 fc for reading in a chair, 30 fc for reading in bed, and 75 fc for study at a desk. Table 2.1 presents the illuminance categories and illuminance values considered in this study.

Table 2.1 – Illuminance categories and illuminance values considered in the study.

Type of Area/Activity	Illuminance Category	Ranges of illuminances		Values considered	
		Lux	**Footcandles**	**Lux**	**Footcandles**
General lighting					
Living space	B	50-75-100	5-7.5-10	75	7.5
Specific visual tasks					
Dining	C	100-150-200	10-15-20	150	15
Kitchen duties					
Critical tasks	E	500-750-1000	50-75-100	750	75
Noncritical	D	200-300-500	20-30-50	300	30
Reading					
In a chair	D	200-300-500	20-30-50	300	30
In bed	D	200-300-500	20-30-50	300	30
At a desk					
Primary task, study	E	500-750-1000	50-75-100	750	75

Source: IESNA (1987), pp 2-5 – 2-20. Illuminance category B is defined by the type of activity as simple orientation for short temporary visits, C as working spaces where visual tasks are only occasionally performed, D as performance of visual tasks of high contrast or large size, and E as performance of visual tasks of medium contrast or small size.

2.2. DAYLIGHTING

2.2.1. History of Daylighting

Daylight has been considered the primary source of light in buildings throughout most of architectural history. Moore (1985) stated that in the past, architects designed small openings or used a diffusing medium in the openings when daylight was ample and constantly bright. Daylight was brought into the buildings only where it was in need. Hopkinson et al. (1966) stated that in the past, daylighting was concerned with esthetic quality rather than quantity. During the last few decades, physicists and engineers have developed principles of illumination and photometry and applied these principles to the daylighting problems. Due to these improvements, more precise approaches to daylight technology have been continually developed.

2.2.2. Daylighting Analysis

According to the *IES Lighting Handbook* (IESNA 1984), the primary factors that influence daylighting include: 1) variations in the amount and direction of the incident daylight, 2) illuminance and luminance distribution of clear, partly cloudy and overcast skies, 3) variations in sunlight intensity and direction, 4) effect of local terrain, landscaping and nearby buildings on the available light.

The availability of daylight depends on the natural light sources. There are three primary daylight sources to be considered when designing daylighting: the sun, the sky, and the ground as a light source (IESNA 1984). For the sun as a light source, two coordinates are used to locate the position of the sun in the sky. These are the solar altitude -- the vertical angle of the sun above the horizon, and the solar azimuth -- the horizontal angle of the sun from true south (Stein and Reynolds 1999). Hopkinson et al. (1966) explained that the daylight availability produced by the sun varies primarily with the sun's apparent position, which is a function of the time of day, season, or day of the year, and the position of the building relative to the earth's surface. There are secondary causes of daylight variation, such as clouds, amount of water vapor in atmosphere, or dust and industrial haze, which are randomly varied (Hopkinson et al. 1966).

In the *IES Lighting Handbook* (IESNA 1984), three sky conditions should be considered in daylighting design: overcast sky, clear sky, and partly cloudy sky. The amount of light received from the overcast sky depends on the cloud patterns. The light distribution also varies with geographical locations, time, density and uniformity of the overcast clouds. Uniformly overcast skies are two and a half to three times as bright overhead as at the horizon. Hopkinson et al. (1966) also suggested that for a fully overcast sky, the horizontal illuminance at any point of the same elevation is equal, irrespective of the altitude of the sun. For clear sky, as mentioned by Ander (1995), the light is diffused because of the refraction and reflection of the sunlight in the atmosphere. Under these conditions, the sky is brighter along the horizon than the overhead. In a partly cloudy sky, the illuminance level varies with the position of the clouds correspondent to the sun's position. Because of this, the horizontal illuminance under a partly cloudy sky may be higher than under a clear sky.

The ground is also a light source, as stated in the *IES Lighting Handbook* (IESNA 1984), and provides 10 to 15% of the total daylight reaching a window area on sunny elevations. Architects or engineers may control ground light through the use of selected ground surfacing materials near the building. These daylight design considerations will be considered in this study.

2.2.3. Daylighting Calculations

There are many methods used for daylighting calculations, including: the Computation of Illuminance, the Lumen Method for sidelighting (IESNA 1984), the daylight analysis or CIE method, the Graphic Daylighting Design Method: GDDM (Stein and Reynolds 1999), and the Daylight Factor method (Hopkinson et al. 1966). Two of the methods were considered the most suitable for conducting the proposed research. These methods are the Lumen Method for sidelighting (IESNA 1984) and the Daylight Factor Method (Hopkinson et al. 1966).

According to the current IESNA recommended practice: RP-23-1989, the Lumen Method for sidelighting treats the window as a large area lighting source. The lighting levels are calculated at five predetermined points in the room at the positions of 10%, 30%, 50%, 70%, and 90% of the room depth. In calculation, the working plane is always at the window sill height. The cavity reflectances are fixed at 70%, 50%, and 30% for ceiling, room, and floor cavities respectively. This method is an analysis tool, rather than design tool. Therefore, it is usable in only one mode; that is, given a location and full architectural data, daylighting can be calculated.

The Daylight Factor method, adopted by CIE (the Commission Internationale de I'Eclairage), evaluates the illuminance from daylight that occurs at a point inside a room as a percentage of the simultaneous outdoor horizontal illuminance from an unobstructed sky (i.e., CIE-defined overcast sky). This ratio is called the Daylight Factor, and is defined by the equation:

$$\text{DF (\%)} = \frac{\text{Indoor Illuminance, at a given point}}{\text{Unobstructed horizontal illuminance}}$$

In the Daylight factor method, daylight is composed of three components: 1) a Sky Component, or light received at the design point directly from the sky, 2) an Externally Reflected Component, or light received directly onto the design point from external reflecting surfaces, and 3) an Internally Reflected Component, which is light reaching the design point after one or more inter-reflections from interior surfaces. Daylight Factor measurements are used in the current study to evaluate the effectiveness of the window designs.

2.2.4. Shading Design Methods and Evaluation Techniques

Three methods are primarily used to evaluate daylighting strategies. One is the shading mask and sun path diagram, another is the DOE-2 daylighting analysis, and third is the use of a physical scale model on a heliodon or on a tilt table that simulates the sun altitudes and solar time in different seasons.

2.2.4.1. Shading mask and sun path diagram

The sun path diagram displays the path of the sun across the sky visualized as seven paths (i.e., December, January-November, February-October, March-September, April-August, May-July, June) traced on the overhead skydome, which translated onto a two-dimensional presentation (Moore 1985). Olgyay and Olgyay (1957) studied and displayed the analysis of shading devices using the equi-distant sun path diagrams and shading masks. They recommended plotting the cooling season of the year on the sun path to show where shading was beneficial in maintaining thermal comfort. Then the effectiveness of a shading device was evaluated based on how the shading mask covered this cooling period. Example of Olgyay’s sun path and shading mask protractor can be found in the American Institute of Architects and Architectural graphics Standards.

The Libbey-Owens-Ford sun angle calculator (LOF 1974), a commonly used tool for shading analysis, is another sun path chart used almost exclusively in the United States. It includes a complete set of sun path charts for north latitudes from 24 to 52 degrees, in steps of 4° of latitude. A transparent shading mask, when combined with a sun path diagram, can be used to study daylight efficacy, including hourly and annual of the solar exposure for a fenestration, and the degree of shading provided by architectural features such as overhangs and fins.

One of the computerized sunpath program is the SOLRPATH computer simulation program (Oh 2000). This software initially began as a class project in the Mechanical Engineering HVAC class by Jay Mattern in spring of 1992 at Texas A&M University. This was followed by the computerized program for plotting the sunpath diagram and the shading effects by the use of shading mask protector was developed by McWatters and Haberl. The development of program included clipping and rotating functions for various sun azimuths and a complete FORTRAN SOLRPATH code for the sunpath diagram (McWatters and Haberl 1994a, 1994b, 1995). Oh and Haberl (1996, 1997) then improved and developed the MS-Windows version of the SOLRPATH program. The work was later extended as part of Kie Whan Oh’s Ph.D. dissertation in Architecture at the Energy Systems Laboratory, Texas A&M University. The resultant program is a user-friendly program for displaying and designing energy-efficient shaded fenestration, which will be used in this study.

2.2.4.2. DOE-2 daylighting simulation and analysis

The DOE-2 daylighting calculation allows users to study what effect daylighting has on energy use, peak loads, and energy cost (LBL 1993). The DOE-2 program was originally developed to perform an extensive thermal analysis and includs calculations of different incident angles, which results in the determination of solar, conduction, and convection gain on shaded building fenestration systems.

The Daylight Factor prediction in the DOE-2 program is performed in the LOADS sub-program. DOE-2 analyzes the contribution of direct light through a window, the surroundings, and the interior reflections to the specified reference points by integrating over the area of each window, and affected surface. The primary factors considered in the DOE-2 processing include window size and orientation, pane of glass glazing transmittance, interior surface reflectance, sun-control or shading devices, and the luminance distribution of the sky. The preprocessor calculates a set of Daylight Factors, which are stored for later as hourly calculations. The illuminance contribution from each window is calculated by interpolating the stored daylight factors which are multiplied by the exterior horizontal illuminance data obtained from measurements, weather data files, or calculations. The DOE-2 daylight calculation is preformed for both standard clear and overcast sky conditions. The program carries an analysis through a series of 20 different solar altitudes and azimuths covering the annual range of sun positions. Besides an hourly illuminance calculation, DOE-2 also performs a glare analysis. Additional information on Daylighting calculations in the DOE-2 program is available in the DOE-2 Supplement, Version 2.1E (LBL 1993).

Since the DOE-2 program allows users to analyze the effect of selected fixed shades, fins and overhangs applied on the building’s exterior, this study will use the DOE-2 daylighting calculations to analyze the effect of the proposed shading strategies in terms of lighting quantity and energy-efficient design.

2.2.4.3. The use of a physical scale model

Another method used in daylighting evaluations is the physical scale model. Scale models provide a simple means of changing one variable at a time (e.g. window geometry, shading system, surface reflectance) Scale models have been used extensively in the previous literature on daylighting.

In the study by Randall and Martin (1928), models were tested under an artificial sky to predetermine the illumination in a multistoried industrial building. To study the potentiality of using scale models in providing a simple, non-mathematical means for practicing architects as well as engineers to study the daylight performance of the proposed buildings, Vezey (1951) and his research team conducted a feasibility study of using models for predetermining natural lighting. This work was part of research report series of the Texas Engineering Experiment Station at Texas A&M University. Results from the study showed that models could be used, under proper conditions, to predetermine natural lighting performance of proposed buildings as wells as to compare various architectural designs regarding natural lighting.

Scale models were also used as a design tool in space planning, as presented in the work conducted by Gon Kim (1996) as part of his Ph.D. dissertation in Architecture at Texas A&M University. The experiment was conducted using scale models to study the effect of interior partitions on performance of daylighting in office buildings. The scale model measurements were performed under an artificial sky (sky simulator) and the performance of daylight was studied in terms of Daylight Factor

(DF) and Reflected Sunlight Illuminance Ratio (RSIR). Based on the evaluations using the scale models, his study concluded that the use of partitioned space in an open plan of office models could offer a large potential for daylighting and lighting energy savings. This study built a historical knowledge in the use of a physical scale model in daylighting study for this proposed research.

The use of scale models, together with photometric instrumentation systems, provided a tool for parametrically evaluating proposed daylighting designs, in the work by Kyoo Dong Song (1993). This Ph.D. dissertation in Architecture at Texas A&M University aimed at providing daylighting and sunlighting performance data and guidelines for designing well and canopy configurations of sunlit atria. His study combined the use of a video-based luminance mapping system to determine geometric and photometric daylighting parameters with the use of physical scale models which contained well configurations and canopy designs. The measured data were analyzed to evaluate different design configurations regarding their impacts on illuminance levels and luminance distributions on the building atrium space under different sunlight and sky conditions. This study developed a method which used physical scale models together with the photometric mapping systems for daylighting quantitative study. This study provided an overview in the daylighting data acquisition and built an understanding in the use of physical scale models for daylighting study for the proposed research.

Bryan et al. (1981) conducted a study on the use of physical scale models for daylighting analysis, as part of Lawrence Berkeley Laboratory’s Windows and Daylighting Program. Their work provided recommendations on the application of physical scale modeling. The study stated that models constructed for use in quantitative studies did not require the same amount of detail as for qualitative study. However, modeling used for both studies was particularly sensitive to the reflectivity of internal surfaces. They suggested that surfaces might be finished with paper or paint which approximated the appropriate reflectance values. The scale models used in the LBL research is 1 in. = 1 ft., and is used to study the effectiveness of a physical scale model in representing a daylighting space. The study concluded that a physical scale modeling provided a tool in studying the daylighting performance which could be related to the existing building. This study provided useful recommendations and guidelines in constructing and using a physical scale model for this proposed work.

2.3. DAYLIGHTING STRATEGIES

The daylighting strategies reviewed in this research include: the availability of daylight, the effects of daylight on a building's occupants, fenestration design considerations, integration with supplemental electric lighting, simulation and measuring energy use, and previous work on a case study building.

2.3.1. The Availability of Daylight

Besides the size of the windows or openings, another important factor that should be considered in designing daylighting systems is the availability and variability of daylight. Selkowitz and Johnson (1980) stated that daylight was an instantaneous phenomenon, its availability in certain illumination levels could not be easily averaged over time. For the daylighting design, hourly records of available daylight at certain locations are as important as the estimation of solar radiation for thermal analysis. Different approaches in recording as well as predicting daylight availability at a certain location have been developed.

In the United States, the commonly accepted daylight availability data is found in the IESNA (1984) and is based on the work of Kimball and Hand (1921) conducted in Washington D.C. during the 1920s. The need for reliable, local data on daylight availability for the study of daylighting and energy-related impacts in a building lead to the developments of approaches for collecting, analyzing and predicting daylight availability for different U.S. locations. Navvab et al. (1983) collected daylight availability and solar radiation data in San Francisco, as part of the broader research program to investigate the energy savings potential of daylighting at Lawrence Berkeley Laboratory, Berkeley, California. These data formed the basis for a detailed study of illuminance characteristics in the bay area and provided a database for the development and the testing of various algorithms for daylight availability analysis. The availability of daylight is an important factor that should be considered in conducting the proposed daylighting study.

A daylight prediction model was another effective approach to define the daylight availability. Robbins and Hunter (1983) developed the Robbins-Hunter model based on computing exterior illuminance data on a surface of any orientation as a function of location, sky conditions, and environmental conditions. Based on model tests, they derived the hourly daylight and sunlight availability data for Denver, Colorado.

Another work on daylight availability predetermining was conducted by Pierpoint (1983). He developed a sky model for the prediction of daylight availability. A set of formulas were presented for the calculation of horizontal and vertical illuminances from the sun and various sky conditions. The ratio of vertical to horizontal illuminance was used to select a proper coefficient of utilization table determined by the IES Lumen method for sidelighting. These studies provided a historical knowledge in the development of daylighting model for this proposed research.

2.3.2. The Effects of Daylight on a Building's Occupants

A number of studies have been performed that assessed the qualitative effects of daylight on occupants in buildings, including the studies of Evans (1961), Kim (1997), and Wotton and Barkow (1983).

Evans (1961) studied the physiological and psychological factors in properly designing space for human occupancy as part of his Master thesis in Architecture at Texas A&M University. He concluded three primary factors that should be considered for the achievement of good lighting, which included the visual response to lighting, the availability and types of lighting, and the methods for controlling light. These factors will be considered in this proposed study.

The study of Kim (1997) provided an understanding of the subjective responses to daylight, sunlight, and views in college classrooms with windows. This study, as part of his Ph.D. dissertation in Architecture at Texas A&M University, investigated the psychological effects of daylight, sunlight, and classroom views through windows and explored the design criteria for the use of daylight in classrooms. Results from the study showed daylight and view had a positive impact on college classrooms since they provided positive emotion to the classroom environment and contributed to the increase in academic satisfaction. These factors could influence residential use as well.

Another study on human responses to daylight spaces was conducted by Wotton and Barkow (1983) in a study commissioned by Health and Welfare Canada. The study investigated the effects of windows and lighting on the performance and well being of office workers. The office lighting in the experiment included electric lighting, daylighting, and a combinations of both. Results from the study found no significant relationship between work productivity and access to daylight or between percent of glazing area and worker's physical comfort and health. However, the study discovered that mental well being and pleasantness of work place depended on the subjective perception of workers to daylighting. The study concluded that daylighting design could improve pleasantness in the workplace if it was effectively employed. The author also concluded that the goal of good daylighting design in a building is to create both visual ability and subjective comfort in the buildings occupants. These studies established a good understanding on daylighting and its impact on human visual response, which will be considered in the proposed study.

2.3.3. Fenestration Design Considerations

The application of daylight in buildings depends on the design objective of how the natural light will be conveyed into the building space. In the design of sidelight openings, the design strategy should aim at projecting light deep into the space to enhance the illuminance of interior space that is at some distance from the sidelight. A number of authors have studied the design of daylighting, including Selkowitz et al. (1983), Kang-Soo Kim (1987), Boyer and Song (1994), Arasteh et al. (1985), Pletzer (1987), Soebarto and Degelman (1994), Farray-Nagy (2000), and Abdulmohsen (1995).

Selkowitz et al. (1983) conducted a study on the design performance of light shelves, which considered the effectiveness of the daylighting system in projecting light deep into space. Surprisingly, their studies discovered that the use of interior lightshelf could result in lower illuminance levels than the bare window under uniform, overcast and clear sky conditions without direct sunlight. The reductions found were greatest near the window where the lightshelf obstructed the direct view of the sky. The authors also showed the use of interior lightshelf could provide glare control. They also concluded that the use of exterior lightshelf increased interior illuminance compared to the bare window under all sky conditions. The study recommended that, to use the lightshelf design for the greatest illuminance improvement, the lightshelf reflectance and the ceiling surface were the most important factors that should be taken into consideration. There are important findings that will be used to guide the current study.

The design of daylighting in large-scale buildings involved the extent of daylight admitted and distributed into a large space. The study of Kang-Soo Kim (1987) focused on the development of daylighting prediction algorithms for atrium design. His research analyzed the daylighting performance in actual building atriums including 4-sided, 3-sided, and linear atriums, and also developed and validated algorithms for daylight predictions under various sky conditions. This work constituted a logical extension of lighting and energy performance of office buildings. The idea of combining lighting and energy savings into the study's results is good advice for the current study.

The study conducted by Boyer and Song (1994) focused on the daylighting prediction and sunlighting strategies for atrium design in hot climates. The study explored the guidelines for effective atrium design with adequate lighting, minimum sunlighting, mitigation of passive solar heat gain, and glare control consideration. Their work provided conclusions on sunlighting case studies and the evaluation of solar gain and glare potential in complex atrium canopy and space configurations. The study established references for extended studies on designing glare-free atria with sufficient daylight to minimize electric lighting and with the potential for solar heat gain reduction. Although this study focused on atria design, the concept of a combined energy and daylighting study is valuable to the current study.

Several other studies of daylight performance have focused on the illuminance enhancement and the contribution of daylight to energy-efficient design. Arasteh et al. (1985) conducted research about the energy impacts of fenestration systems: windows, skylights, and shading systems. They found that daylighting was a cooler light source than artificial lighting and therefore was a more efficient source in terms of cooling loads. Daylighting can contribute to cooling energy savings when the followings are considered: 1) Shading Coefficient and Visible Transmittance of glazing systems, 2) lighting distribution and distance from the window, and 3) time, climate, and sky conditions. From the study of the aperture size, daylighting lowers energy use for lighting significantly until reaching the point at which daylight saturates the space, indicating that maximum energy savings have been attained at this point. After the daylight saturation point, increasing opening size only leads to the increase of solar-induced cooling loads. The study recommended that the effective use of daylight fenestration systems depended on the selection of glazing with high visible transmittance (VT) and low solar heat gain coefficient (SHGC), and should consider daylight orientation and the appropriate shading systems. This research provides useful guidance in daylight and energy applications to the proposed study.

Pletzer (1987) studied the load reduction and potential annual energy savings resulting from window shading devices on three residential buildings in Austin, Texas, as part of his Master's thesis in Architecture at the University of Texas an Austin, and as part of an ASHRAE funded project. The interior shadings studied in this research include shades, blinds, draperies, window films, and tinted windows. The exterior shading devices include solar screens, awnings, overhangs, and the effect of recessed windows and vegetation. The analysis was conducted by using the DOE-2.1c Energy Simulation Program. He concluded that the interior shadings performed well in terms of simulated annual energy cost savings. The best exterior shading, offering the most energy reduction, is an awning configuration with sidewalls on East and West window. Pletzer also concluded that annual heating and cooling energy savings, normalized to glazing area, correlated well with shading coefficient and overall U-value for a shading device. Although Pletzer did not focus on daylighting aspects, his study does provide useful information on energy savings resulting from shadings, which will be considered in energy-efficient shading designs for the proposed study.

Soebarto and Degelman (1994) explored the effectiveness of external window attachments based on daylight utilization and cooling load reduction for small office buildings in hot and humid climates. Their research concluded that the optimum ratio of the overhang length to the window height varied according to the building location. In hot and humid tropical regions, there was a tendency to have more overhangs even though the sun was at higher noontime angles. The study results showed that external shading devices (e.g., overhangs and lightshelves) could have the same energy performance as using low-e glazing. Using specialized glazing systems would result in a better energy performance in colder climates, while using external shading devices would be more cost effective in locations where heating was not critical. Results from the study contribute to an understanding in both energy efficiency and illuminance properties in daylighting designs, which are useful to the proposed study.

Soebarto's study was confirmed by the study of Farray-Nagy (2000), she studied the solar heat gain reduction, influenced by the use of selective glazing, architectural shadings, and site shading from adjacent buildings. The building performance was modeled by using the DOE-2.1e energy simulation tool. The site measurement was conducted for two weeks during unoccupied summer-time period. Results from the study showed that the combination use of architectural shading and standard glazing had approximately the same cooling energy reduction as using shading with specialized glazing. The study suggests that the use of architectural shading can contribute to a significant impact on reducing cooling loads, especially when the sun is at high incidence angles i.e., at the solar noon time period.

According to Kreider and Rabl (1994), the SC for the certain glazing equals to the SHGC of that glazing divided by the SHGC of the reference glazing, which is 0.87. Therefore, the glazing used in Texas buildings as required by the Residential Code must have the maximum SHGC of 0.40 or SC of 0.46. Data shown in Stein and Reynolds (1999) indicated that a single pane glass had the SC value of 0.98, and 0.88 for a double pane glazing. They also stated that external shading could reject about 80% of solar energy on window. According to the data provided, Shading Coefficients of external shading devices are ranged from 0.43 for awnings of venetian blind to 0.25 for completely shaded window with overhang, and as little as 0.10 for movable louvers. To comply with the Texas Residential Building Code, the reduction of SC and SHGC of normal glazing can be achieved by the use of permanent external shadings on windows, which results in a SHGC of 0.40 or less for climates with 3,500 HDD or less. This suggestion also corresponds to results from the study of Soebarto and Degelman (1994) and Farray-Nagy (2000), as previously stated.

Abdulmohsen (1995) studied the effectiveness of lightshelves in daylighting delivery systems. His work investigated four sets of shades: overhangs, internal lightshelves, external lightshelves, and combined lightshelves (internal and external lightshelves). This study showed that if designed properly, a lightshelf should redirect sunlight or diffuse daylight onto the ceiling (based on the reflectance of the upper surface of lightshelf), thus enhance lighting conditions in the space by improving the light distribution and reducing glare. Results from the study showed that for daylighting considerations, the combined lightshelf daylighting delivery system was the best system for the south aperture of a multi-story office building. Among these systems, the best were those which had an exterior shelf depth of 2 to 3 times the height of the view aperture as well as an interior shelf depth of also 2 to 3 times the height of the daylight aperture. Results from the study of energy performance showed that the combined lightshelf with the optimum depth offered the most cooling and lighting energy reductions on the south windows. This study provides useful daylighting and energy guidance for the proposed research.

2.3.4. Integration with Supplemental Electric Lighting

A complete daylighting system can be achieved by the design of various architectural features to capture and disperse natural light. Several authors have studied the use of daylighting control devices, which included the studies of Arasteh et al. (1985), Ander (1995), and Floyd and Parker (1998). Automatic photosensitive controls adjust the electric lighting levels during period of insufficient daylight (Ander 1995). One technique is called the PSALI technique (Permanent Supplementary Artificial Lighting Interiors). This technique views artificial lighting as supplementary to daylighting and not vice versa. The PSALI technique considers that non-residential buildings are principally used during daylight hours. This technique intends to provide sufficient daylight during these working hours (Stein and Reynolds 1999).

Arasteh et al. (1985) studied the proper fenestration designs and the use of daylight-responsive dimming controls on electric light. They suggested that the fractional savings (for all installed power densities) depend on the design illuminance levels and the lighting control strategy. At the same illuminance level, continuous dimming offered more energy savings than one and two step switching controls. The study suggested the use of continuous dimming system to gain the most energy savings from daylighting control. However, this system required time delays for reducing the rapid changes in light intensity and could affect the need of occupants in response to varying illuminance. This study provided useful information for the proposed study on energy savings resulting from the use of lighting controls.

Ander (1995) suggested a technique that uses automatic control devices, categorized into three types: switching controls (on/off controls), stepped controls, and dimming controls. Switching controls are typically the most economical, but offer the least amount of energy savings because the luminaires often remain on when the available daylight is below the specified design level. Stepped controls provide intermediate steps of electric lighting control. With this technique, transitional levels of illumination can be achieved. Dimming controls continuously adjust the electric lighting by modulating the power input to the lamps to compliment the illumination level provided by daylight. Factors that should be considered in selecting the control systems include type and function of space (e.g., industrial, office, etc.), types of luminaires, layout of fixtures, and shape and size of the room. The study provided the proposed research with useful information on an overview of different types of automatic lighting control devices.

Floyd and Parker (1998) measured the effectiveness of lightshelves and manually controlled horizontal blinds in an automatic daylighting system in four identical south-facing private offices in Florida. They found that energy savings from dimming increased by more than 50 % when lightshelves were used rather than horizontal blinds. In their study, since the horizontal blinds were controlled by the occupants, savings varied depending upon the occupant’s personal lighting preference. This topic may be beyond the scope of the proposed research since the proposed study focuses on low-income housing. The proposed research will assume that the occupants can manually control the blinds to adjust lighting levels while the use of high windows will provide interior lighting for visual tasks.

2.3.5. Building Energy and Daylighting Simulations

2.3.5.1. Building energy simulation programs

Methods of simulating and measuring energy use from daylighting design include hand calculations and the use of energy simulation programs. The widely used computerized energy simulations program in the U.S. include the Building Loads And Systems Thermodynamic program or

BLAST program (BSO 2000), the DOE-2 energy simulation program (LBL 1993), and the new EnergyPlus program which is the newest program developed with U.S. D.O.E. funding (BTS 2001). The development of computer simulation technology during the last three decades have led to the creation of user-friendly programs developed for using on personal computers such as ENER-WIN (Soebarto and Degelman 1994) and SOLAR5 (Milne et al. 1988). In general, energy simulation programs calculate the dynamic heat transfer through building materials and the corresponding energy use of the heating and cooling systems, to evaluate the overall energy performance of the building being studied.

In 1976, the Lawrence Berkeley Laboratory created and developed the DOE-2 Energy Simulation Program. DOE-2 is an hourly-based thermal simulation program which contains four FORTRAN subprograms: LOADS, SYSTEMS, PLANT, and ECONOMICS. DOE-2 can perform hourly simulations, based on hourly weather files, for either a whole year or a partial year, and for specific design days. DOE-2 has a feature called an hourly report, which extracts the output results into an hourly format for the specified period. The hourly reports are advantageous for detailed analyses of the building's energy use. The proposed research will use DOE-2.1e (version 119) Energy Simulation Program to analyze the energy savings resulting from daylighting.

2.3.5.2. Daylighting analysis and simulation programs

The Window and Daylighting Program[1] at the Lawrence Berkeley National Laboratory (LBNL), in Berkeley, California has developed new simulation programs for studying the energy-efficient use of daylight and electric lighting in buildings. RADIANCE, developed by LBNL, is an advanced lighting simulation program that uses ray-tracing methods to predict the light behavior in spaces (LBNL 1997).

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[1] Window and Daylighting Program
Lawrence Berkeley Laboratory,
University of California
Berkeley, California 94720
Phone: (510) 486-5605
Website: http://windows.lbl.gov/default.htm

To input data in RADIANCE, the user describes the geometry of the space and the surface material characteristics of the building's interior. Then, the user adds photometric data for electric light sources. If daylighting is desired, the user also needs to provide time-of-day, latitude, longitude, and calendar day. The RADIANCE program uses a technique called ray tracing to follow light backward from an observer to the light sources of a hypothetical scene. The luminance associated with each ray is computed from the candle power distribution of the light source and the reflective properties of the intervening surfaces. The final output is a realistic photo-like rendering displayed either on the screen or copied onto a paper, or film. Although the RADIANCE program is considered state-of the-art, the need for photo-realistic rendering is beyond the scope of the proposed project.

Another lighting simulation program is the SUPERLITE program, also developed by LBNL (LBNL 1994). The program's flexible geometric system can calculate illuminance levels for any building configuration that can be defined by walls and windows. Such a feature is more useful than RADIANCE for modeling complicated building shapes. To calculate daylighting, SUPERLITE accounts for the effect of direct sunlight in the room. The program adopts a very detailed point-by-point illumination calculation for the date, time, and specified sky conditions. Although the use of computer rendering and simulation program is beyond the scope of this proposed study, the review of the advantages of these programs provided useful information regarding the computer simulations of a daylighting space and built a reference for further studies.

Nowadays, several lighting analysis programs were developed for use on desktop computers. The programs provide user-friendly interfaces and the abilities to incorporate with geometric input files from other programs. Bryan and Autif (2002) conducted a study on the comparison of the daylighting/lighting analysis tools. Their study compared four simulation programs, which include Lightscape 3.2, desktop RADIANCE 1.02, Lumen Micro 2000, and FormZ RadioZity 3.80, in terms of modeling and input, daylighting setup, space surface properties, rendering and simulation, simulation output, user interface, and online help and miscellaneous.

Lightscape is a visualization program for simulating both natural and artificial light in space, licensed by AutoDesk, Inc. (Autodesk 1999). The desktop RADIANCE is a MS Windows version of

Radiance, developed in cooperation between the Lawrence Berkeley National Laboratory, the Pacific Gas & Electric and the California Institute of Energy Efficiency. Lumen Micro 2000 is based on Lumen II program which was introduced into lighting simulation study in the late 1970's. The Lumen Micro 2000 program was created and licensed by Lighting Technologies Inc. (Lighting Technologies, Inc. 2002). FormZ RadioZity is the lighting version of formZ program, which is recognized as a general-purpose solid and surface modeler (Auto-des-sys 2001). The FormZ RadioZity includes radiosity based rendering function for lighting simulation.

The study of Bryan and Autif (2002) concluded that daylighting simulation programs should be user-friendly, accurate, and capable of photo-realistically rendering. Among the programs tested, Lightscape offered the most realistic views in photo rendering but had inaccurate sky models. Desktop RADIANCE was considered the most accurate but had problems with the program's stability and was not user-friendly. Lumen Micro was the simplest to use, however, it lacked abilities to model complex room geometries. Finally, FormZ RadioZity is not an effective program in daylighting analysis since its daylighting algorithms were based on approximations. The study suggested that the selection of simulation programs in daylighting analysis should be based on the study objective, requirements, and priorities.

The proposed research will use the DOE-2.1e Energy Simulation Program to evaluate the energy use of a case study house, and the new designs with and without daylighting.

2.3.6. Previous Work on the Case Study Building

A case study building, a Habitat for Humanity house in Bryan, Texas, is a low cost, high quality, energy efficient house constructed with volunteer labor and materials that utilize no or low-interest loans to keep monthly payments low (Kootin-Sanwu et al. 2000). Houses constructed as part of the Habitat for Humanity program were equipped with energy saving features incorporated to lower the owners' utility costs.

Haberl et al. (1998) conducted the study using two Habitat for Humanity houses in Houston, Texas, to study an evaluation of residential energy conservation options using side-by-side measurements and calibrated simulations. Their study objective was to assess the performances of energy improvement features incorporated into the houses. Results from the study concluded that the efficient air conditioner was the only equipment that could be properly evaluated using the calibrated simulation to remove the effect of confounding factors. The confounding factors that were removed and normalized using the calibrated simulation included the weather conditions, occupants' life styles, space temperature settings, and certain omissions in the house construction. The study revealed that excessive use of energy for air conditioning, lighting, equipment, and domestic hot water heater energy consumption. To achieve the annual energy savings in Habitat Housing, the study suggested that reducing lighting and equipment loads must be considered in any future efforts.

The case study building used in this study is a single-story 1,120 ft^2, three-bedroom house with an attic space, located in Bryan, Texas. The study by Kootin-Sanwu et al. (2000) reported the energy and environment conditions of the house by installing a 50-channel data logger to record 15-minute data. Electrical monitoring included the whole-house electricity and sub-metering for the air-conditioner, blower, cloth washer and dryer, refrigerator, and other appliances.

The study found that because of privacy concern, the occupants tended to draw the curtains during daytime and left the interior lights on almost all the time. Moreover, the luminaires used in the house were incandescent lights, which had low efficacy and burned out frequently. Results from the study showed a significant amount of electricity used in electric lighting. According to the results from the study of Haberl et al. (1998), this study also determined the effect of lighting loads in building occupancy. The application of daylight in building is considered one effective solution in reducing the lighting electricity loads and can contribute to energy savings in the Habitat housing.

2.4. SUMMARY OF LITERATURE REVIEW

The literature review provided an overview in lighting performances and constituted an understanding on daylighting designs and applications on building. It can be concluded from the literature review that:

- The review of lighting analysis and residential lighting provided the basic concepts of lighting in residential building, including important considerations on daylighting design for residential purpose.
- From the review of daylighting analysis, the primary natural light sources and the sky conditions are important factors when considering daylighting design in buildings. Daylighting models and analysis methods were developed as approaches to analyze the theoretical sky conditions for daylighting study since natural light is considered unpredictable and uncertain overtime.
- The review of daylighting study tools included available methods such as scale model, sun path analysis, calculation procedures, and rendering and simulation program. These tools were developed for daylighting studies as well as design evaluations.
- The review of daylighting strategies included the previous work which focused on the effect of daylight on human visual comfort, effective space illuminance, including the contribution of daylighting to energy savings in building. The previous studies illustrated the advantages of using daylighting to achieve the improvement in space illuminance, as well as lighting energy reductions.
- The review of previous studies on the case study building provided background of the building studied regarding the patterns of energy uses and the primary factors that affected the energy consumption of the building.

2.5. SIGNIFICANCE OF THE STUDY

The review of literature on daylighting studies provided an overview on the use of daylighting in buildings. However, most researches conducted focused on the application of daylight in large scale and commercial buildings. Although there were many researches concentrated on the study of daylighting in residential buildings, only a few studies focused on the application of daylighting and the contribution of energy savings in low-cost housing. Therefore, this study aims at providing useful information in daylighting studies and evaluation of proposed strategies including the reference for further studies on the use of daylight related to energy-efficient designs in low-income housing.

This study will simulate a case study building: a single-family, low-income residence in hot and humid climate, with and without the applications of daylighting design. This research is expected to provide the following benefits to the development of architectural design:

1) An evaluation of the effectiveness of daylighting design strategies in enhancing or maintaining the required illuminance levels while shading the windows and reducing the solar heat gain.
2) The development of using daylighting in low-cost housing to achieve the energy savings.
3) The development of alternatives in fenestration designs for a low-cost residential building.

CHAPTER III

METHODOLOGY

This chapter describes the methodology used in this research study. The methodology employed in conducting this thesis is composed of 3 primary tasks: 1) the use of a case study low-income house as a basecase model for this study, 2) the use of a physical scale model for generating Daylight Factor measurements and evaluations, and 3) the use of DOE-2 energy simulations to compare the energy use of a basecase building and a similar building with proposed daylighting designs. These processes are presented in Figures 3.1 A – C.

As is shown in Figure 3.1 A, the three primary steps are used in the case study building including data input, simulation processes, and results from the simulations. A basic description of the case study building used in the data input was obtained from 2 types of data: monthly utility bills from January to December of 1999, and data collected from multi-channel data loggers which were installed in the house (Kootin-Sanwu 2003). The monthly utility bills provided the total monthly electricity usage for 1999, while the hourly data collected from the data loggers provided the detailed energy use attributed to cooling, lighting, heating, and other appliances. Data from the data logger also included information on the building's thermal conditions (i.e., dry bulb temperature and relative humidity). Both energy use and environmental data were analyzed to determine the energy use pattern, and to obtain the data input necessary for the DOE-2 simulations of the basecase building. To obtain the final DOE-2 basecase model that accurately represented the case study building characteristics, variables used in the simulations were adjusted and the simulation outputs were calibrated against the case study site data.

Figure 3.1 B shows the second task in this methodology. This task involves the use of a physical scale model for the Daylight Factor measurements. Model testing was conducted under an actual overcast sky for quantitative studying. Additional qualitative results from the model measurements conducted in the daylighting lab (the sky simulator) were evaluated in terms of the shading effectiveness of the proposed daylighting designs. A light meter, the instrument used to measure light levels, was calibrated against an appropriate reference instrument to assure that accurate measurements were obtained. Daylight Factors measured from the basecase model under overcast sky were then compared with the measurements taken from the case study site. The proposed shading designs for daylight applications were also analyzed by using the SOLRPATH program to evaluate the placement and position of the possible shading configurations. Finally, Daylight Factors measured from the models with daylighting designs were evaluated and compared to the measurements taken from the basecase model.

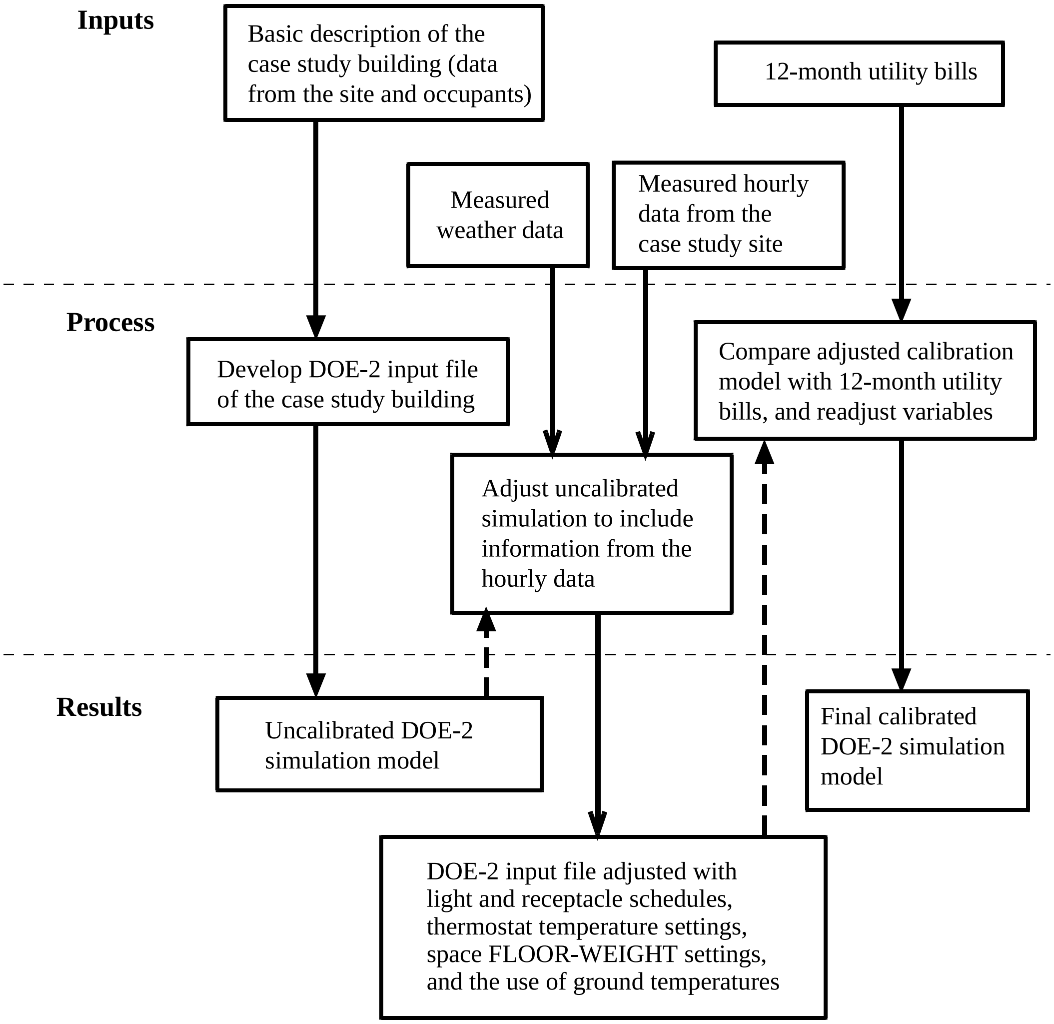


Figure 3.1A – The use of the case study building.

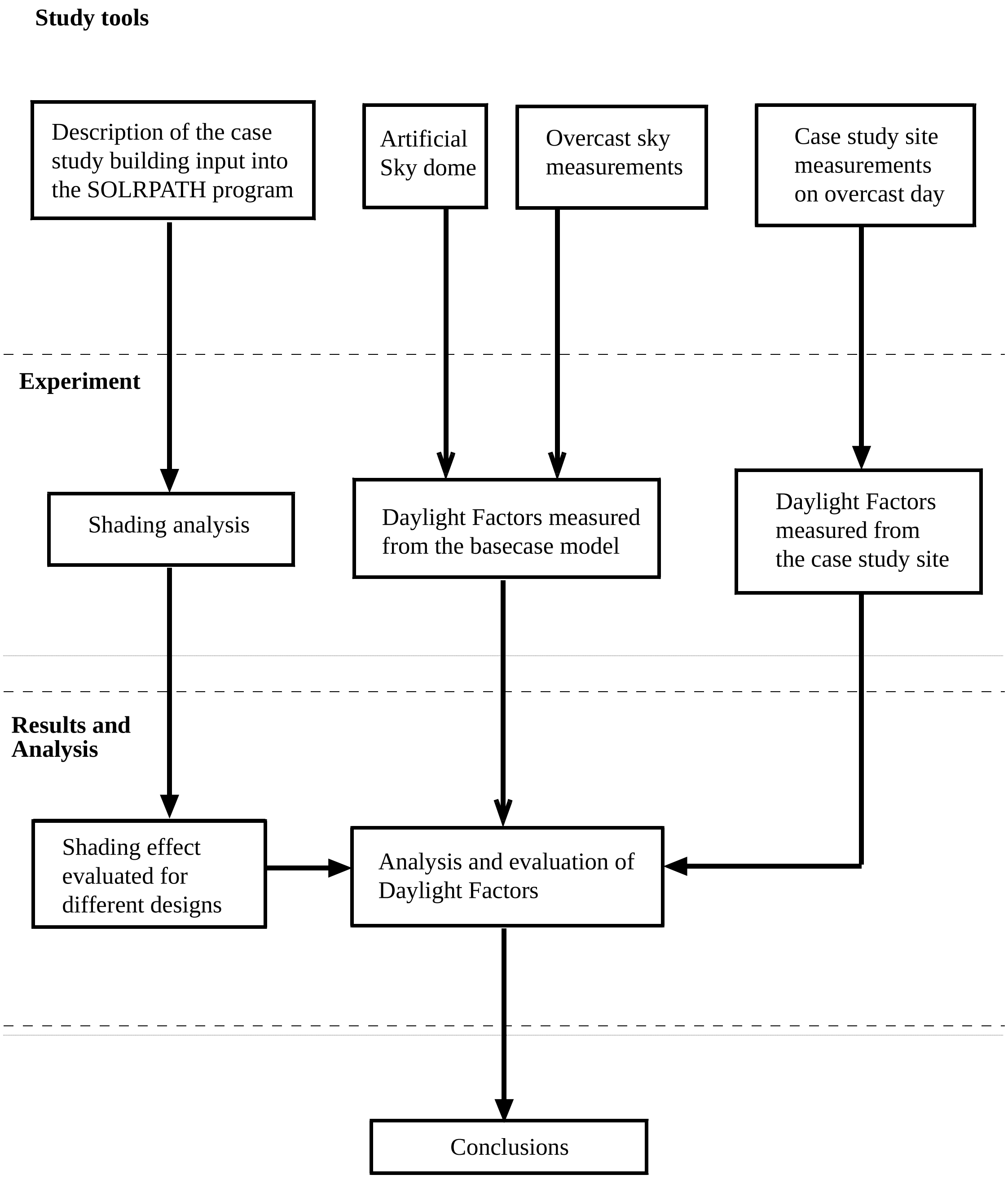


Figure 3.1 B – The use of physical scale model for Daylight Factor measurements.

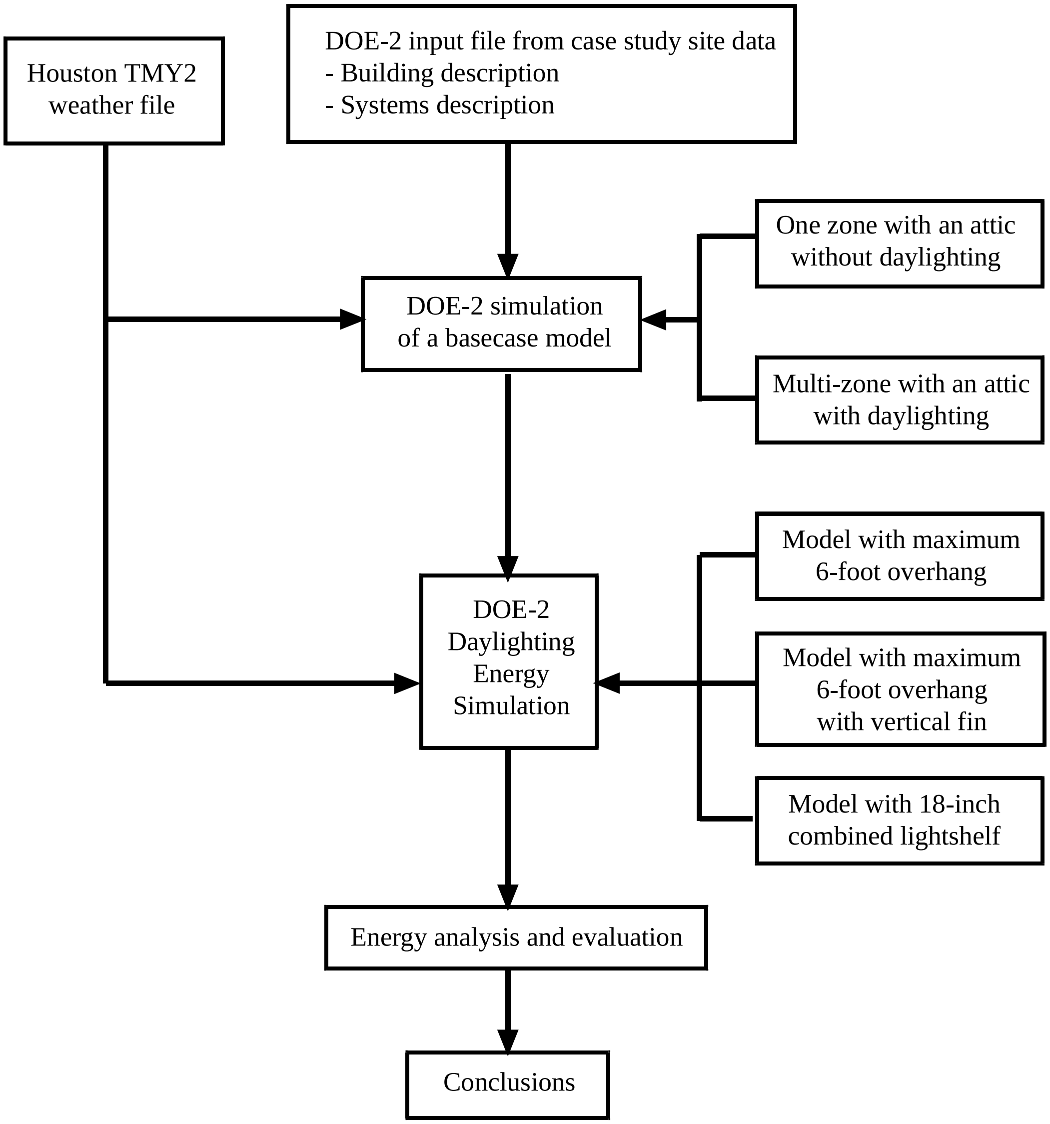


Figure 3.1 C – The use of DOE-2 energy simulation program.

As shown in Figure 3.1 C, the final task is the use of the DOE-2 energy simulation program. The data taken from the case study site were converted into DOE-2 input files. The simulations in this study used the Houston TMY2 weather tape for the annual analysis. After the basecase model was simulated with DOE-2, the results of the energy use and indoor dry bulb temperature were calibrated with the data measured from the case study site. The Daylight Factors calculated with the DOE-2 basecase model simulation were compared to the Daylight Factors obtained from on-site measuresments of the physical scale model and the case study site. The basecase model simulated in DOE-2 was one-zone model with an attic, without daylighting. The results from the basecase model simulation were employed in the monthly energy use and temperature calibrations. A multi-zone model with an attic and daylighting was then created and simulated to obtain the results of the energy use, temperature, and Daylight Factors. After the basecase model calibration, models proposed with different daylighting designs: a model with maximum 6-foot overhang, a model with maximum 6-foot overhang with vertical fin, and a model with 18-inch combined lightshelf were then simulated with the DOE-2 program in order to study the effects of daylight and its relationship to energy use. Finally, conclusions were drawn from the comparison of energy use and the daylighting effect between the basecase model and the models bearing new designs. Additional details regarding this methodology are available in Section 3.1.

3.1. THE USE OF THE CASE STUDY BUILDING

3.1.1. Background of the Case Study Building: The Habitat House

Habitat for Humanity houses are low-cost houses constructed with volunteer labor organized by the Habitat for Humanity organization. The design of each Habitat house varies with its location, but all assume on objective of achieving an energy-efficient and durable house (Kootin-Sanwu et al. 2000). The Habitat house used for this study is a single-story, 1,120 ft^2 three-bedroom house with an attic space located in Bryan, Texas. The house is constructed with composite 2x4 stud walls on a 4-inch concrete slab floor with 24-in grade beams every 14 feet and 36-in grade beams around the perimeter, finished with linoleum tile. The ceiling is 5/8-inch gypsum supported by 2x6 inch joists, 24-in off center, with fiberglass insulation on the ceiling above the conditioned space. The roof construction is a composite shingle roof on a 5/8-inch plywood deck supported by 2x6 inch trusses, and has an 18-inch overhang on all sides. The house has a central air-conditioner and a forced-air natural gas furnace for its cooling and heating systems, located in the attic.

According to Kootin-Sanwu et al. (2000), a 50-channel data logger was installed during the construction of the house in 1997 in order to record 15-minute data regarding energy use and thermal conditions. Electrical monitoring recorded the whole-building's electricity use, with sub-metering for the clothes washer and dryer, air-conditioner, blower, refrigerator, and all other appliances. Thermal metering included the whole-building's natural gas use, as well as thermal measurements of the domestic hot water heater. Environmental metering observed three ground temperatures located 6-inch into the soil: (1) beneath the slab in the center of the house (C), (2) 3 feet from the edge of the slab on the north side (N), and (3) on the south side (S). Environmental metering also included the indoor temperature and humidity, and CO_2: the attic temperature and humidity, the supply temperature and humidity, and the outdoor conditions (temperature, humidity, CO_2, horizontal solar radiation and wind speed). Energy use and environmental conditions from the loggers were converted to hourly averaged data to be used for this study's calibration and comparison, with the results to be used for the new designs. The hourly data converted from the data loggers is presented in Appendix A.

3.1.2. Building Description

Table 3.1 – Case study house description.

Building Characteristics	
Building Type	Residential building/ single-story
Location	Bryan, Texas
Built	1997
Area	1,120 ft2
Construction	Slab on grade/ Composite wall
Materials	
Floor	4-inch concrete slab on grade with grade beams
	Linoleum tile
Wall	Composite stud wall
	1/2 inch gypsum, R-13 insulation
	Vinyl siding
Ceiling	5/8 inch gypsum board with insulation
Roof	5/8 inch plywood deck
	Composite shingles
Window	Aluminium frame
	Double-pane clear glazing
Door	Wood door with aluminium frame

Table 3.1 summarizes the description of the case study house. As seen in Figure 3.2, the case study house is a single-story building, facing northeast. The house consists of a living/dining/kitchen area, a utility room, three bedrooms and two bathrooms. Figures 3.3 – 3.12 show this house in further detail.

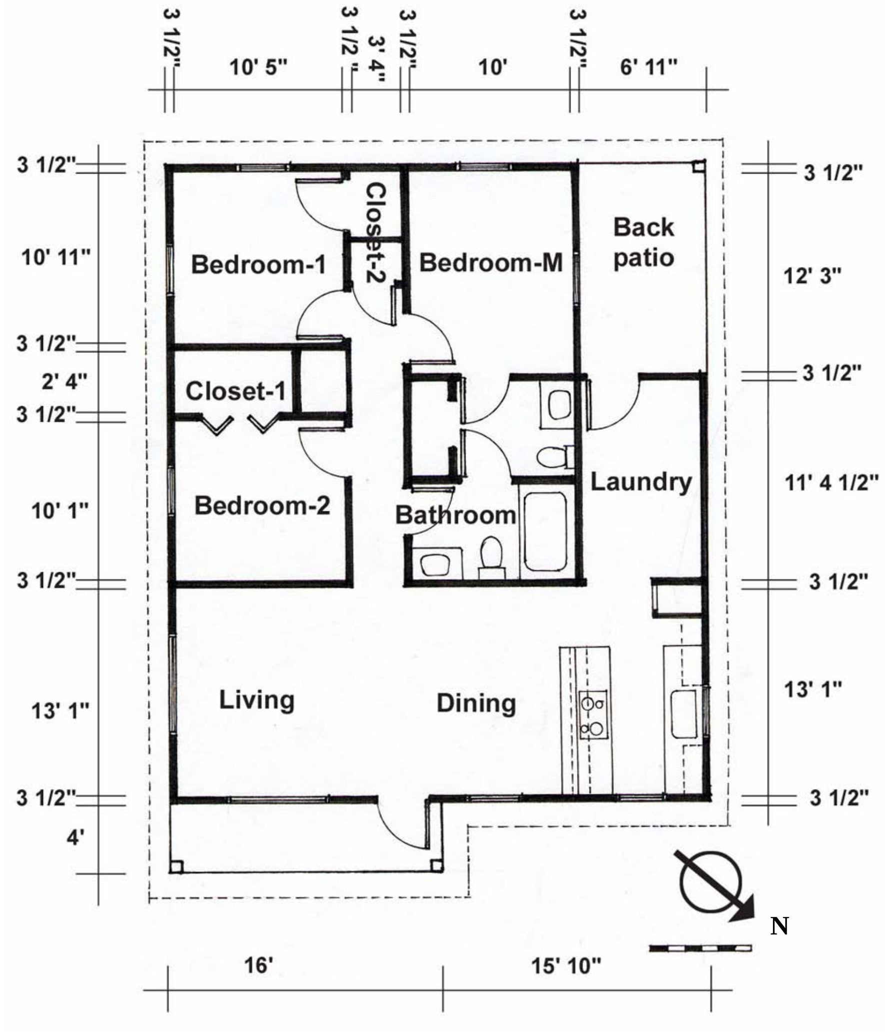
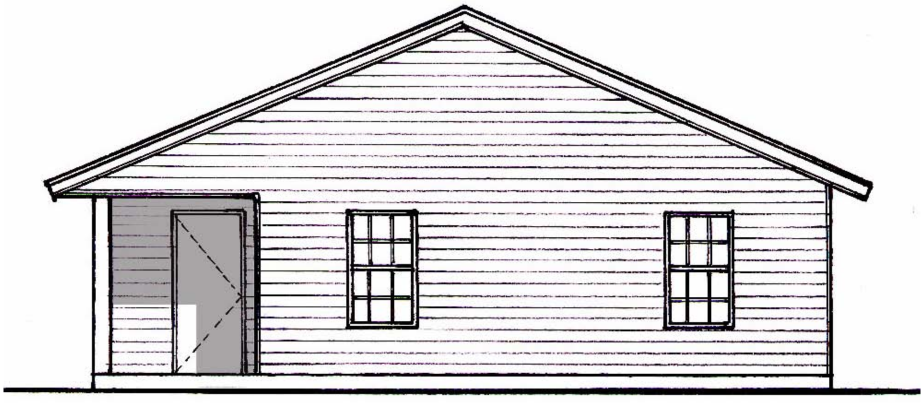


Figure 3.2 – Floor plan of the case study house.

Front elevation of the house



Back elevation of the house

Figure 3.3 – Front elevation and back elevation.

Right elevation of the house

Left elevation of the house

Figure 3.4 – Right elevation and left elevation.

Figure 3.5 – Photograph of the front elevation of the case study house (facing northeast). The photograph was taken on February 25th, 2001 at the case study site.

Figure 3.6 – Photograph of the back elevation of the case study house (facing southwest).

Figure 3.7 – Photograph of the right elevation of the case study house (facing southeast).

Figure 3.8 – Photograph of the left elevation of the case study house (facing northwest).

Figure 3.9 – Photograph of the living area. It can be seen from the photograph that the occupants tended to keep the curtain drawn almost all day due to privacy concerns. Therefore, the need for using electric lighting during daytime resulted in high consumption of lighting energy during building occupancy.

Figure 3.10 – Photograph of the dining area.

Figure 3.11 – Photograph of the bedroom next to living area (Bedroom –2). This bedroom has one window opening facing southeast.

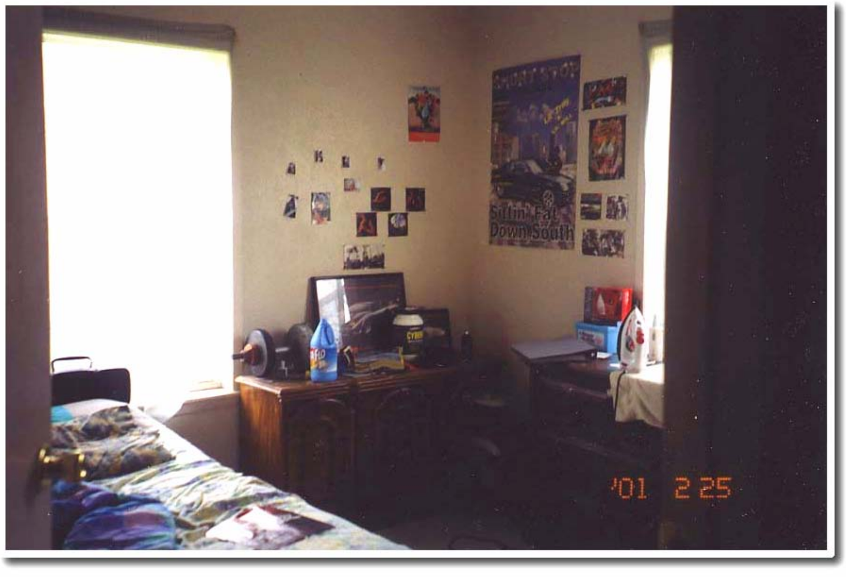


Figure 3.12 – Photograph of the bedroom on the southeast side (Bedroom-1). This bedroom is located at the back corner of the house. It has 2 window openings facing southwest and southeast.

The house has a building floor area of 1,121 ft^2. It also has a 64 ft^2 front patio and an 87 ft^2 back patio. Table 3.2 summarizes the details of floor area.

Table 3.2 – Summary of floor area allocation.

Floor Allocation				
Space	**Width**	**Length**	**Area**	**Volume**
	ft	**ft**	**ft2**	**ft3**
Living room	13	31.87	414.3	3366.3
with Dining area				
Bedroom-2	10	10.37	103.7	842.6
next to Living room				
Closet-1	4	10.37	41.5	337
Bedroom-1	10.87	10.37	112.7	915.9
on Southeast side				
Closet-2	7	4.25	29.8	241.7
Bedroom-M	12.5	10.25	128.1	1041
on Southwest side				
Bathroom and Storage	12.5	10.25	128.1	1041
Laundry area	12.5	7	87.5	710.9
Hallway	17.87	4.25	75.9	617.1
Total			1121.7	9113.5

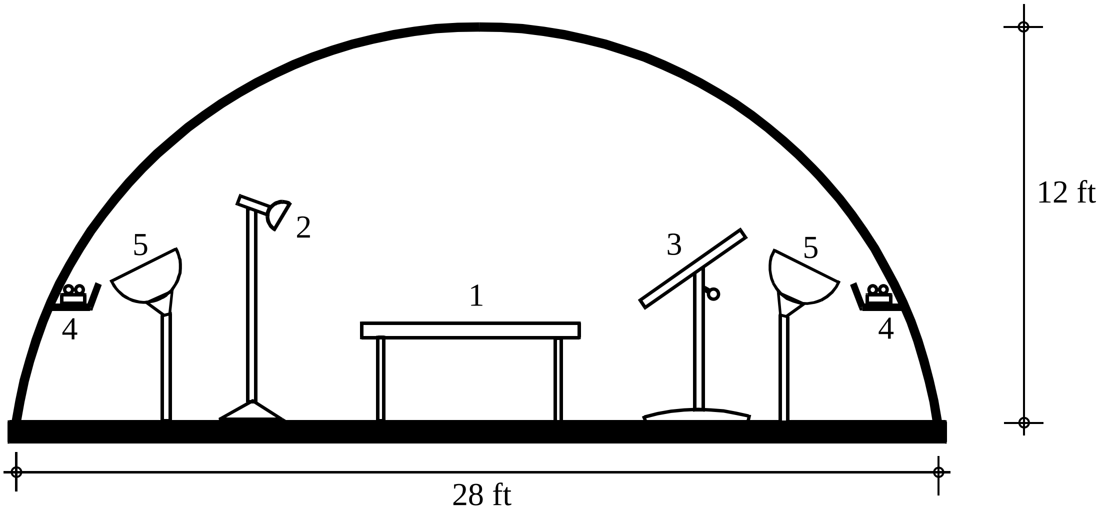
3.2. THE USE OF PHYSICAL SCALE MODEL FOR DAYLIGHT FACTOR MEASUREMENTS

3.2.1. The Use of an Overcast Sky in Daylighting Measurement

Physical scale model testing can be conducted either in a daylighting laboratory or under actual sky conditions. The development of sky simulators has provided researchers with a means for studying daylight under controllable environments. For quantitative studies, it is necessary that the sky simulator provide a luminance distribution as if it is under the real non-uniform overcast sky. According to the CIE formulation, the completely overcast sky has a zenith luminance, which is three times the horizon luminance (Stein and Reynolds 1999). Before conducting an experiment using the sky simulator, such a calibration is required for tuning the sky luminance distribution of the artificial sky to simulate an overcast sky condition. Unfortunately, at the time this study was performed, the sky simulator located at the College of Architecture, Texas A&M University had not been recently calibrated, and was therefore not reliable for quantitative results. Nonetheless, the sky simulator did prove useful for qualitative results.

Daylight Factor measurements of the scale model were conducted under real sky conditions on a completely overcast day. Sky luminance was measured at different degrees from the horizon to the zenith to verify the overcast sky conditions according to the CIE sky. The results of illuminance measurements were used in Daylight Factor calculation, which was considered a means to evaluate daylight in the quantitative study.

A qualitative study of the shading properties was conducted using the College of Architecture sky simulator. Two analyses were performed in the sky simulator. First, a shading analysis was performed using the heliodon table, which was set for 30.5° North latitude. Figure 3.13 provides an illustration of the sky simulator in cross section. This was used to confirm that each of proposed designs achieved the intended shading objective. Second, a preliminary analysis was performed on several of the proposed shading designs to determine which ones shade the windows and also provided appropriate Daylight Factor values. Additional information about these preliminary measurements can be found in Appendix D. A quantitative study for these proposed designs was analyzed based on the experiments conducted under overcast sky conditions.



(1) Model table
(2) Sky simulator: artificial sun source (650-watt cool beam PAR lamp) for sun simulator
(3) Heliodon table
(4) Sky simulator light source (110-watt cool white fluorescent lamps)
(5) Sky simulator light source (1000-watt high pressure sodium HID lamps)

Figure 3.13 – Illustration of a cross section of the TAMU College of Architecture Daylighting Laboratory.

3.2.2. Instruments Used for Measuring Daylight Illuminance Levels

There are two types of light meters involved in this study. One is an electronic, digital, color and cosine-corrected light meter that measures illuminance (0 to 20,000 fc) in four ranges. The other is an autoranging digital light meter that displays the intensity of the photometric excitation of the sensor in those units where the sensor is connected (lux, or footcandles). When measuring illuminance at the case study site, the sensor was held parallel to the floor plane on windowsill levels (2 feet above the floor), with the sensor facing the ceiling.

To calibrate the light meters, an NIST-traceable reference light meter was used as a comparison. This reference light meter was an autoranging digital light meter manufactured by Greenlee Textron Inc. (model number 93-172), which has a maximum of 1 % error. The two light meters employed in this study were an autoranging digital light meter (model number DL1076) from Pacer Industries, Inc., and a four-range illuminance light meter model SLM-110 from A.W. Sperry

Instruments, Inc. Pictures of the three light meters are presented in Figure 3.14. Table 3.3 provides the light meter descriptions and Figure 3.15 shows the x-y plot of the results of the model calibration. In Figure 3.15, it can be clearly seen that the light meter no. 1 matched the results of the reference light meter, and was therefore used to obtain the measurements in this study.

The reference light meter (model 93-172)

Light meter no. 1 (model DL-1076)

Light meter no. 2 (model SLM-110)

Figure 3.14 – Photographs of the light meters.

Table 3.3 – Description of the light meters.

Code Name	Manufacturer	Model Number
Reference Light meter	Greenlee Textron Inc.	93-172
	4455 Boeing Drive, Rockford	
	IL 61109	
Light meter no. 1	Pacer Industries , Inc.	DL 1076
	1450 First Avenue	
	Chippewa Falls, WI 54729	
Light meter no. 2	A.W. Sperry Instruments, Inc.	SLM-110
	245 Marcus Boulevard	
	Hauppauge, NY 11788	

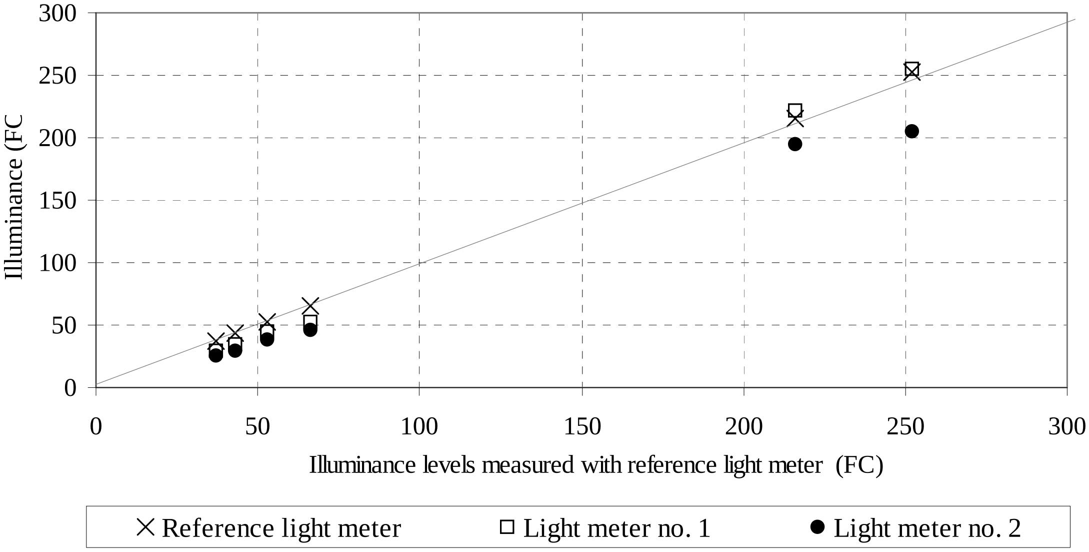


Figure 3.15 – X-Y plot of the illuminance values measured from the light meters vs. from the reference instrument.

3.2.3. Constructing the Physical Scale Model

The model constructed for this research was used for the quantitative and qualitative study. It was built as a replica of the case study house, but substantial interior details were not considered. The scale used for constructing the model was 1 inch = 1 foot. The model interior walls and ceilings were finished with white matte paint with the approximate reflectance value as the case study house's interior paint, and the floor was covered with a sheet of paper with approximately the same reflectance as the case study house's floor tile. Clear 1/8" glass panes, which were the same type as the case study house's glazing, were attached to the window openings of the model. The model roof was not fixed and could be opened to show the rooms inside. Voids in the wall panels were provided for easy access to the light meter cable while measuring illuminance levels. Figure 3.16 presents photographs of the model.

Another model was then constructed using foam boards finished as stated above. This foam board model offered considerably more flexibility for changing wall panels and window configurations, which was necessary for proposing new designs. The results gathered from calibrating the Daylight Factors measured from the wooden and the foam board models together, combined with the measurements from the case study and DOE-2 daylighting simulations, will be discussed in Chapter 4, Section 4.2.

Front view with the roof on

Front view without the roof

Figure 3.16 – Photographs of the physical scale model.

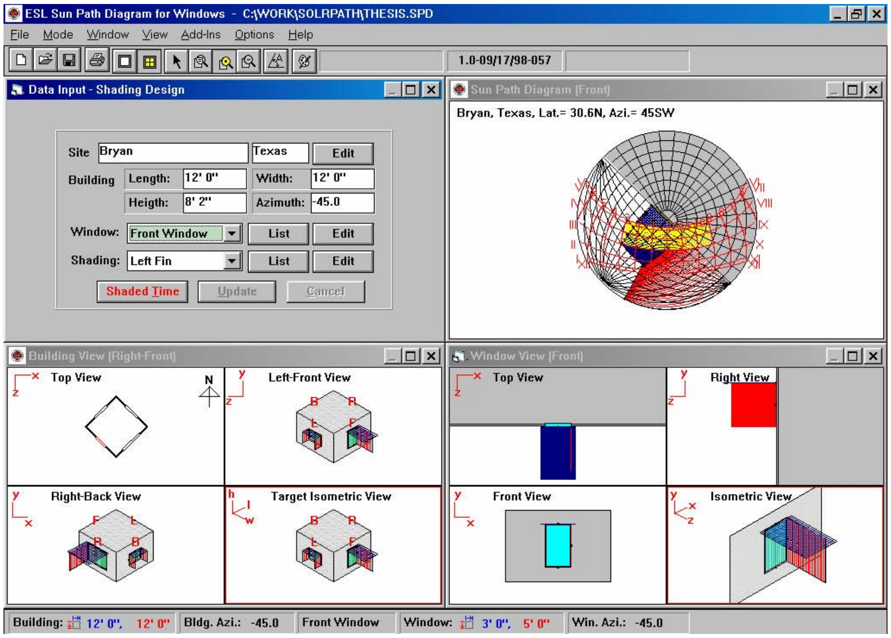
3.2.4. The Use of the SOLRPATH Program

The SOLRPATH program was created by Kie Whan Oh as part of his Ph.D. dissertation in Architecture at the Energy Systems Laboratory at Texas A&M University (Oh 2000). SOLRPATH is a user-friendly MS Windows program that designs energy-efficient shaded fenestrations. Several functions included in this program include the calculation of solar angles, the calculation of direct, diffuse, and reflected solar radiation, and shading device designs. Additional features include the management of weather data, and the graphical display of weather information.

This research used the SOLRPATH program as a tool for evaluating window shading design. The objective in designing exterior window shading is to prevent direct sunlight from penetrating into a space, while allowing only diffuse light to enhance the room's brightness. Window shading designs in the SOLRPATH program use the concept of sunpath diagrams and shading masks to accomplish the shading analysis. In other words, the effectiveness of a shading device is evaluated based on how closely the mask covers the required shading period during a single year. The shading period in this study was from March 21 to September 21, from 9 A.M. through 3 P.M. Table 3.4 shows a description of the case study site data used for SOLRPATH's input. Figure 3.17 presents the interface window of the program calculating the exterior shading for the southwest window of the case study house. Figure 3.18 shows the calculation of the southeast window shading.

Table 3.4 – Case study site description for SOLRPATH input data.

Site Data	
Location	Bryan, Texas
Latitude	30.6 N
Longitude	96.4 W
Altitude	106 ft.
Azimuth	-45 degree
Shaded Time	
Month/ Date	March 21 - September 21
Time	9:00 AM - 3:00 PM



ESL Sun Path Diagram for Windows - C:\WORK\SOLRPATH\THESIS.SPD

1.0-09/17/98-057

Data Input - Shading Design

Site: Bryan, Texas

Building: Length: 12' 0" Width: 12' 0"

Heigth: 8' 2" Azimuth: -45.0

Window: Front Window

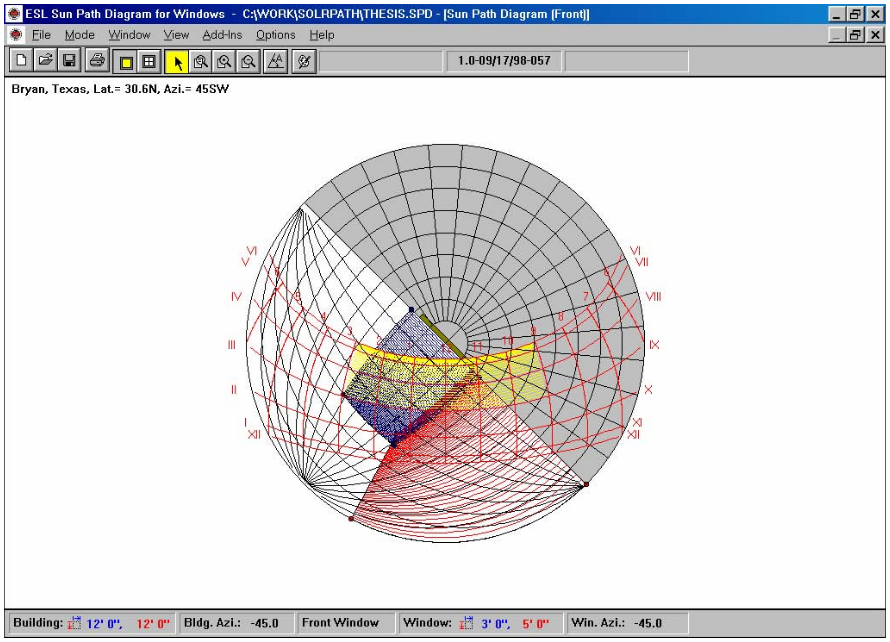
Shading: Left Fin

Sun Path Diagram (Front)

Bryan, Texas, Lat.= 30.6N, Azi.= 45SW

Building: 12' 0", 12' 0" | Bldg. Azi.: -45.0 | Front Window | Window: 3' 0", 5' 0" | Win. Azi.: -45.0

Main screen of the SOLRPATH program showing multiple views



ESL Sun Path Diagram for Windows - C:\WORK\SOLRPATH\THESIS.SPD - [Sun Path Diagram (Front)]

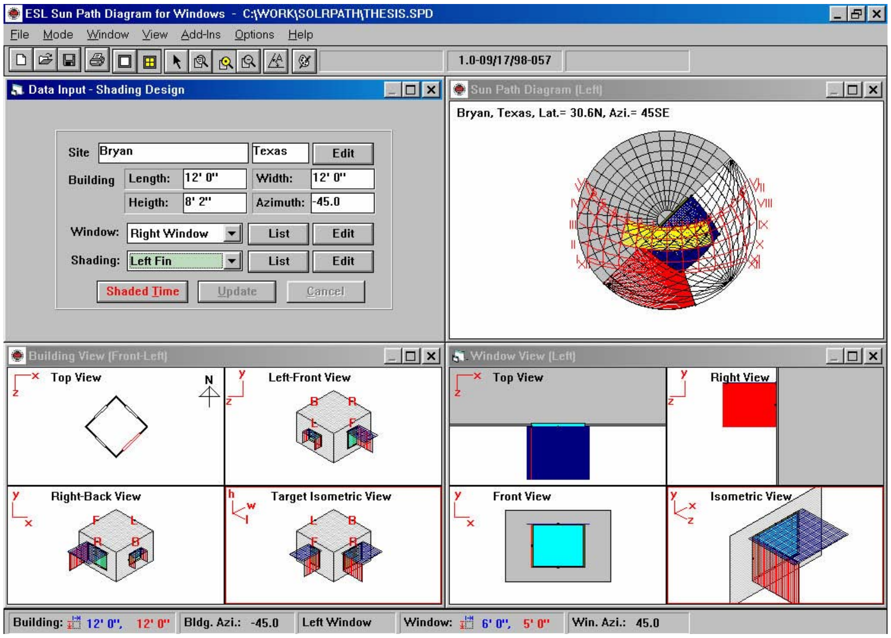
1.0-09/17/98-057

Bryan, Texas, Lat.= 30.6N, Azi.= 45SW

Building: 12' 0", 12' 0" | Bldg. Azi.: -45.0 | Front Window | Window: 3' 0", 5' 0" | Win. Azi.: -45.0

Enlarged window showing the view of sunpath diagram calculation

Figure 3.17 – SOLRPATH program diagram calculating the southwest window shading of the case study house.



ESL Sun Path Diagram for Windows - C:\WORK\SOLRPATH\THESIS.SPD

1.0-09/17/98-057

Data Input - Shading Design

Site: Bryan, Texas

Building Length: 12' 0" Width: 12' 0"

Heigth: 8' 2" Azimuth: -45.0

Window: Right Window

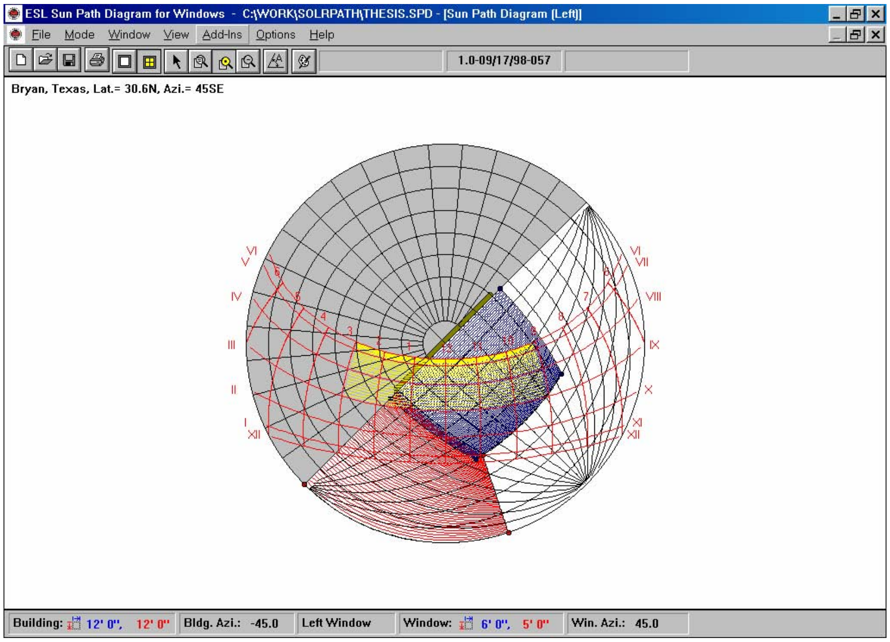
Shading: Left Fin

Sun Path Diagram (Left)

Bryan, Texas, Lat.= 30.6N, Azi.= 45SE

Building: 12' 0", 12' 0" | Bldg. Azi.: -45.0 | Left Window | Window: 6' 0", 5' 0" | Win. Azi.: 45.0

Main screen of the SOLRPATH program showing multiple views



ESL Sun Path Diagram for Windows - C:\WORK\SOLRPATH\THESIS.SPD - [Sun Path Diagram (Left)]

1.0-09/17/98-057

Bryan, Texas, Lat.= 30.6N, Azi.= 45SE

Building: 12' 0", 12' 0" | Bldg. Azi.: -45.0 | Left Window | Window: 6' 0", 5' 0" | Win. Azi.: 45.0

Enlarged window showing the view of sunpath diagram calculation

Figure 3.18 – SOLRPATH program diagram calculating the southeast window shading of the case study house.

3.2.5. Daylight Factor Measurements Using the Physical Scale Model

The calculation of Daylight Factors is referred to Section 2.2.3 of Chapter II. The illuminance-level measurements of the scale model were conducted using light meter no. 1 (model DL 1076) under the overcast sky conditions. The scale model illuminance levels were measured at the windowsill height level (2 feet from the floor), at the middle point of each room, with the light sensor pointing towards the ceiling. The position of the light meter when taking the measurements is shown in Figure 3.19.

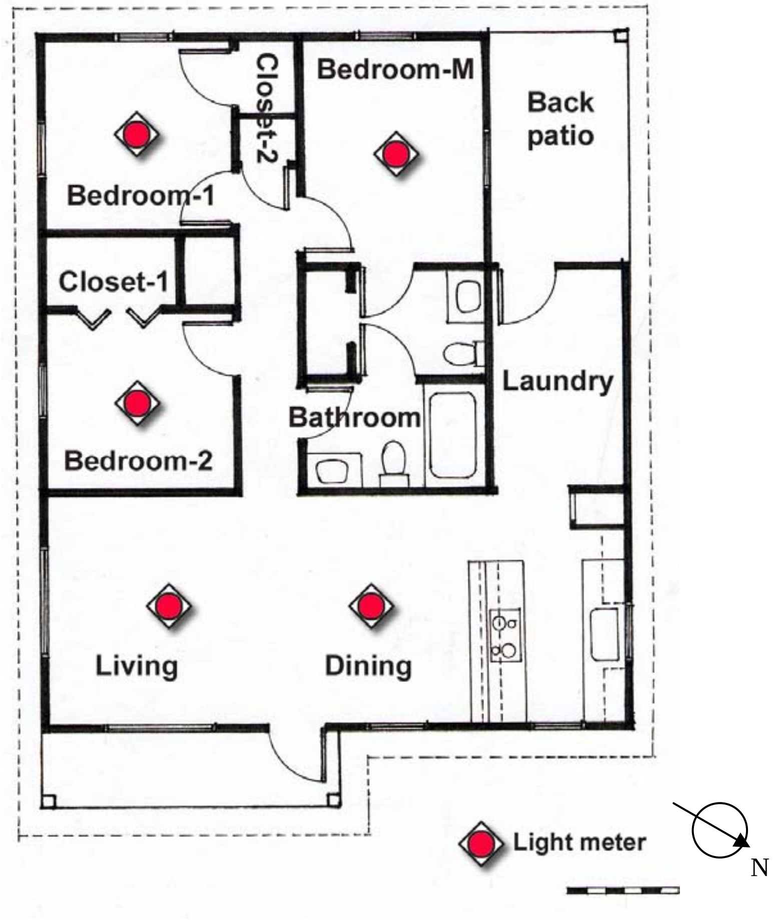


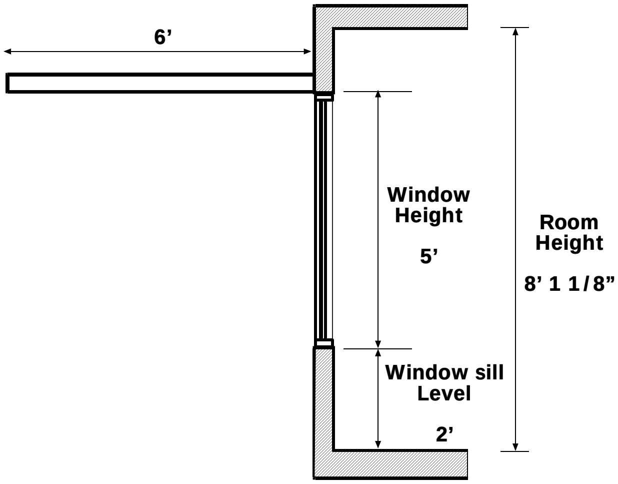
Figure 3.19 – Position of the light meter in measuring the illuminance levels of the scale model. The measuring point was at windowsill level (2 feet from floor), with the light meter sensor held horizontal facing up.

The shading designs proposed in this study resulted from calculations obtained by using the SOLRPATH program. These designs fall into three types: a model with a maximum 6-foot overhang, model with a maximum 6-foot overhang with a vertical fin, and model with an 18-inch combined lightshelf. The first two design options acquired from the SOLRPATH program offered optimum results in blocking direct sunlight during the required shading period. However, the overhang size of 6 feet and the vertical fin of 4 feet were considered impractical for construction and were not cost-effective. Therefore, the design of an 18-inch shade was regarded as more appropriate and was selected for the final shading size. From the previous study, it was concluded that the application of a combined lightshelf (both an interior and exterior shelf) could enhance lighting conditions in a space by improving the light distribution and reducing glare (Abdulmohsen 1995). Lightshelf with an interior and exterior overhang sizes of 18 inches was selected as the final design for this study.

In the foam board model, wall panels can be easily changed to input the different window shading configurations. Measurements were then performed at the reference point of each room in the house; the results of the illuminance values were then calculated with an exterior horizontal illuminance under the sky in order to derive the Daylight Factor of each reference point. There were four sets of Daylight Factors measured from all reference points in the model, which included Daylight Factors from the base case model, as well as the three models with proposed window shading designs. Figures 3.20 - 3.23 present renderings of the base case model and the models with other 3 proposed designs.

Figure 3.20 – Rendering of the basecase model.

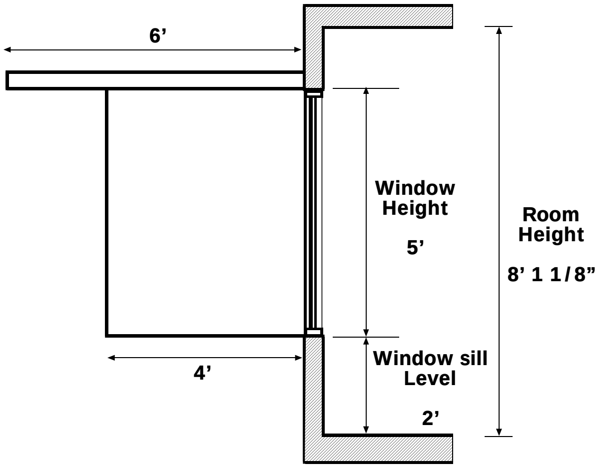
Overview picture of the house



Dimensions of shading

Figure 3.21 – Rendering of the model with maximum 6-foot overhang.

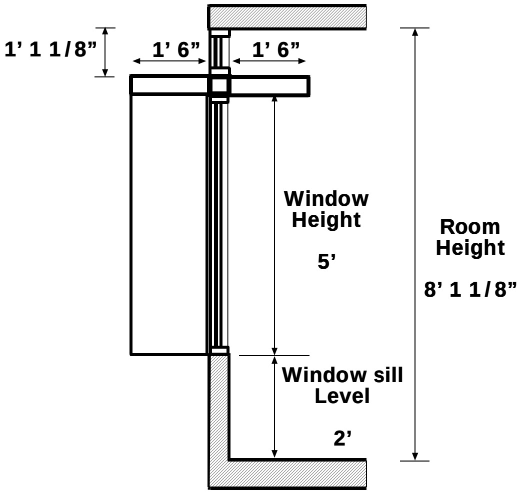
Overview picture of the house



Dimensions of shading

Figure 3.22 – Rendering of the model with maximum 6-foot overhang with vertical fin.

Overview picture of the house



Dimensions of shading

Figure 3.23 – Rendering of the model with 18-inch combined lightshelf.

The final proposed design included the application of a lightshelf, and also included a clerestory window on the northeast wall. The clerestory window had a trapezoid shape with a total area of 26.5 ft^2. Daylight Factors from the combination of window shading and this clerestory window were studied from the illuminance levels measured in the living and dining area. This study was only performed for the living room since the clerestory window was included on its northeast wall. The results from this living room study with its combination of shading and the clerestory window are presented in Appendix D.

3.3. THE USE OF THE DOE-2 ENERGY SIMULATION PROGRAM

To analyze the building's energy use, this study simulated the case study house with and without the proposed daylighting designs using the DOE-2 energy simulation program (DOE-2.1e, version 119 2002). The basecase model was first simulated in order to represent the energy use and environmental conditions of the case study building. To accurately simulate that building, measured data from the case study site was extracted from the database at the Energy Systems Laboratory to provide building description and an energy usage profiles for DOE-2's data input. The annual simulations used the Houston TMY2 weather tape for its simulations. Specially prepared weather files were used for the selected calibration periods (Kootin-Sanwu 2003).

Results from the basecase model simulation were calibrated by matching the simulated results against the measured data. Two primary comparisons were considered in the calibration: the average monthly energy use, and hourly zone temperatures for representative winter and summer conditions. Further details of this DOE-2 simulation calibration are presented in Chapter IV, Section 4.1 – Results of the DOE-2 calibration.

3.3.1. Case Study House Description for DOE-2 Input File

For the DOE-2 building energy simulation, descriptions of the case study building were developed as DOE-2 input files for input into the LOADS, SYSTEMS, and PLANT sections of the DOE-2 program. These descriptions include the details for the BUILDING-LOCATION command, the building material thermal properties, the SPACE-CONDITIONS details, and the SYSTEMS descriptions, as presented in Tables 3.5 – 3.8 respectively. A complete printout of the input file is provided in Appendix C.

Information regarding the case study building description was obtained from several sources, which include the data mesurements at the case study site (Kootin-Sanwu 2003), and the reference data from the DOE-2 engineering manual (LBL 1980, 1993). The case study building is located in Bryan, Texas. Besides the architectural and construction drawings of the building geometry and the building systems description, data obtained from the case study site also contains the measured 15-minute data of building energy uses and environmental conditions. Data obtained from the case study site were used to analyze the building energy use patterns and occupancy schedules, which were derived from the profiles of the measured data and input into the DOE-2 program.

Table 3.5 – Details for the case study BUILDING-LOCATION command.

Building Location Data	
Latitude	30.6
Longitude	96.4
Altitude	367
Time Zone	6
Azimuth	225
Building Gross Area	
Attic	1,209 ft2
Residence	1121.5 ft2
Measured Average Monthly Ground Temperature (F)*	
January	70.35
February	72.22
March	73.38
April	74.61
May	75.72
June	77.46
July	77.48
August	77.54
September	76.24
October	77.01
November	72.26
December	71.09

** Temperature from channel 3798, 3799, and 3800 for the north, center, and south*

Table 3.6 – Material thermal properties.

Material Thermal Properties						
Material		**Thickness** Feet	**Conductivity** (Btu-ft)/(hr-ft2-F)	**Density** lb/ft3	**Specific Heat** Btu/lb-F	**Resistance** (hr-ft2-F)/Btu
Wall	Asbestos-Vinyl tile	N/A	N/A	N/A	0.30	0.05
	Plywood	0.0417	0.0667	34.0	0.29	0.63
	R-13 Cellulose ins.	0.2917	0.0225	3.0	0.33	12.96
	Gypsum board	0.0417	0.0926	50.0	0.20	0.45
Roof	Asphalt shingles	N/A	N/A	70.0	0.35	0.44
	Plywood	0.0521	0.0667	34.0	0.29	0.78
Ceiling	R-19 Fiberglass ins.	0.4583	0.0270	6.3	0.20	16.97
	Gypsum board	0.0521	0.0926	50.0	0.20	0.56
Floor	Linoleum tile	N/A	N/A	N/A	0.30	0.05
	Concrete slab	0.3333	0.7576	140.0	0.20	0.44
Glass Type		**Transmittance** (%)		**Reflectance** (%)		**U-Value** Btu/(hr-ft2-F)
Window	Double Clear	70		13		0.57

Table 3.7 – SPACE-CONDITIONS details.

SPACE-CONDITIONS Subcommand	**Residence Zone**	**Source**
TEMPERATURE	70.5	Estmated from the case study site data
NUMBER-OF-PEOPLE	3	Actual data
PEOPLE-HEAT-GAIN	400	ASHRAE Standard
LIGHTING-TYPE	Incandescent	Actual data
LIGHTING-W/SQFT	0.892	Estmated from the case study site data
LIGHT-TO-SPACE	1	Incandescent -DOE-2 Reference Manual
EQUIPMENT-W/SQFT	0.892	Estmated from the case study site data
INF-METHOD	AIR-CHANGE	Kootin Sanwu's Dissertation
AIR-CHANGES/HR	0.32	Kootin Sanwu's Dissertation
FLOOR-WEIGHT	0	Custom Weighting Factors
ZONE-TYPE	Conditioned	Actual data
SPACE-CONDITION	**Attic**	**Source**
Subcommand	**Zone**	
TEMPERATURE	80	Average value from the case study site data
NUMBER-OF-PEOPLE	0	Actual data
INF-METHOD	AIR-CHANGE	Residential -DOE-2
AIR-CHANGES/HR	0.2	Approximate value
FLOOR-WEIGHT	0	Custom Weighting Factors
ZONE-TYPE	Unconditioned	Actual data

Table 3.8 – SYSTEMS descriptions.

ZONE-CONTROL		**Source**
DESIGN-HEAT-T	73	Estimate from the case study site data
DESIGN-COOL-T	68	Estimate from the case study site data
THERMOSTAT-TYPE	Proportional	Residential -DOE-2
THROTTLING-RANGE	2	Residential -DOE-2
SYSTEM-FANS		**Source**
SUPPLY-DELTA-T	2	Kootin Sanwu's Dissertation
SYSTEM-EQUIPMENT		**Source**
COMPRESSOR-TYPE	Single-Speed	Actual data
COOLING-EIR	0.341	Actual data -Equivalent to 10 SEERS
FURNACE-HIR	1.1765	Actual data

3.3.2. The Simulation of the Basecase Model: One Zone Model with an Attic without Daylighting

Creating the basecase model using the DOE-2 simulation program includes 2 primary simulations. First was the simulation of the basecase model having a single conditioned zone with an unconditioned attic zone which did not include any of DOE-2's daylighting commands. This model was used as the basecase building for studying the energy uses and environmental conditions, which was compared and calibrated with the data obtained from the case study site. The second model created was a special multi-zone basecase model with an attic space and with daylighting zones that correspond to each room. This model represented the basecase building with daylight application, and was used as the baseline case for the evaluation of proposed daylighting designs in terms of Daylight Factor contribution and energy reductions from using daylighting to supplement artificial lighting. Results of the monthly energy use from the two simulations were compared and analyzed in order to understand the difference between these two models. The display of the basecase simulation geometry of the one-zone model with an attic space and without daylighting is presented in Figure 3.24, by using the DrawBDL program (Joe Huang and Associates 1993-1994).

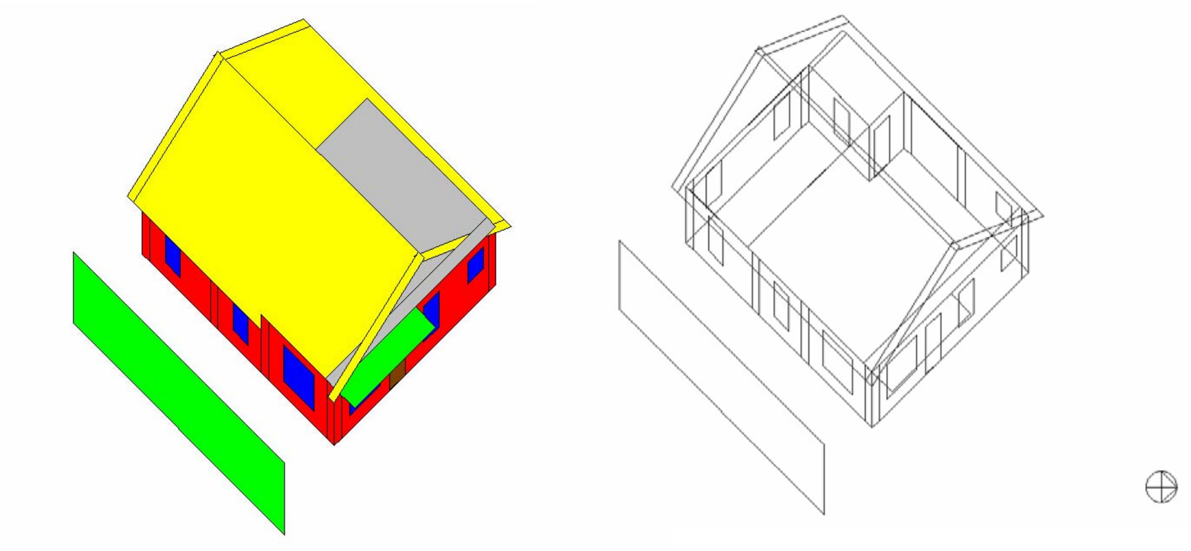


Figure 3.24 – Display of the basecase DOE-2 model simulation geometry.

All displays of the DOE-2 simulation models used in this study were created by using the DrawBDL program version 2.02 (1993) instead of the DrawBDL version 3.0 (2000), which had problems displaying shading surfaces for this study. The problems with DrawBDL that were discovered and recommendations for future work are discussed in Chapter V. Unfortunately, DrawBDL version 2.02 could not display geometries other than rectangular shapes. For example, in Figure 3.24, the triangular walls on the gable ends are not displayed with DrawBDL version 2.02.

In simulating the basecase building, four data profiles - lighting electricity use, equipment electricity use, space temperature, attic temperature and ground temperature profiles - were considered in the calibration process. The lighting and equipment use profiles were developed from the case study house's measured data and input into the DOE-2 simulation as electricity use schedules. Profiles of the lighting and equipment electricity uses, including the simulation results, are discussed in Chapter IV.

The space temperature profile was also developed using the case study house's measured data, including both the supply and the return temperatures. Figure 3.25 shows the case study house HVAC supply temperature scatter plot. As can be seen from the graph, the house supply temperature clustered according to the outdoor dry bulb temperature. At outdoor temperatures less than 60°F, a "heating" cluster appears that represents 15-minute periods when the furnace was operating and therefore supply duct temperatures were 90°F or higher. At outdoor temperatures greater than 65°F, a "cooling" cluster appears that represents 15-minute periods when the air-conditioner was operating and therefore supply duct temperatures were less than 60°F. Finally, a third cluster represents all other periods where the supply temperatures were floating. These measured temperatures were used in the DOE-2 variable settings to help tune the simulated systems.

Figure 3.26 displays the plot of the return temperature from the case study house versus the outdoor temperature during the period studied from January to December 1999. Figure 3.27 displays the plot of return temperature in time series format. As seen from the graph, the house thermostat was set between 60 – 80°F year round.

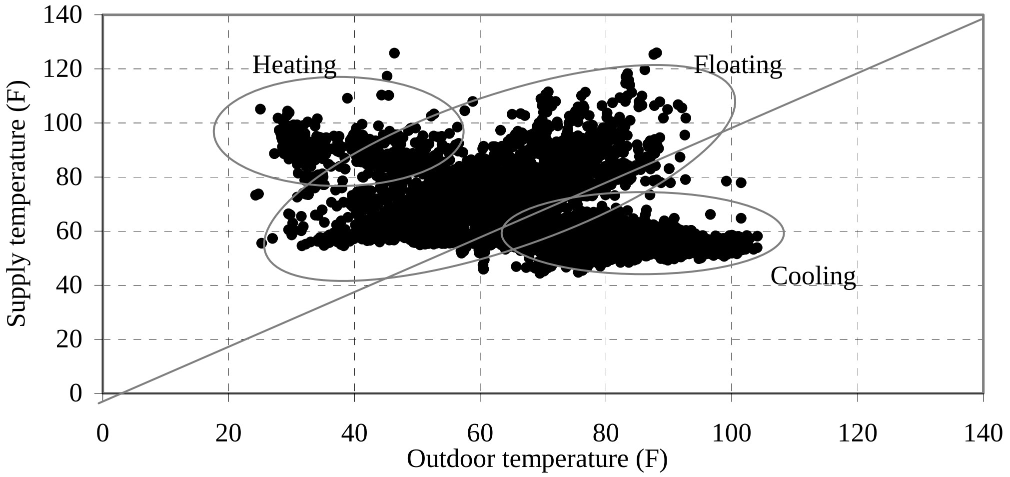


Figure 3.25 – HVAC supply temperature vs. outdoor temperature from the case study site. The measured data was collected from the case study building during the period from January to December 1999.

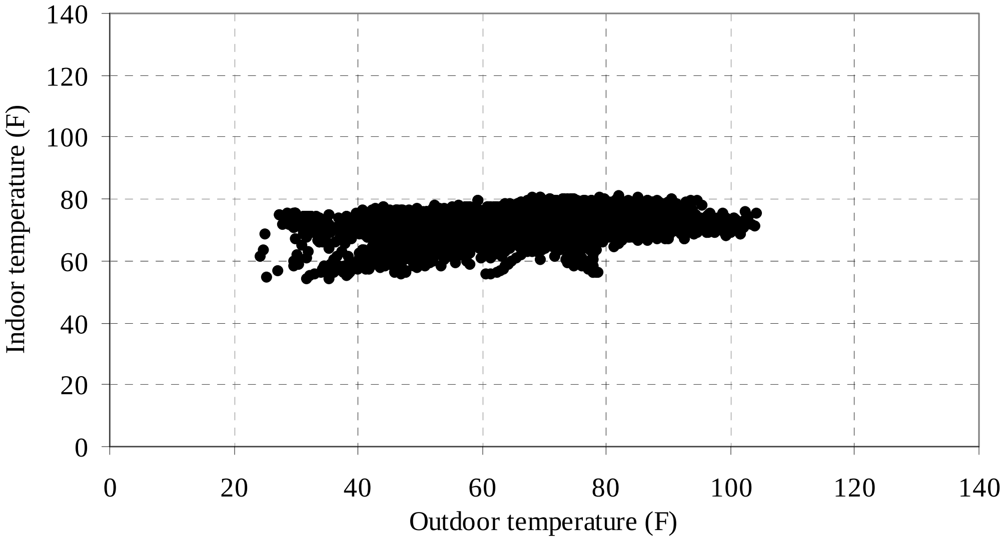


Figure 3.26 – Return temperature vs. outdoor temperature from the case study site. The data was collected from the case study site from January to December 1999.

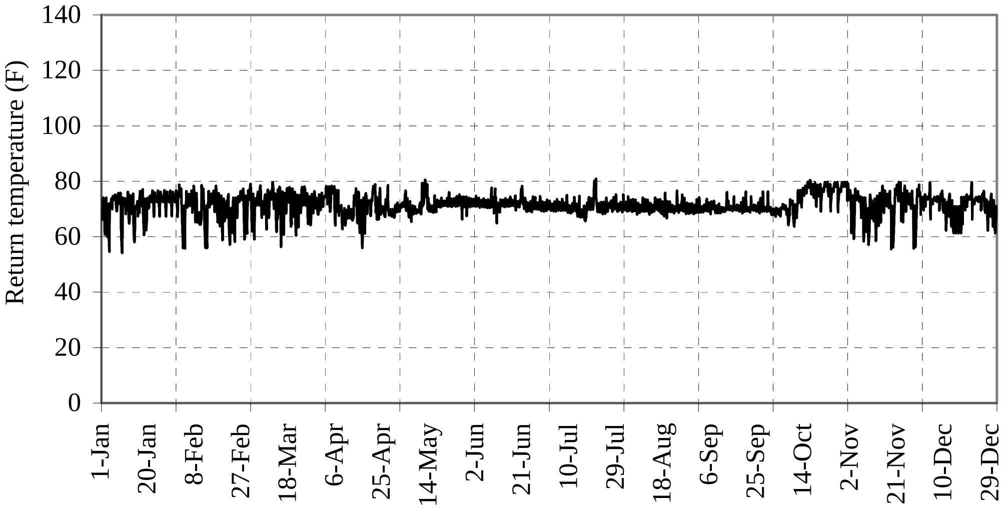


Figure 3.27 – Return temperature from the case study house. In the heating season (January – March, and November – December), the in door temperatures can be seen to fluctuate between 55-80°F, indicating the homeowner's tolerance of periods of lower indoor temperatures. In the cooling season (April – October), the indoor temperatures were more consistent at about 70°F.

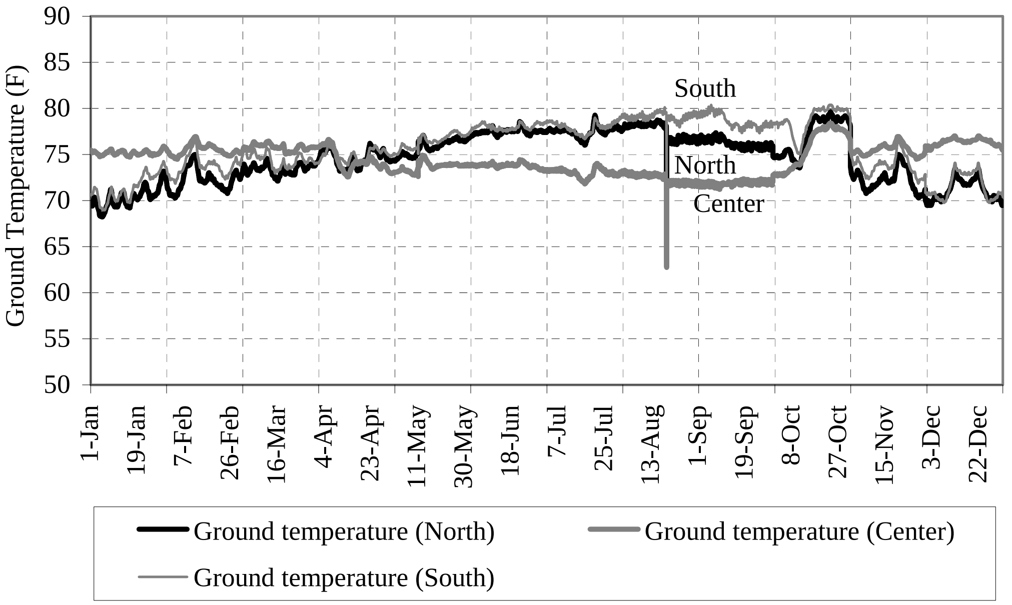


Figure 3.28 – Ground temperature from north, south, and center sensors of the case study house.

The ground temperature profile used for calibrating the simulation input data was derived from the case study site's measured ground temperature data. Three ground temperatures from the case study site were measured by using sensors that were installed during the house's construction (Kootin-Sanwu et al. 2000). Ground temperature sensors were installed in 3 locations: below the slab at the center of the house, and 3 feet from the edge of the slab on the north, and the south side. Figure 3.28 shows the ground temperature plots from 3 locations. It can be seen from the graph that the center ground temperature varies in the range of 70° – 75°F throughout the year, suggesting the relationship to the case study building's return temperature. Considering the north and south ground temperatures, the plot illustrates that the ground temperature at the south side tends to be higher than at the north, indicating the effect of solar radiation on the southwest side of the building. The simulations in this study used the ground temperature measured from the north side sensor. Future study might consider the use of ground temperature from the center of the house. The discussion regarding the use of center ground temperature in the simulation was presented in Chapter V.

3.3.3. The Simulation of the Basecase Model: Multi-zone Model with an Attic Zone with Daylighting Controls

After the calibration of the single zone model without daylighting, additional inputs for DOE-2 daylighting simulations were entered. The basecase model for daylighting simulation required a multi-zone building with an attic. To accomplish this, the model was partitioned with represent to the actual rooms within the case study house. In the daylighting simulation, DOE-2 simulates daylighting sensors as if they were placed in the middle of each room at the specified height (2 feet from the floor for this study) in order to measure the illuminance levels. Before developing other daylighting models with the application of proposed daylighting strategies, the basecase multi-zone model was calibrated against the one-zone basecase model without daylighting. The calibration considered both the monthly energy use and environmental conditions; results from the calibration were compared to the measured data from the case study site. Figure 3.29 shows the DrawBDL display of the basecase model simulation geometry with daylighting sensors.

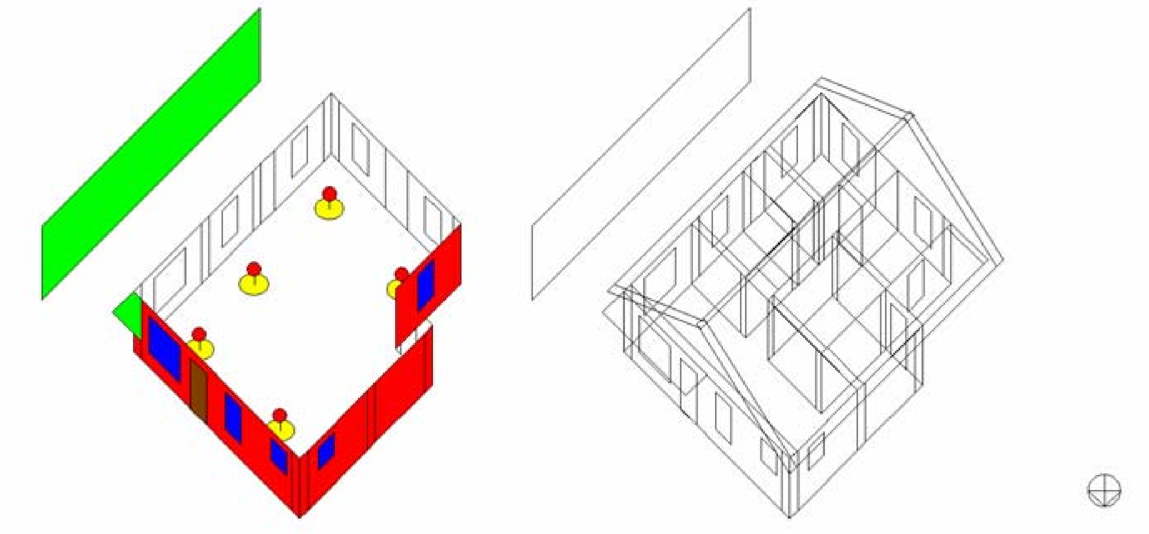


Figure 3.29 – Display of the basecase DOE-2 model simulation geometry with daylighting sensors.

3.3.4. Solar Radiation and Exterior Horizontal Illuminance Data from the Houston TMY2 Weather Tape

To study the available daylight, solar radiation and sky illuminance data were taken into consideration. From the Houston TMY2 weather tape, the data from 4 selected days were analyzed. The days selected were vernal equinox, summer solstice, autumnal equinox, and winter solstice (March 21, June 21, September 21, and December 21 respectively). These days represent the four primary seasons. Figures 3.30 – 3.35 show the solar radiation and exterior illuminance data from the Houston TMY2 weather file for these specified days.

As seen from Figure 3.30, March 21 and December 21 were clear days, while June 21 and September 21 were partly cloudy days. From an inspection of the four days, it was determined that the date of March 21 would be used for further investigation. The results of this analysis are presented in Section 4.3 of Chapter IV.

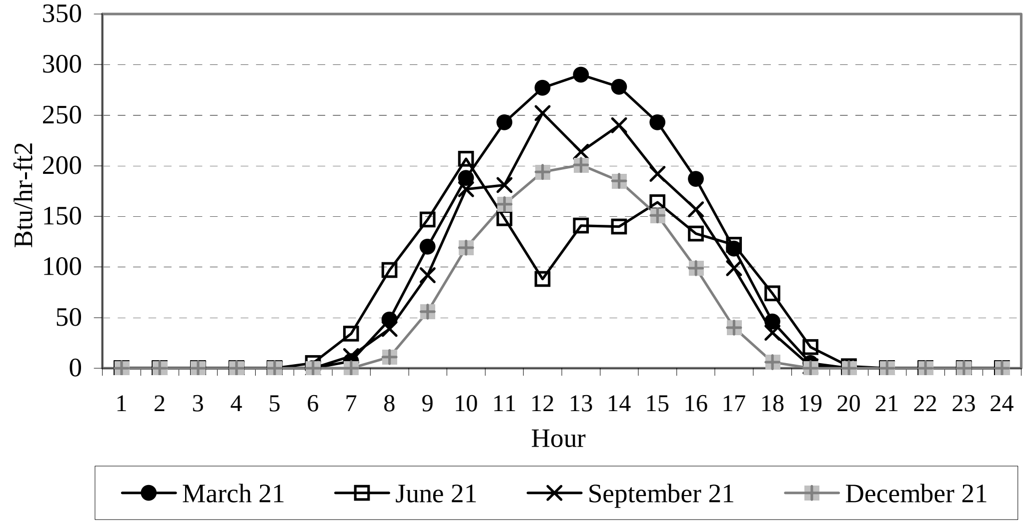


Figure 3.30 – Global horizontal solar radiation from the Houston TMY2 weather tape.

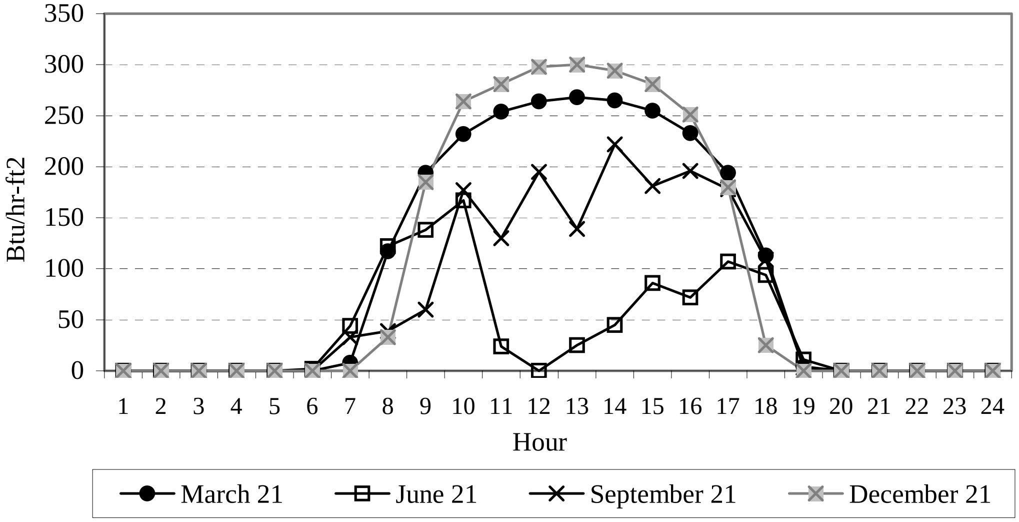


Figure 3.31 – Direct normal solar radiation from the Houston TMY2 weather tape.

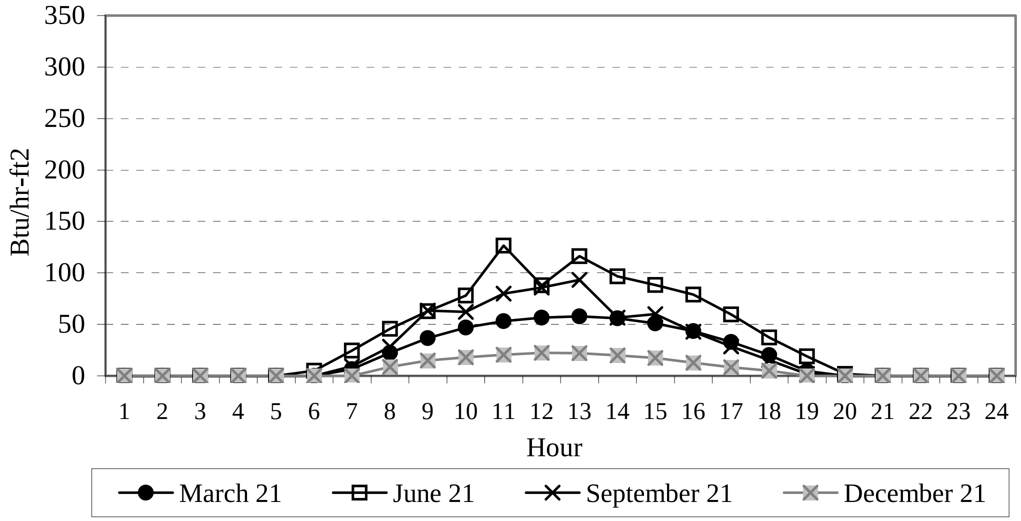


Figure 3.32 – Diffuse solar radiation from the Houston TMY2 weather tape.

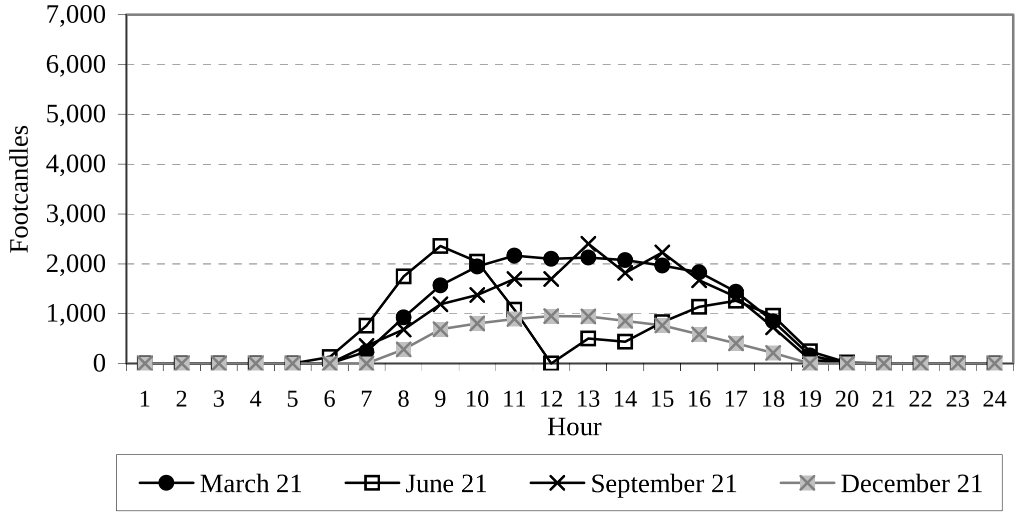


Figure 3.33 – DOE-2 calculated exterior horizontal illuminance from clear portion of the sky.

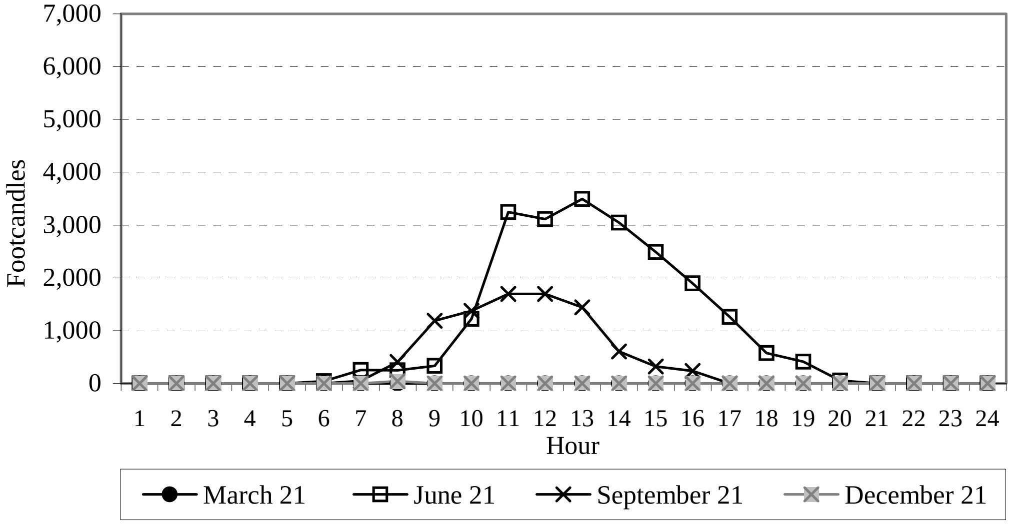


Figure 3.34 – DOE-2 calculated exterior horizontal illuminance from overcast portion of the sky.

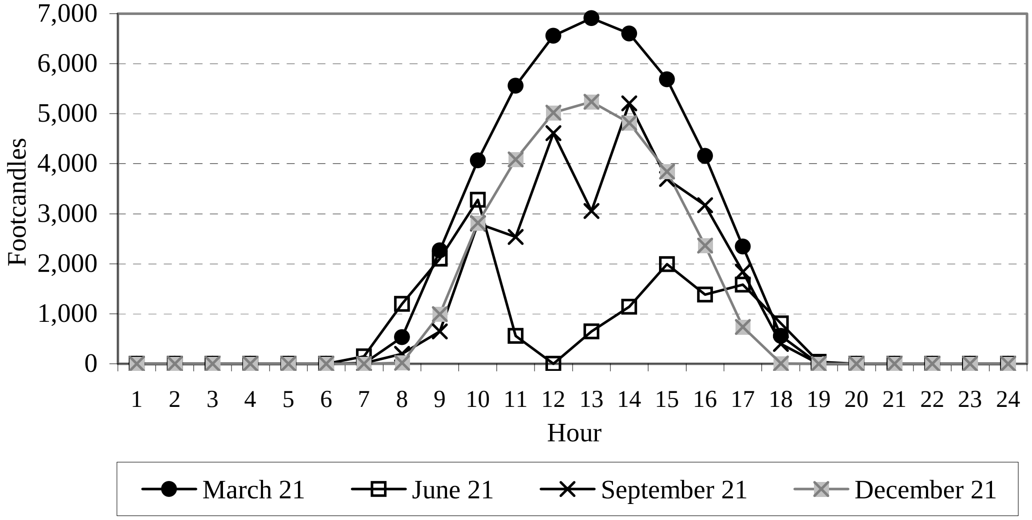


Figure 3.35 – DOE-2 calculated exterior horizontal illuminance from direct sun.

3.3.5. DOE-2 Daylighting Simulations of the Multi-zone Model with Proposed Designs

From the analysis conducted using the SOLRPATH program, the proposed designs of window shading were selected for the daylighting study and simulation. In the DOE-2 simulation, analysis and comparisons focused on the daylighting simulation for March 21^{st}, because it represented a clear day and offered the highest available daylight for the comparative analysis (as concluded in Section 3.3.4.).

To simulate the models with the proposed designs, shading configurations and additional details on light settings, material absorptance, and reflectance values were added through the DOE-2 SPACE-CONDITIONS subcommand. Input files for daylighting simulations are discussed further in Appendix D.

Daylighting models simulated with the DOE-2 program included 4 cases, as previously stated in Section 3.2.5: 1) the basecase multi-zone model, 2) the model with maximum 6-foot overhang, 3) the model with maximum 6-foot overhang with a vertical fin, and 4) the model with 18-inch combined lightshelf (i.e., 18-inch overhang, vertical fin, and interior lightshelf). Figures 3.36 – 3.38 display the simulation geometry of daylighting models by using DrawBDL version 2.02 (1993). Each figure shows 2 illustrations displaying different components in the simulation geometries. In part A, the figures show the simulation models with opaque exterior walls and includes the daylighting sensors at the studied positions. Part B displays the structural construction of the models, which includes the roof, interior walls and studs, and ceiling structures.

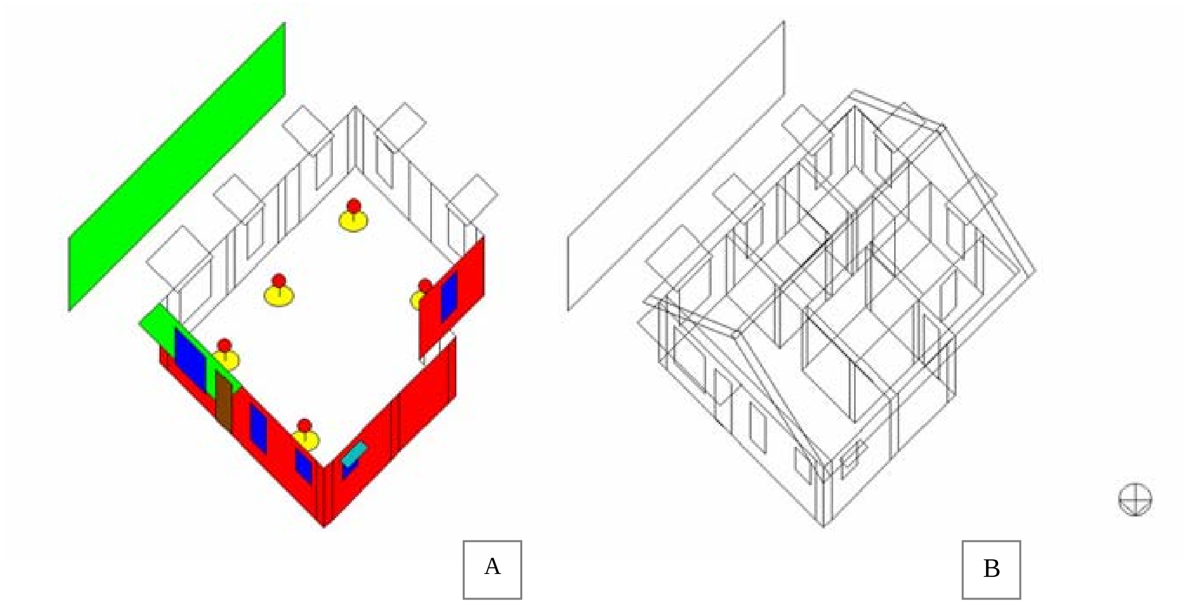


Figure 3.36 – Display of the model with maximum 6-foot overhang simulation geometry.

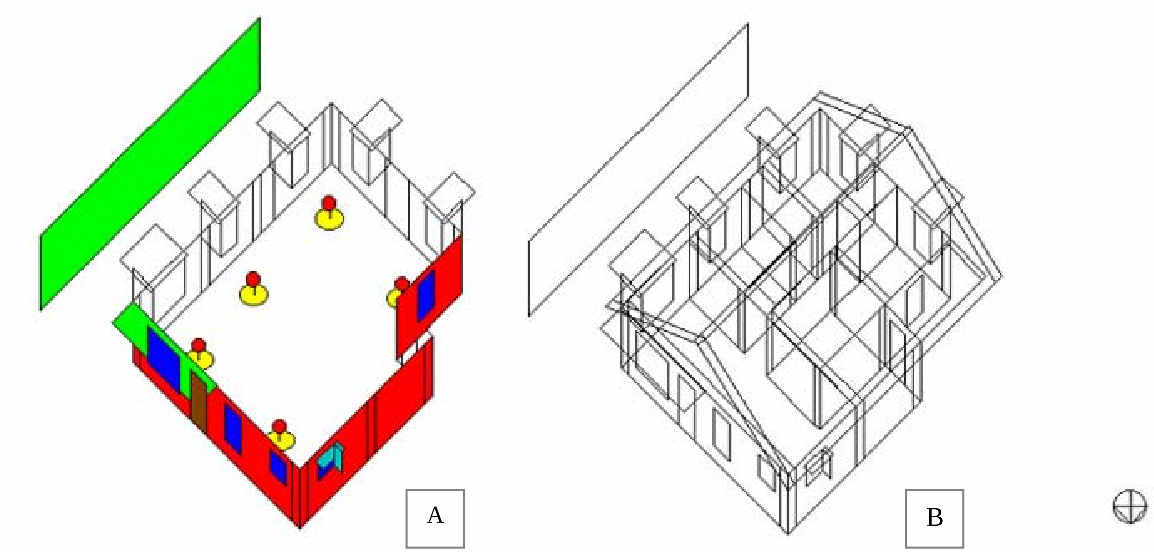


Figure 3.37 – Display of the model with maximum 6-foot overhang with vertical fin simulation geometry

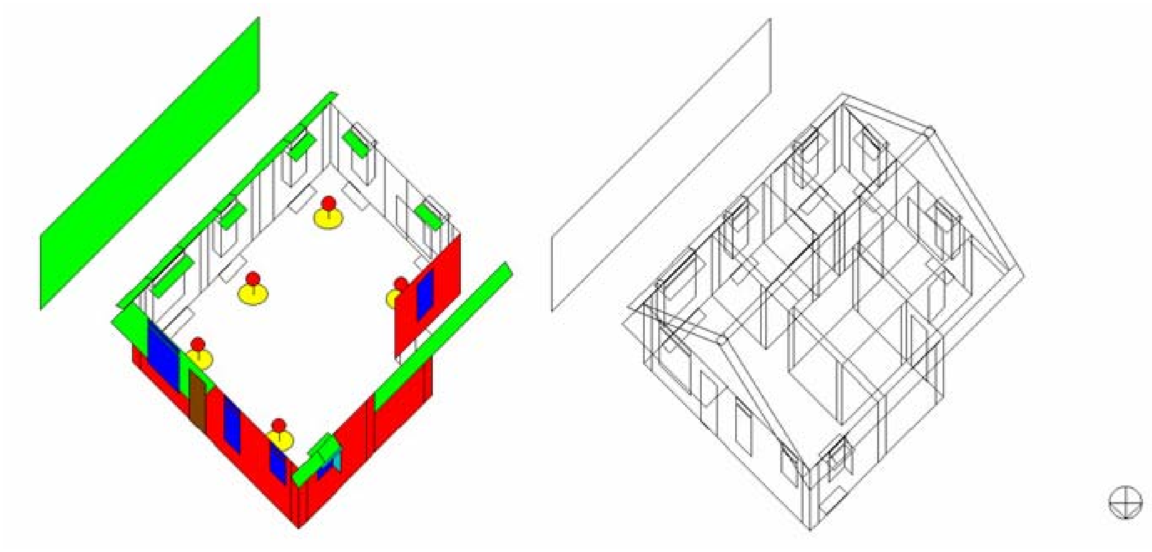


Figure 3.38 – Display of the model with 18-inch combined lightshelf simulation geometry.

In the final design model, as shown in Figure 3.38, the shading surfaces representing the eaves of the house as part of the lightshelf systems design were added in the simulation.

3.4. SUMMARY

The objective of this study is to explore and evaluate the use of proposed daylighting designs to achieve effective daylight utilization that contributes to energy savings through reducing electricity for lighting. The methods employed in conducting this research include the use of the case study building, the use of a physical scale model, shading analysis, and the use of DOE-2 hourly simulation program.

The case study house hourly data were obtained from the 15-minute measurements at the case study site (Kootin-Sanwu 2003), which were used in analyzing the building's energy use patterns for DOE-2 model calibration. The basecase models simulated with the DOE-2 program included a single zone model with an attic without daylighting and a multi-zone model with an attic with daylighting. These models of the case study building were then used to analyze the energy consumption, thermal conditions, and daylight performance of the building.

The SOLRPATH program was used to provide an analysis of the proposed shading designs. Physical scale models were used to provide a means to evaluate the proposed shadings in terms of shading objective and interior daylight illumination. Two experiments using the physical scale models were conducted in this study: 1) the analysis of shading properties using the heliodon table in the sky simulator, 2) the evaluation of proposed shadings in contributing to the interior daylight as measured by the Daylight Factor under actual overcast sky conditions. Results from the experiments were used to evaluate the effectiveness of proposed shading designs.

The DOE-2 energy simulation program was then used to study the application of daylighting to the building and its effects on reducing building energy use. This study used the DOE-2 program to simulate the basecase model representing the case study building and three additional models with proposed daylighting designs. The calibrated multi-zone model was used as the basecase daylighting model, which provided a comparison with the proposed daylighting models in terms of daylight evaluation and energy use reduction.

Data from the case study site, results from the physical scale model measurements, and results from the DOE-2 simulations were all used to perform the model calibration. This study analyzed the results and evaluated the effectiveness of the proposed designs in terms of shading quality, daylighting quantity, and energy consumption and savings. Results from these experiments are discussed in Chapter IV – Results and Analysis.

CHAPTER IV

RESULTS AND ANALYSIS

This chapter discusses the results of the research methodology presented in Chapter III. There are three primary sections in this chapter. The first describes how the data from the case study building were used to produce a calibrated DOE-2 simulation. In this section, selected data from the case study site were specially prepared to provide input parameters for the calibrated DOE-2 simulation. The objective of calibration was to match the DOE-2 simulation model with the case study house in terms of the inside building environmental conditions and energy usage profiles. The calibrated DOE-2 basecase simulation model was then considered a representative model for the case study building and it was then used for studying the benefits of proposed daylighting designs and strategies.

In the second section, the results from the physical scale model for daylight factor measurements are discussed. The discussion focuses on the results from the scale model calibration, the effectiveness of the proposed shadings, and compares the results of Daylight Factors from both physical model measurements and DOE-2 daylighting simulations.

The last section discusses the results from the DOE-2 simulation program, focusing on energy reductions by applying the proposed designs to the case study building. Energy savings from each shading application were evaluated and compared. The most effective design was the one offering the highest energy savings.

4.1. RESULTS OF CASE STUDY BUILDING MODEL CALIBRATION

Basecase model calibrations conducted in this study included three primary steps, which are the general model calibration, the calibration with different FLOOR-WEIGHT settings, and the calibration with different ground temperature inputs. The case study site data were selected from the database at the Energy Systems Laboratory – additional details are provided in Appendix A –, converted and used as DOE-2 inputs for an initial simulation. Such data included the physical building description, and thermal characteristics, including hourly building energy use. After the basecase model was simulated with DOE-2, reports from the simulation output representing the simulated model's thermal conditions and monthly energy use were compared with the actual measured data of the case study building. Some variables used in the DOE-2 input were then adjusted and simulations were run again until the simulations matched the measured data.

The variables focused on in this study were the use of FLOOR-WEIGHT settings and ground temperatures. The calibration with FLOOR-WEIGHT settings included both the attic and interior temperature calibration, and the monthly energy use calibration. Results from the calibrations showed a significant effect of using different space FLOOR-WEIGHT in model simulations. The calibration with ground temperature input analyzed the DOE-2 simulation outcomes as a result of using ground temperature from two different sources. The model calibrations were conducted to develop the DOE-2 basecase model that represented the case study building and was used in the comparison studies of the proposed design models.

4.1.1. Basecase Model General Calibration

To create the basecase model using the DOE-2 program, selected data from the case study site were converted into inputs for the DOE-2 program, including: the lighting and receptacle electricity use, equipment electricity use, air conditioning and heating supply temperatures, including indoor thermostat set points. From the case study data, lighting and receptacle and equipment electricity use were converted to 3 types of 24-hour profiles: average 7-day schedule (i.e., one schedule for each day: Monday, Tuesday, etc.), average weekday and weekend schedules, and one average daily schedule. Each

24-hour profile was then input into the DOE-2 simulation and the results from each simulation were evaluated. Figures 4.1A – 4.1C present the 24-hour profiles of average 7-day, average weekend and weekday, and one average daily lighting and receptacle electricity use respectively.

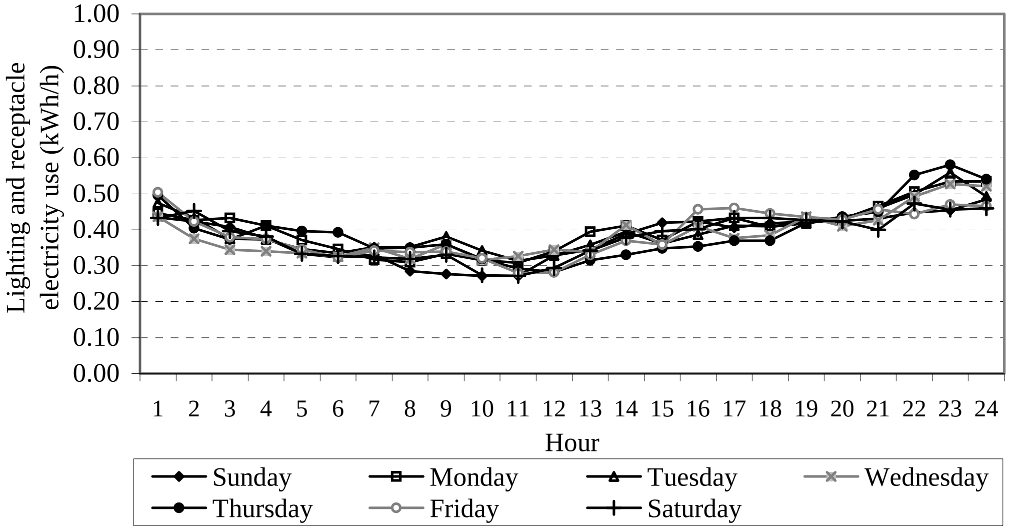


Figure 4.1A – Average 7-day lighting and receptacle electricity use for each day. The plots of 24-hour profiles were derived from measured data of the case study site (January to December 1999).

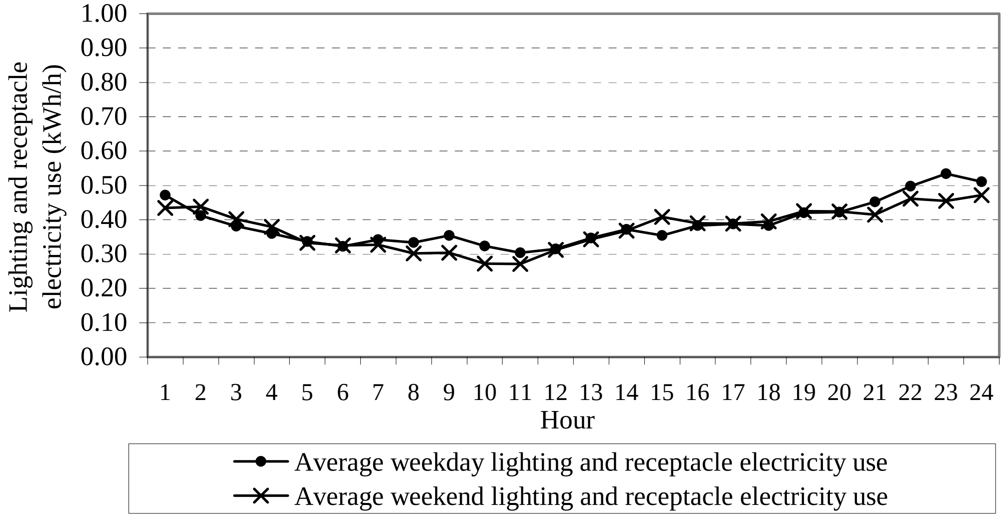


Figure 4.1B – Average weekday and weekend lighting and receptacle electricity use (January to December 1999).

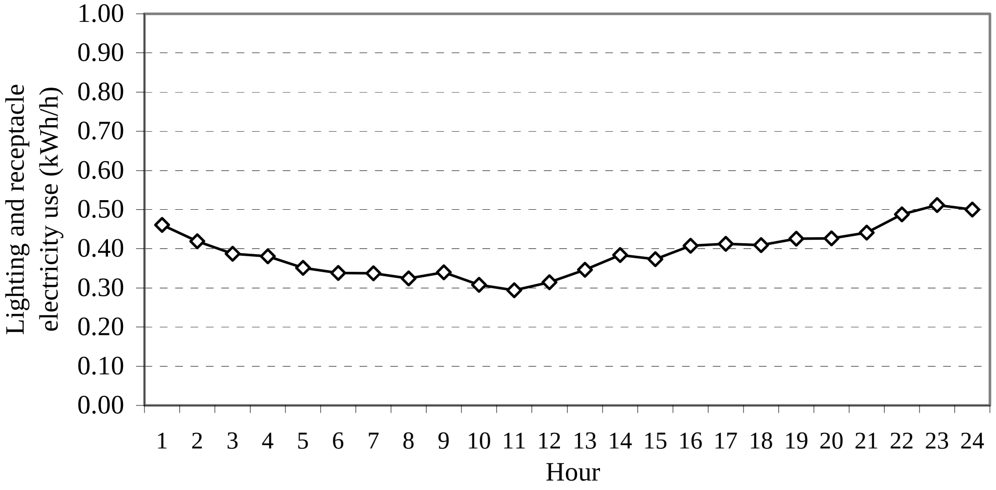


Figure 4.1C – Average daily lighting and receptacle electricity use. The plot represents data for all 7 days from January to December 1999.

Figures 4.2A – 4.2C show the 24-hour profiles of average 7-day, average weekday and weekend, and one average daily equipment electricity use. Additional plots on the average 7-day schedule of lighting and receptacle and equipment electricity uses are shown in Appendix B.

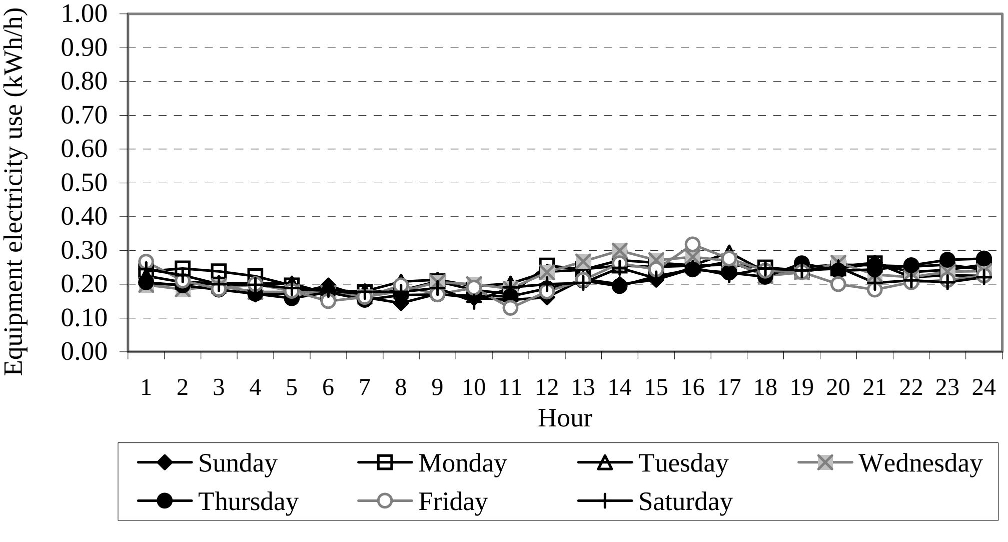


Figure 4.2A – Average 7-day equipment electricity use for each day. The plot of 24-hour profile was derived from measured data of the case study site for the period from January to December 1999.

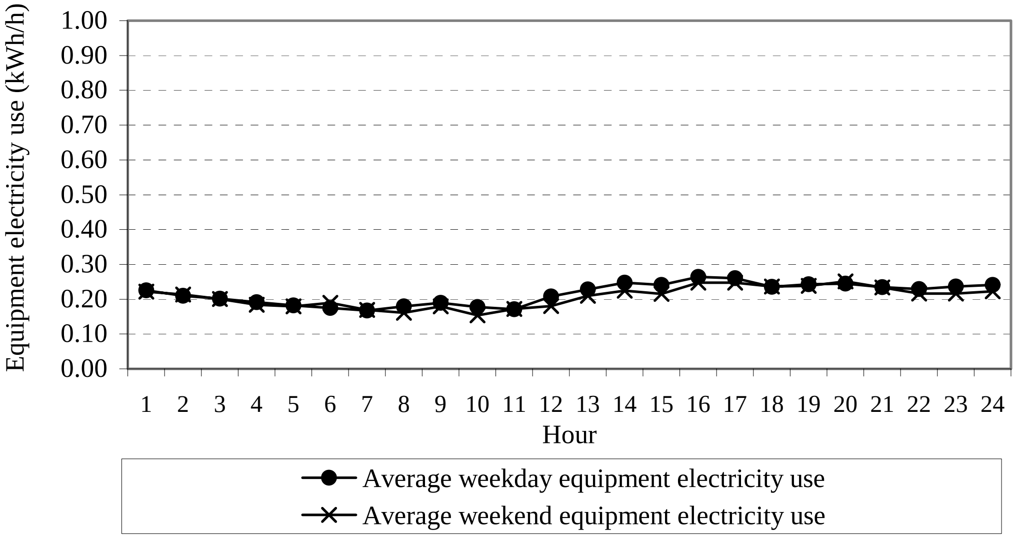


Figure 4.2B – Average weekday and weekend equipment electricity use (January to December 1999).

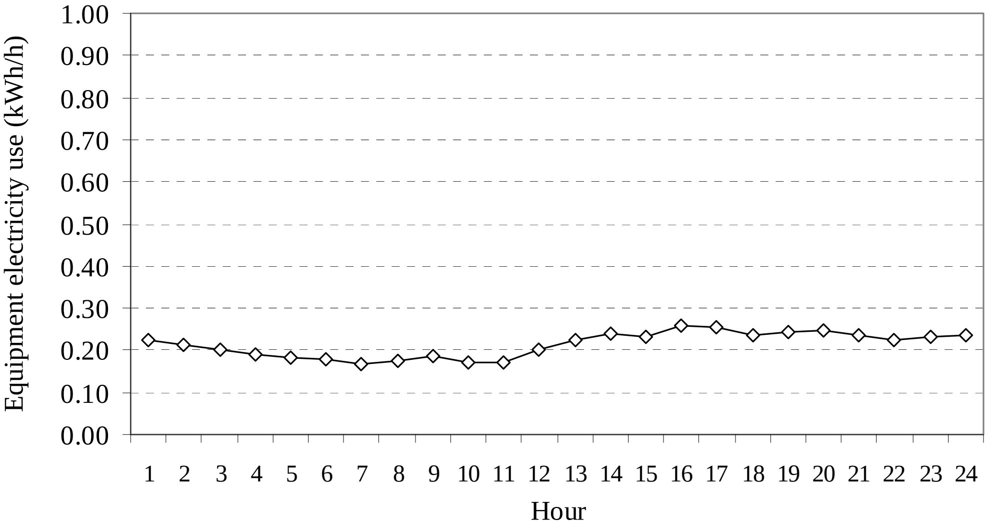


Figure 4.2C – Average daily equipment electricity use. The plot represents data for all 7 days from January to December 1999.

Tables 4.1 and 4.2 and Figure 4.3 show the results of using the three different schedules in the basecase DOE-2 model as compared against the measured electricity use from the case study site. In the tables and figures, the building was simulated with the three different 24-hour profiles. From Table 4.1, it can be seen that the one average daily lights and receptacles schedule produced the best results.

In Table 4.2, the 7-day profile and the one average daily profile produce similar results. However it can be seen that the one average profile produce slightly better results in matching the total annual equipment electricity use with the case study data. Seen in both Tables 4.1 and 4.2, the weekday – weekend profile produced the worst results. From these simulations, it was concluded that the one average daily 24-hour profile was appropriate for simulating the case study house.

Table 4.1 – Comparison of lighting and receptacle electricity use from the 3 types of schedule input.

Category	**Total Annual Lighting Electricity Use**		
	(kWh)	Difference	Deviation (%)
Case study site measured hourly data	3,436.0		
DOE-2 schedule type			
DOE-2 with 7-day schedule	3,425.0	11.0	0.3%
DOE-2 with weekday and weekend schedule	3,371.0	65.0	1.9%
DOE-2 with average daily schedule	3,428.0	8.0	0.2%

Table 4.2 – Comparison of equipment electricity use from the 3 types of schedule input.

Category	**Total Annual Equipment Electricity Use**		
	(kWh)	Difference	Deviation (%)
Case study site measured hourly data	2,744.3		
DOE-2 schedule type			
DOE-2 with 7-day schedule	2,701.0	43.3	1.6%
DOE-2 with weekday and weekend schedule	2,689.0	55.3	2.1%
DOE-2 with average daily schedule	2,703.0	41.3	1.5%

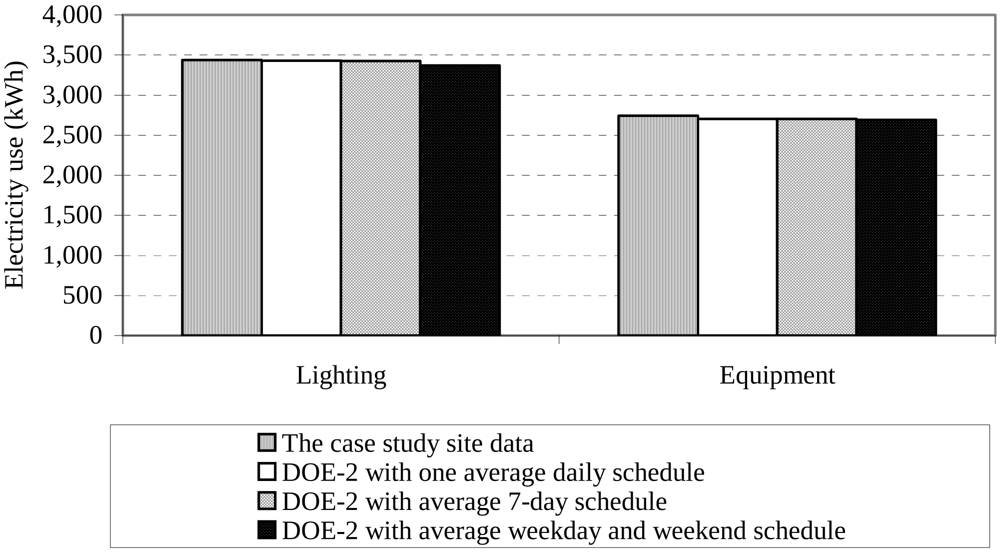


Figure 4.3 – The comparison of the 3 types of schedule input in total lighting and receptacle and equipment electricity use.

For indoor temperature profiles, average thermostat schedules were derived from the case study site data. The data obtained from the case study site were divided into 2 types of schedules: heating season and cooling season temperatures. The heating and cooling season temperatures were determined by selecting 2-week periods representing the hottest and coldest periods during the year studied. The heating season was determined during the period from January 1 to January 15 of 1999, and the cooling season was during the period from August 18 to September 2, 1999. These thermostat temperature schedules were then input in the SYSTEM-CONTROL in the DOE-2 simulations as the DAY-SCHEDULE temperatures. Figure 4.4 shows the average cooling, heating, and average daily schedules, including the average outdoor temperature derived from the measured data of the case study site.

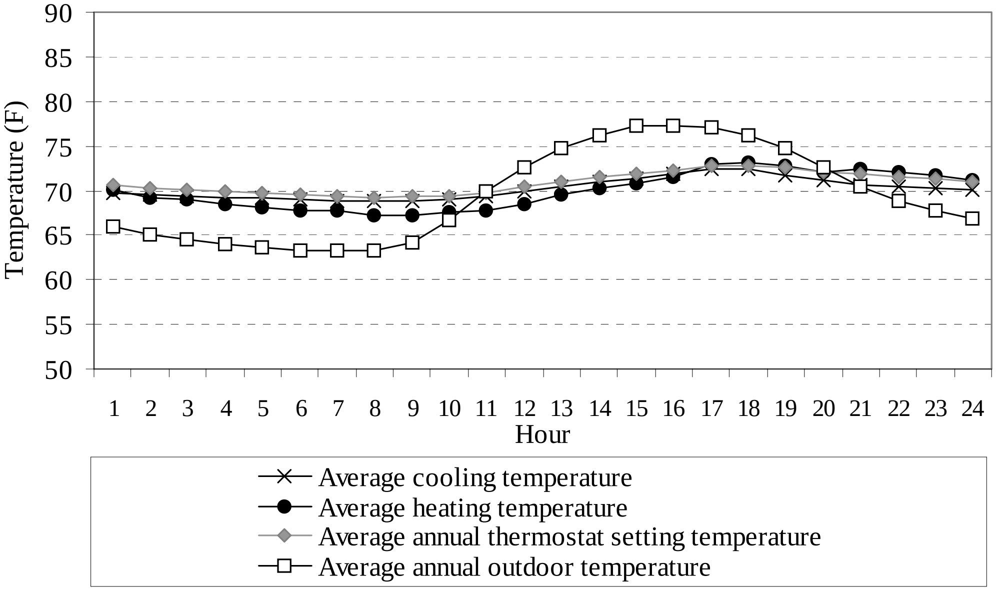


Figure 4.4 – Average outdoor and heating/cooling thermostat temperature schedules from the case study site. The heating period as determined in this study was from January 1 to January 15, and the cooling period was from August 18 to September 2, 1999.

4.1.2. Calibration with FLOOR-WEIGHT Settings

4.1.2.1. Temperature calibration

The DOE-2 basecase model calibration with different FLOOR-WEIGHT settings focused on 2 main procedures: interior zone temperature calibrations and the monthly energy use calibrations. Temperature calibrations included the comparison of measured versus simulated attic and residence zone temperatures. Figure 4.5 shows the measured attic space temperature from the case study site. From the plot, the attic temperature reaches a high of 140°F in the summer, while the lowest temperature is 28°F in winter.

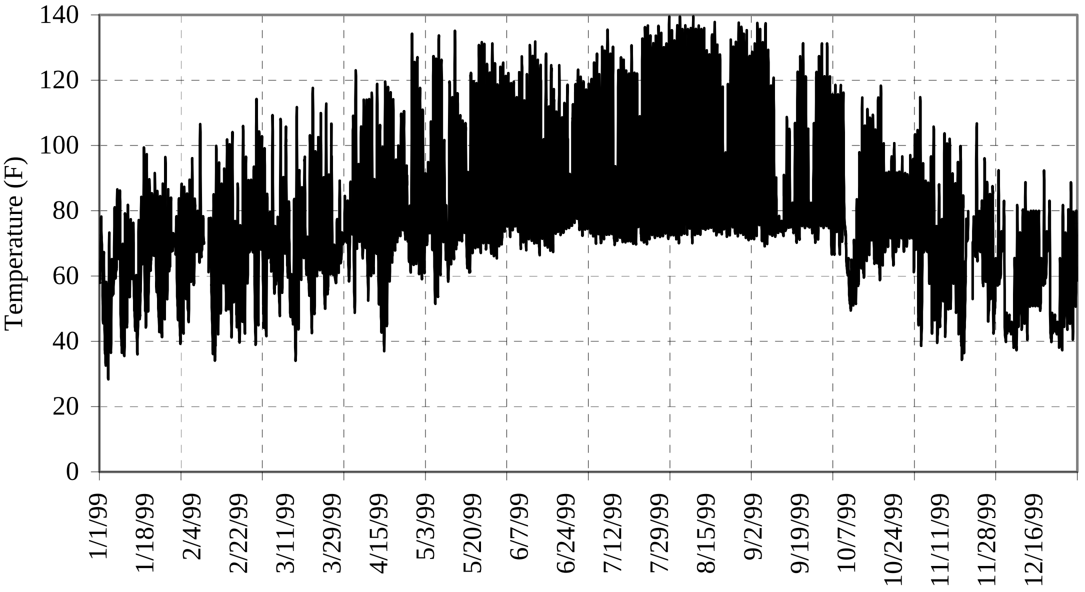


Figure 4.5 – Measured attic space temperature from the case study site.

In the analysis of attic space temperatures, the primary variable adjusted in DOE-2 simulation was attic the FLOOR-WEIGHT settings. The study compared the results from simulating the attic space with FLOOR-WEIGHT = 70 (i.e. using standard, pre-calculated ASHRAE weighting factors that represent medium construction, LBL 1980), and with FLOOR-WEIGHT = 0 (i.e. using custom weighting factors). The simulation results showed dramatic hourly differences between the use of these 2 floor-weight calculations.

Figure 4.6 presents the simulated attic space temperatures from DOE-2 with the attic space FLOOR-WEIGHT = 70, which used the Houston TMY2 weather file. The graph shows a much narrower range of temperature deviations. The highest temperature in summer reaches only 100°F while the lowest is at 35°F. Although these simulated temperatures may be acceptable for average conditions, it did not adequately represent the attic temperatures.

When simulating the attic space using custom weighting factors, the results were much more consistent in amplitude with the measured temperatures. However, to activate these temperature profiles, the use of custom weighting factors had to apply to both the attic and residence FLOOR-WEIGHTs.

Figure 4.7 presents the attic space temperature from DOE-2 simulation with FLOOR-WEIGHT = 0, using the TMY2 weather file for Houston.

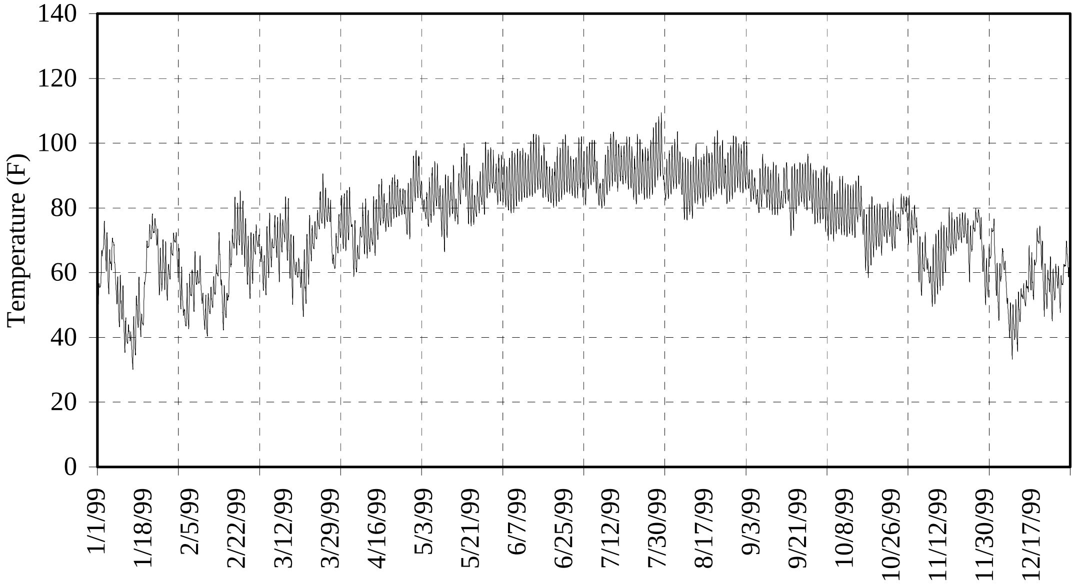


Figure 4.6 – Attic space temperature from DOE-2 simulation with attic FLOOR-WEIGHT = 70.

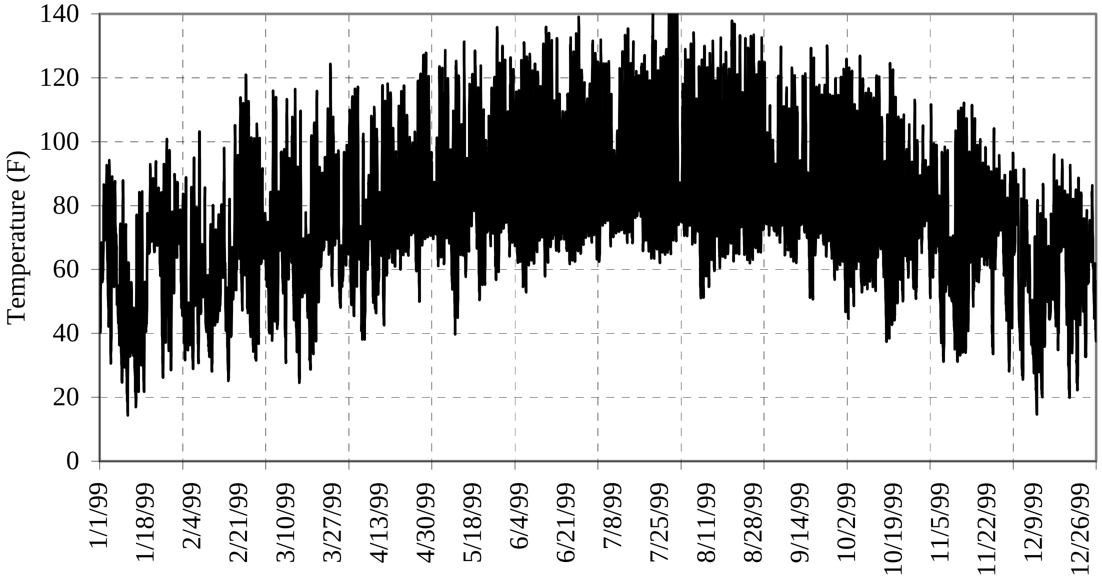


Figure 4.7 – Attic space temperature from DOE-2 simulation with attic FLOOR-WEIGHT = 0 (i.e., using custom weighting factors).

Figure 4.8 – Figure 4.10 show the measured attic temperature vs. measured outdoor temperature during the cooling season of the case study site data, DOE-2 simulation (i.e., with the Houston TMY2 weather file), with attic FLOOR-WEIGHT = 70 and DOE-2 simulation with attic FLOOR-WEIGHT = 0 respectively. The cooling season considered in this study was the 2-week hottest period of the year from August 18 to September 2, 1999. The cooling season attic temperature plots showed a similar trend of temperature profiles in both the case study site data and the DOE-2 simulation with custom weighting factors, while the simulation with medium construction setting presented very different plot.

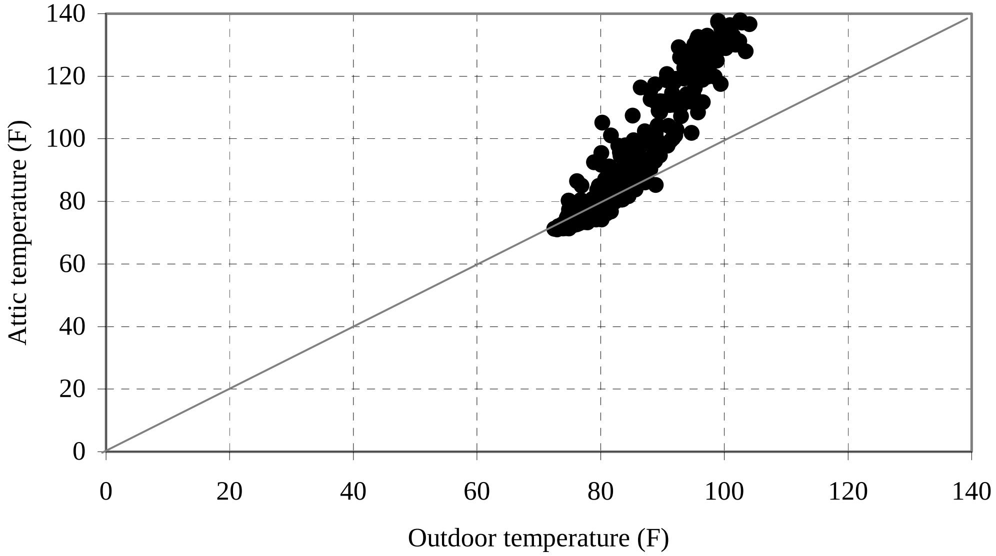


Figure 4.8 – Measured attic space temperatures of the case study site vs. outdoor temperature during the cooling season. The cooling season was a 2-week period from August 18 to September 2, 1999.

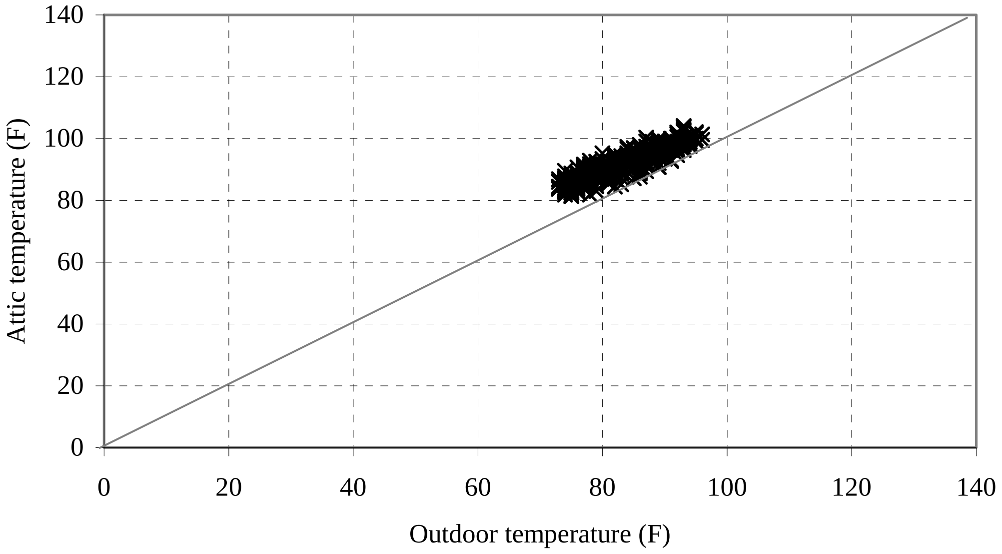


Figure 4.9 – Simulated attic space temperature obtained from DOE-2 simulation with FLOOR-WEIGHT = 70 vs. Houston TMY2 outdoor temperatures during the selected period in cooling season (August 18th to September 2nd, 1999).

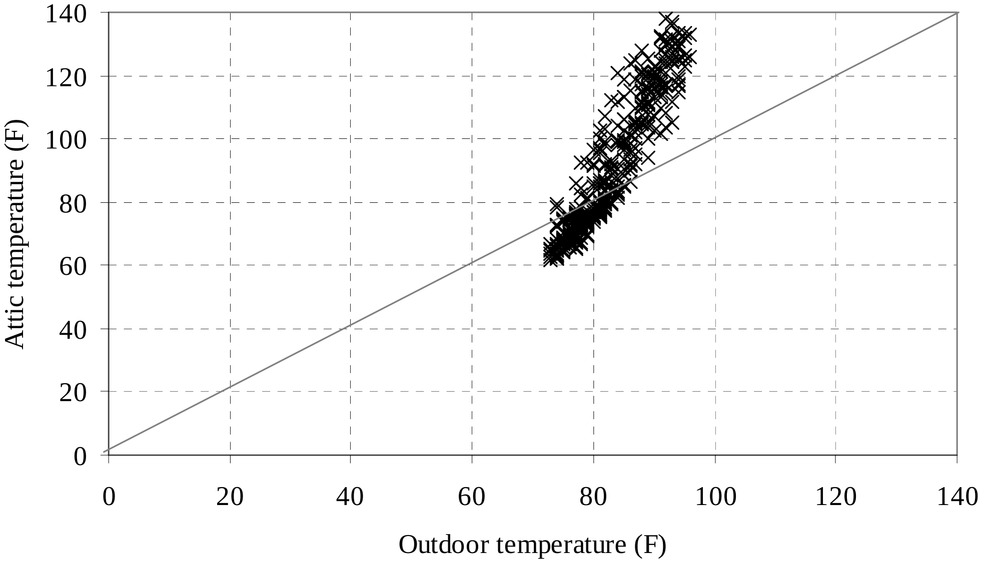


Figure 4.10 – Simulated attic space temperatures from DOE-2 simulation with FLOOR-WEIGHT = 0 vs. Houston TMY2 outdoor temperatures during the selected period in cooling season (August 18th to September 2nd, 1999).

Figure 4.11 – Figure 4.13 show the measured attic temperatures from the case study site data, and DOE-2 simulated temperatures with FLOOR-WEIGHT = 70, and FLOOR-WEIGHT = 0 during the heating season from January 1 to 15, 1999. The graphs suggest an acceptable calibration of DOE-2 simulation with attic FLOOR-WEIGHT = 0 with the case study site data. Interestingly, there was better agreement with the F-W = 70 simulation. However, the best agreement was still found to be the F-W = 0 simulation. In conclusion, this study simulated the DOE-2 basecase model by using custom weighting factors in both the attic and space FLOOR-WEIGHT settings.

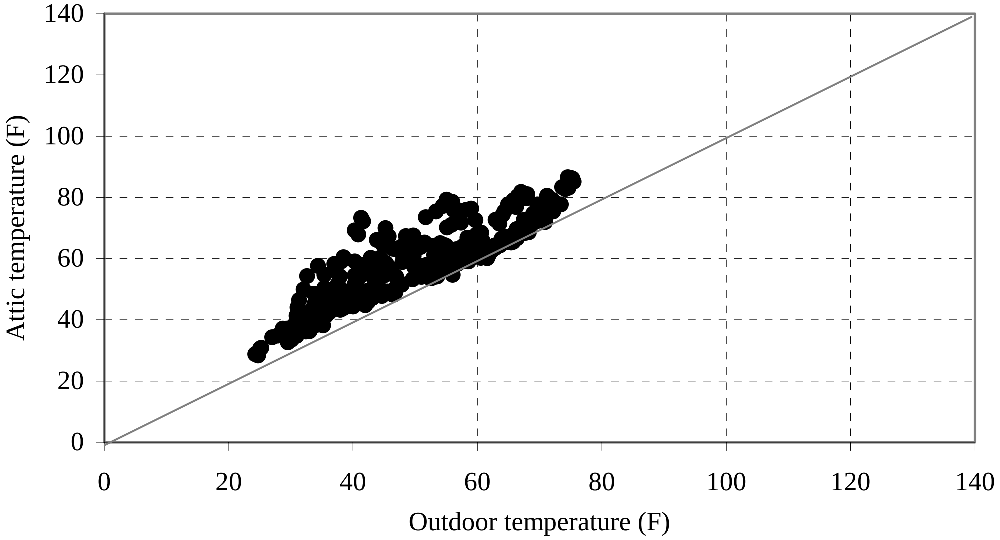


Figure 4.11 – Measured attic space temperatures of the case study site vs. outdoor temperature during the heating season (January 1st to 15th, 1999).

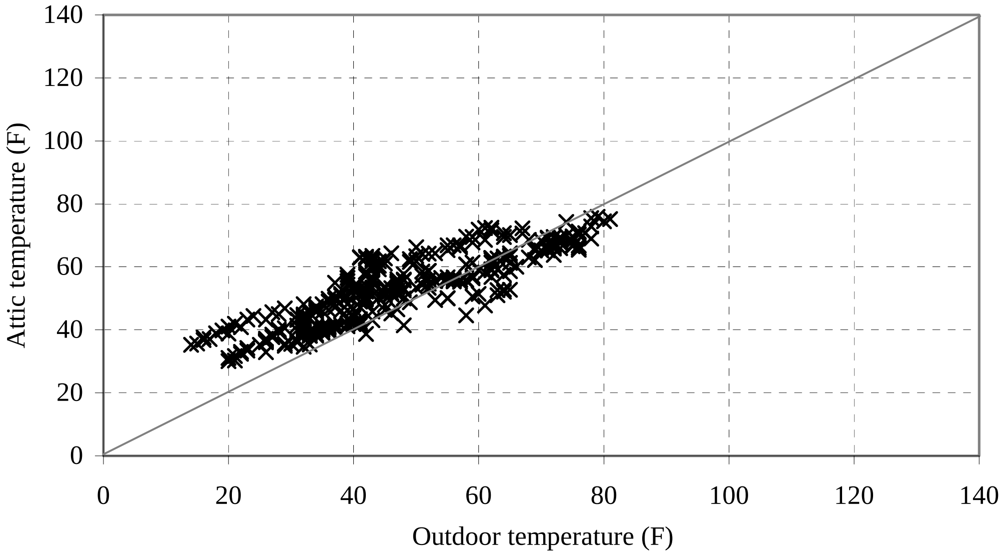


Figure 4.12 – Simulated attic space temperatures from DOE-2 simulation with FLOOR-WEIGHT = 70 vs. Houston TMY2 outdoor temperature during the selected period in heating season (January 1st to 15th, 1999).

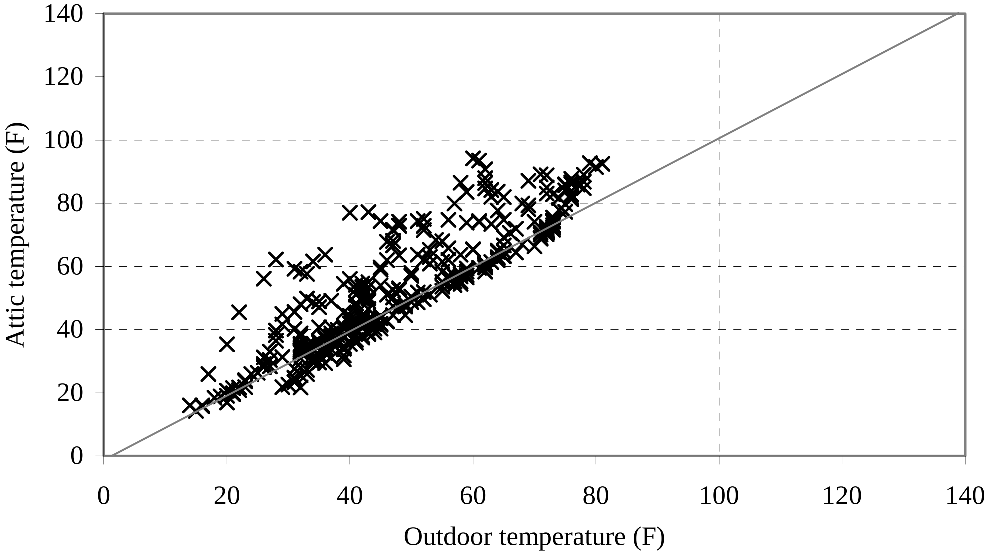


Figure 4.13 – Simulated attic space temperature from DOE-2 simulation with FLOOR-WEIGHT = 0 vs. Houston TMY2 outdoor temperature during the selected period in heating season (January 1st to 15th, 1999).

In calibrating the residence space temperature, the results from DOE-2 simulation were compared with the measured temperature profiles from the case study site data. Interior temperatures of the case study site were measured at the air-conditioner return temperature, and approximately indicate the thermostat set points in the space. Figure 4.14 shows the measured residence space temperature of the case study site vs. outdoor temperature. The graph suggests that the thermostat was set between 60° – 80°F during the year. The results of indoor temperature from DOE-2 basecase simulations with space FLOOR-WEIGHT = 70 and 0 (using custom weighting factors) were compared with the temperature data from the case study site. Figure 4.15 and Figure 4.16 present the DOE-2 residence temperature vs. outdoor temperature from the Houston TMY2 weather file, simulating with space FLOOR-WEIGHT = 70, and space FLOOR-WEIGHT = 0 respectively.

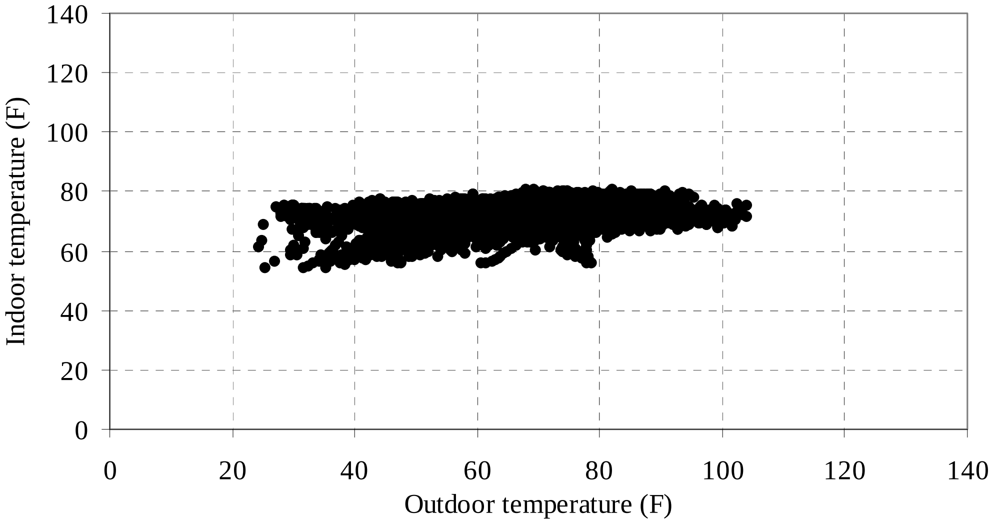


Figure 4.14 – Measured indoor space temperatures from the case study site vs. outdoor temperatures. The data were from the measurements at the case study site during the period from January to December 1999.

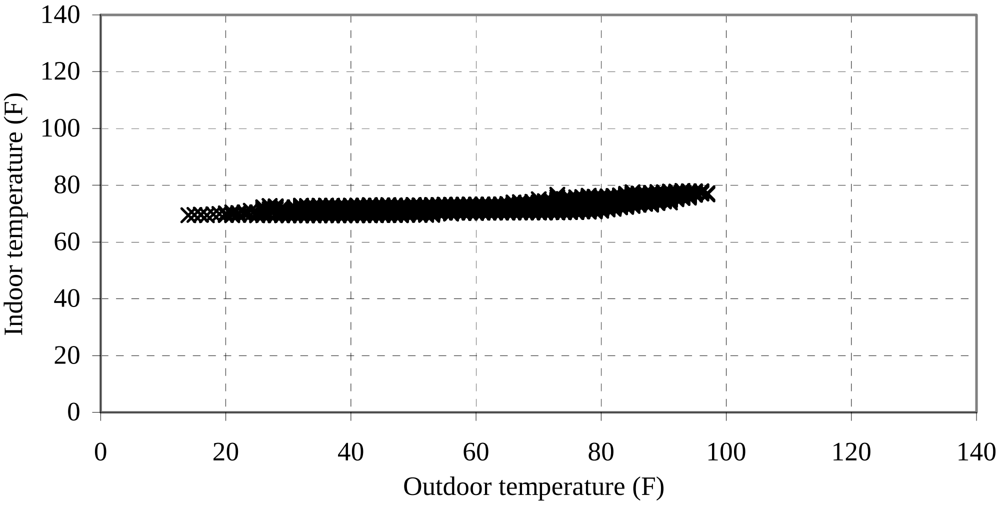


Figure 4.15 – Indoor space temperatures from the DOE-2 simulation with space FLOOR-WEIGHT = 70 vs. TMY2 (Houston) outdoor temperature. The attic F-W = 0.

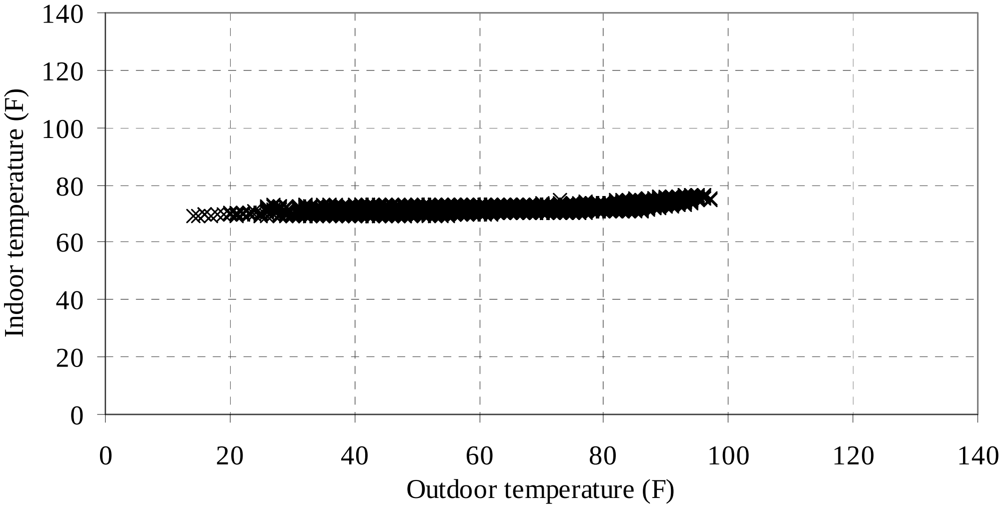


Figure 4.16 – Indoor space temperatures from the DOE-2 simulation with space FLOOR-WEIGHT = 0 vs. TMY2 (Houston) outdoor temperature. The attic F-W = 0.

When one compares the measured data against the simulated data, it is clear that the results show very little discrepancy between these two simulations (i.e., F-W = 70 vs. F-W = 0). To some extent, this is explained by the fact that these temperatures are a result of the thermostat setting in the DOE-2 SYSTEMS input file, and therefore indicate how well the choice of thermostat setting matches the actual condition. The results from the energy calibration, which are discussed in the next section, discuss the impact of custom weighting factors in the space FLOOR-WEIGHT setting for the DOE-2 simulations.

Figure 4.17 and Figure 4.18 present the residence space temperature plots of DOE-2 (F-W = 0 for both attic and residence spaces) and the case study site during the 2-week periods in cooling and heating seasons. The plots show the comparison of indoor temperatures between the case study site and DOE-2 simulation. The results from the temperature calibrations suggested the use of custom weighting factors in both attic and residence space FLOOR-WEIGHT settings for DOE-2 simulating the basecase model in this study.

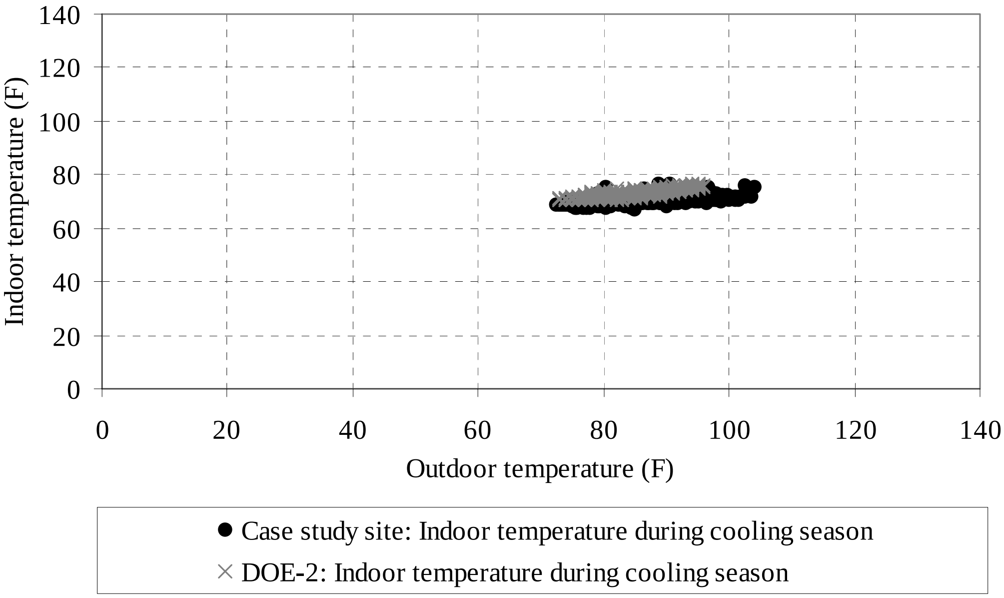


Figure 4.17 – Interior space temperatures during the cooling season from the case study site vs. measured outdoor temperature and DOE-2 simulation vs. TMY2 outdoor temperature. The cooling season was the period from August 18 to September 2, 1999.

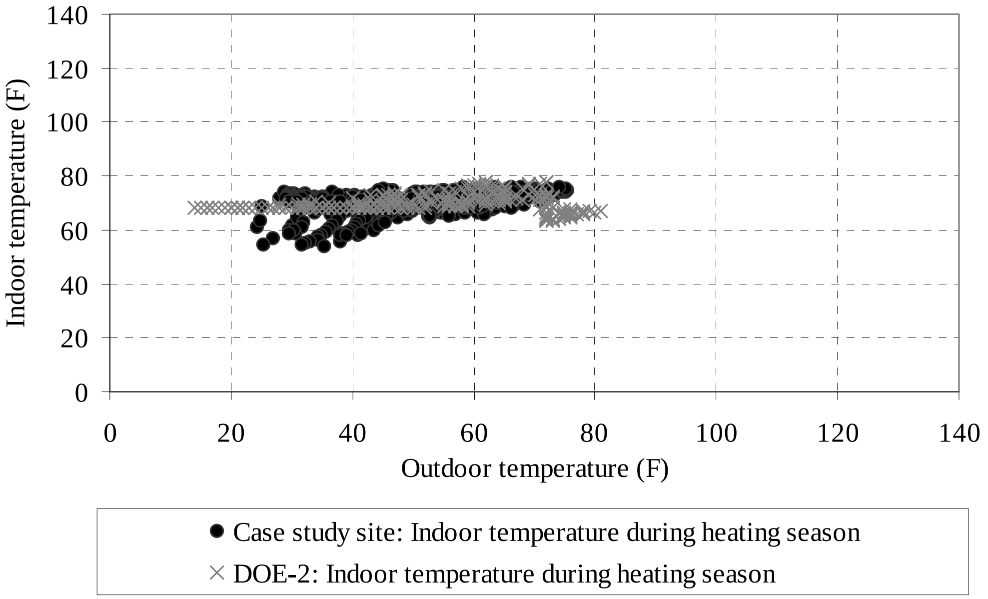


Figure 4.18 – Interior space temperature during the heating season from the case study site vs. measured outdoor temperature and DOE-2 simulation vs. TMY2 outdoor temperature. The heating season was the period from January 1 to 15, 1999.

4.1.2.2. Monthly energy use calibration

To accomplish the final calibration, selected variables in the DOE-2 input files were adjusted. The adjustments were run in DOE-2 until the simulated monthly energy use best matched the actual data. In this study, two of the most effective variables adjusted in DOE-2 simulations were the FLOOR-WEIGHT settings and the ground temperatures. The results of the monthly energy use comparisons sought to minimize the difference between the simulated and measured monthly electricity and natural gas uses.

Regarding the average monthly electricity use, Figure 4.19A and Figure 4.19B show the results of the monthly electricity use comparison between the case study site data and DOE-2 simulations with space FLOOR-WEIGHT settings. The graph shows the results in the unit of monthly kWh/day to avoid problems associated with different monthly periods. The study found that the use of the medium construction FLOOR-WEIGHT setting (i.e., FLOOR-WEIGHT = 70) over-estimated the monthly electricity uses, compared to the use of custom weighting factors.

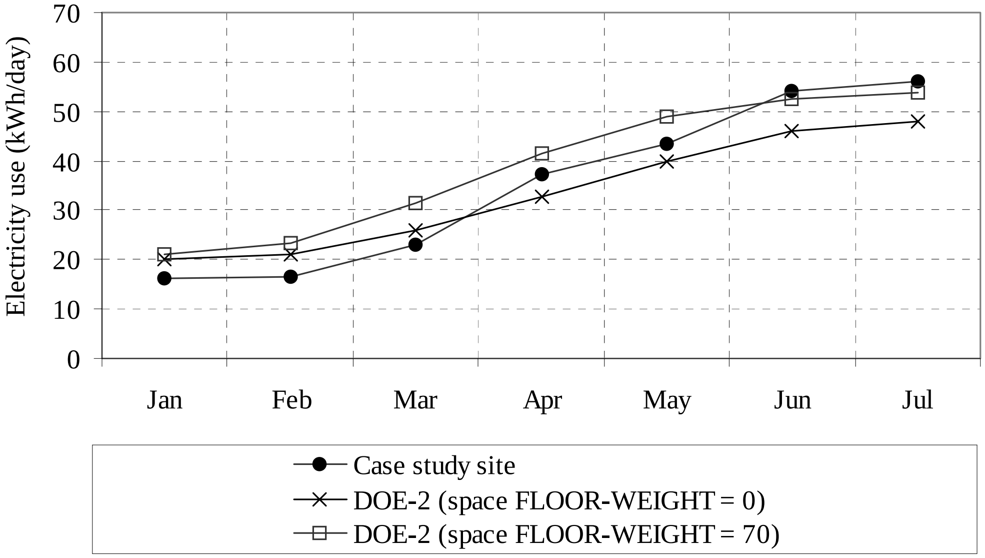


Figure 4.19A – Measured monthly electricity use and simulated DOE-2 energy use with space FLOOR-WEIGHT settings. The case study site data were obtained from the 15-minute measurements at the case study site.

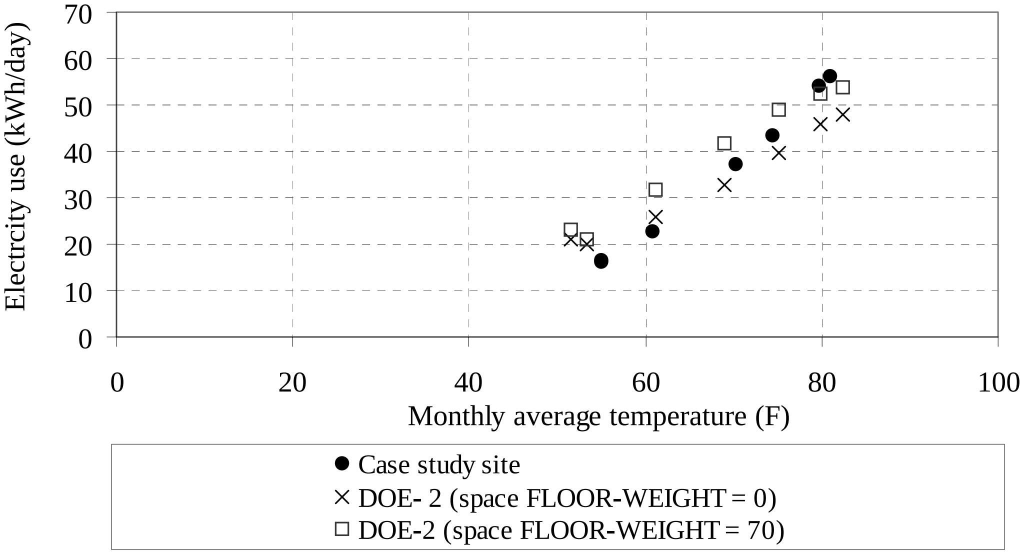


Figure 4.19B – Monthly electricity use from DOE-2 simulation with space FLOOR-WEIGHT settings vs. average outdoor temperature.

In order to analyze the natural gas use, results from the stuDOE-2 simulations using different FLOOR-WEIGHT settings were compared against the monthly Btu/day for the period of January to July 1999. Figure 4.20A and Figure 4.20B present the results of monthly natural gas use resulting from space FLOOR-WEIGHT variables input in DOE-2. In these figures, it can be seen for the first six months of 1999. It could be seen that the use of different FLOOR-WEIGHT settings produced little effect on the monthly natural gas use.

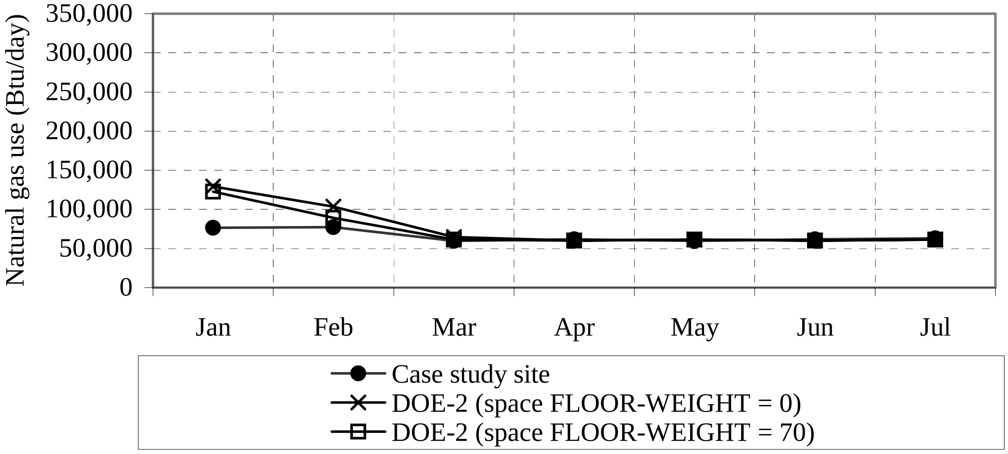


Figure 4.20A – Monthly natural gas use from DOE-2 simulation with space FLOOR-WEIGHT settings. The DOE-2 simulations used attic F-W = 0, with different F-W settings for residence space.

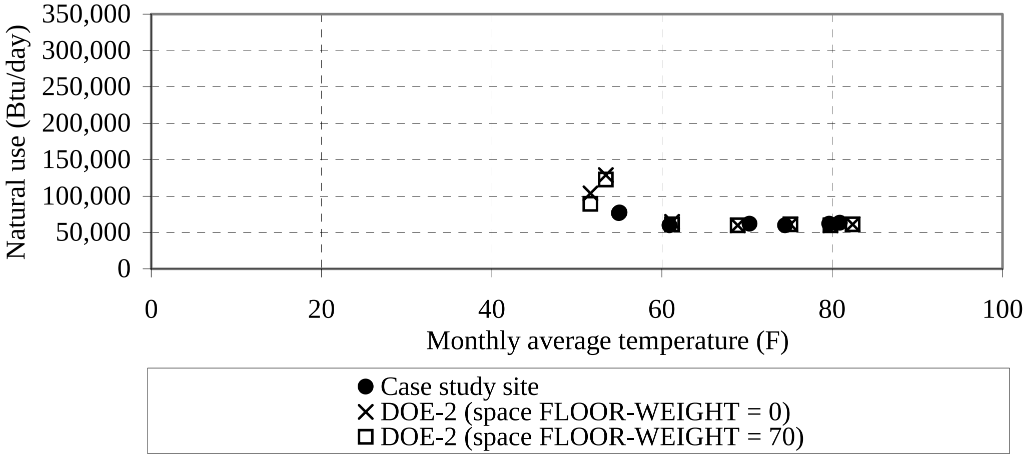


Figure 4.20B – Monthly natural gas use from DOE-2 simulation with space FLOOR-WEIGHT settings vs. average outdoor temperature.

4.1.3. Calibration with Ground Temperature

Kusuda and Achenbach (1965) conducted the study on the analysis of earth temperatures and the calculations of thermal diffusivity at selected stations in the United States. Their study developed methods regarding the analyses of thermal diffusivity of the earth and the calculation of earth temperatures, including the correlation of earth, air and ground water temperatures. Their study provided tabulated data of the monthly average earth temperatures for different locations throughout the United States, which could be served as a general guide in estimating earth temperatures in the vicinities of those selected stations. However, the use of data from the selected earth temperature stations might not represent the earth temperatures of other sites in the near vicinity due to various effects including differences in air temperature, humidity, solar radiation, soil composition, and other pertinent environmental factors. Also, Kusada and Achenbach's study only considered the base ground temperature at a depth of which did not include the effect of the building itself. DOE-2 uses the Kusada – Achenbach algorithm to generate ground temperatures at sites where ground temperatures are not available.

Figure 4.21 shows the large variations in the ground temperatures measured on-site versus the temperatures reported by DOE-2 for the Houston TMY2 site. The plot shows different trends of ground temperatures between these 2 sources, especially in the period from January to June. Such discrepancy caused a very large deviation in the simulation outcomes. This study found that DOE-2 simulations with the different sources of ground temperature (the case study site and the Houston TMY2 weather tape) made a significant difference in both monthly electricity and natural gas uses. The simulating results shown in Figure 4.22A and Figure 4.22B are monthly electricity use resulting from the DOE-2 simulations with the different ground temperatures. Both simulations used the F-W = 0 or custom weighting factors.

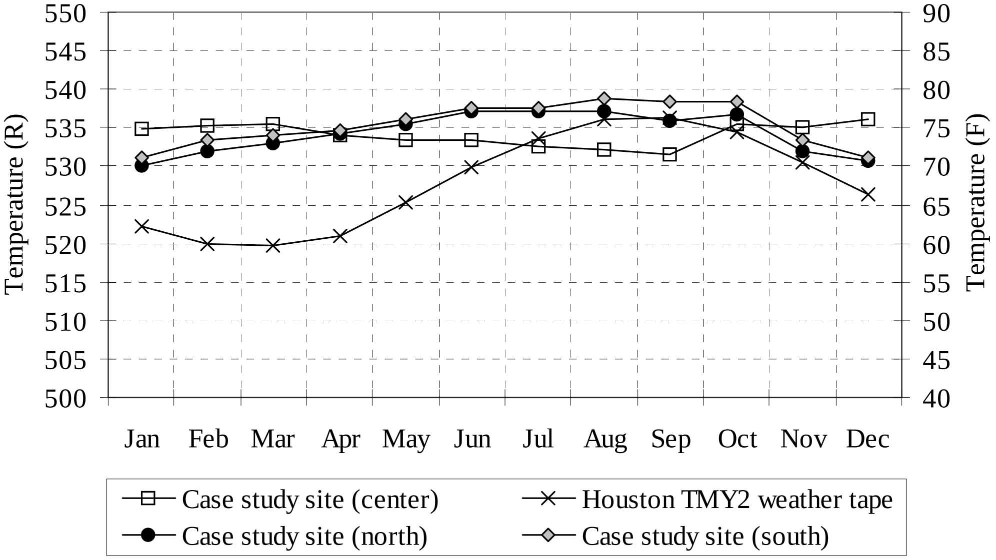


Figure 4.21 – Monthly average ground temperature from the case study site and the Houston TMY2 weather tape.

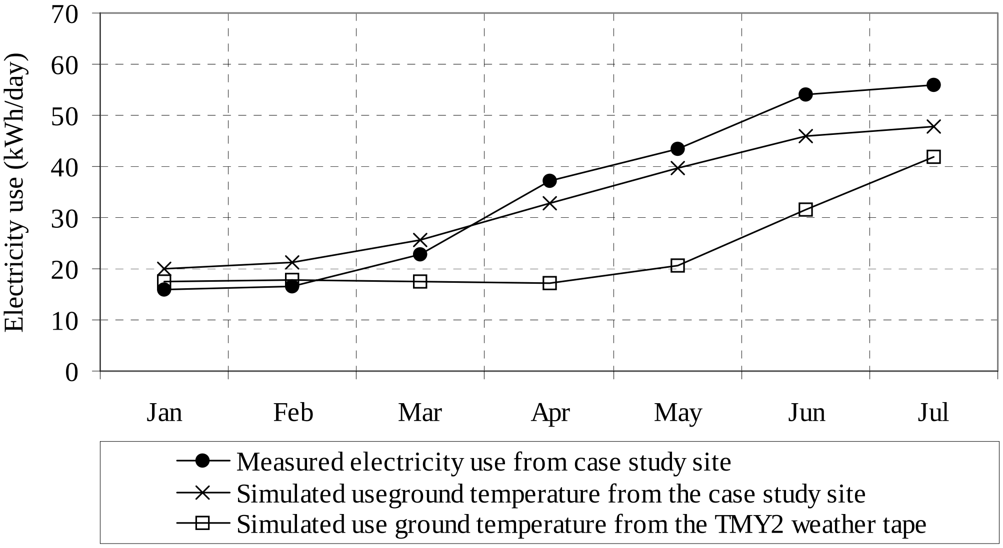


Figure 4.22A – Monthly average-daily electricity use from DOE-2 simulation with ground temperatures from the case study site and the Houston TMY2 weather tape versus measured electricity use from the case study site.

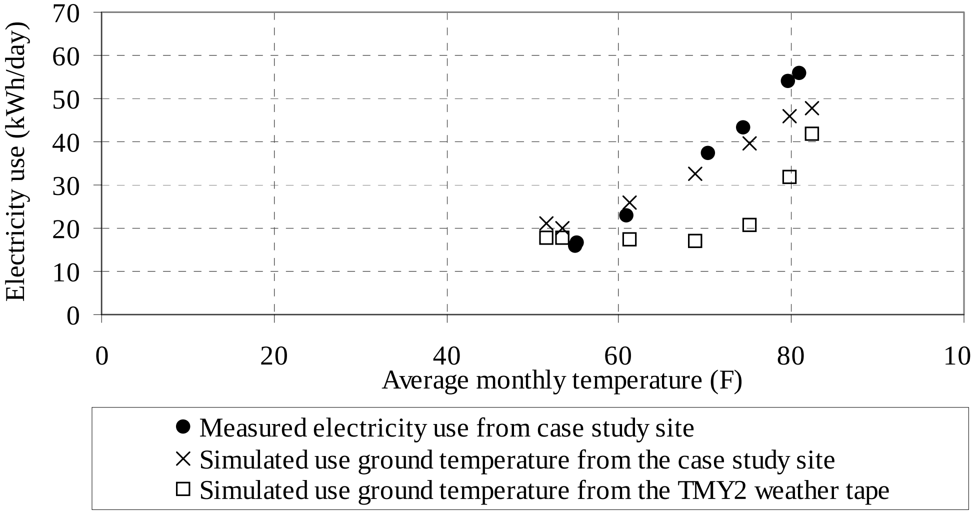


Figure 4.22B – Monthly average-daily electricity use versus average monthly temperatures (measured vs. DOE-2 simulated).

The plot of monthly natural gas use also indicated a noticeable deviation from using these two variables. The results clearly indicated an overestimation of monthly natural gas use of the DOE-2 simulation with the ground temperatures from the TMY2 weather tape. Figure 4.23A and Figure 4.23B present the results of the simulations.

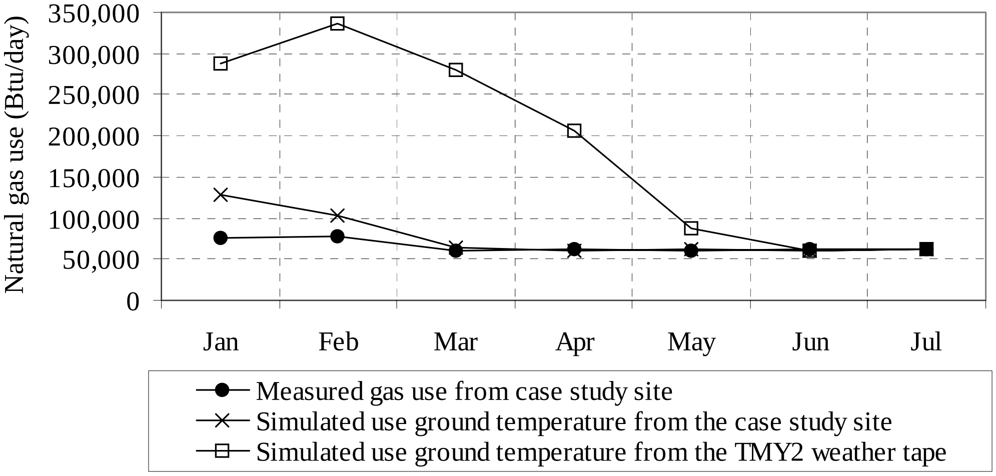


Figure 4.23A – Monthly average-daily natural gas use from DOE-2 simulations with ground temperatures from the case study site and the Houston TMY2 weather tape versus measured gas use from the case study site.

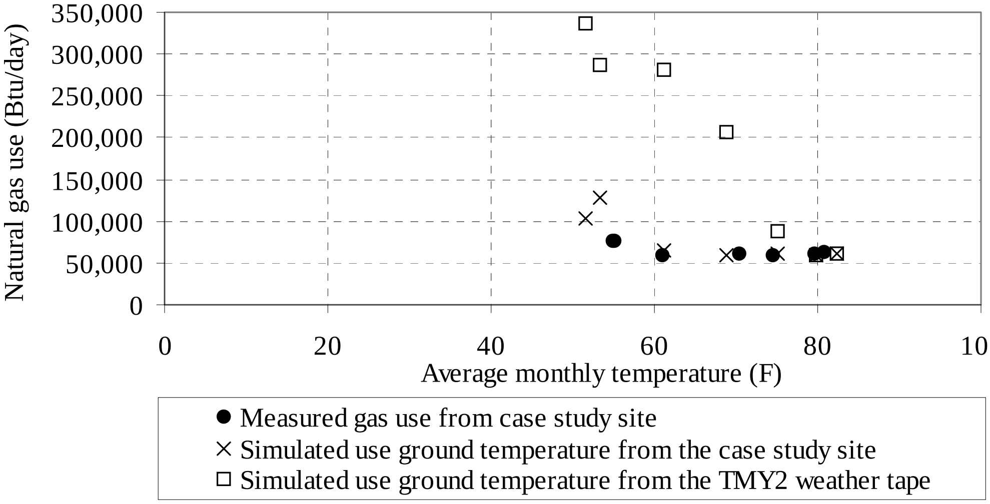


Figure 4.23B – Monthly average-daily natural gas use versus average monthly temperatures (measured vs. DOE-2 simulated).

4.1.4. Summary of Calibration

4.1.4.1. Monthly energy use calibration

The case study house's monthly electricity data were derived from the measured monthly hourly data, while the natural gas data were obtained from the monthly utility bills. These data were collected for the period of January to July 1999 and were used to calibrate the DOE-2 simulation. The calibration in this study was based on the standard statistical measures of the coefficient of variation of the root-mean square error, CV (RMSE) and mean bias error , MBE, which was defined by Kreider and Haberl (1994).

Coefficient of variation, CV (RMSE):

$$\mathrm{CV} = \frac{\sqrt{\dfrac{\sum\limits_{i=1}^{n} (y_{pred,i} - y_{data,i})^2}{n}}}{\overline{y}_{data}}$$

Mean bias error (MBE):

$$MBE = \frac{\sum_{i=1}^{n} (y_{pred,i} - y_{data,i})}{n \times \overline{y}_{data}}$$

Where

$y_{data,i}$ = data value of the dependent variable corresponding to a particular set of values of the independent variables,

$y_{pred,i}$ = predicted dependent variable value for the same set of independent variables above (these values are the predictions by the model),

$\overline{y}_{data}$ = mean value of the dependent-variable in the data set, and

n = number of records of data in the data set.

From the previous discussions on the calibration efforts, it was decided to use attic and space FLOOR-WEIGHT using custom weight factors (i.e., F-W = 0), and the use of ground temperature from the case study site data instead of DOE-2 TMY2 weather file. The model calibration and the evaluation of variables used in DOE-2 simulation for each run were analyzed based on the standard statistical measures of the CV (RMSE) and mean bias error (MBE) as previously stated. Table 4.3 and Figure 4.24 present the total energy use summary of the case study building data and each DOE-2 run.

Table 4.3 – Total energy use from the case study site data and different DOE-2 runs.

Energy use (MBtu)	**Run # 1**	**Run # 2**	**Run # 3**	**Run # 4**	**Run # 5**	**Run # 6**	**Case study site**
Electricity	53.2	38.7	40.1	40.5	49.4	42.2	43.8
Natural gas	21.1	33.3	24.0	25.1	26.2	27.5	24.7
Total	74.3	72.0	64.1	65.6	75.6	69.7	68.5

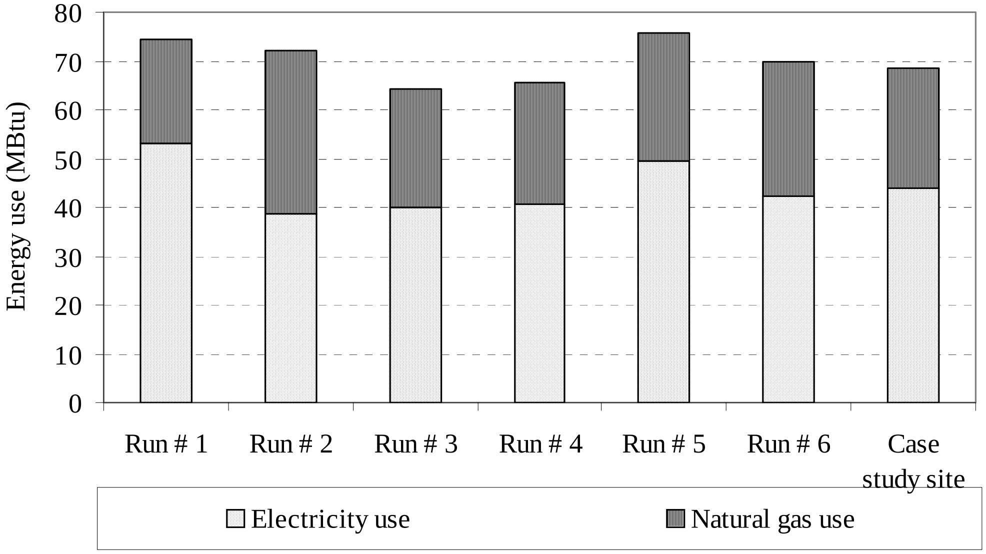


Figure 4.24 – Total energy use from the case study site and different DOE-2 runs (from the BEPS report).

Table 4.4 provides the monthly average outdoor temperature and energy use data collected from the case study site. The data shown in table were obtained from the installed data logger in the studied building. The measured 15-minute data were converted into hourly data and then summarized and averaged into monthly data. The electricity use reached its peak in August when the average outdoor temperature was 85.5°F, indicating the high usage of air conditioning during that time. The natural gas use included heating domestic hot water and kitchen utilities in the house. The usage was highest in December as the average outdoor temperature was as low as 53.6°F.

Table 4.4 – Average outdoor temperature and monthly summary of energy use from the case study site.

Year 1999	Measured data and energy use from the case study site					
Month	Average outdoor Temperature (F)	Total electrictiy use		Electricity use (kWh/day)	Total N.G. use	Natural gas use (kBtu/day)
		(MBtu)	(kWh)		(MBtu)	
January	55.0	1.7	498.2	16.1	2.4	76.4
February	55.0	1.6	463.1	16.5	2.2	77.3
March	60.9	2.4	710.7	22.9	1.9	59.8
April	70.3	3.8	1,118.9	37.3	1.9	61.8
May	74.5	4.6	1,341.9	43.3	1.9	59.8
June	79.7	5.5	1,619.9	54.0	1.9	61.8
July	80.9	5.9	1,737.8	56.1	2.0	63.1
August	85.5	6.8	2,000.9	64.5	2.0	63.1
September	81.0	5.6	1,641.7	54.7	1.9	61.8
October	65.3	2.1	621.4	20.0	2.2	69.8
November	61.3	1.8	519.3	17.3	2.4	79.0
December	53.6	1.9	560.2	18.1	2.5	79.7
Total		43.8	12,834.2		24.7	

4.1.4.2. Summary of calibration results

The calibration based on CV (RMSE) and MBE statistical standard was studied as the variables were adjusted in each DOE-2 run. The objective was to match the total energy, total electricity and natural gas use with the case study site data. Table 4.5 provides a summary of the input file used in the first DOE-2 simulation of the basecase single zone model with an attic space. Tables 4.6 to Table 4.8 explain the variable adjustment for each DOE-2 simulation and the result of energy use from each run.

Table 4.5 – Summary of DOE-2 input file description for the first simulation of the single-zone basecase model.

LOADS		
Subcommand	**Residence Zone**	**Source**
Building Location		
AZIMUTH	225	Building orientation
GROUND-T	Default	Houston TMY2 weather tape
Material and Construction		
Building Geometry	No polygon input	
Window description	No frame input	
SPACE-CONDITIONS		
Occupancy schedule	1	Estimated of all day occupancy
Lighting schedule	WD and WEH schedule	Estimation
Equipment schedule	WD and WEH schedule	Estimation
AIR-CHANGES/HR	0.32	Kootin-Sanwu (2003)
FLOOR-WEIGHT	0	Custom weighting factors
SYSTEMS		
ZONE-CONTROL	**Residence Zone**	**Source**
DESIGN-HEAT-T	73	Estimated from measured data
DESIGN-COOL-T	68	Estimated from measured data
THERMOSTAT-TYPE	Two-position	The Habitat House specification
SYSTEM-CONTROL		
MAX-SUPPLY-T	130	Estimated from measured data
MIN-SUPPLY-T	50	Estimated from measured data
PLANT		
PLANT-EQUIPMENT	**Residence Zone**	**Source**
DHW-SIZE	0.034	Estimation

Table 4.6 – RMSE and NMBE of different DOE-2 runs for total energy use calibration (i.e., natural gas plus electricity use).

Run #	Comment	Total Energy Use (MBtu)	CV(RMSE) (%)	MBE (%)
Case study site data	Electricity uses from Hourly data, and Natural gas uses from utilities bill	68.51		
Run # 1	- The first run with 2 zones: space and attic	74.50	28.12	8.81
Run # 2	- Input polygon in the attic space - Input lighting and equipment schedule based on the hourly data - Change Design-Cool-T = 70 F - Increase DHW size to match natural gas use	72.00	36.87	5.17
Run # 3	- Correct lighting and equipment schedule - Change Air-Change/hour = 0.2 (Space) - Input Heating and Cooling temperature schedule based on the hourly data - Input Heat-off and Cool-off schedule - Input glass type code and frame characteristics - Set Design-Heat-T = 73, and Design-Cool-T = 68	64.38	15.39	-6.03
Run # 4	- Input ground temperature from the hourly data (N) - Correct occupancy scheule - Use custom weighing factor for attic - Change Air-Change/hour = 0.32 (Space) - Change CFM/SqFt. in systems = 0.8 - Change azimuth from 180 to 225 degree	65.60	16.46	-4.25
Run # 5	- Change the maximum-supply-T= 130 F, the minimum-supply-T = 50 F - Turn off cooling and heating capacity in systems - Input cooling EIR and furnace HIR - Take off Heat-off and Cool-off schedule	75.60	20.98	10.64
Run # 6	- Set space Floor-Weight = 0	69.70	21.48	1.87

Table 4.7 – RMSE and NMBE of different DOE-2 runs for total natural gas use calibration.

Run #	Comment	Total Natural gas Use (MBtu)	CV(RMSE) (%)	MBE (%)
Case study site data	Electricity uses from Hourly data, and Natural gas uses from utilities bill	24.72		
Run # 1	- The first run with 2 zones: space and attic	21.30	31.77	-13.83
Run # 2	- Input polygon in the attic space - Input lighting and equipment schedule based on the hourly data - Change Design-Cool-T = 70 F - Increase DHW size to match natural gas use	33.30	77.76	34.71
Run # 3	- Correct lighting and equipment schedule - Change Air-Change/hour = 0.2 (Space) - Input Heating and Cooling temperature schedule based on the hourly data - Input Heat-off and Cool-off schedule - Input glass type code and frame characteristics - Set Design-Heat-T = 73, and Design-Cool-T = 68	24.20	16.33	-2.10
Run # 4	- Input ground temperature from the hourly data (N) - Correct occupancy scheule - Use custom weighing factor for attic - Change Air-Change/hour = 0.32 (Space) - Change CFM/SqFt. in systems = 0.8 - Change azimuth from 180 to 225 degree	25.10	14.87	1.54
Run # 5	- Change the maximum-supply-T= 130 F, the minimum-supply-T = 50 F - Turn off cooling and heating capacity in systems - Input cooling EIR and furnace HIR - Take off Heat-off and Cool-off schedule	26.40	24.89	6.80
Run # 6	- Set space Floor-Weight = 0	27.60	30.24	11.65

Table 4.8 – RMSE and NMBE of different DOE-2 runs for total electricity use calibration.

Run #	Comment	Total Electricity Use (kWh)	CV(RMSE) (%)	MBE (%)
Case study site data	Electricity uses from Hourly data, and Natural gas uses from utilities bill	12,834.18		
Run # 1	- The first run with 2 zones: space and attic	15,606.00	41.67	21.60
Run # 2	- Input polygon in the attic space - Input lighting and equipment schedule based on the hourly data - Change Design-Cool-T = 70 F - Increase DHW size to match natural gas use	11,358.00	32.97	-11.50
Run # 3	- Correct lighting and equipment schedule - Change Air-Change/hour = 0.2 (Space) - Input Heating and Cooling temperature schedule based on the hourly data - Input Heat-off and Cool-off schedule - Input glass type code and frame characteristics - Set Design-Heat-T = 73, and Design-Cool-T = 68	11,776.00	23.57	-8.25
Run # 4	- Input ground temperature from the hourly data (N) - Correct occupancy scheule - Use custom weighing factor for attic - Change Air-Change/hour = 0.32 (Space) - Change CFM/SqFt. in systems = 0.8 - Change azimuth from 180 to 225 degree	11,870.00	23.94	-7.51
Run # 5	- Change the maximum-supply-T= 130 F, the minimum-supply-T = 50 F - Turn off cooling and heating capacity in systems - Input cooling EIR and furnace HIR - Take off Heat-off and Cool-off schedule	14,478.00	29.70	12.81
Run # 6	- Set space Floor-Weight = 0	12,365.00	27.06	-3.66

The summary of Table 4.6 – Table 4.8 was presented in Figure 4.25A to Figure 4.25C.

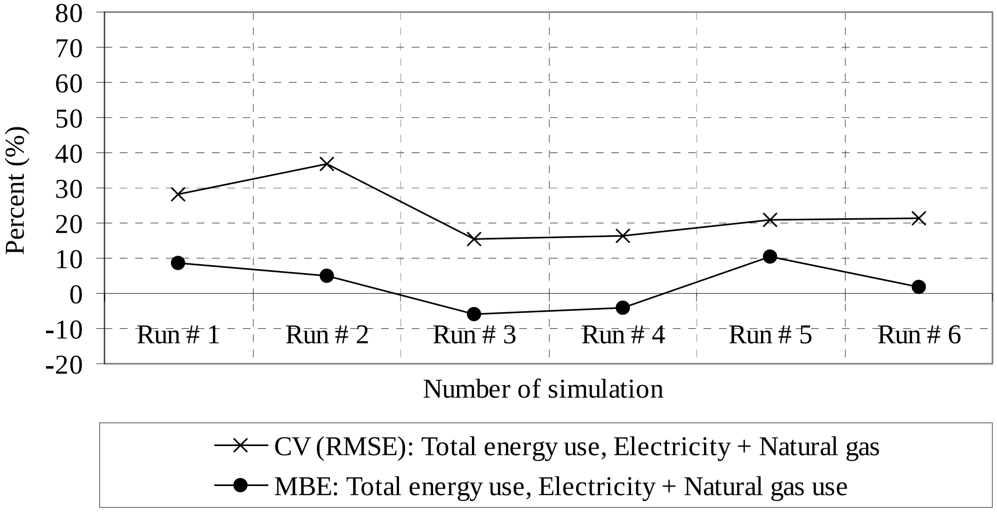


Figure 4.25A – CV (RMSE) and NMBE of different DOE-2 runs for total energy use calibration.

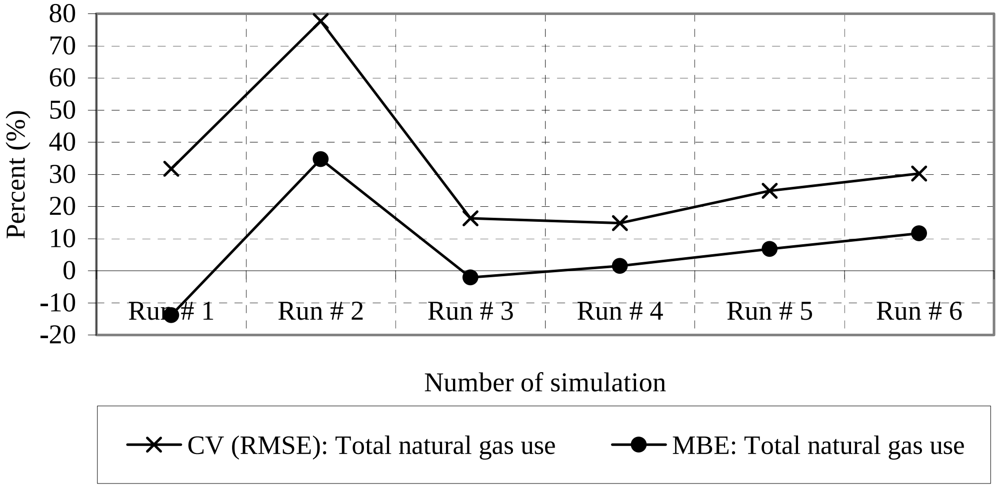


Figure 4.25B – CV (RMSE) and NMBE of different DOE-2 runs for total natural gas use calibration.

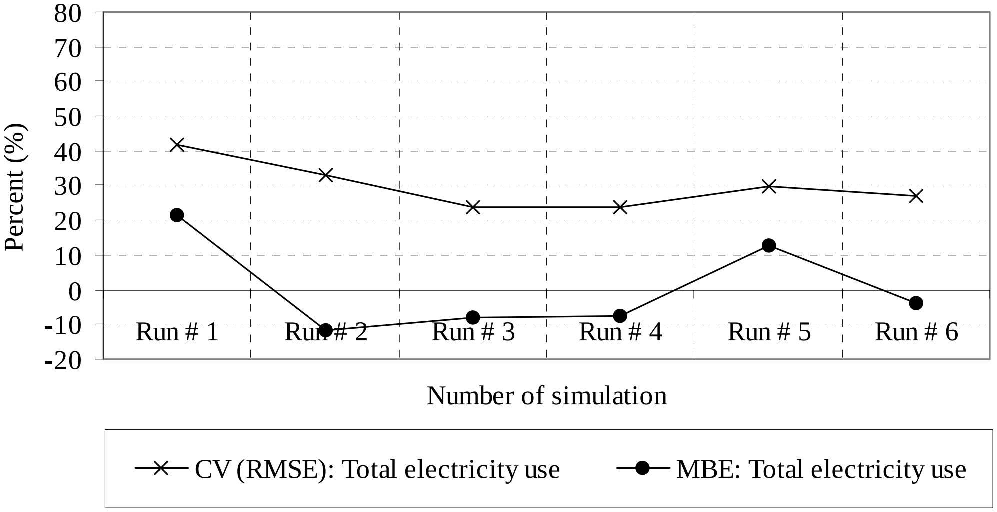


Figure 4.25C – CV (RMSE) and NMBE of different DOE-2 runs for total electricity use calibration.

As can be seen in Tables 4.6 – 4.8 and Figures 4.25A – 4.25C, the first three runs produced significant improvements in the CV (RMSE). However, run # 2 and run # 3 had varied effects on the CV (RMSE) of the total electricity and natural gas uses. In run # 2, the new equipment schedule improved the electricity CV (RMSE), however, the new DHW schedule increased the gas CV (RMSE). In run # 3, all three CV (RMSE) were improved. Run # 4 – 6 had modest improvements to the calibration. Even though the CV (RMSE) of run # 3 was the lowest, Run # 6 was chosen as the calibrated simulation since this simulation included the custom weighting factors as well as improvements made in runs # 4 and # 5.

Once the DOE-2 model was calibrated, it was then used to represent the case study building. The basecase simulation results were then used to develop other models with the proposed daylighting design. An analysis of DOE-2 daylighting simulation and the comparative study of the proposed shading systems are discussed in Section 4.3 of this chapter. In the next section, the analysis of the physical scale models of the daylighting design is discussed as well as DOE-2's calculations of the Daylight Factor.

4.2. RESULTS OF THE USE OF THE PHYSICAL SCALE MODEL AND THE DAYLIGHT FACTOR EVALUATION

This section discusses results from the study of the proposed shadings, regarding the evaluation of their shading properties and the Daylight Factor (DF) obtained from the measurements of the physical scale model and from the DOE-2 daylighting simulations. The shading analysis was also studied with the SOLRPATH program from which proposed designs were partially derived. Results from the analysis using the SOLRPATH program is discussed in Section 4.2.1.

The evaluation of the proposed daylighting designs included 4 primary tasks: 1) the shading evaluation, 2) the examination of Daylight Factors from the physical scale model measurements, 3) Daylight Factors from the DOE-2 daylighting simulations, and 4) the comparison of Daylight Factors between the scale model measurements and the DOE-2 simulations.

In the first task, the proposed shadings were evaluated regarding their ability to block the solar beam radiation from the windows during the cooling periods. The tools used in this evaluation also included photographing of the physical scale model on the heliodon table under the Daylighting Sky Dome. Results from the evaluation are discussed in Section 4.2.2. of this chapter.

The evaluation of the interior illuminance of each of the proposed shadings, as proposed in the second task was conducted through a series of Daylight Factor measurements of physical scale models with each proposed device. The interior horizontal illuminance of each scale model was measured relative to the ambient horizontal illuminance under actual overcast sky conditions to obtain the Daylight Factors of a position that represented the windowsill height (2 feet from the floor level). Daylight Factors of the models with each proposed device were then evaluated and compared with the measured results of the basecase model. The discussion of results is presented in Section 4.2.3.

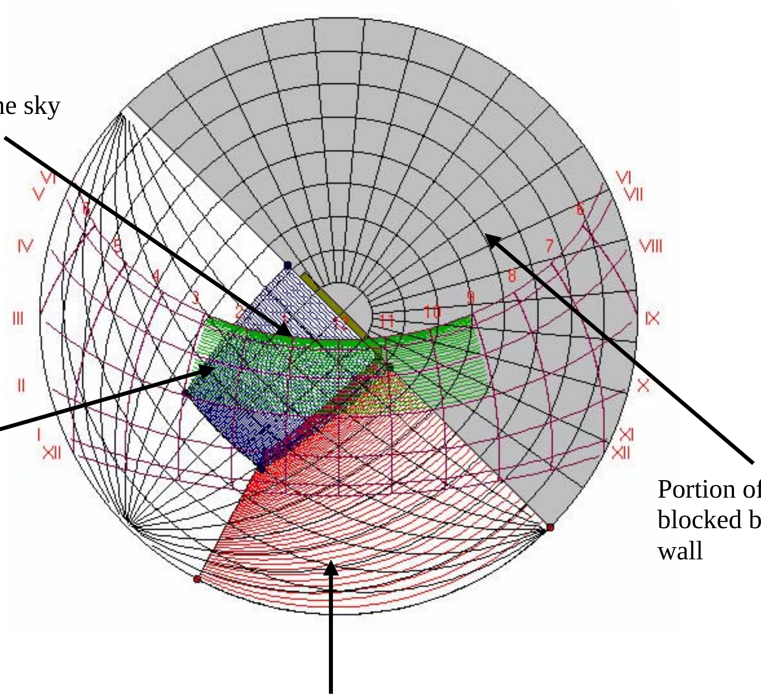
In the next task, the Daylight Factors of the basecase and the three proposed models were calculated using the DOE-2 daylighting simulation program. To accomplish this, the input file of the DOE-2 program was modified to include the proposed designs and the Daylight Factor calculated by DOE-2 for a point specified in the center of the room at a height of 2 feet in a horizontal position. Results of Daylight Factors from the simulations were evaluated and presented in Section 4.2.4.

Finally, Daylight Factors from the scale model measurements and from the DOE-2 daylighting simulations were compared against each other, and the relationship between these varying results was analyzed. The comparison is discussed in Section 4.2.5. Additional results from the preliminary qualitative analysis of shading options performed in the College of Architecture Artificial Sky Dome are discussed in Appendix D.

4.2.1. The Shading Design Analysis

The proposed shading designs were first analyzed and evaluated by using the SOLRPATH program. The program uses the concept of the sunpath diagram and shading masks to evaluate how effectively an exterior device provides shading on a window during the required period. Unfortunately, the application of shading on window, despite shielding the window from the penetration of solar beam radiation, can obstruct the distribution of daylight into building interior and therefore diminish space illuminance. Therefore, this study aimed at evaluating the proposed shading designs concerning their ability to shade the windows during the cooling periods and enhance or at least maintain the basecase interior illuminance.

The application of the proposed shadings on the case study building's windows included the windows facing southwest, southeast, and northwest. Each proposed application was configured in the SOLRPATH program and the shading analysis was calculated and evaluated. An example of graphical display of the SOLRPATH program illustrating the sun path diagram when calculating a shading is shown in Figure 4.26.



Portion of the sky blocked by overhang

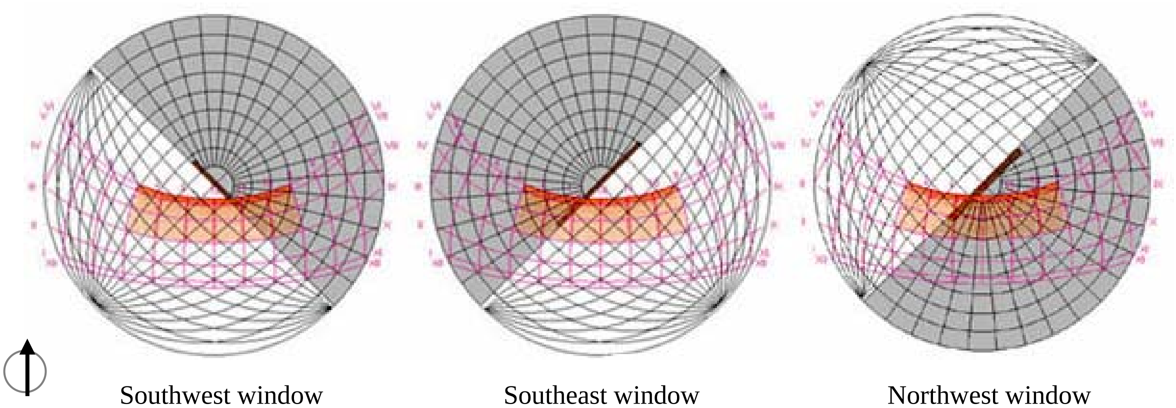
Shading objective = hours from 9 a.m. to 3 p.m. during the months of March - September

Portion of the sky blocked by vertical wall

Portion of the sky blocked by left-hand fin

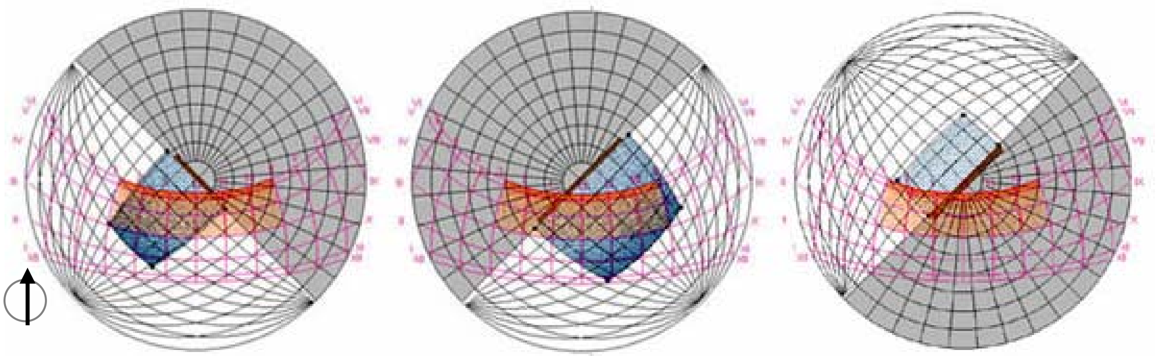
Figure 4.26 – Illustration of the sun path diagram displaying shading calculation in the SOLRPATH program.

Figures 4.27 illustrates the renderings of the SOLRPATH program for the studied windows (southwest southeast and northwest windows) of the basecase model, a model with a maximum 6-foot overhang, and a model with a maximum 6-foot overhang with a vertical fin.



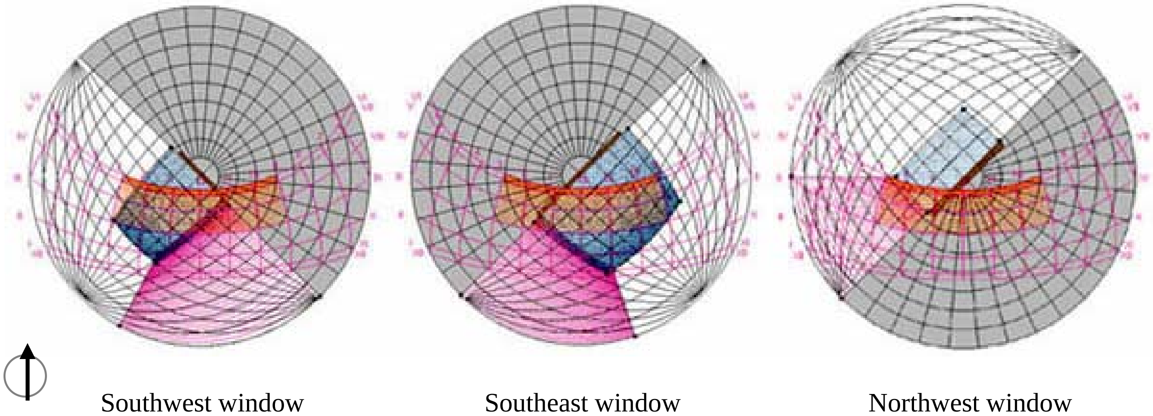
Southwest window Southeast window Northwest window

The basecase model



Southwest window Southeast window Northwest window

The model with a maximum 6-foot overhang



Southwest window Southeast window Northwest window

The model with a maximum 6-foot overhang with a vertical fin

Figure 4.27 – Illustrations of the shading diagram calculated in the SOLRPATH program for the southwest, southeast, and northwest windows of the studied models.

The SOLRPATH program provided a means to visually investigate and evaluate the capability of the proposed designs regarding their shading abilities. The configuration of the shading designs resulted from the SOLRPATH evaluations of each orientation. SOLRPATH program allows user to visually determine if a particular shading device is going to block the direct solar gain for a given combination of latitude, orientation, season, and time-of-day. The maximum 6-foot overhang with 4-foot vertical fin, as shown in Figure 4.27, were determined by SOLRPATH analysis to provide complete shading on the windows during the required periods. Although it is doubtful such a design would ever be recommended, it was analyzed, none-the-less to allow for a comparison to be made with the final design.

The three final shading designs were photographed with the heliodon table to confirm the SOLRPATH analysis. Results from this testing suggested a different placement of the vertical fin. For example, on the southwest windows, the analysis from the SOLRPATH program had suggested the fin to be placed on the southern side of the window. However, as shown in Figure 4.28 from Oh (2000), the intensity of solar radiation through a vertical window glazing was greater in the late afternoon than in the morning. Therefore, vertical fins were moved to the northern side of the southwest windows.

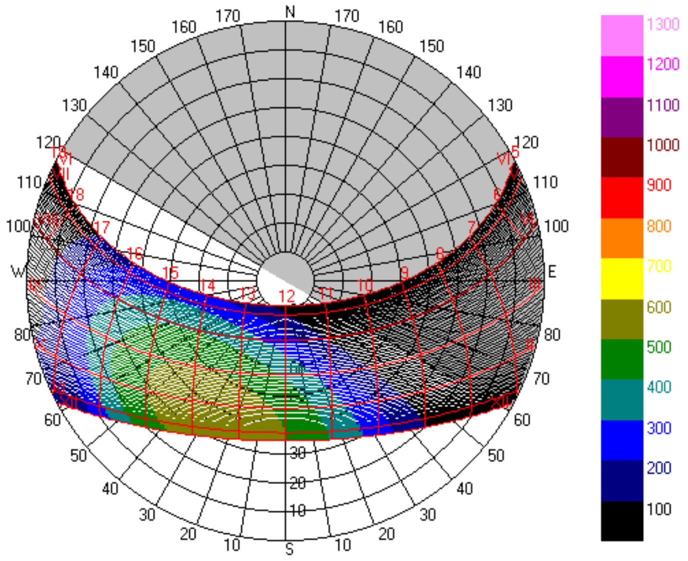


Figure 4.28 – Equidistant sunpath diagrams displaying the transmitted radiation through a vertical glazing. This figure was obtained from Oh (2000) under the permission of Kie Whan Oh.

The configuration of the proposed final design, the 18-inch combined lightshelf with the clerestory window, was then developed. The final design incorporated the property of exterior shading device and interior overhang with the use of high windows above the lightshelf to create daylighting system.

This study evaluates the three proposed designs with respect to their shading property and the contribution to enhancing interior illuminance, when compared to the basecase model. Results from the shading property evaluation performed under the artificial sky dome are discussed in the next section.

4.2.2. Shading Property Evaluation

Regarding the qualitative study, this research evaluated the proposed shadings in terms of their effectiveness in preventing the penetration of direct sunlight into space during the daytime. To accomplish the evaluation, photographs of the models were taken at 9:00 A.M., 12:00 noon, and 3:00 P.M. The experiment focused on 4 days that represented the seasonal altitudes of the sun. The seasonal days included vernal equinox (March 21), summer solstice (June 21), autumnal equinox (September 21), and winter solstice (December 21). To evaluate the proposed shadings, photographs at the proper time and season were compared. An effective design was assessed on its capability in blocking direct sunlight from entering a space and in offering a complete shade over the window during the required period. Figures 4.29 – 4.31 present the study of shading properties, focusing on vernal/autumnal equinox, and summer and winter solstices.

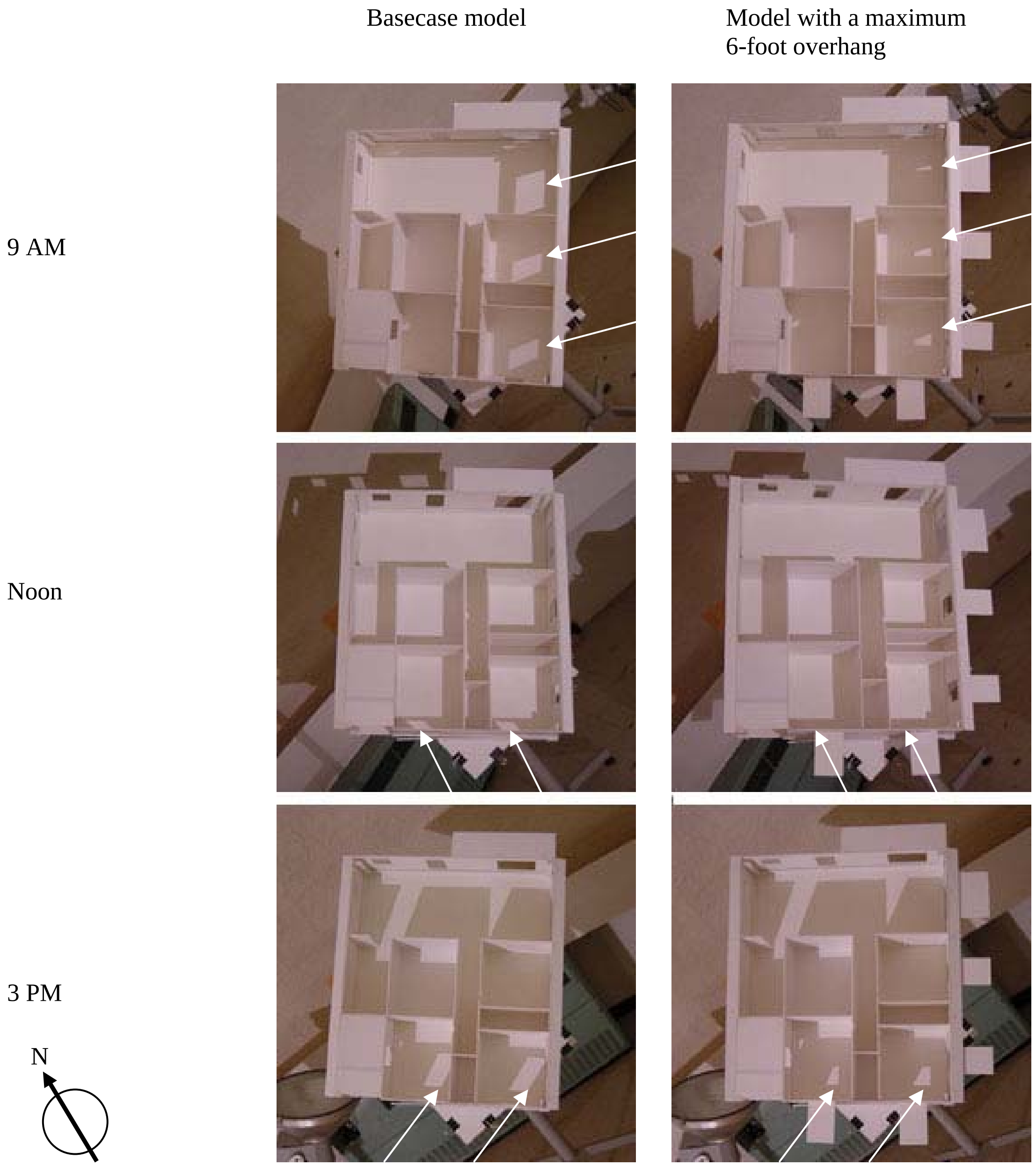


Figure 4.29 – The evaluation of shading on September/March 21. The photographs show a shading comparison between the basecase model and the model with a maximum 6-foot overhang during a fall/spring day. The experiments were conducted using the heliodon table set at 30° Latitude. The arrows indicate the direct solar radiation penetrating into the residence.

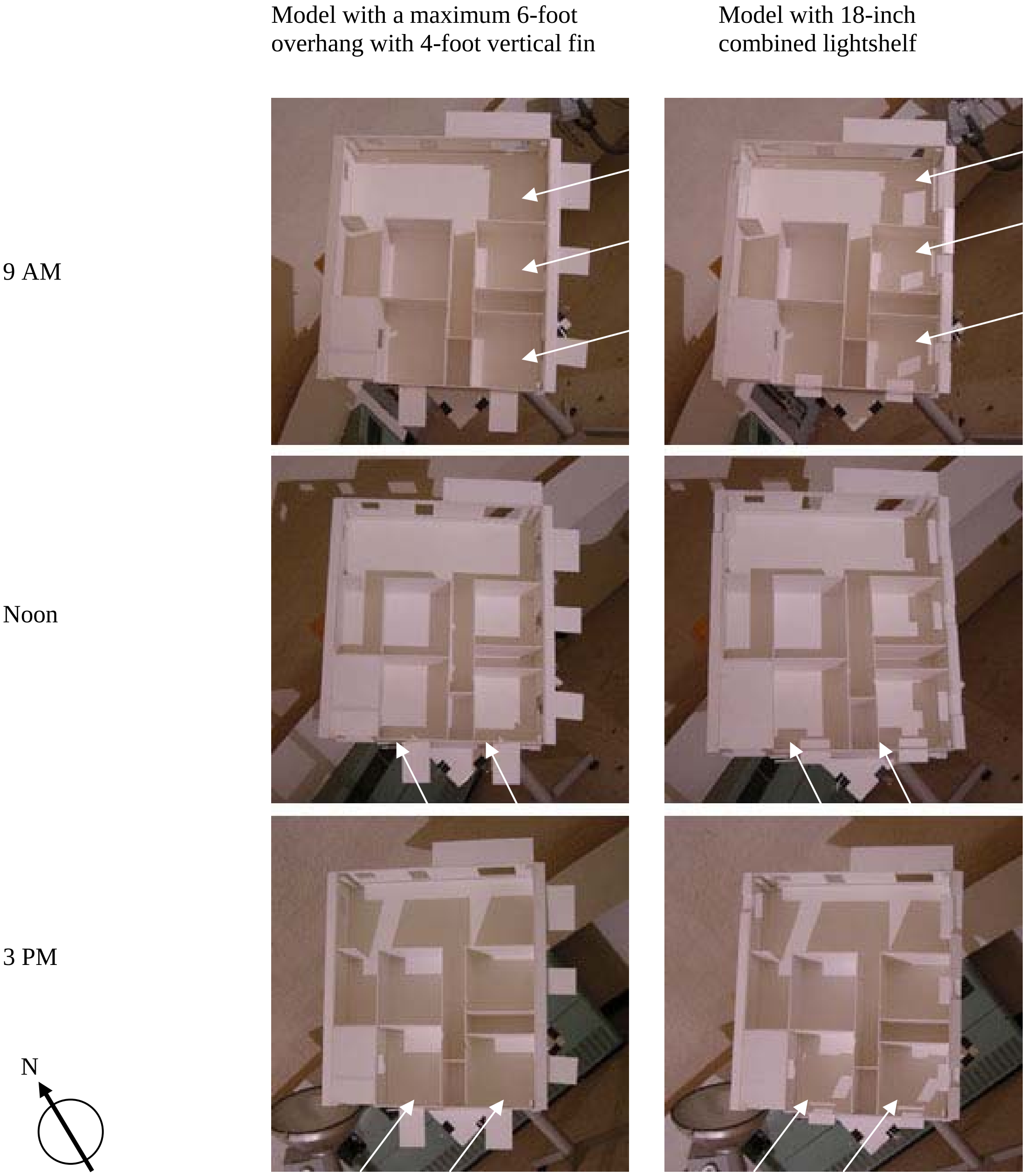


Figure 4.29 – Continued. The photographs present a shading comparison between the model with a maximum 6-foot overhang with 4-foot vertical fin and the model with 18-inch combined lightshelf (the final design) during a fall/spring day. The experiments were conducted using the heliodon table set at 30° Latitude. The arrows indicate the direct solar radiation penetrating into the residence.

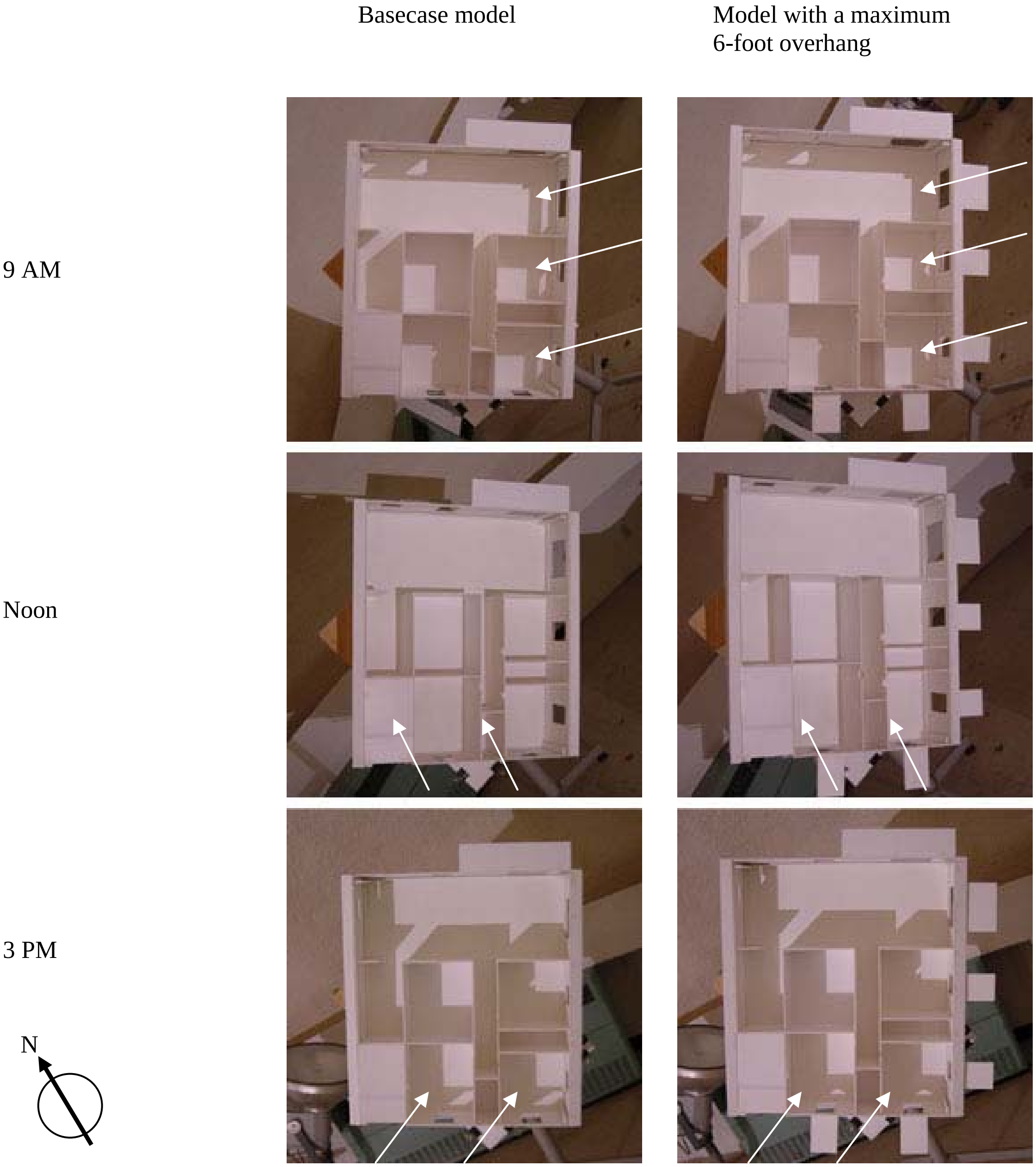


Figure 4.30 – The evaluation of shading on June 21. The photographs present a shading comparison between the basecase model and the model with a maximum 6-foot overhang during a summer day. The proposed shadings aimed at protecting the windows from sunlight penetration during this cooling period. The experiments were conducted using the heliodon table set at 30° Latitude. The arrows indicate the direct solar radiation penetrating into the residence.

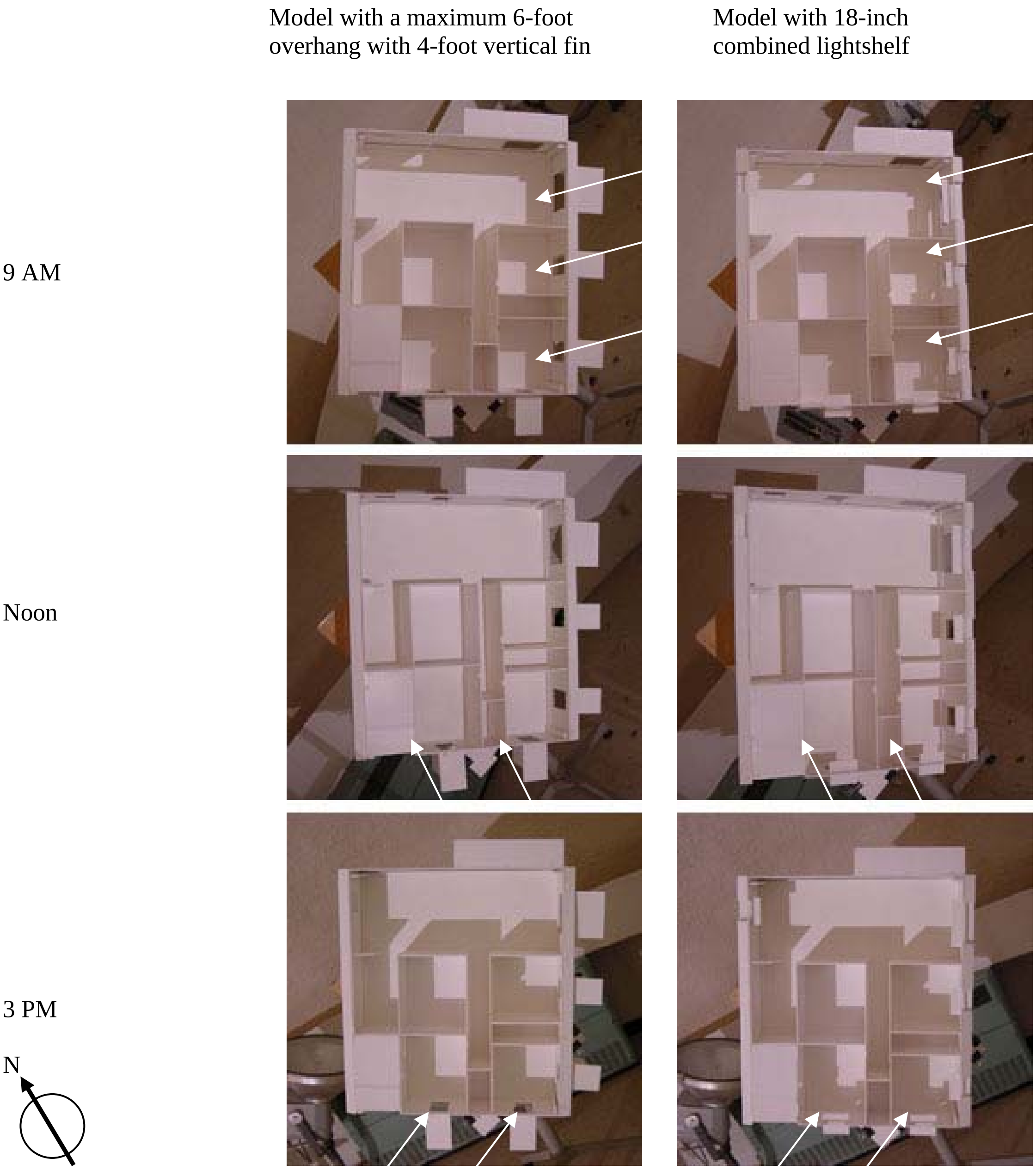


Figure 4.30 – Continued. The photographs present a shading comparison between the model with a maximum 6-foot overhang with 4-foot vertical fin and the model with 18-inch combined lightshelf during a summer day. The proposed shadings protected the windows from the solar beam radiation during the summer periods, when compared to the basecase model. The experiments were conducted using the heliodon table set at 30° Latitude. The arrows indicate the direct solar radiation penetrating into the residence.

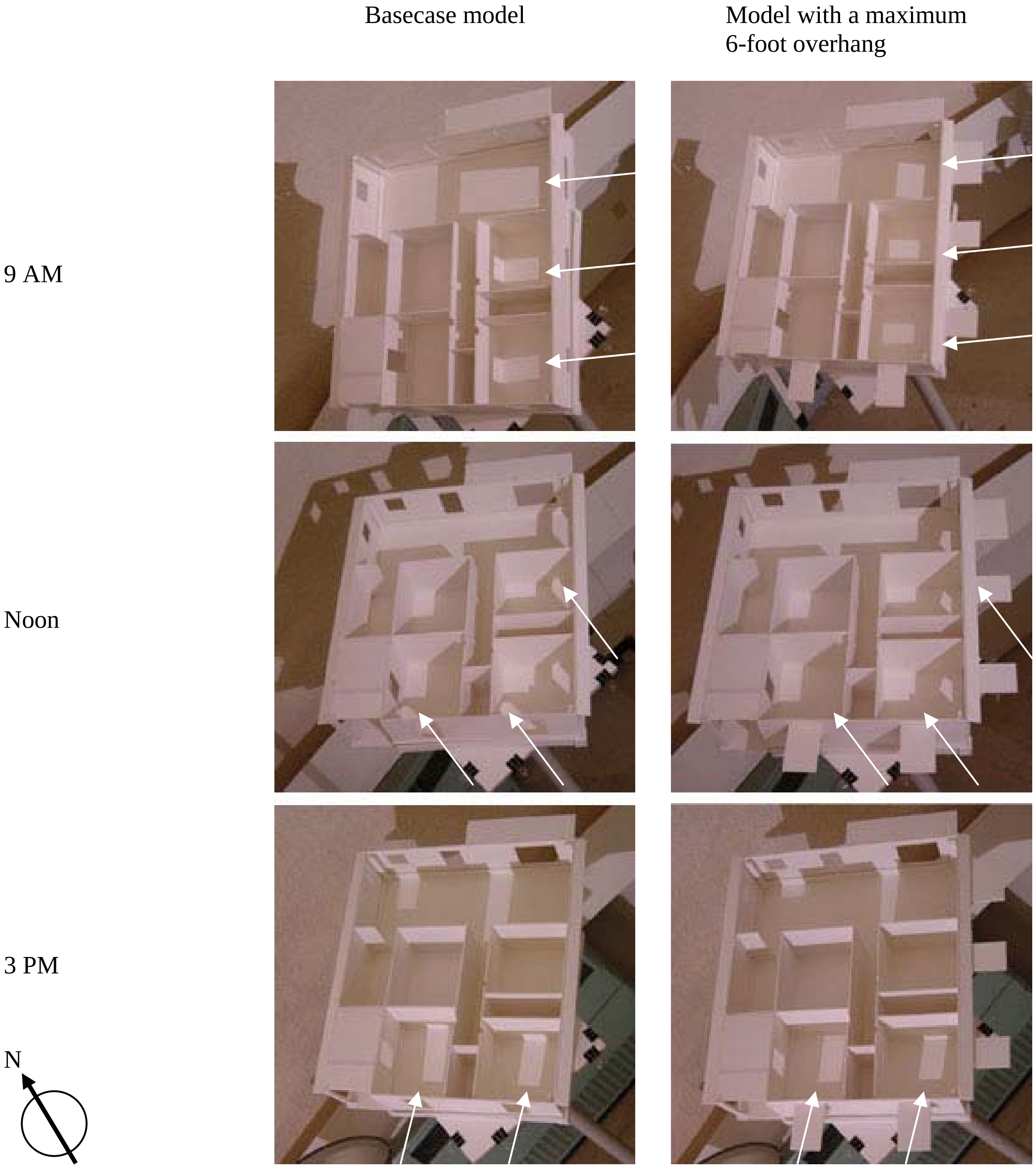


Figure 4.31 – The evaluation of shading on December 21. The photographs present a shading comparison between the basecase model and the model with a maximum 6-foot overhang during a winter day. The sunlight penetration during the winter periods was not considered a critical problem since the solar radiation could contribute to space heating which was required during the heating periods. The experiments were conducted using the heliodon table set at 30° Latitude. The arrows indicate the direct solar radiation penetrating into the residence.

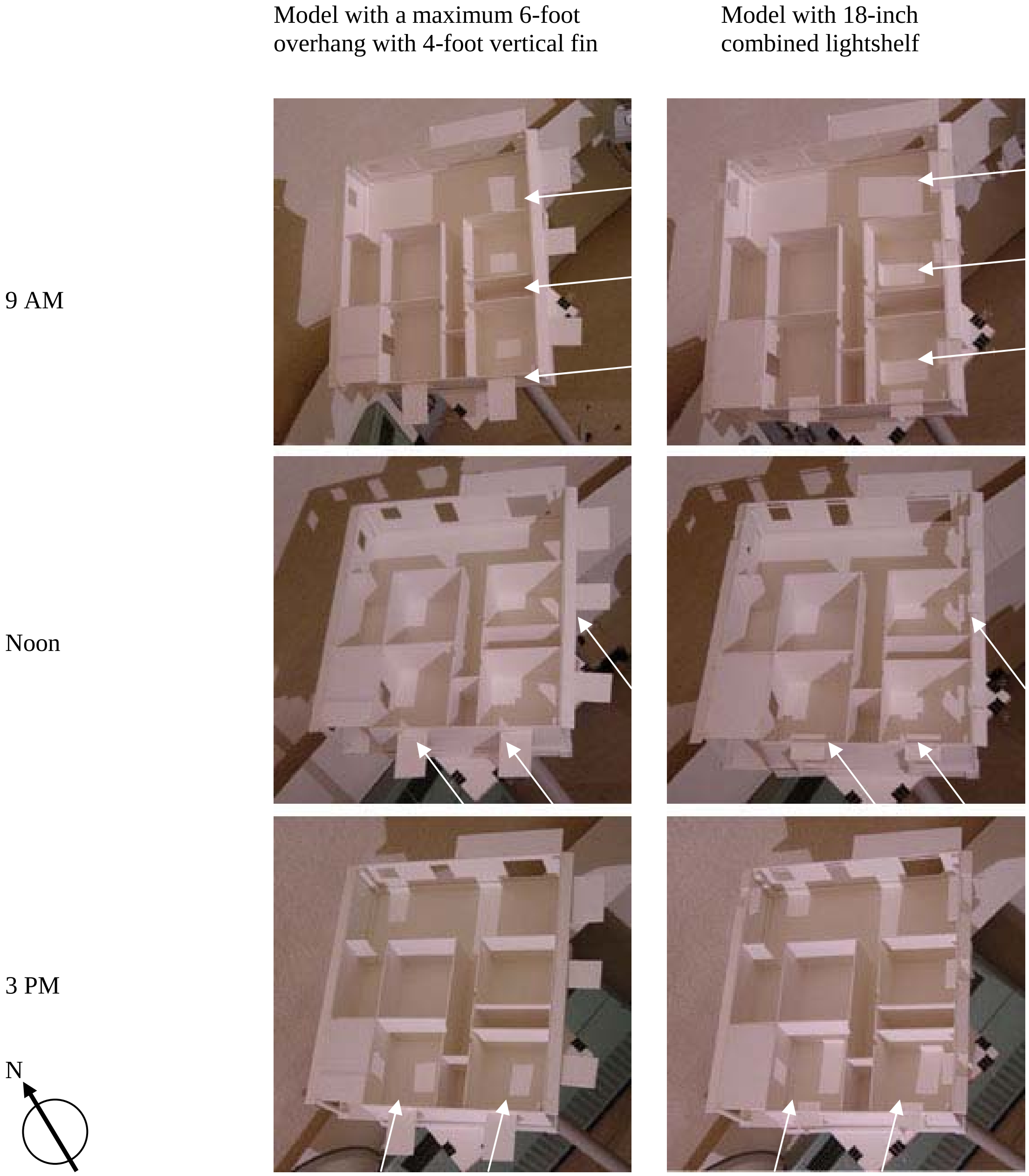


Figure 4.31 – Continued. The photographs present a shading comparison between the model with a maximum 6-foot overhang with 4-foot vertical fin and the model with 18-inch combined lightshelf during a winter day. The experiments were conducted using the heliodon table set at 30° Latitude. The arrows indicate the direct solar radiation penetrating into the residence.

Figures 4.29 – 4.31 show the use of shading application during 9 AM to 3 PM in fall/spring, summer, and winter respectively. The photographs show how direct sunlight penetrates the different windows at the different times. The penetration of sunlight leads to solar heat gain and increased cooling load. Sunlight penetrating into a room can also cause problems with glare. The results of this shading study showed that the maximum 6-foot overhang with 4-foot vertical fin completely blocked all direct solar gain in the summer, yet allowed direct gain into the room in the winter. Although the maximum 6-foot overhang with vertical fin was regarded as the most effective design, its size was not practical for construction. Future research on alternative shading designs is needed to explore other types of shading systems, such as horizontal light shelves with vertical slats that hang down over the lower window.

The 18-inch combined lightshelf shading design was proposed as a final design for this study. This shading design was composed of an 18-inch overhang with an 18-inch vertical fin, including a high window and an interior lightshelf. The shading employed the use of exterior and interior overhangs and a clerestory opening that worked together as a lightshelf daylighting system. In other words, the exterior lightshelf acts as shading for the lower portion of window; the upper clerestory window and the interior lightshelf block direct view of the sky while redirecting sunlight and skylight onto the ceiling of the room.

4.2.3. Daylight Factors from the Physical Scale Model Measurements

To analyze the Daylight Factor, measurements were taken with a physical scale model under overcast sky conditions. Table 4.9 and Figure 4.32 present the data obtained from Daylight Factor measurements in the physical scale model under an overcast sky. This study also compared the model measurement results with the Daylight Factors obtained from the DOE-2 daylighting simulations. The comparison of Daylight Factors is discussed in Section 4.2.4 of this chapter.

Table 4.9 – Daylight Factors from the physical scale model measurements. These measurements were taken under an overcast sky. The light meter was positioned face-up horizontally at windowsill level, which was 2 feet above the floor in the middle of each room.

Position of light meter	Measurement location	Daylight Factor (%) from the scale model	
		Basecase	lightshelf 18-inch
Windowsill Level	Living	10.2	10.9
	Dining	7.4	10.2
	Bedroom-2 (next to Living)	5.8	5.2
	Bedroom-1 (east)	10.7	10.0
	Bedroom-M (west)	11.1	10.3

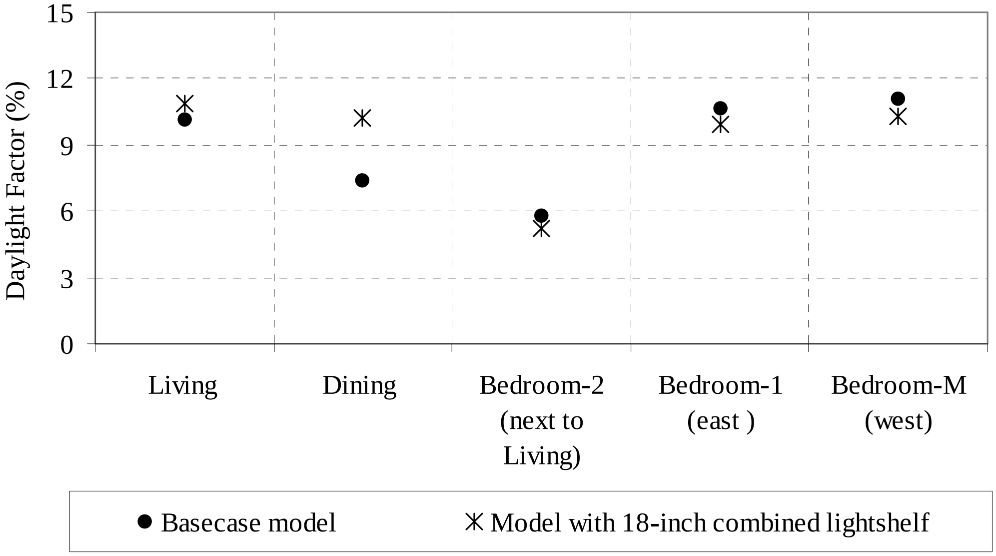


Figure 4.32 – Daylight Factors from the physical scale model measurements under an overcast sky. The results present a comparison between the basecase model and the model with 18-inch combined lightshelf.

The measurements performed under an overcast sky focused on a comparison between the basecase model and the model with 18-inch combined lightshelf, which was the final proposed design. Additional Daylight Factor measurements of the other 2 proposed designs, which were the model with maximum 6-foot overhang and the model with maximum 6-foot overhang with vertical fin, were performed in the daylighting laboratory and are discussed in Appendix D.

As seen in Figure 4.32, with the exception of the dining room, the Daylight Factors obtained from the model with the final design were very similar to the basecase model. The new design increased the Daylight Factor in the living room and the dining room. Seen from the figure, the increase was small in the living room. However, in the dining room the increase was quite large which is due in part to the addition of the clerestory window, as seen in Figure 4.33. In the three bedrooms, the new design decreased the Daylight Factor by a small amount.

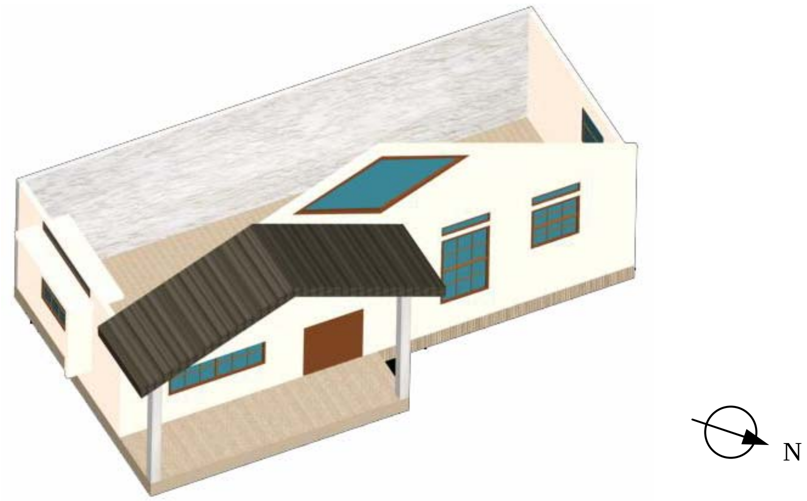


Figure 4.33 – Model of the living/dining room with an 18-inch combined lightshelf and the clerestory window on its northeast wall.

4.2.4. Daylight Factors from the DOE-2 Daylighting Simulations

The Daylight Factors gathered from the measurements under an actual sky were compared against the DOE-2 daylighting simulation results. The DOE-2 program allows users to model a building and determined the effect of daylighting in partitioned zones. The program calculates a Daylight Factor (interior illuminance divided by exterior horizontal illuminance) at a specified reference point by integrating over the window area the contribution of light from window, sky and ground and includes space inter-reflections.

Table 4.10 and Figure 4.34 present the DOE-2-calculated Daylight Factors of the basecase model compared with the model with the 18-inch combined lightshelf.

Table 4.10 – Daylight Factor comparison of the basecase model and the model with 18-inch combined lightshelf from DOE-2 daylighting simulations. Daylight Factors represent the ratio of an interior illuminance to an exterior horizontal illuminance at the reference point in the middle of each room on overcast days.

Position of light meter	Measurement location	Daylight Factor (%) from DOE-2	
		Basecase	lightshelf
Windowsill Level	Living	7.8	6.7
	Dining	2.7	3.0
	Bedroom-2 (next to Living)	3.7	2.2
	Bedroom-1 (east)	3.5	2.0
	Bedroom-M (west)	2.3	1.6

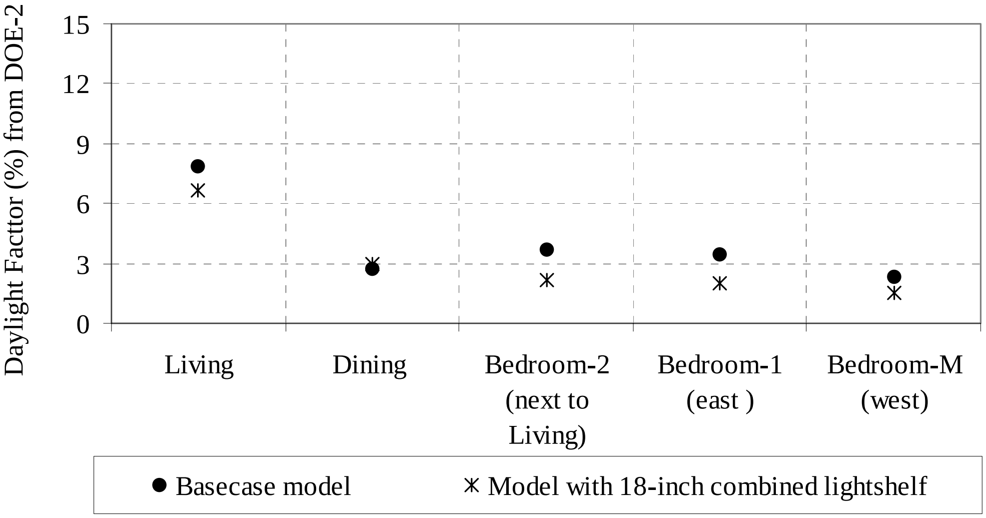


Figure 4.34 – DOE-2 simulated Daylight Factor comparison of the basecase model and the model with 18-inch combined lightshelf.

DOE-2 calculated Daylight Factor also presented for the model with 6-foot overhang in Figure 4.35 and Table 4.11, as well as for the model with 6-foot overhang with vertical fin in Table 4.12 and Figure 4.36. In general, the DOE-2 calculated Daylight Factors were lower than the model measurements. However, as will be discussed in the next section, the changes in Daylight Factor from the basecase to the 18-inch design were not consistent in all cases. In the 18-inch design, DOE-2 had similar trend for all rooms except the dining room, where it appeared that DOE-2 was unable to calculate the increase Daylight Factor due to the presence of the clerestory window.

Table 4.11 – Daylight Factor comparison of the basecase model and the model with maximum 6-foot overhang from DOE-2 daylighting simulations.

Position of light meter	Measurement location	Daylight Factor (%) from DOE-2	
		Basecase	6-foot overhang
Windowsill Level	Living	7.8	4.8
	Dining	2.7	2.2
	Bedroom-2 (next to Living)	3.7	0.8
	Bedroom-1 (east)	3.5	0.8
	Bedroom-M (west)	2.3	1.9

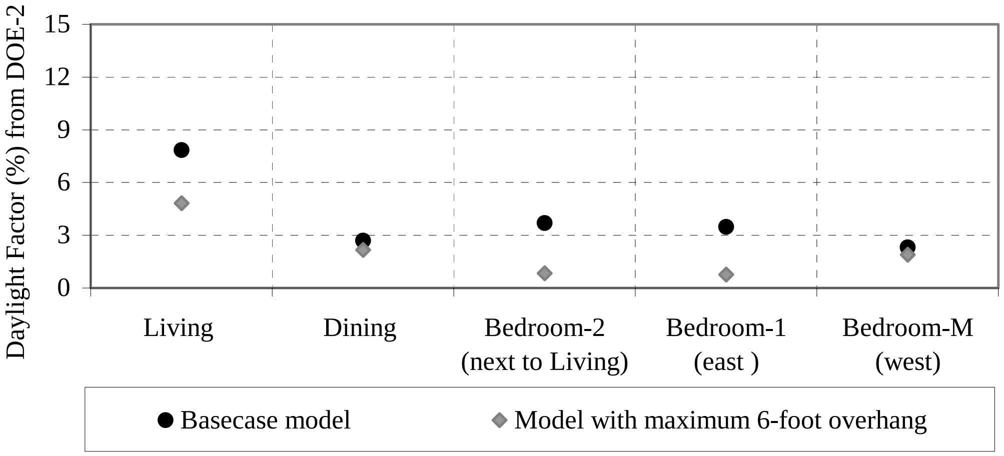


Figure 4.35 – DOE-2 simulated Daylight Factor comparison of the basecase model and the model with maximum 6-foot overhang.

In the DOE-2 simulated Daylight Factors for the 6-foot overhang and 6-foot overhang with vertical fin models, the reduction in the Daylight Factor is more pronounced than in the 18-inch design.

Table 4.12 – Daylight Factor comparison of the basecase model and the model with maximum 6-foot overhang with vertical fin from DOE-2 daylighting simulations.

Position of light meter	**Measurement location**	**Daylight Factor (%) from DOE-2**	
		Basecase	**6-foot overhang w/ vertical fin**
Windowsill Level	Living	7.8	4.5
	Dining	2.7	2.1
	Bedroom-2 (next to Living)	3.7	0.6
	Bedroom-1 (east)	3.5	0.4
	Bedroom-M (west)	2.3	1.9

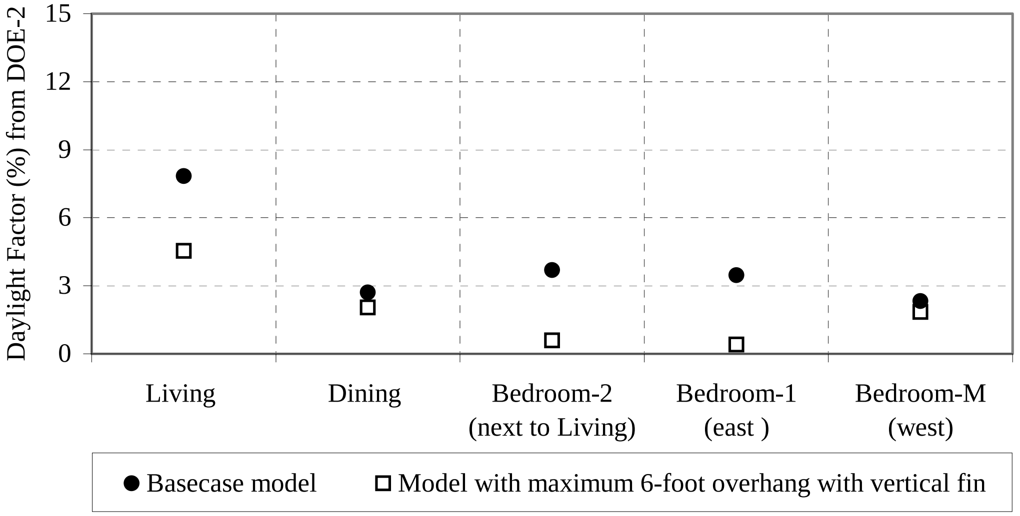


Figure 4.36 – DOE-2 simulated Daylight Factor comparison of the basecase model and the model with maximum 6-foot overhang with vertical fin.

4.2.5. Daylight Factor Comparison

Unfortunately, an exact numerical comparison of the Daylight Factors from the overcast sky model against the DOE-2 program was complicated by several factors including the measurement of actual surface reflectances, actual window transmissivity and inter-reflections from the lightshelf. Therefore, this section presents a comparison of the relative trends for the different window treatments.

Table 4.13 – Daylight Factors of the basecase model obtained from the case study site, overcast sky model measurements, and DOE-2 simulation.

Position of light meter	**Measurement location**	**Daylight Factor (%) of the basecase model**		
		Case study site	**DOE-2**	**Model**
Windowsill Level	Living	7.0	7.8	10.2
	Dining	8.3	2.7	7.4
	Bedroom-2 (next to Living)	1.9	3.7	5.8
	Bedroom-1 (east)	4.4	3.5	10.7
	Bedroom-M (west)	4.0	2.3	11.1

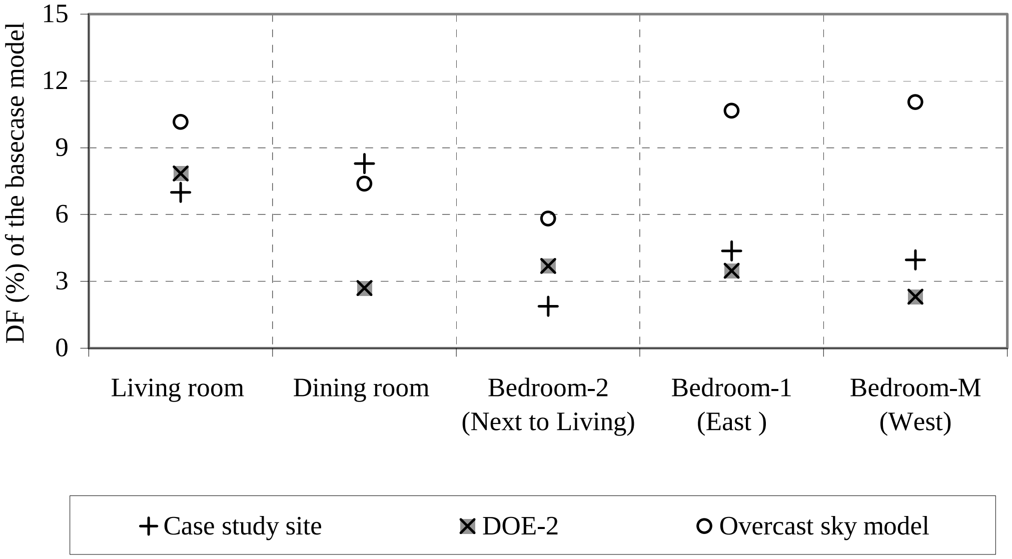


Figure 4.37 – Daylight Factors from the case study site, overcast-sky model measurements and DOE-2 (basecase) simulations.

Table 4.13 and Figure 4.37 present a three-way comparison of the Daylight Factors from the measurements taken at the site, the overcast sky model, and the DOE-2 values with the exception of the dining room, the overcast sky model over predicted the Daylight Factor. Remarkably, the DOE-2 model had similar trend to the case study site, with the exception of the dining room.

Table 4.14A – The measurements of interior and exterior vertical illuminance of the case study building's windows with and without screen.

Location	Location	Exterior (FC)	Interior with screen (FC)	Interior without screen (FC)	(%) Diff
Living	Northeast window	257	113.6	207.4	82.6
Bedroom-2	Southeast window	432	198.0	347.3	75.4
Bedroom-1	Southwest window	130	64.9	105.5	62.6

Table 4.14B – The ratio of interior to exterior vertical illuminance of the case study building's windows with and without screen.

Location	Window location	Ratio of interior vertical illuminance to exterior vertical illumiance (%)	
		With screen	Without screen
Living	Northeast window	44.0	80.7
Bedroom-2	Southeast window	45.8	80.4
Bedroom-1	Southwest window	49.9	81.2

One of the possible explanations for the difference is the presence of bug screens on the lower half of the window, which were not accounted for on the overcast sky model and in the DOE-2 model. Tables 4.14A and 4.14B present measurements made at the site to confirm the effect of the screens. As indicated, the transmissivity of the window with the screen is almost a half of the transmissivity without the screen, which corresponds roughly to the differences in the observed Daylight Factors.

Unfortunately, resolving the difference was beyond the scope of this thesis. Therefore, a simple analysis of the trends was felt to be a sufficient indication of the Daylight Factors. Tables 4.15 and 4.16 and Figure 4.38 show the trend analysis. For the overcast sky model, there was a modest decrease in three of the bedrooms, a slight increase in the living room and a large increase in the dining room. These trends are felt to accurately reflect the performance of the basecase and the 18-inch lightshelf in a house without bug screen, or privacy curtains.

Table 4.15 – Daylight Factors from DOE-2 daylighting simulations vs. model measurements.

Position of light meter	**Measurement location**	**Daylight Factor (%) of the model**		**Daylight Factor (%) of the DOE-2**	
		Basecase	**Lightshelf**	**Basecase**	**Lightshelf**
Windowsill Level	Living	10.2	10.9	7.8	6.7
	Dining	7.4	10.2	2.7	3.0
	Bedroom-2 (next to Living)	5.8	5.2	3.7	2.2
	Bedroom-1 (east)	10.7	10.0	3.5	2.0
	Bedroom-M (west)	11.1	10.3	2.3	1.6

Table 4.16 – The comparison of Daylight Factors between the basecase model and the model with 18-inch combined lightshelf from DOE-2 daylighting simulations vs. model measurements.

Location	**Difference in DF of Basecase and Lightshelf**		**Direction of DF Basecase to Lightshelf**		Symbol used in **Figure 4.37**
	Model	**DOE-2**	**Model**	**DOE-2**	
Living	7.2%	-15.2%	Increase	Decrease	──▶
Dining	38.4%	9.6%	Increase	Increase	──◆
Bedroom-2	-10.9%	-41.7%	Decrease	Decrease	⟶
Bedroom-1	-6.6%	-41.5%	Decrease	Decrease	⟶
Bedroom-M	-6.7%	-33.2%	Decrease	Decrease	⟶

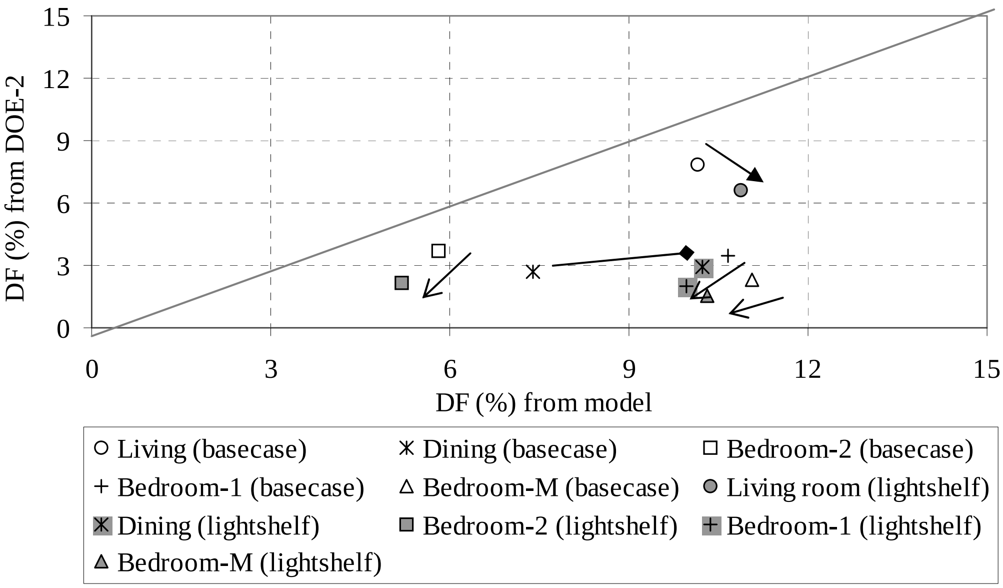


Figure 4.38 – Daylight Factors from DOE-2 daylighting simulations vs. overcast sky model.

4.2.6. Summary of Daylight Factor Analysis

The use of the physical scale model provided a useful tool to evaluate the proposed shading designs especially their ability to protect the interior from direct solar radiation in the cooling season and the evaluation of the distribution of daylight into the interior. The investigation of the shading properties was conducted from this by photographing the model on the heliodon table. Results form this experiment suggested the effectiveness of the maximum 6-foot overhang with vertical fins in providing complete shade on the windows during the cooling periods. However, the size of this shading system was of concern in building construction. The 18-inch combined lightshelf was therefore proposed as the final design for this study. This lightshelf system included an exterior shading device, which shaded the window from direct solar radiation and an interior lightshelf that reflected the direct and diffuse light onto the ceiling. In addition to the lightshelf devices, the final model also included a clerestory window on the northeast wall of the living/dining room. The evaluation of the proposed designs in terms of their ability to enhance illuminance was examined through the Daylight Factor measurements of the model under actual overcast sky conditions and through the daylighting simulations using the DOE-2 program.

Results from the model measurements under overcast sky conditions were presented as Daylight Factors. The study evaluated the proposed designs by comparing the Daylight Factors of the proposed models with those of the basecase model. The study found that the application of exterior devices on the windows reduced the penetration of the direct solar radiation, while only modestly reducing the interior illuminance. The lightshelf system proposed as the final design integrated the use of an exterior shading device and an interior lightshelf redirecting sunlight and skylight into the space. The measurement results presented in this chapter focused on the comparison between the basecase and the final lightshelf model. Additional results from the measurements conducted under the artificial sky dome are discussed in Appendix D.

This study also used the DOE-2 daylighting simulation program to perform Daylight Factor calculations of the basecase model and the models with proposed shadings. Daylight Factors from the simulations were compared with the basecase model and the proposed models. Unfortunately, only limited agreement could be found between the DOE-2 Daylight Factor and the overcast sky model. Therefore, the overcast sky model results were felt to be a better indication of the potential performance of the lightshelf. Resolving the differences between the two Daylight Factors is beyond the scope of this thesis. In general, the analysis of the overcast sky model provided a consideration on the lightshelf performance, as it will decrease solar gain without significantly decrease the interior illuminance.

Results from the study also suggested that adding a clerestory window on the wall oriented away from the direct sun could enhance the room brightness without adding excessive solar heat gain. The evaluation of energy reduction from using daylighting applications is discussed in the next section.

4.3. RESULTS OF DOE-2 DAYLIGHTING AND ENERGY SIMULATION

One of the main objectives of this study is to investigate the energy reductions from the use of daylighting in a low-income residence. To accomplish this, the DOE-2 simulation program was used to simulate thermal conditions and energy uses of the case study building with and without the proposed window shadings. The proposed daylighting models were then evaluated in terms of their contributions to building energy savings, compared to the energy use of the basecase model.

There are two main results discussed in this section, which include a detailed look at the heat gain through specific windows with and without the new shading devices, and an analysis of the annual energy use. The first section discusses the building internal loads and the energy end use resulting from the application of daylighting designs on selected windows, focusing on the simulations on the vernal equinox (March 21). The thermal analysis on the window conduction and the solar heat gain evaluation was studied through two specific windows: the southeast-facing window of bedroom-2 and the southwest-facing window of bedroom-1. Finally, the building energy use evaluation on this specified day was investigated through the simulation results on the hourly building cooling loads and the energy end use.

The second section focuses on the monthly energy use evaluation. The discussions include the calibration of monthly energy use of the basecase model with and without the daylighting application, and the monthly energy use of each proposed model. This section concludes with a summary of annual energy savings from using daylighting in the proposed models.

4.3.1. Vernal Equinox Daylighting Characteristics (March 21)

Results from the analysis in the methodology section (Section 3.3.4.) suggested a closer inspection of the simulation on vernal equinox since this day represented clear sky conditions with high daylight availability. The solar radiation and exterior illuminance characteristics of vernal equinox shown in Figure 4.39 and Figure 4.40 indicate a symmetrical global horizontal, with the solar radiation highest at noontime. As seen in Figure 4.40, the highest exterior horizontal illuminance was from the direct sun and clear portion of the sky. No illuminance was received from the overcast portion of the sky since clouds did not presented.

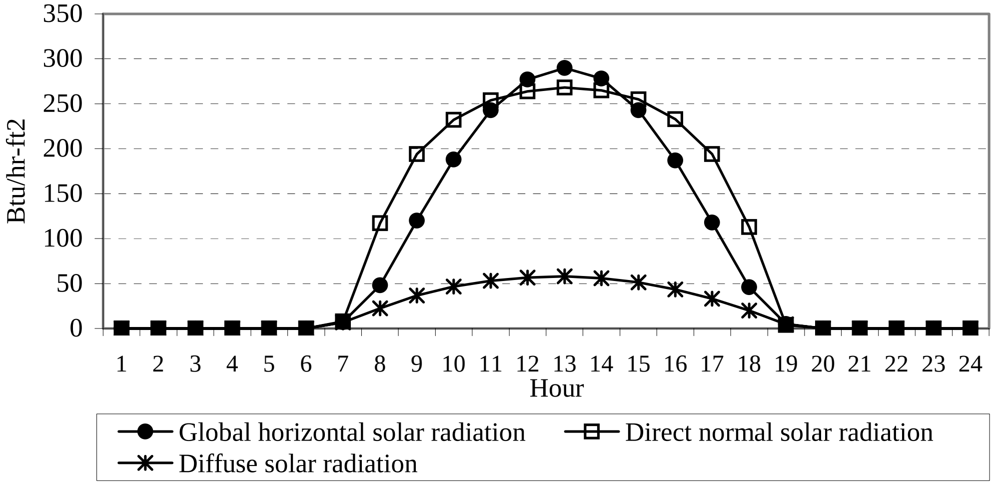


Figure 4.39 – Global horizontal, direct normal and diffuse solar radiation from Houston TMY2 weather tape of March 21.

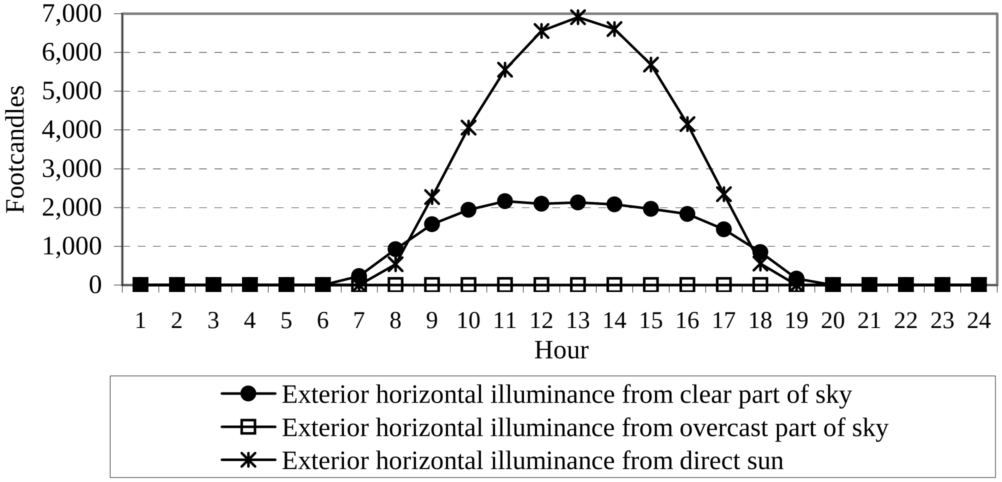


Figure 4.40 – Exterior horizontal illuminance from clear, overcast portion of the sky, and from direct sun of March 21.

4.3.2. DOE-2 Daylighting Simulations of Proposed Design Options on Vernal Equinox (March 21)

This section discusses the DOE-2 daylighting simulation results from the proposed shading applications compared to the basecase study, with a focus on vernal equinox. Evaluation of the results included four primary issues: window conduction and solar heat gain, indoor temperature, building cooling load, and building energy use.

4.3.2.1. Window conduction and solar heat gain evaluation

The study of thermal conduction and solar heat gain on the window focused on 2 windows, the window of bedroom-2 on the southeast side (BD2WE-1), and the window of bedroom-1 on the southwest side (BD1WS-1). Figure 4.41 shows the location of the windows on the house plan. The study of each window involved the evaluation of transmitted plus reconducted solar heat gain, conduction heat gain through window and the contribution of window to the daylight illuminance at the reference point. Please refer to DOE-2.1E (LBL 1993), Appendix A for the description of each variable used in reporting the output.

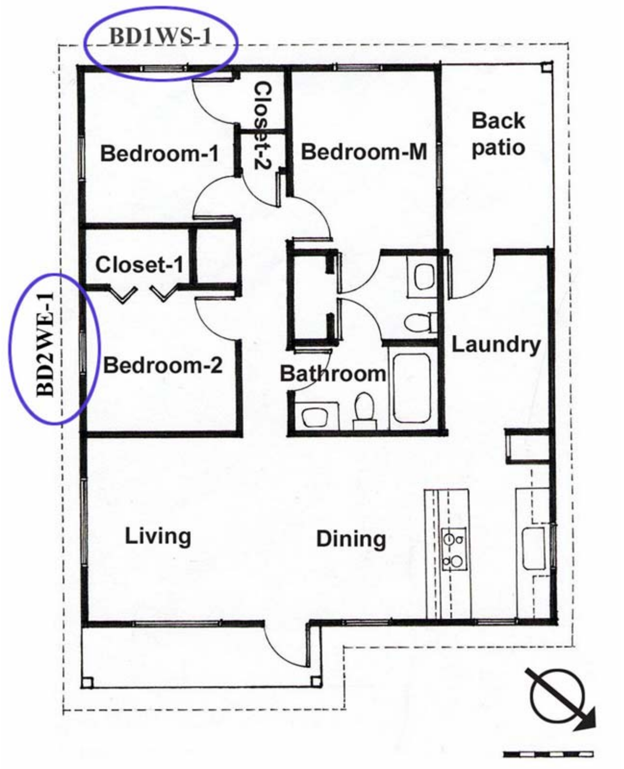


Figure 4.41 – Location of the windows selected for the vernal equinox study.

Figures 4.42 - 4.44 display the simulation results of window BD2WE-1 (Bedroom-2) on vernal equinox day. In Figure 4.42, the transmitted plus reconducted solar heat gain through window of the basecase model is the highest, while the gain through window of the model with a maximum 6-foot overhang and a vertical fin is the lowest. The results showed that the maximum 6-foot overhang with vertical fin provided almost complete shading for the window throughout the day, which accounted for the large decrease in solar heat gain. In Figure 4.43, most of the conduction heat gain through windows of all 4 cases is in negative values, indicating conduction heat loss. The occurrence of window conduction heat loss was affected by the difference between outdoor and indoor temperature on that day. The average outdoor temperature on March 21 was 60.9°F, while the indoor temperature of the house was set at 70°F. In Figure 4.44, the effective use of the proposed shadings compared to the unshaded window of the basecase model is shown. It could be concluded from the graph that daylight illuminance at the reference point in the basecase model was obviously high in the morning from 8 AM to 12 AM, the period when the sun passed from east to south during that day.

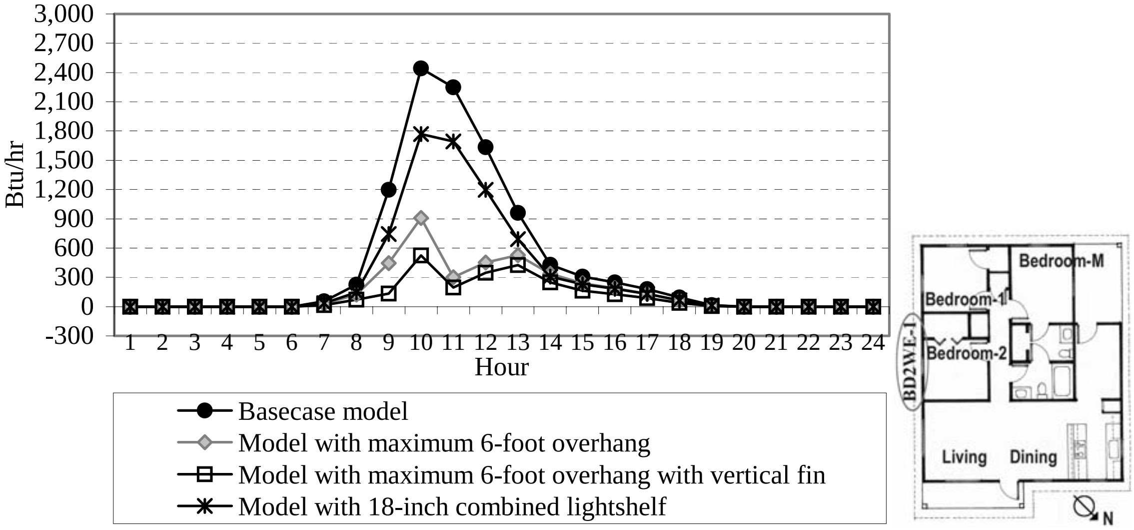


Figure 4.42 – Transmitted plus reconducted solar heat gain through window BD2WE-1 on March 21. Results are from the DOE-2 Hourly-Report with Variable-List 15 (QSOLG+QABSG) in LOADS.

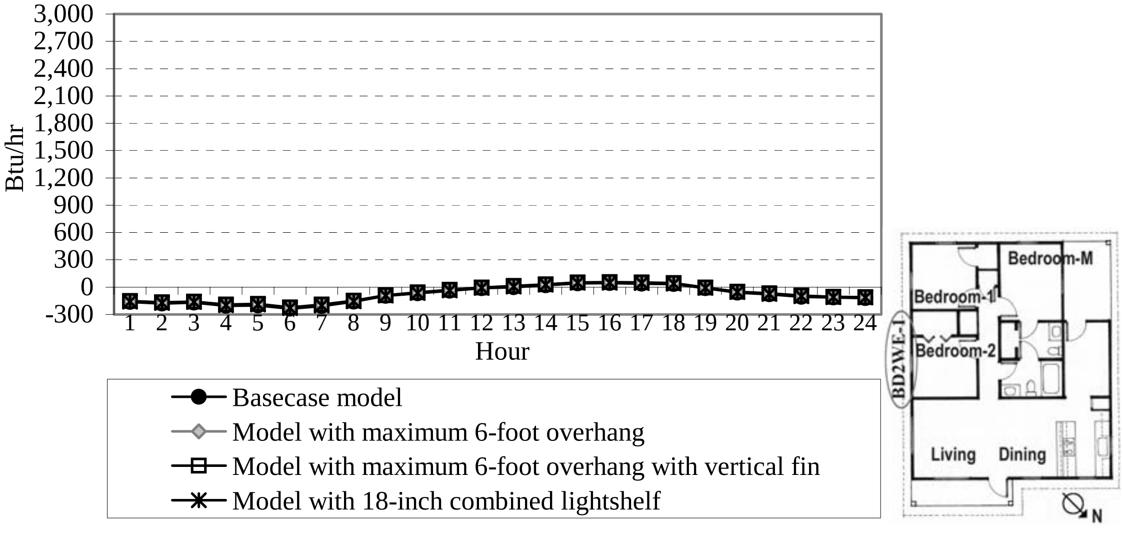


Figure 4.43 – Conduction heat gain through window BD2WE-1 on March 21. Results are from the DOE-2 Hourly-Report with Variable-List 17 (QCON+QCONFR) in LOADS.

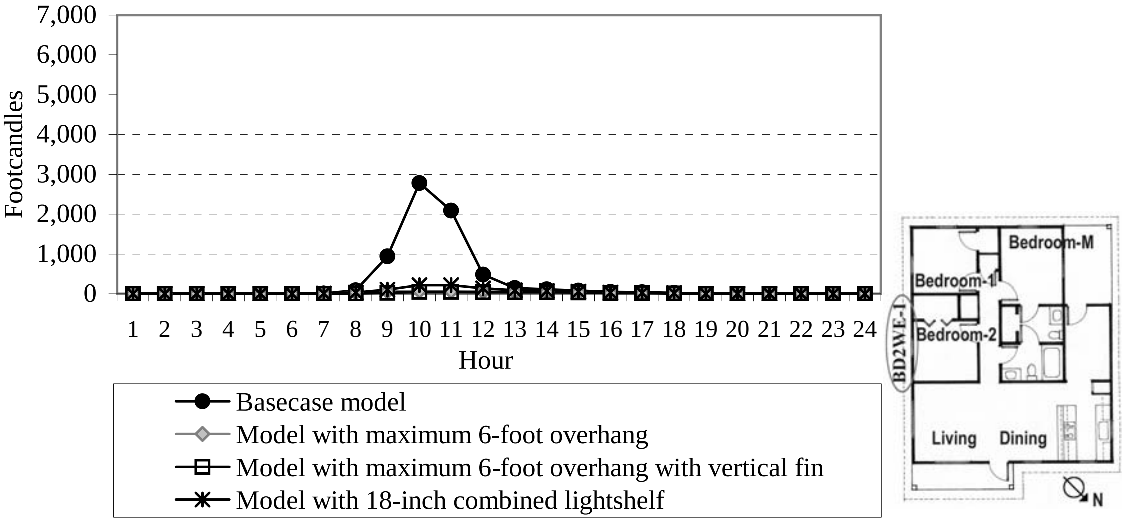


Figure 4.44 – Contribution of window BD2WE-1 to daylight illuminance at the reference point on March 21. Results are from the DOE-2 Hourly-Report with Variable-List 24 (ILLUMW$_1$) in LOADS.

As for the window on southwest side (BD1WS-1), Figure 4.45 to Figure 4.47B present the simulation results in solar and conduction heat gain through this window, including the contribution of window to daylight illuminance based on the hourly reports on vernal equinox. Similar to the solar heat gain characteristics that occurred to the window on the southeast side discussed previously (BD2WE-1), Figure 4.45 suggests that the total solar heat gain through window of the basecase model be the highest among the 4 cases, while the model with the maximum 6-foot overhang with vertical fin the lowest. Because of the window orientation, the peak solar heat gain hour was at 4 PM, the period when the sun was almost due west. This small incidence angle results in high solar heat gain. This effect can also be seen graphically in the sun path diagram in Figure 4.28 in Section 4.2.

Figure 4.46 shows the heat loss through the window during the evening hours, when the outdoor temperature was lower than the thermostat set point inside the house. The shading configuration not only affected on the solar and conduction heat gain through window, but also on the contribution of daylight to interior illuminance, as shown in Figure 4.47A. The y-axis scale of the graph shown in Figure 4.47B was minimized in order to better illustrate the effect of daylight on interior illuminance, compared to Figure 4.47A. Figure 4.48 shows the indoor and outdoor temperature from the TMY2 weather tape. In conclusion, Daylight illuminance in the basecase model interior was the highest during afternoon and reached its peak at 5 PM. The 6-foot overhang and vertical fin provided almost a full shade on window during the day and produced the lowest daylight illuminance among the 4 cases studied.

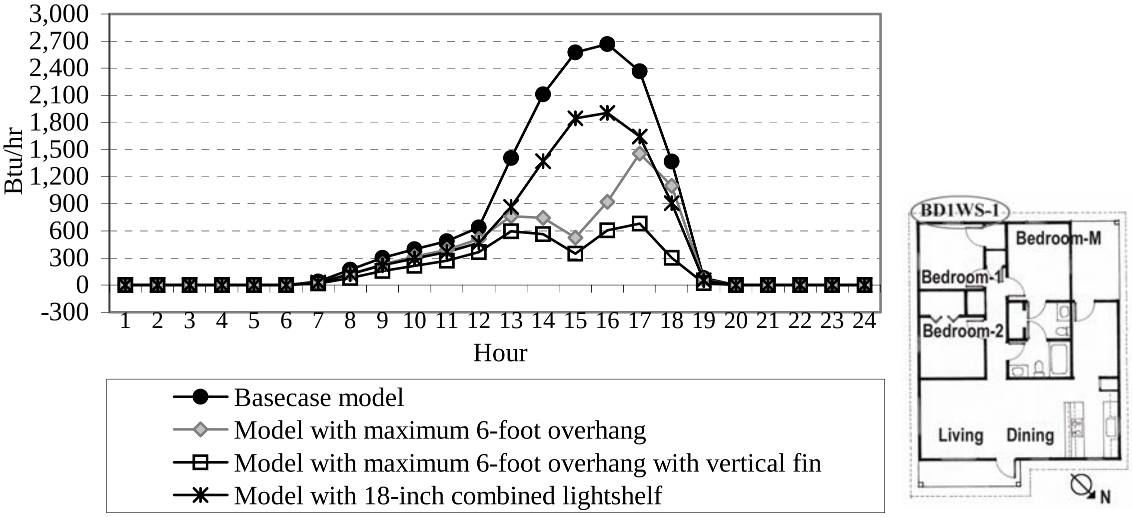


Figure 4.45 – Transmitted plus reconducted solar heat gain through window BD1WS-1 on March 21.

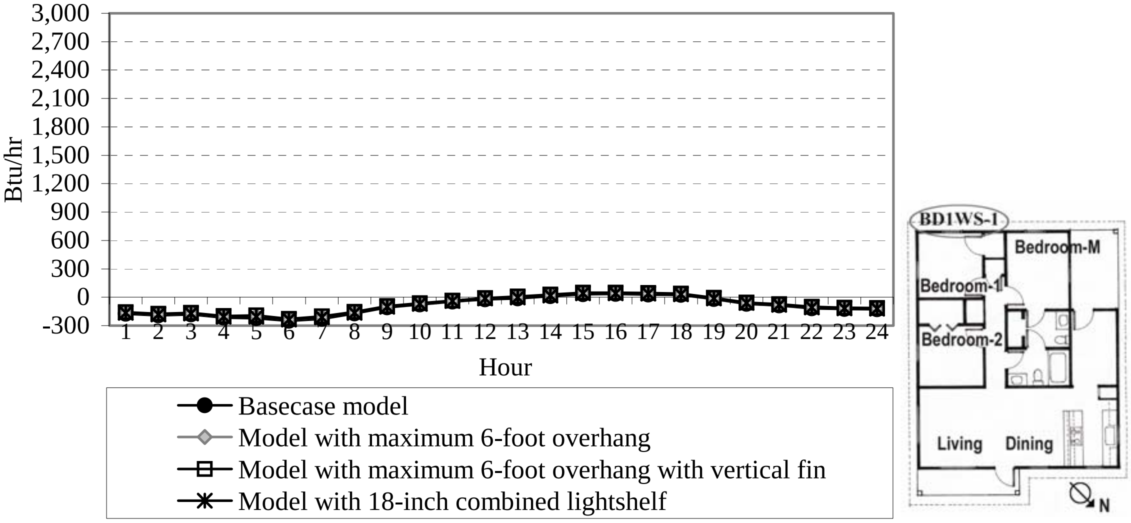


Figure 4.46 – Conduction heat gain through window BD1WS-1 on March 21.

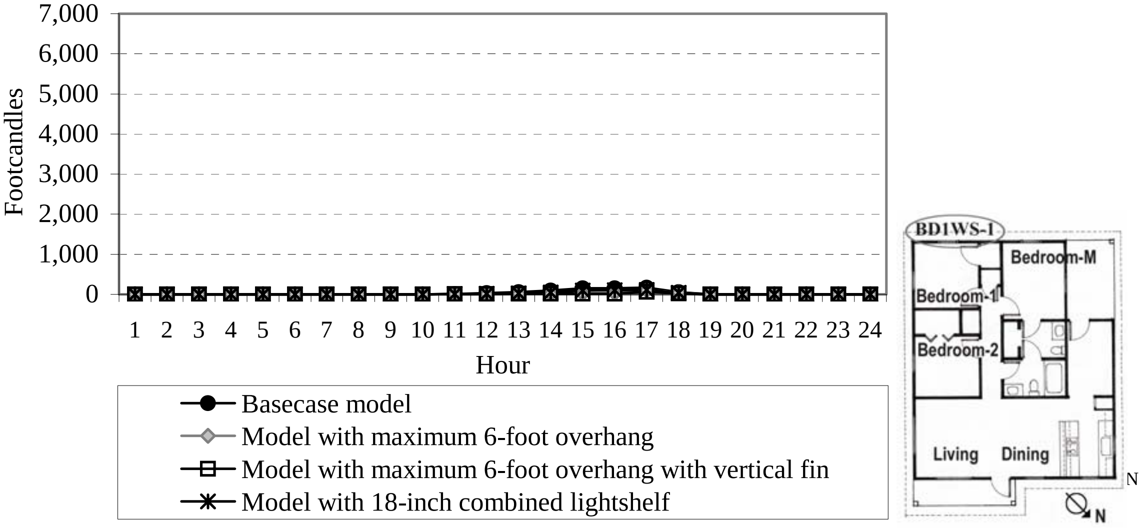


Figure 4.47A – Contribution of window BD1WS-1 to daylight illuminance at the reference point on March 21. Results were from DOE-2 Hourly-Report with Variable-List 24 (ILLUMW$_1$) in LOADS.

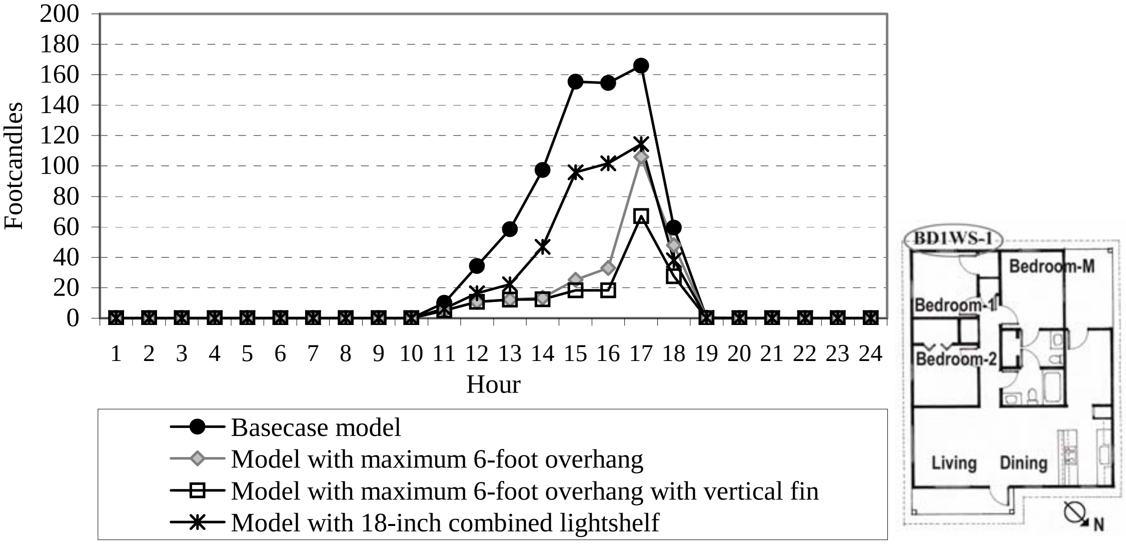


Figure 4.47B – Contribution of window BD1WS-1 to daylight illuminance. The Y-axis was minimized scale to present the footcandle range of 0 – 200.

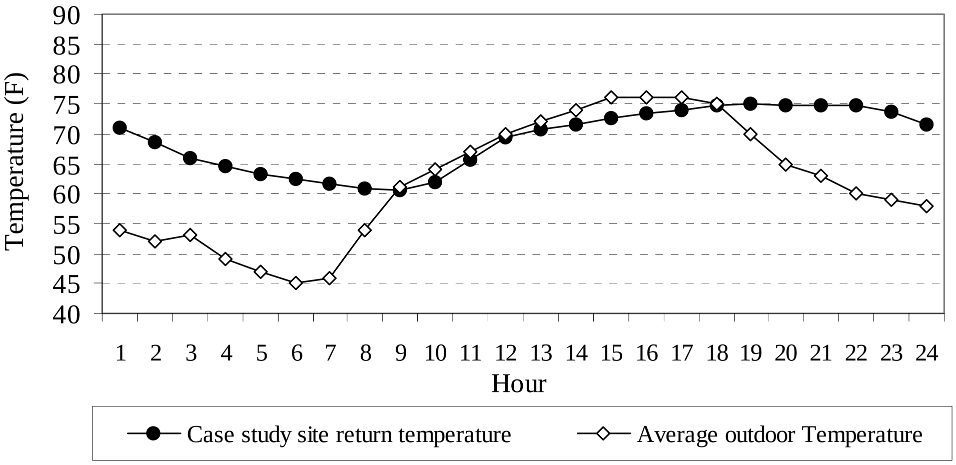


Figure 4.48 – Indoor and ambient temperature from the Houston TMY2 weather tape for March 21.

4.3.2.2. Building cooling load evaluation

In studying the building cooling load, there were 2 sources of heat gain through window involved. The first was the cooling load from the window conduction, The other was the cooling load from solar radiation. The analysis of the building cooling load from the window heat gain that occurred in all 4 models focused on March 21. Table 4.17 summarizes the building cooling load from window heat gain that took place in each case.

Table 4.17 – The summary of building cooling load from window conduction and solar radiation on March 21.

Model	Building cooling load from window		Total	Difference in total from basecase
	Conduction (Btu/hr/day)	Solar radiation (Btu/hr/day)	(Btu/hr/day)	(%)
Basecase	-9,083	43,199	34,116	
6-foot Overhang	-11,833	24,742	12,909	62.2
6-foot Overhang with vertical fin	-12,419	19,490	7,071	79.3
18-inch Lightshelf	-11,739	38,397	26,658	21.9

Note: The negative number means heat loss through window.

From the data shown in Table 4.17, it can be seen that the model with 6-foot overhang with vertical fin has the lowest building cooling load from solar radiation through the windows. However, it offers the highest window heat loss. This result could be explained by the effectiveness of window shading: the maximum 6-foot overhang with vertical fins provides full shade on windows and blocked direct sunlight during the day. The solar radiation that occurred on the window was minimized compared to the unshaded window of the basecase model. However, the shading of the direct sunlight caused the heat loss to increase when the outdoor temperatures were lower than the space temperatures, as seen in Figure 4.48. To illustrate the effect of each shading application, Figure 4.49 and Figure 4.50 present the simulation results on building heating/cooling load from the windows on March 21.

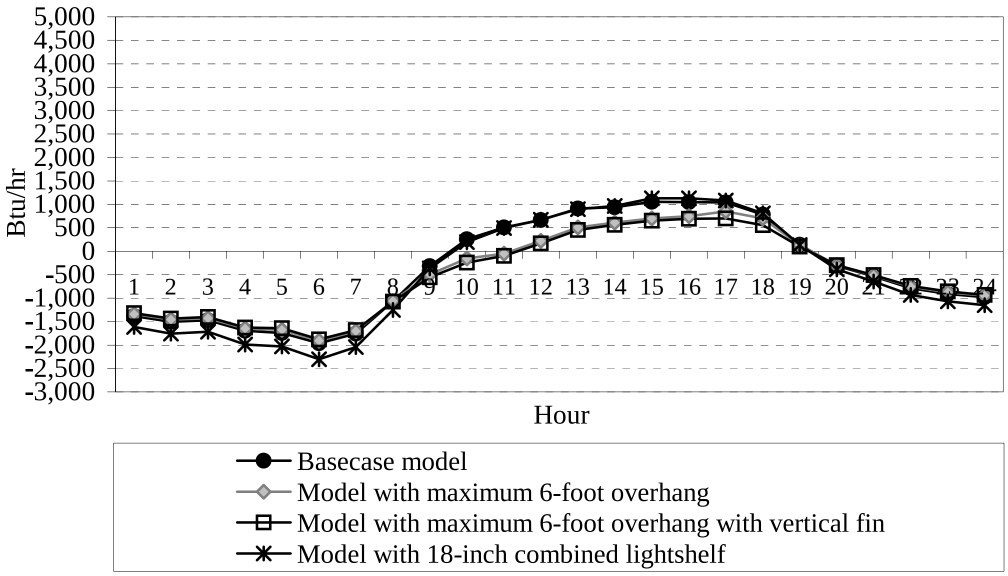


Figure 4.49 – Total building heating/cooling load from window conduction on March 21. The graph shows the cooling load from conduction of all windows in each model.

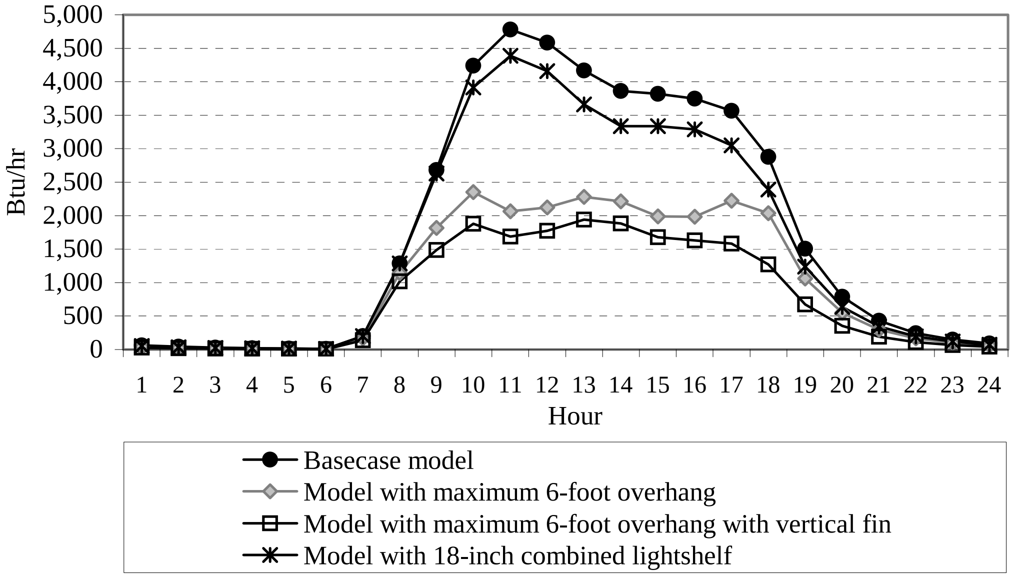


Figure 4.50 – Total building cooling load from solar radiation on March 21. The graph shows the cooling load from solar radiation of all windows in each model.

In Figures 4.49 and 4.50, The model with the 6-foot overhang and the 6-foot overhang with vertical fin produced the largest reductions in the solar heat gain for the total building cooling load. The model with the 18-inch lightshelf actually produced only a modest reduction.

4.3.2.3. Total building energy use evaluation

The analysis of the total energy consumption covers both the lighting electricity use and the overall energy use obtained from the DOE-2 end-use reports. Figure 4.51 presents lighting electricity use of the basecase model and the 3 models with shading applications. The graphs present the highest usage of lighting electricity in the basecase model and show the savings potential from the uses of different shadings.

In analyzing the overall building energy use, the DOE-2 simulations reported the end-use energy from PLANT in 6 categories: lighting electricity use, equipment electricity use, ventilation electricity use, cooling electricity use, pump and auxiliary electricity use, and heating fuel use. All these reports were plotted in the graphs shown in Figures 4.52 - 4.55. Each figure presents the 6 categories of building energy uses of each case. In addition, Figure 4.56 shows an evaluation of building energy savings from daylighting by illustrating the total energy uses comparison of all 4 studied models.

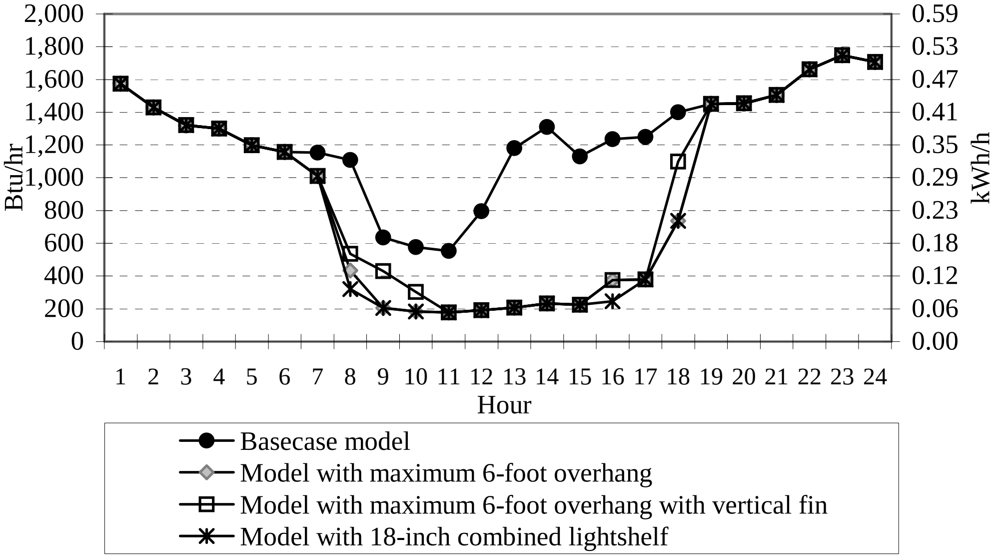


Figure 4.51 – Lighting electricity use from the DOE-2 simulations with 3 proposed designs on March 21. The results are from the DOE-2 Hourly-Report with Variable-List number 1 (LITEKW) in PLANT.

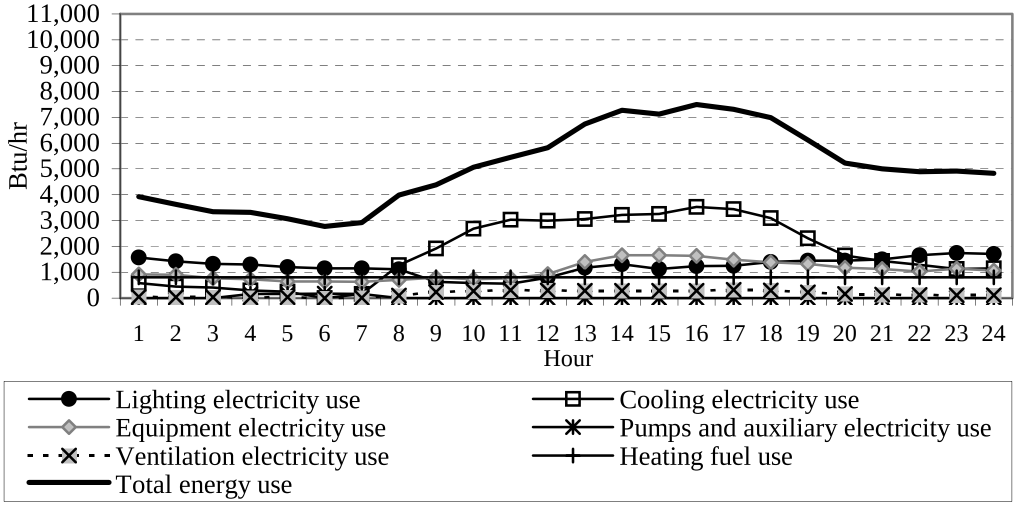


Figure 4.52 – Energy end-use from the DOE-2 simulation of the basecase model on March 21. The results are from the DOE-2 Hourly-Report with Variable-List number 1, 3, 6. 8, 9, and 15, Variable-Type = END-USE in PLANT.

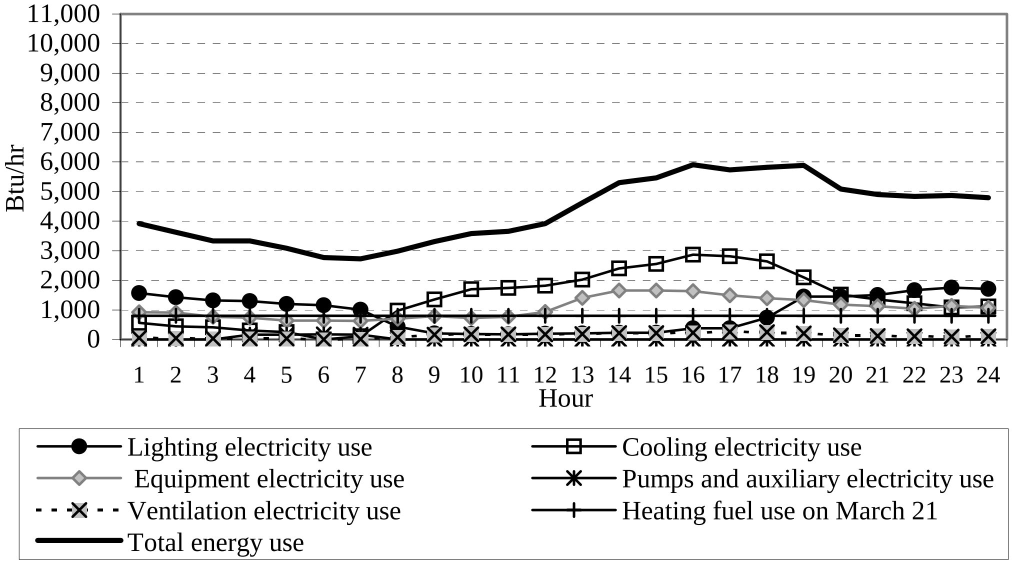


Figure 4.53 - Energy end-use from the DOE-2 simulation of the model with maximum 6-foot overhang on March 21.

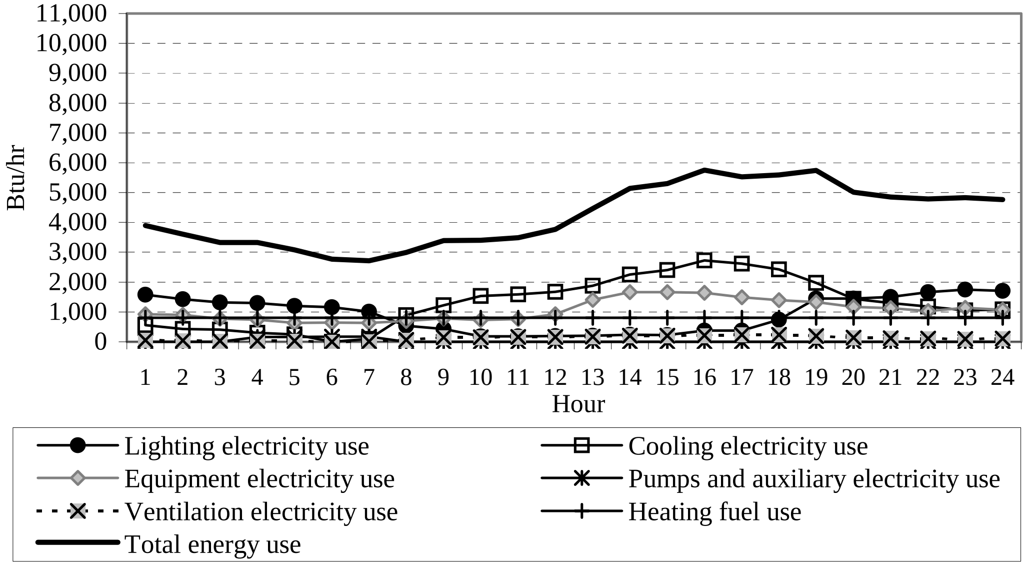


Figure 4.54 - Energy end-use from the DOE-2 simulation of the model with maximum 6-foot overhang with vertical fin on March 21.

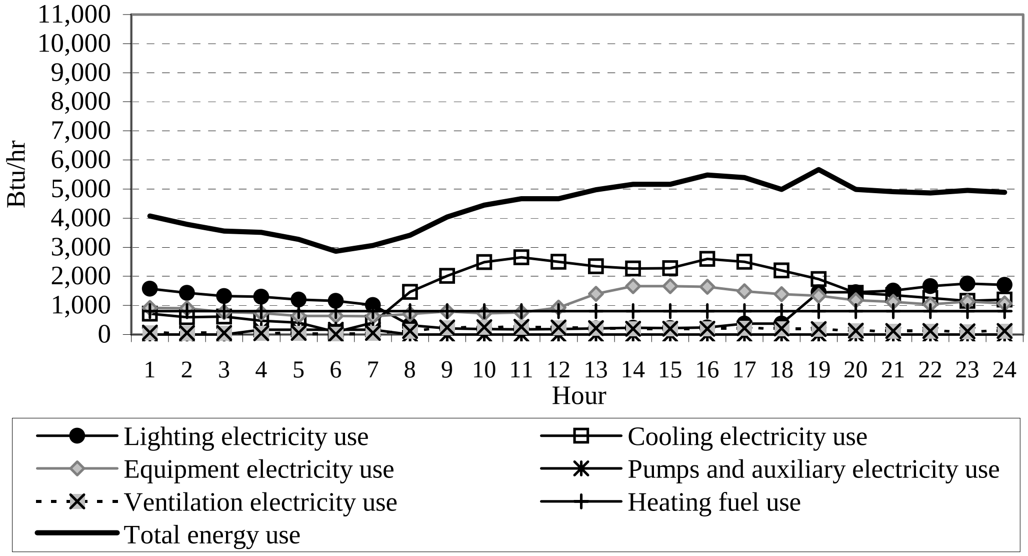


Figure 4.55 - Energy end-use from the DOE-2 simulation of the model with 18-inch combined lightshelf on March 21.

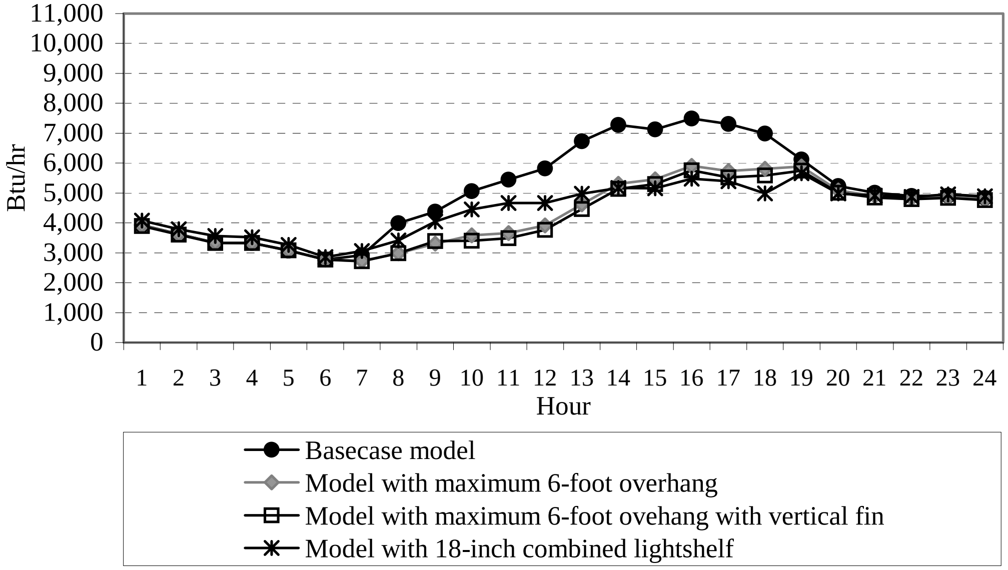


Figure 4.56 – The comparison of total energy use from DOE-2 simulations of all 4 studied models on March 21.

From Figure 4.56, it can be concluded that the energy consumption of the basecase model is highest during the day. The maximum energy savings can be obtained from the use of the model with a maximum 6-foot overhang and the model with a maximum 6-foot overhang with vertical fin. When considering the energy savings from the use of the model with an 18-inch combined lightshelf, the graph indicates that energy savings were achieved during March 21st, especially in the afternoon. The results of the annual energy analysis, including the annual energy savings are discussed in the next section.

4.3.3. DOE-2 Simulated Daylighting Energy Savings

This section discusses the results from the DOE-2 simulations regarding the calibration of monthly energy use of the multi-zone model with daylighting with the one-zone model without daylighting application, including the results of monthly energy use and the annual energy savings from each design application.

4.3.3.1. The calibration of monthly energy use

To study the results of monthly energy use from the DOE-2 daylighting model, the daylighting command was added to the DOE-2 input file to represent the multi-zone basecase model. The daylighting command added into the basecase-input file included the position of reference point, zone fraction for each reference point, light control system, view azimuth, and maximum glare set point. Further details of these daylighting commands are described in Appendix E. Using the simulation results, the monthly energy use of the one-zone model without daylighting and the multi-zone model with daylighting application were compared. Figures 4.57A – 4.57B plot the monthly electricity use comparison of these 2 studied models, and Figures 4.58A – 4.58B focus on the monthly natural gas use.

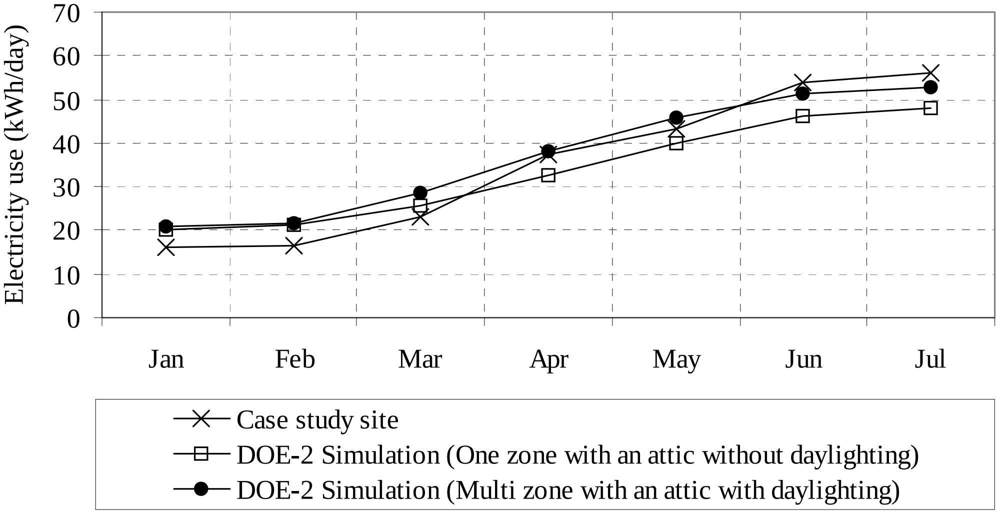


Figure 4.57A – Monthly electricity use comparison between the basecase model with and without daylighting.

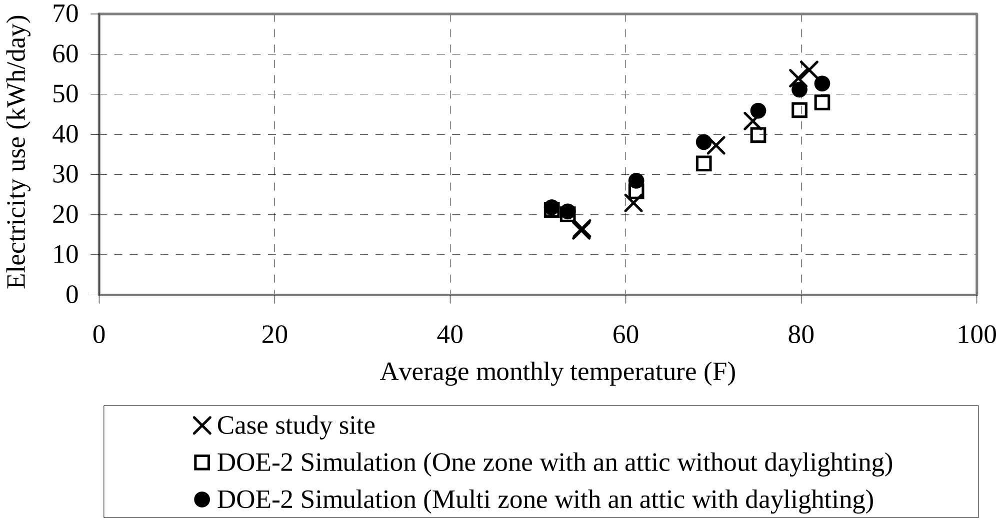


Figure 4.57B – Monthly electricity use vs. monthly average outdoor temperature.

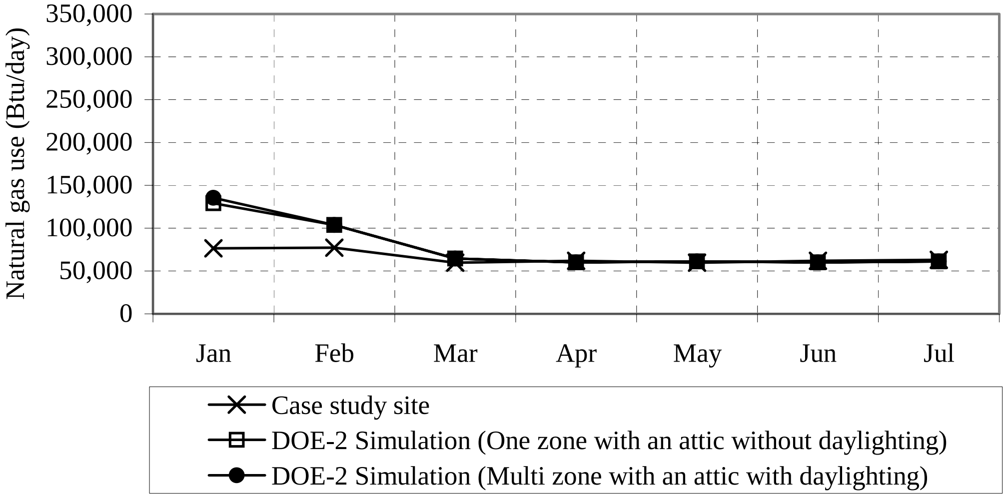


Figure 4.58A - Monthly natural gas use comparison between the basecase model with and without daylighting.

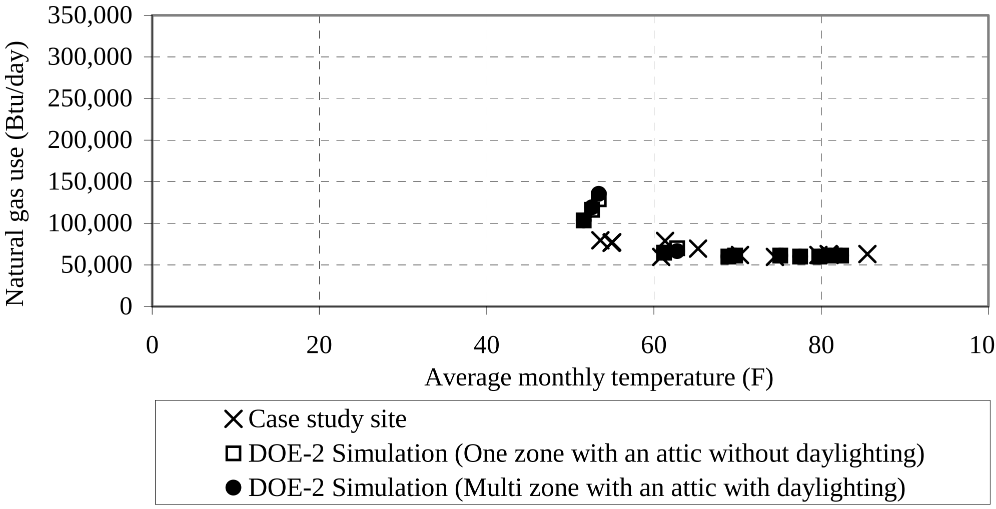


Figure 4.58B - Monthly natural gas use vs. monthly average outdoor temperature.

As seen from the plots, the daylighting commands increased the monthly electricity consumption. However, they had no effect on the monthly natural gas use. This increase appears to be due to the “switching-on” of the daylighting command. To examine the increase in electricity use after daylighting was applied to the basecase simulation, the results of the monthly cooling and lighting electricity use of the 2 cases were compared. The comparisons are presented in Figure 4.59 and Figure 4.60 respectively.

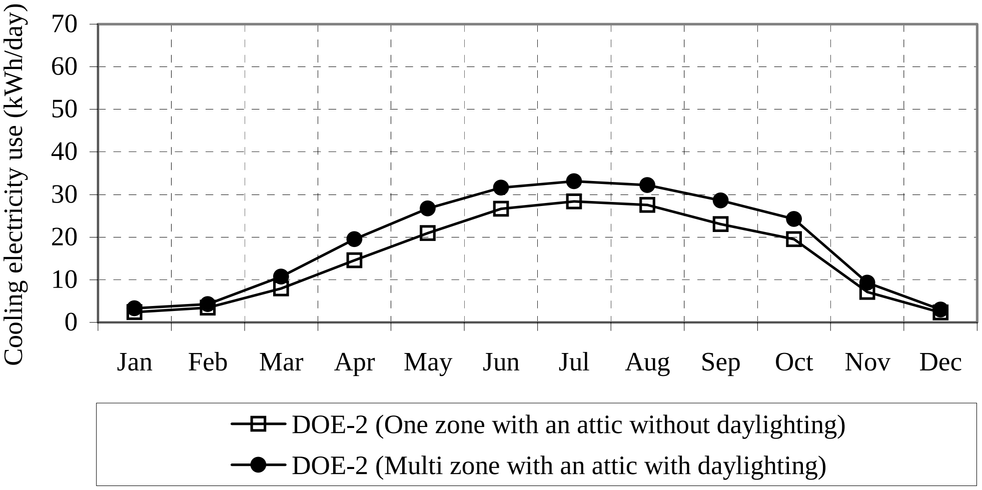


Figure 4.59 - Monthly cooling electricity use comparison between the basecase model with and without daylighting.

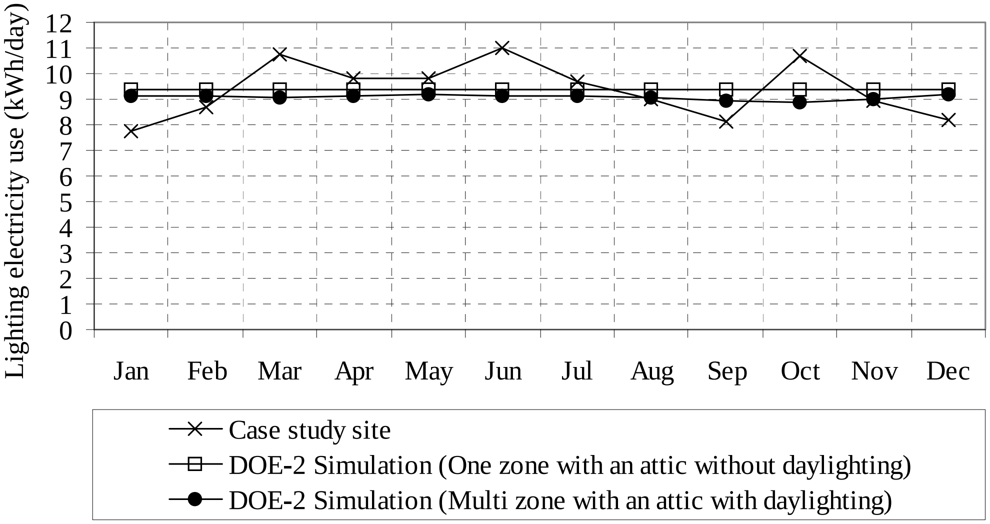


Figure 4.60 – Monthly lighting electricity use comparison between the basecase model with and without daylighting.

Figures 4.59 – 4.60, including Figure 4.61 clearly show that daylighting application in the simulation did increase the cooling electricity use. Nevertheless, there was a slight reduction in lighting electricity use when daylighting was employed. In calibrating the monthly lighting electricity use of the multi-zone daylighting model with the one-zone model, the input data in daylighting command section was adjusted in order to acquire the result matching.

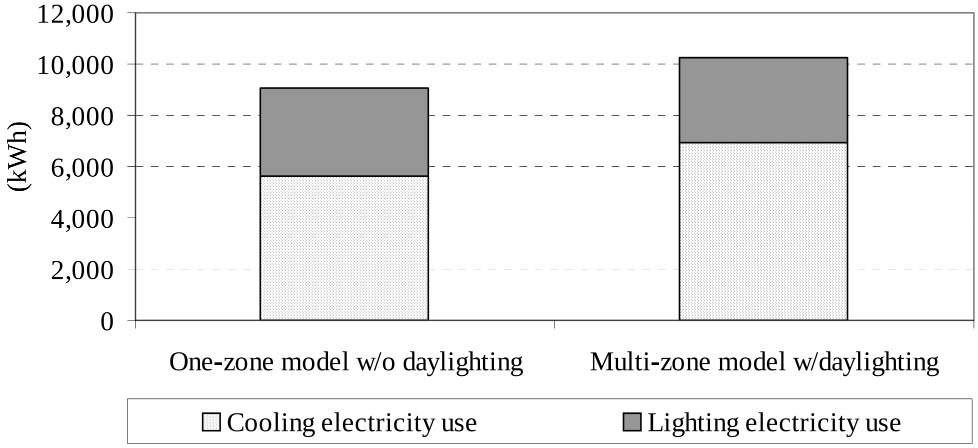


Figure 4.61 – Cooling and lighting electricity use comparison between the basecase one-zone model without daylighting and the multi-zone model with daylighting.

The study discovered that, in the simulation, DOE-2 could not recognize the use of lighting electricity if the set point level of the light was not high enough to turn the light on. In other words, DOE-2 considered daylight as the lighting source that contributed to the interior set point level and disregarded the use of artificial lighting. To obtain the lighting electricity consumption of the multi-zone model with daylighting, and to match the result of lighting electricity use with the one-zone basecase model, the light set point level in the simulation was set so high that DOE-2 could recognize the use of lighting in the model. Additional details in daylighting command input are shown in Appendix E.

4.3.3.2. Monthly energy use evaluation

After the acceptable calibration was achieved, the multi-zone basecase model with daylighting was then used as the basecase model for studying the comparison of energy savings from using daylighting. To analyze the energy savings resulting from the use of proposed shadings, this study simulated the models with the proposed design options and compared the results of the monthly energy uses with the basecase model. Figures 4.62 – 4.65 illustrate the comparisons of monthly energy uses between the basecase model and the models with proposed designs. These figures show the monthly electricity use, natural gas use, cooling electricity use, and lighting electricity use respectively.

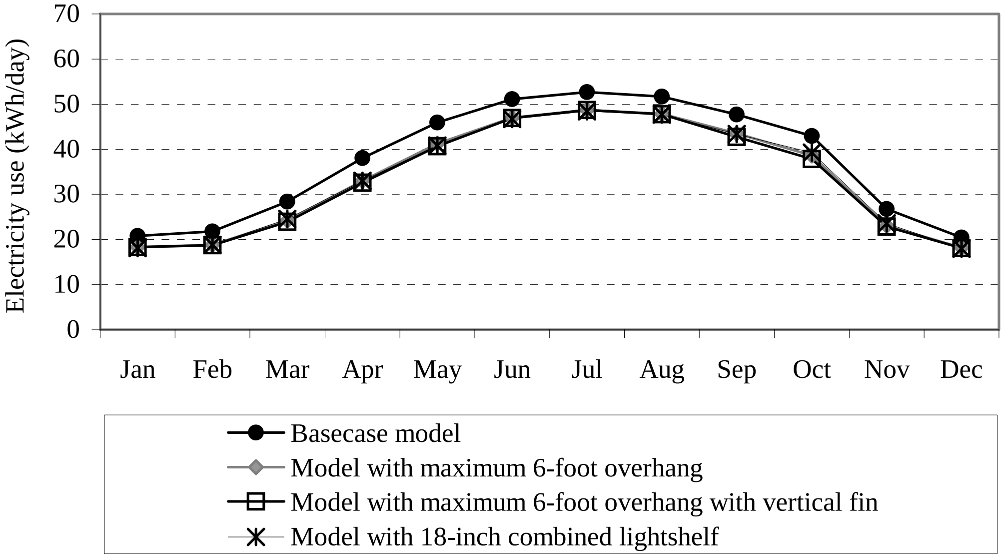


Figure 4.62 – Monthly electricity use comparison of the proposed models and the basecase daylighting model.

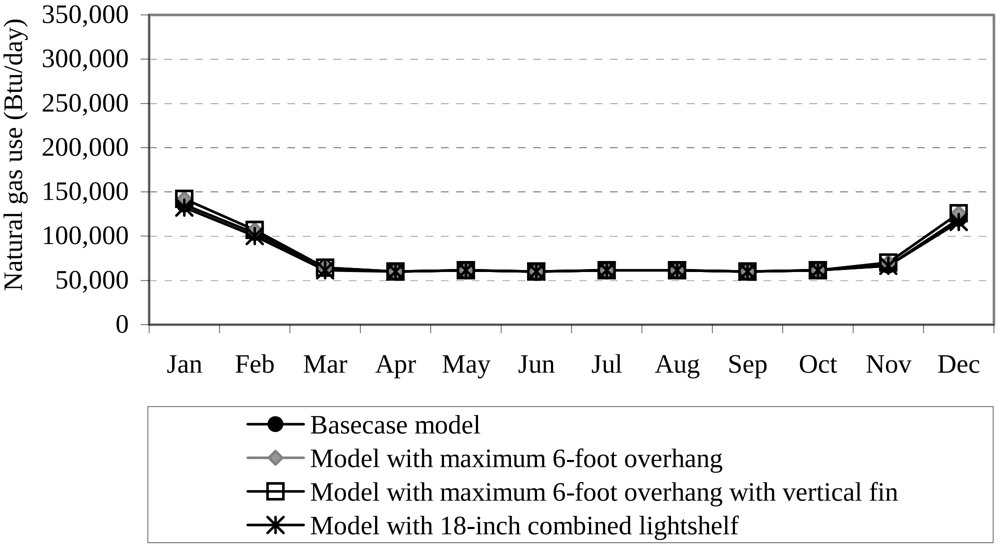


Figure 4.63 – Monthly natural gas use comparison.

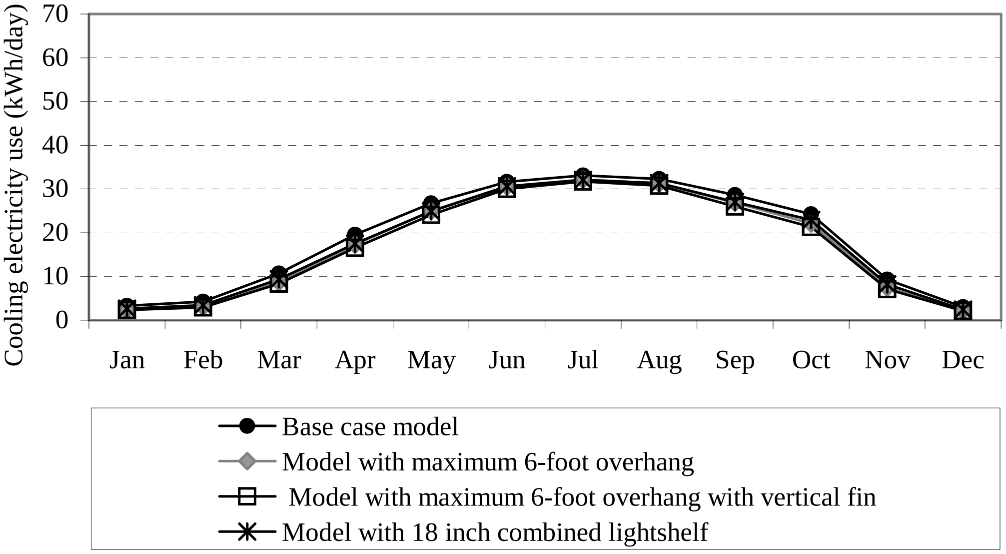


Figure 4.64 – Monthly cooling electricity use comparison.

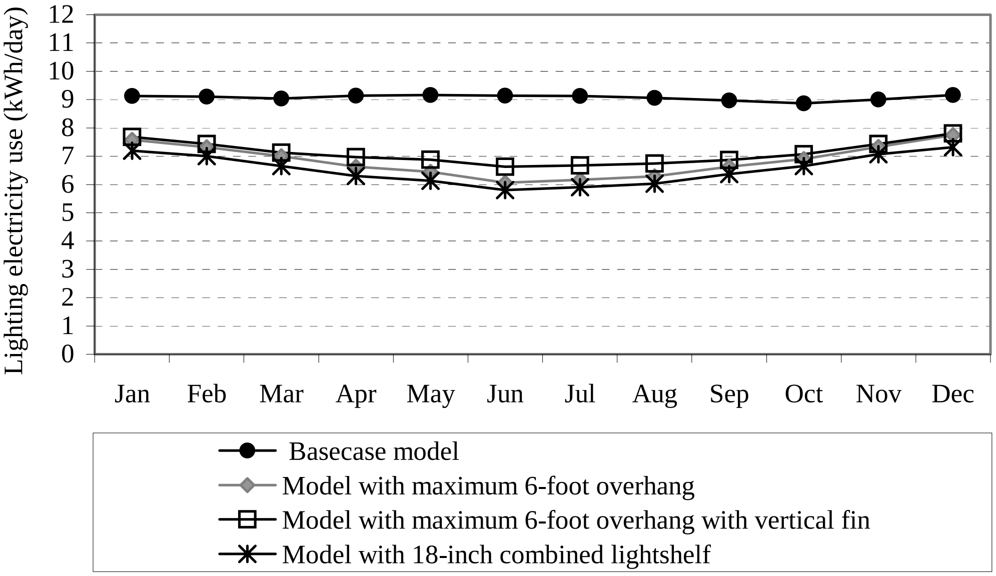


Figure 4.65 – Monthly lighting electricity use comparison.

As seen from Figure 4.62, the basecase model consumes the highest electricity, which is because of the high cooling and lighting electricity use. In the cooling electricity use, the models with maximum shadings (6-foot overhang, and 6-foot overhang with vertical fin) produced some reductions in the cooling energy use since the shadings contributed to the reduction of solar heat gain. From the simulation results, most of energy savings were obtained from lighting. As seen in Figure 4.65, the basecase model used the highest monthly lighting electricity while the model with 18-inch combined lightshelf consumed the lowest. Among the three proposed models, the model with maximum 6-foot overhang with vertical fin was most effective in preventing the solar heat gain. However, it gained the least benefit of daylight. The model with 18-inch combined lightshelf had a clerestory window and internal shelves that enhanced the use of daylight, and accounted for the reduction of lighting energy use.

Table 4.18 summarizes the annual energy end use from the simulations of the basecase model and the other 3 models with design shadings. The difference in energy uses among the models studied is also illustrated in Figure 4.66, which shows the report of total energy uses in 7 categories including domestic hot water, miscellaneous equipment, pumps and miscellaneous, ventilation fan, space heating, space cooling, and lighting.

Table 4.18 – Energy end use reports of the basecase model and the models with proposed designs.

Categories (MBtu)	Basecase	6-foot overhang	Diff (%)	6-foot shading	Diff (%)	18-inch lightshelf	Diff (%)
DHW hot water	14.9	14.9	0.0	14.9	0.0	14.9	0.0
Misc. equipment	9.2	9.2	0.0	9.2	0.0	9.2	0.0
Pumps and misc.	0.2	0.2	0.0	0.2	0.0	0.2	0.0
Ventilation fan	2.3	2.1	-8.7	2.1	-8.7	2.1	-8.7
Space heating	12.8	13.4	4.7	13.3	3.9	12.3	-3.9
Space cooling	23.6	21.8	-7.6	21.2	-10.2	22.1	-6.4
Lighting	11.3	8.5	-24.8	8.9	-21.2	8.1	-28.3
Total	74.3	70.1	-5.7	69.8	-6.1	68.9	-7.3

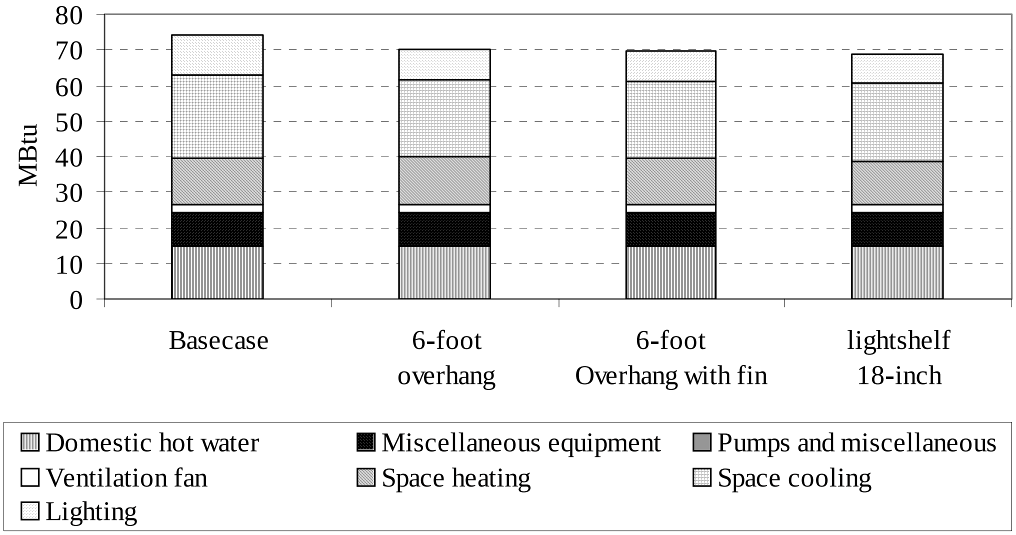


Figure 4.66 – Report of total energy use of the basecase model and the models with proposed designs.

4.3.3.3. Energy and cost savings evaluation

The data provided in Table 4.18 and Figure 4.66 suggest the total energy savings resulting from the use of proposed shadings. The optimum cooling energy savings were achieved in the model with maximum 6-foot overhang with vertical fin, which resulted in 10 % savings. The model with 18-inch combined lightshelf, offered the least cooling energy savings, yet provided lighting electricity savings up to 28%, which was the highest among the 3 design options. For the space heating energy use, the model with maximum overhang, and the model with maximum overhang with vertical fin consumed more heating energy than the basecase model did since the optimum shadings provided by these 2 models caused a heat loss during the heating season. However, around 3% heating energy saving was gained from the model with lightshelf.

In conclusion, despite the increase in heating energy use in the models with optimum shadings, the three studied models with proposed daylighting designs consumed less energy than the basecase model did in terms of the annual total energy uses. Table 4.19 presents the summary of energy savings categorized into electricity use in cooling and lighting, and natural gas use in heating. And Table 4.20 shows the annual energy savings. The cost savings were calculated based on the electricity costs at $0.075 per kWh and the natural gas costs at $0.60 per CCF.

Table 4.19 – Energy savings from the model with proposed daylighting designs.

DOE-2: Energy savings from basecase		
	Total use (MBtu)	
Type	**Electricity**	**Saving (%)**
Basecase model	46.6	
6-foot overhang	41.8	10.3%
6-foot overhang with vertical fin	41.6	10.7%
18-inch combined lightshelf	41.7	10.5%
Type	**Lighting elec.**	**Saving (%)**
Basecase model	11.3	
6-foot overhang	8.5	24.8%
6-foot overhang with vertical fin	8.9	21.2%
18-inch combined lightshelf	8.1	28.3%
Type	**Cooling elec.**	**Saving (%)**
Basecase model	23.6	
6-foot overhang	21.8	7.6%
6-foot overhang with vertical fin	21.2	10.2%
18-inch combined lightshelf	22.1	6.4%
Type	**Heating + DHW**	**Saving (%)**
Basecase model	27.7	
6-foot overhang	28.3	-2.2%
6-foot overhang with vertical fin	28.2	-1.8%
18-inch combined lightshelf	27.2	1.8%
Total energy use reduction (Electricity + Natural gas)		
Type	**Total use (MBtu)**	**Saving (%)**
Basecase model	74.3	
6-foot overhang	70.1	5.7%
6-foot overhang with vertical fin	69.8	6.1%
18-inch combined lightshelf	68.9	7.3%

Table 4.20 - Energy cost savings from the model with proposed daylighting designs.

DOE-2: Energy cost savings from basecase			Annual	Savings
	Total use (kWh)		savings ($)	(%)
Type	***Electricity**	**Total cost ($)**	**Electricity**	**Electricity**
Basecase model	13,657.7	1,024.3		
6-foot overhang	12,250.9	918.8	$105.5	10.3%
6-foot overhang with vertical fin	12,192.3	914.4	$109.9	10.7%
18-inch combined lightshelf	12,221.6	916.6	$107.7	10.5%
Type	**Lighting elec.**	**Total cost ($)**	**Lighting**	**Lighting**
Basecase model	3,311.8	248.4		
6-foot overhang	2,491.2	186.8	$61.5	24.8%
6-foot overhang with vertical fin	2,608.4	195.6	$52.8	21.2%
18-inch combined lightshelf	2,374.0	178.0	$70.3	28.3%
Type	**Cooling elec.**	**Total cost ($)**	**Cooling**	**Cooling**
Basecase model	6,916.8	518.8		
6-foot overhang	6,389.2	479.2	$39.6	7.6%
6-foot overhang with vertical fin	6,213.4	466.0	$52.8	10.2%
18-inch combined lightshelf	6,477.1	485.8	$33.0	6.4%
Type	***Heating (CCF)**	**Total cost ($)**	**Natural gas**	**Natural gas**
Basecase model	270.5	162.3		
6-foot overhang	276.4	165.8	-$3.5	-2.2%
6-foot overhang with vertical fin	275.4	165.2	-$2.9	-1.8%
18-inch combined lightshelf	265.6	159.4	$2.9	1.8%
Total energy cost (Electricity + Natural gas)			**Elec. + N.G.**	**Elec. + N.G.**
Type	**Total cost ($)**		**Total savings**	**(%)**
Basecase model	1,186.6			
6-foot overhang	1,084.6		$102.0	8.6%
6-foot overhang with vertical fin	1,079.7		$107.0	9.0%
18-inch combined lightshelf	1,076.0		$110.6	9.3%

** The electricity costs were calculated at $0.075 per kWh and *the natural gas costs at $0.60 per CCF.*

4.4. SUMMARY

This chapter discusses the results from the DOE-2 basecase model calibrations, the Daylight Factor measurements and shading evaluation, and the DOE-2 energy simulations.

Results from the model calibrations suggested the acceptable variables used in simulating the DOE-2 basecase single zone model with an attic zone. These appropriate variables included the use of average daily schedules for representing lighting and receptacle and equipment electricity use, the use of custom weighting factors in both the attic and the residence space, and the use of ground temperatures collected from the case study site rather than the TMY2 weather tape. This calibrated DOE-2 model was used to represent the case study building and was then used in the comparative study of the proposed daylighting models.

Results from the shading evaluation concluded that the most effective design in protecting the windows from the direct solar radiation during the cooling season was the model with the maximum 6-foot overhang with a vertical fin. However, regarding the Daylight Factors, this design considerably reduced the interior illuminance and was also consider impractical for building construction. The proposed final design, the model with 18-inch combined lightshelf, incorporated the benefit of an exterior shading device with an interior lightshelf that redirected sunlight and skylight into the space. The final design was found decreasing the Daylight Factors by only a small amount.

Results from the DOE-2 energy simulations focused on the daylighting simulations on vernal equinox, and the DOE-2 simulated monthly energy savings. The study on vernal equinox included the thermal analysis on the window conduction and the solar heat gain evaluation through two specific windows. Results from the study showed that the 6-foot overhang model and the model with 6-foot overhang with vertical fin produced the most reductions in the solar heat gain and resulted in the highest savings on building cooling load. The analysis on building energy consumption showed that the basecase model consumed the highest electricity in cooling and lighting use. The two models with maximum overhang and shading produced the most reductions in cooling energy use, while the lightshelf model offered the most savings in lighting electricity. The study concluded that for the total building energy use, the 18-inch lightshelf model produced the maximum energy savings.

The summary showed that energy savings could be achieved by the use of daylighting application in building. The evaluation of proposed shading designs, in terms of their contribution to the energy savings in building operation, was based on the simulations using DOE-2 daylighting and energy simulation program. Results from the study suggested the benefit of using daylighting in building and also provided useful information for developing guidelines on daylighting application in low-cost housing.

CHAPTER V

FUTURE WORK AND RECOMMENDATIONS

This chapter presents recommendations about future work concerning the use of daylighting to achieve energy savings in low-income housing. Discussions in this chapter include the recommendations for the case study building model calibration, the use of a physical scale mode in Daylight Factor measurement, and the DOE-2 daylighting and energy simulations.

5.1. RECOMMENDATIONS FOR THE CASE STUDY BUILDING MODEL CALIBRATION

The basecase model calibration in this study focused on 2 primary results, which covered the temperature calibration and monthly energy use calibration. The DOE-2 input variables were adjusted in order to match the simulation results with the case study site data. The calibrated model was assumed to represent the basecase building and was then used for studying and evaluating the proposed daylighting strategies in terms of their contribution to interior Daylight Factors and energy reduction in operating building. This section suggests future work covering the basecase simulation with the use of U-EFFECTIVE in calculating the heat transfer through the underground surface, the simulation with the use of the case study site's center ground temperature, and recommendation on the zone temperature calibration.

5.1.1. The Basecase Model Simulation with the Use of U-EFFECTIVE for UNDERGROUND-FLOOR

Winkelmann (1998) reported the corrections and bug fixes for calculating the heat transfer through underground surfaces in DOE-2.1e. Since the program calculates the thermal mass of the underground surfaces, according to the use of custom weighting factors, by multiplying the U-value with the surface area and the temperature differences between zone temperature and ground temperature, the results of heat transfer are grossly overcalculated, when using TMY2 weather data. Therefore, he suggested the use of U-EFFECTIVE and the procedure for defining the underground surface construction using the perimeter conduction factor. This section presents the simulation results focusing on monthly energy uses from the simulations with corrected U-value of the UNDERGROUND-FLOOR.

Winkelmann (1998) suggested the procedure for defining the underground surface construction. Steps in calculating the U-EFFECTIVE for the basecase model simulation in this proposed study are presented below.

The slab-on-grade of the case study house is 31.9’ x 37.9’, is uninsulated and consists of uncarpeted, 4-inch heavy weight concrete (CC03 in DOE-2.1e library), with the linoleum tile finishing.

Use F2 (Perimeter Conduction Factors for concrete slab-on-grade) from Table 1 (Winkelmann 1998), which F2 = 1.10 Btu/hr-F-ft

Slab surface area: A = 31.9 x 37.9 = 1,209 ft^2

Slab exposed perimeter: P_{exp} = (2 x 31.9) + (2 x 37.9) = 139.6 ft

Effective slab resistance: R_{eff} = A/(F2 x P_{exp})

= 1209/(1.10 x 139.6) = 7.87

Effective slab U-value: U-EFFECTIVE = 1/R_{eff} = 0.127

Actual slab resistance: R_{us} = $R_{concrete} + R_{linoleum} + R_{film}$

= 0.44 + 0.05 + 0.77 = 1.26

Resistance of fictitious layer: R_{fic} = $R_{eff} – R_{us} – R_{soil}$

= 7.87 – 1.26 – 1.0 = 5.61

From DOE-2 Reference Manual (LBL 1980), the average air film resistance for heat flow up = 0.77 hr-ft^2-F/Btu. And from Winkelmann (1998), a 1-foot layer of soil has resistance = R_{soil} = 1 hr-ft^2-F/Btu.

Parts of the new DOE-2 input file using U-EFFECTIVE in specifying the UNDERGROUND-FLOOR materials and construction are shown in Figures 5.1 and 5.2.

```
$SLAB OB GRADE

MAT-FIC-1 = MATERIAL
            RESISTANCE = 5.61  ..             $ R-FIC VALUE

SOIL-1    = MATERIAL
            THICKNESS = 1.0  CONDUCTIVITY = 1.0
            DENSITY = 115    SPECIFIC-HEAT = 0.1  ..

FL-1-1 = LAYERS
         MATERIAL = (MAT-FIC-1,SOIL-1,CC03,LT01)
         I-F-R = 0.77  ..

$       CC03 =CONCRETE 4", HEAVY WEIGHT, RESISTANCE =0.44
$       LT01 =LINOLEUM TILE, RESISTANCE =0.05
```

Figure 5.1 – DOE-2 input in specifying building material description of the new underground slab.

```
U-F       CONS = FLOOR-1
          AREA = 1209
          TILT = 180
          U-EFFECTIVE = 0.127  ..
$         SOLAR-FRACTION =        ONLY IF CWF TO BE  CALCULATED
$         INSIDE-VIS-REFL = 0.2    DEFAULT FOR FLOOR
$         INSIDE-SOL-ABS =  0.8    DEFAULT FOR FLOOR
```

Figure 5.2 – DOE-2 input using U-EFFECTIVE in specifying UNDERGROUND-FLOOR.

Winkelmann (1998) also suggested the use of ground temperatures from the weather tape when using this method. However, results from the simulations showed some discrepancy between the simulations using the U-effective with the TMY2 ground temperatures and with the ground temperatures from the case study site (north). The comparison of simulated monthly energy uses between the 3 simulations and the hourly data from the case study site are presented. The three simulations included the simulated basecase model without U-EFFECTIVE with the use of the case study site's ground temperatures, the simulation with U-EFFECTIVE with the case study site's ground temperature, and the simulation with U-EFFECTIVE using the TMY2 ground temperatures. Figures 5.3A – 5.3B show the simulation results of monthly electricity use from the three simulations and from the case study site data. Figures 5.4A – 5.4B show the results of monthly natural gas use. Data presented in the figures were in the unit of energy use per day.

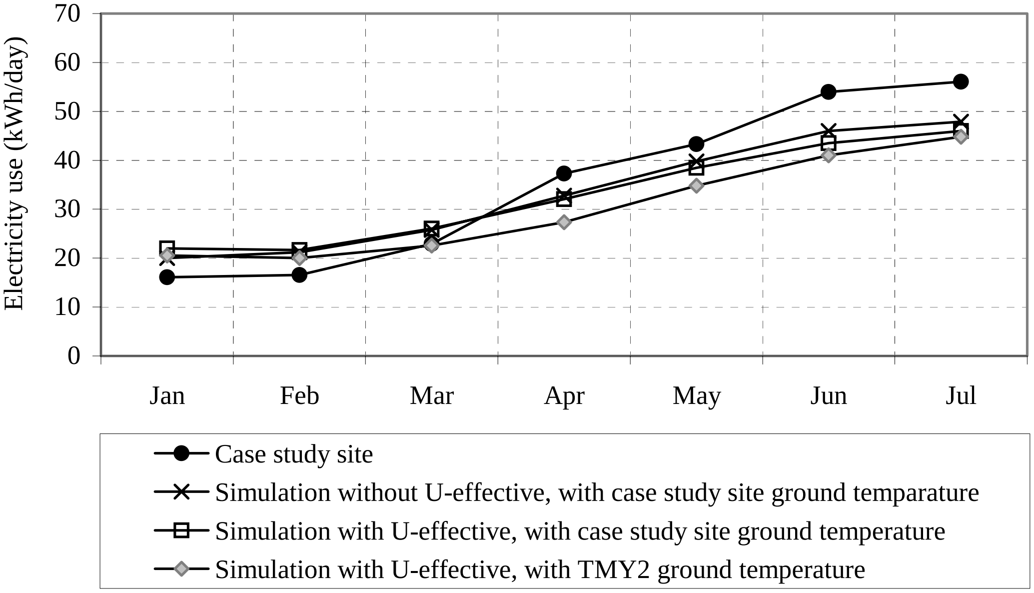


Figure 5.3A – Monthly electricity use from DOE-2 simulations with U-EFFECTIVE and the use of different ground temperatures.

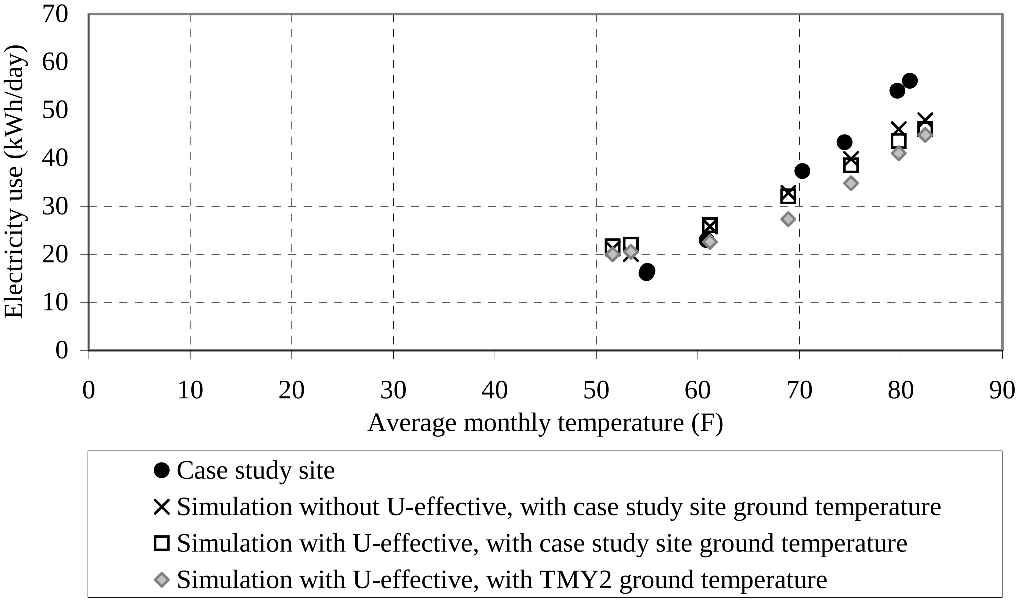


Figure 5.3B – Monthly electricity use from DOE-2 simulations with U-EFFECTIVE vs. average monthly outdoor temperature.

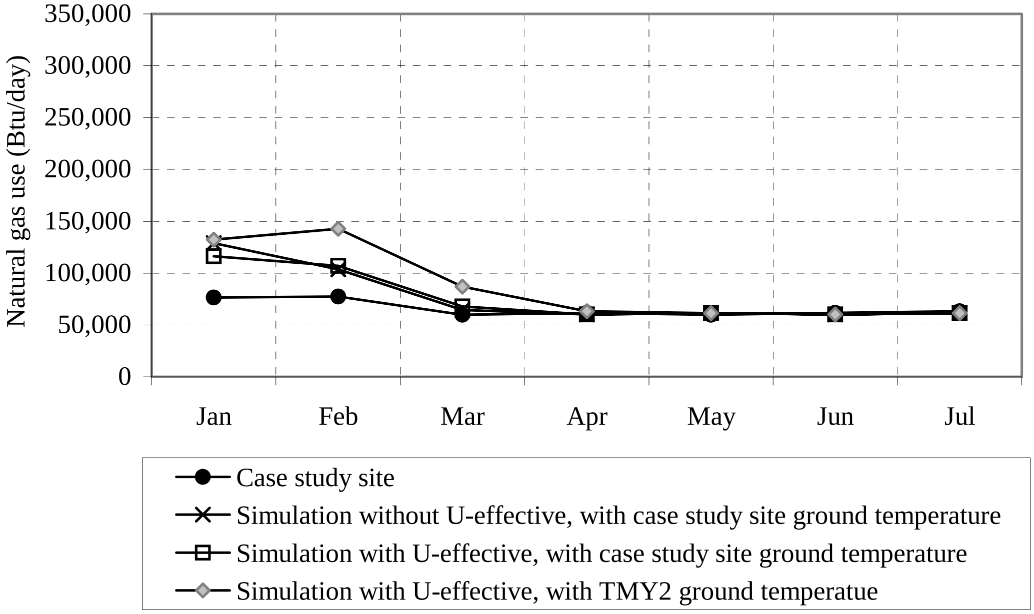


Figure 5.4A - Monthly natural gas use from DOE-2 simulations with U-EFFECTIVE and the use of different ground temperatures.

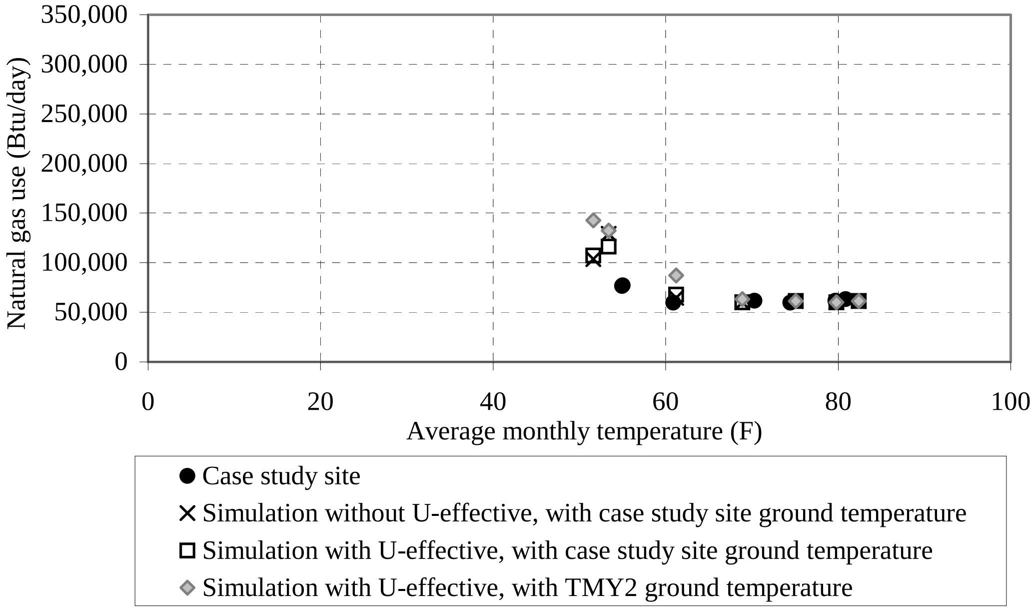


Figure 5.4B – Monthly natural gas use from DOE-2 simulations with U-EFFECTIVE vs. average monthly outdoor temperature.

Results from the simulation as presented in Figures 5.3 A – B and Figures 5.4 A – B showed that the use of different U-values in DOE-2 calculating the heat transfer through underground surfaces altered the results in monthly energy uses. To study the effect of using the calculated U-EFFECTIVE on building energy uses, one of the two models which were simulated with the case study site's ground temperatures was input by the calculated U-EFFECTIVE in UNDERGROUND-FLOOR command. When considering the energy use production compared between these 2 models simulated with and without the use of U-EFFECTIVE, monthly electricity and natural gas uses resulting from the simulated model with U-EFFECTIVE were slightly lower than those of the simulated model with raw U-value. Results from the simulations agreed that the use of the raw U-value in DOE-2 overestimated the calculation of heat transfer through underground surfaces. To achieve a better underground surface heat transfer calculation in DOE-2, the study suggests the use of U-EFFECTIVE in defining the underground surface construction when simulating the building using the custom weighting factors for the UNDERGROUND-FLOOR or the UNDERGROUND-WALL constructions. Please refer to the report by Winkelmann (1998) in the Building Energy Simulation User News, Volume 19 (1) for more information on an input file example.

As seen from the figures above, there was a significant change when simulating the model by using the U-EFFECTIVE and the ground temperatures from the TMY2 weather tape. Results showed that monthly electricity use from this simulation was obviously lower than the electricity uses of the other simulated models, while the natural gas use was higher. The results suggest a notable impact of using ground temperatures in simulating the case study model on the energy use production. In future studies, care needs to be taken when using the ground temperatures from various sources in order to acquire accurate calculations of the building energy use, especially the heating/cooling energy use.

5.1.2. The Monthly Energy Use Calibration

In the energy use calibration, results of monthly energy uses derived from the DOE-2 simulations were calibrated with the energy use data obtained from the case study building. The study found that a closer agreement on monthly energy uses was achieved from the simulation that used the ground temperature obtained from the case study site rather than the use of ground temperature from the TMY2 weather tape. The case study site's measured ground temperature was collected using temperature sensors installed in the house at 3 locations: below the slab at the center of the house, and 3 feet from the edge of the slab on the north and the south sides (Kootin-Sanwu 2003). In Figure 5.5 are the profiles of the case study site's ground temperatures obtained from the center, north and the south side, and the ground temperature from the TMY2 weather tape. As shown in the figure, the north-side temperatures represented a more realistic temperature profile that increased in the summer and decreased in the winter, whereas the center temperature decreased in the summer and increased in the winter.

Although this appears to be a condition of this specific site, it seems to indicate that the center temperatures track the thermostat setting, as show in Figure 5.6, and the north sensor tracks the delayed outdoor ambient temperatures. The south temperatures seem to be influenced by the solar radiation. Future studies of this house might have improved results with three floor slabs, one for each ground temperature.

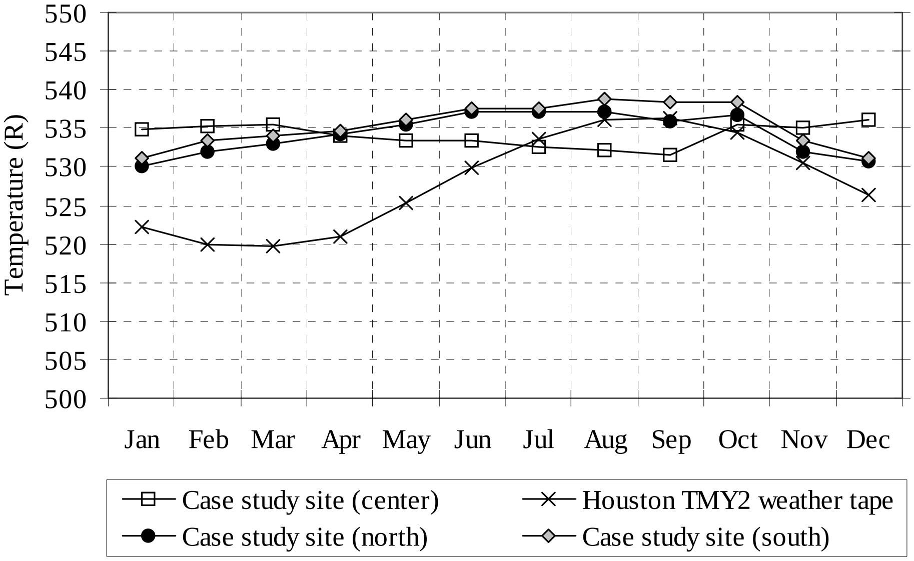


Figure 5.5 – Monthly average ground temperature from the case study site: center, north and south locations, and the Houston TMY2 weather tape.

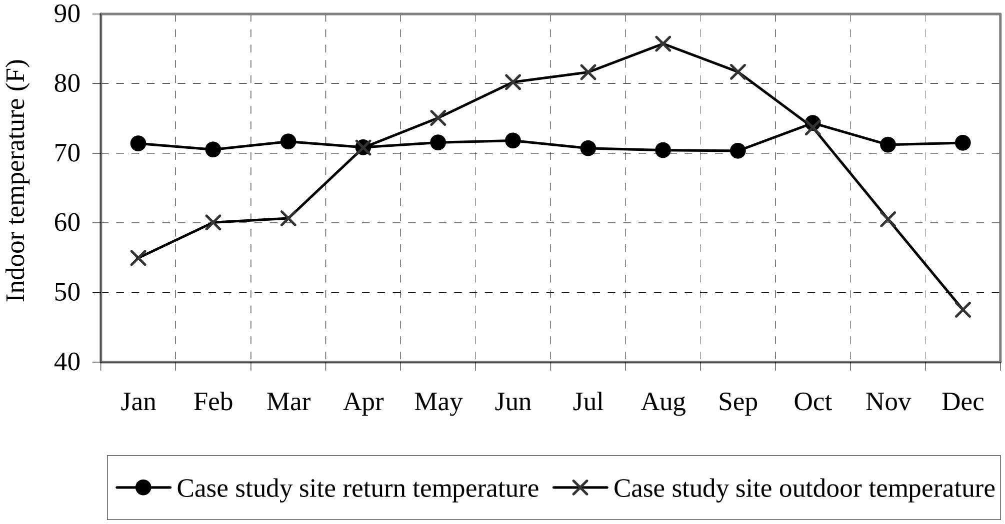


Figure 5.6 – Monthly average indoor and outdoor temperature from the case study site.

In Figures 5.7A – 5.7B show the comparison of the monthly electricity uses from the simulations with the 2 ground temperatures, the case study site data, and the simulation with the ground temperature from the TMY2 weather tape. Figures 5.8A – 5.8B show the comparison of monthly natural gas use. Please note that these simulations were not included the account of U-EFFECTIVE in specifying UNDERGROUND-FLOOR.

When considering the calibration of monthly energy uses from the DOE-2 simulations with the data obtained from the case study site, it can be seen that the DOE-2 simulation with the ground temperature from the center offered a good agreement on monthly natural gas use, compared to the simulation with the north-side ground temperature. However, using the center ground temperature in a simulation caused a significant change in monthly electricity use, and disagreed with the calibration. For future studies, careful consideration should be taken in selecting ground temperatures from different sources or locations for DOE-2 input.

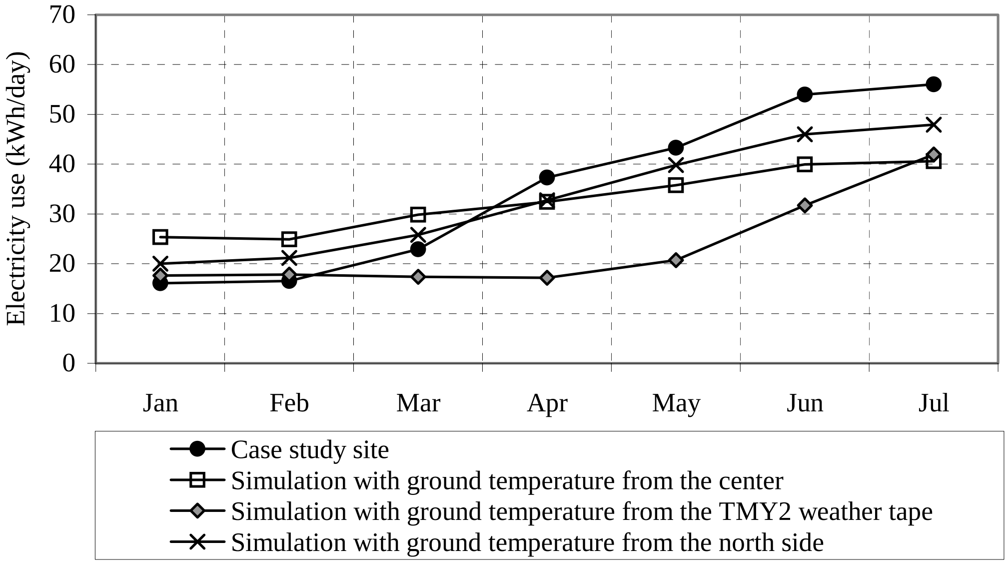


Figure 5.7A – Monthly electricity use from DOE-2 simulations with the 2 ground temperatures.

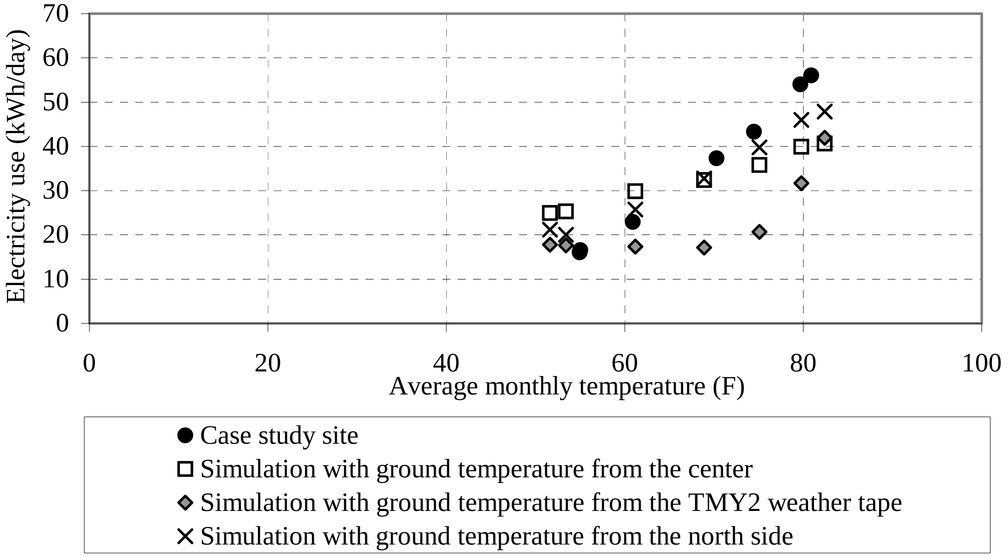


Figure 5.7B – Monthly electricity use from DOE-2 simulations with the 2 ground temperatures vs. average outdoor temperature.

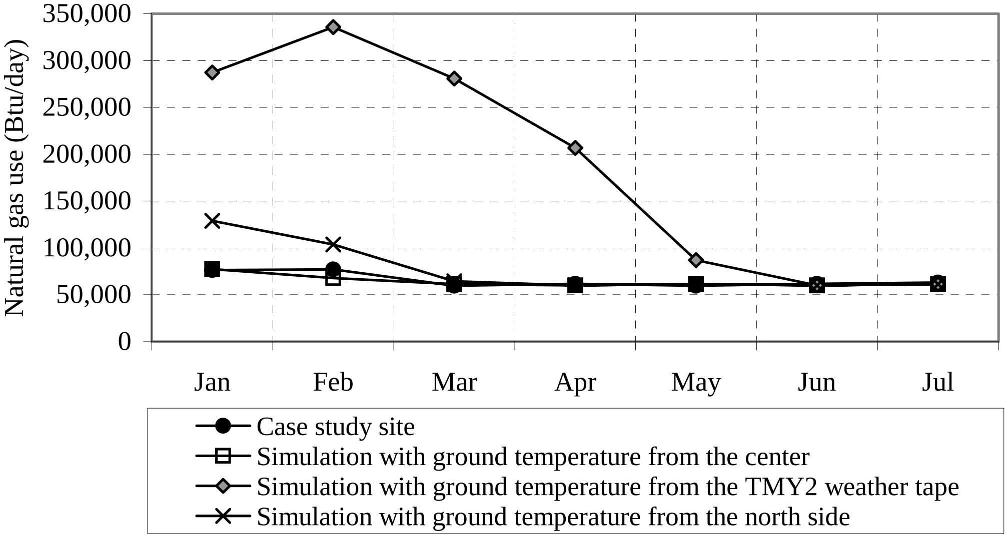


Figure 5.8A – Monthly natural gas use comparison of DOE-2 simulation**s** with the 2 ground temperatures.

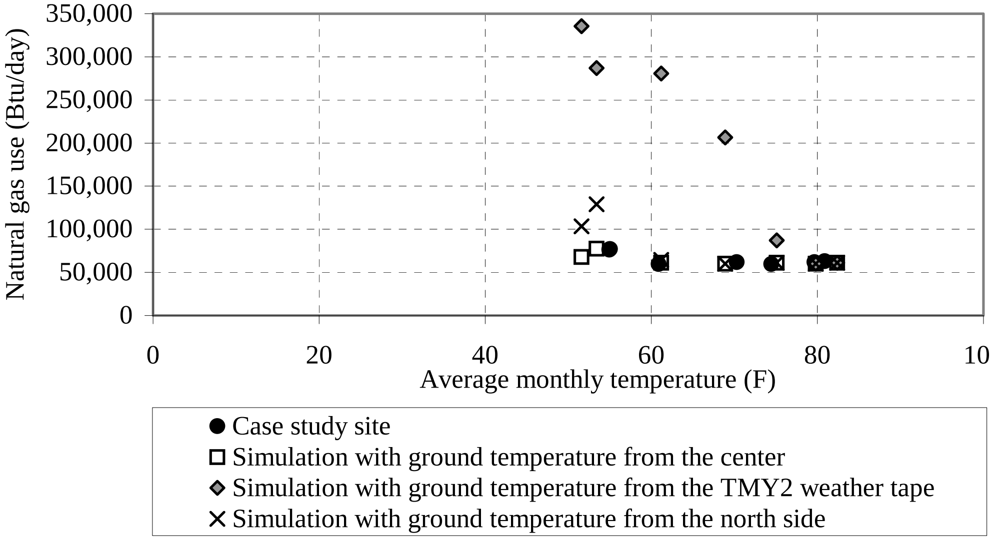


Figure 5.8B – Monthly natural gas use of DOE-2 simulations with the 2 ground temperatures vs. average outdoor temperature.

5.1.3. The Zone Temperature Calibration

This study focused on the calibration of two zone temperatures, namely the attic space and the residence space temperatures. The temperature profiles derived from the DOE-2 simulations were compared with the temperature data obtained from the data loggers installed in the case study building. By plotting the DOE-2 simulation results against the case study site data, it can be seen that the matching temperature profiles indicated acceptable calibration results. However, future study is needed to explore a closer agreement on residence space temperatures. Moreover, additional work on temperature calibration is recommended based on the standard statistical measures of the coefficient of variation (CV) and mean bias error (MBE) as defined by Kreider and Haberl (1994), which can then be combined into a global CV with energy use.

5.2. RECOMMENDATIONS FOR THE USE OF A PHYSICAL SCALE MODEL IN DAYLIGHT FACTOR MEASUREMENTS

In the Daylight Factor analysis, this study used a physical scale model and the measurements under an actual non-uniform overcast sky as a means to evaluate the proposed designs in terms of their contribution to space illuminance. Recommendations on the study of Daylight Factors and some considerations for using the physical scale model method are discussed in this section.

5.2.1. The Use of an Overcast Sky and Recommendations on the Development Using Daylighting Laboratory in Daylight Factor Measurements

5.2.1.1. Recommendations on the use of an overcast sky

To conduct Daylight Factor measurements under an actual sky, the sky conditions and the location of a model were the primary factors that should be taken into consideration. This study focused on an experiment that used the CIE overcast sky. The CIE sky is the non-uniform overcast sky having the zenith luminance three times the horizon luminance. Before conducting the measurement, sky luminance should be measured at different degrees to verify the distribution of luminance from the zenith to the horizon, according to the CIE formulation. However, the changing or uncontrollable conditions of the sky during the testing process can cause a great chance of errors. Measuring daylight in relative measurements rather than absolute terms, as defined in the Daylight Factor formulation, is considered an effective approach in correcting the varying sky conditions and has been used in the field measurement for some time.

Hence, the placement of a model during daylighting experiment is another important consideration. Models should be placed in the position that all of its side openings, which allow outdoor light into an interior, face a sky horizon. The floor around the model should be covered with a light-absorption surface, i.e. a black non-reflectance surface, to prevent the reflection of ground light into the model light openings. During the experiment, care should be taken to guard against local obstructions such as trees and buildings which can affect the distribution of skylight. Attention should also be paid for unwanted direct light penetrating the model space, which can substantially alter test results.

5.2.1.2. Recommendation on the use of daylighting laboratory: sky simulator

Since testing a model under actual sky conditions often experiences problems of unpredictable sky conditions, the development of sky a simulator has provided a means to overcome these problems. The sky simulator, known as the artificial sky, simulates a fixed sky condition usually a uniform or a non-uniform overcast sky used for daylighting study. To assure that the sky simulator bears close simulation to the actual sky, a close calibration of sky luminance is strongly required. Accurate sky simulators need to represent an actual sky condition in terms of its luminance distribution, both vertically and horizontally, according to the CIE overcast sky.

5.2.2. The Construction of a Physical Scale Model

Physical scale models have long been used as an evaluation tool for studying daylight since they can simulate the performance of light and offer visual observations for daylighting analysis in a real space. The complexity of model construction depends on the number of details put into the model. A model for quantitative study does not require as substantial number of details as a model for qualitative study does. Three factors that should be considered in constructing the physical scale model for quantitative daylighting study include the model size, materials used, and window glazing transmittance.

5.2.2.1. The model building scale

Theoretically, the scale used to build a model is of no significance. However, an appropriate scale often depends on practical considerations for daylight measuring; the relative size of a measuring tool such as a light meter or a photo-sensor probe and its access into the model are of primary factors. Recommended sizes for quantitative-study models include a scale of 1 inch to 1 foot for a small building interior with a ceiling height of 10 feet or less, and a scale of ½ inch to 1 foot for a larger interior space (Bryan et al. 1981). Approximate doubling of these scales is needed for a qualitative-study model to provide enough space for realistically visual observations.

Positioning of the light meter during the measurements is another practical consideration. The model should be provided with an access hole to allow the reach of instruments. In addition, the flexibility of the model in modifying architectural components as part of the proposed design is strongly required for easy manipulation of design comparisons.

5.2.2.2. The model materials

There are a variety of materials that can be used in constructing a model, for example plywood, cardboard, and foamboard. The primary concern in selecting materials is their opacity property. Only opaque material can be used in building the daylighting-study model. Another important consideration is the reflectivity of model's internal surfaces. The model for quantitative study may have surfaces finished with paper or paint which provide approximate reflectance as in the building interiors, whereas the models for qualitative study requires the use of surface finishes which duplicates real building materials. Care must be taken to accurately model the details of light openings and the building geometry.

5.2.2.3. The window glazing in models

The use of window glass materials in the model can be either the proposed glazing material or an acrylic plastic sheet which duplicates the building glass. It is very important to always consider that the selected materials need to have the same visible transmission as the proposed building glass. Other architectural or window elements that can affect the glazing transmittance also needed to be accurately modeled. It is recommended to calibrate the window glazing transmittance of the basecase model with that of the actual building.

5.2.3. The Measurement Using a Physical Scale Model

According to the IESNA, the recommended illuminance values for various visual tasks are defined at the work-plane level. The activities of occupants in a building are the primary factor in determining the lighting levels needed and the positions of working plane. The position of a light meter or photo sensor in measuring the room illuminance depends on the objective of the study. In the study of the distribution of light, the use of a reference grid on the room floor is recommended for positioning the light meter in comparative illuminance measurements. While in the study of the vertical illuminance penetration, mostly in a side-lit room with deep space, a light meter should be positioned along the room axis perpendicular to the daylight source.

Results from the model measurement should be compared with the measurements in the building studied. However, the comparison may experience errors which result from household furnishings or local obstructions. Considerations on modeling interior details which affect the performance of light in the building is more concentrated for a qualitative study. As this quantitative study mostly focused on the evaluation of proposed designs in terms of an increase or reduction in interior illuminance, meticulous details in furniture modeling were omitted.

5.2.4. Further Studies on Daylighting Design and Strategy

This study focused on the design of window external shadings aimed at blocking solar beam radiation and enhancing the room brightness. The study proved the effectiveness of the lightshelf daylighting system together with an automatic light dimming system, and verified the energy savings from the use of daylighting. The designs proposed in this study mainly focused on the cooling season. Further studies are needed to investigate alternative designs in low-income housing in other climates.

5.3. RECOMMENDATIONS FOR THE DOE-2 DAYLIGHTING AND ENERGY SIMULATIONS

The use of DOE-2 simulation program provided an evaluation tool for studying daylighting and energy consumption due to the application of daylight in a building. However, since the current version of DOE-2 program allows the user to model only geometric building forms, it has a major limitation in simulating buildings with curved or complex shapes. The simulation geometry is presented by using a DOE-2 plug-in recognized as the DrawBDL program. The latest version of the DrawBDL program (version 3.0) was released in 2000. Comparing to the previous DrawBDL version 2.02 (1993), this latest version has a user-friendly interface and more developed functions that can present other geometric shape besides a rectangular shape. Nevertheless, the study discovered some errors in using the DrawBDL version 3.0 to display the model geometry. The displays of model simulation geometry using the DrawBDL program version 2.02 and version 3.0 taken from the same DOE-2 input file are presented in Figures 5.9 and 5.10 respectively. The differences between the use of these 2 program versions can be noticed in the figures.

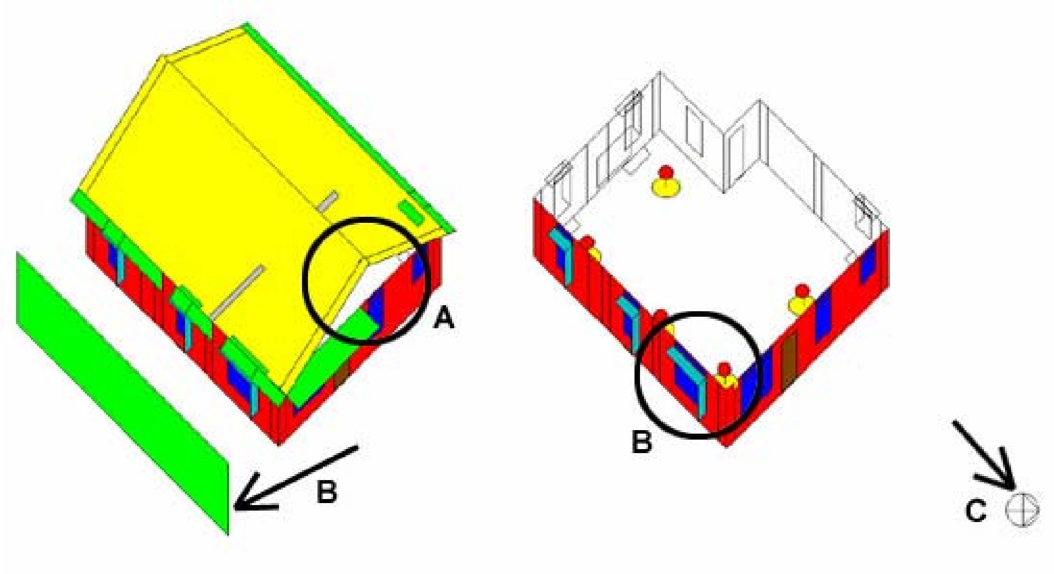


Figure 5.9 – Display of the DOE-2 simulation geometry using the DrawBDL program version 2.02 (1993).

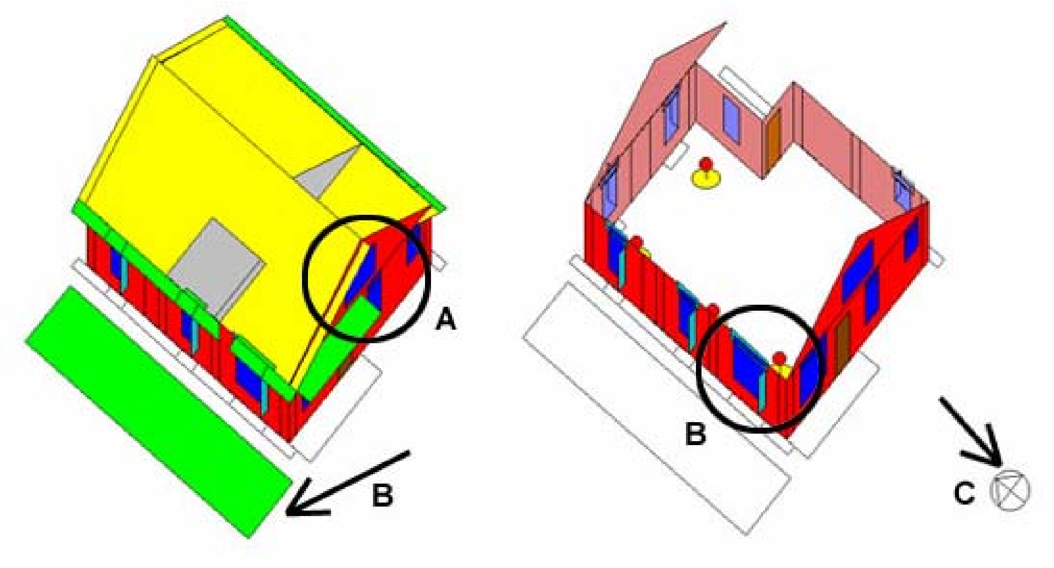


Figure 5.10 – Display of the DOE-2 simulation geometry using the DrawBDL program version 3.0 (2000).

When comparing the simulation geometry in Figure 5.9 and Figure 5.10, it can be seen that the use of the old DrawBDL version (version 2.02), as presented in Figure 5.9 had problems in displaying non-rectangular shapes. Since the version 2.02 program was unable to draw the triangular walls on the gable ends of the simulation geometry, the more accurate presentation could be obtained by using the newer version as indicated in circle A.

However, some errors can be noticed in the display of geometry using the latest DrawBDL version, shown in Figure 5.10. In the differences pointed in circle B of these 2 figures, it can be seen that the use of the new DrawBDL version could not accurately display the angles of the window overhangs and building shades, as shown in circle B. Additional errors are shown in circle C when comparing the 2 figures. The display of compass legend by using the new DrawBDL version indicated an error reading of the building orientation, while the old DrawBDL showed a correct orientation. From this study, it is recommended that careful consideration should be taken in using the DrawBDL program to present simulation geometry of the DOE-2 models.

5.4. SUMMARY

This study focused on the application of daylighting in low-income housing with an objective of enhancing the interior illuminance without increasing heat gain in the building. The use of daylight in a building is also aimed at reducing the energy use in lighting and cooling, which contribute to overall energy savings in operating the building. This study proposed several daylighting strategies and evaluated the designs in terms of the Daylight Factor contributions and building energy reductions. The comparison results analyzed in this study together with the future work presented in this chapter provide recommendations and guidelines for future studies on daylighting and energy reduction in the low-cost housing.

Due to the constraint of time, this study omitted an economic and cost analysis. While future studies are needed in order to explore alternative daylighting and energy-efficient designs for low-income houses, in-depth economic analysis is also necessary to evaluate the economic benefit from the use of daylighting in saving energy.

CHAPTER VI

CONCLUSIONS

This chapter summarizes the results from the previous chapters, which include: 1) conclusions about the use of the case study building and the model calibration, 2) conclusions of Daylight Factor measurements and results, and 3) conclusions of DOE-2 daylighting and energy simulations. This chapter also discusses guidelines for daylighting and energy-efficient design in low-income houses as suggested by the conclusions of the previous chapters as well as their contribution to the reference for future study.

6.1. CONCLUSIONS ABOUT THE USE OF THE CASE STUDY BUILDING AND THE MODEL CALIBRATION

6.1.1. Conclusions of Energy Use of the Case Study Building

The data from the case study building, the Habitat house, was collected from 1999 monthly utility bills and from the recordings of a multi-channel logger installed in the case study building. The records showed that in 1999, the case study house consumed 43.8 MBtu of building electricity and 24.7 MBtu of natural gas. Considering the electricity usage, cooling energy consumption for a 1999 period was 22.7 MBtu, accounting for 52 % of total electricity uses. Annual lighting electricity use was 11.7 MBtu and equipment electricity use was 9.4 MBtu, which represented 27 % and 21 % of the total electricity consumption respectively.

The data from the case study site indicated the high usage of light and receptacle electricity throughout the day with an hourly average use of 0.3 – 0.5 kWh/h (i.e., 300 to 500 Watts of continuous use). This result suggested that lighting was used almost all day in operating the building. The case study site data also suggested the high usage of cooling energy. What influenced the cooling electricity consumption included the internal cooling load and the external heat gain from the solar beam radiation. The study discovered that on the vernal equinox, the building cooling load from window solar radiation of the case study building could reach 43,200 Btu/hour-day. The increase in cooling energy use, influenced by the solar heat gain problem, could be avoided by the use of shading on windows. Results from this study pointed to the benefits of using appropriate shadings, which contributed to daylight in building and energy savings. Further conclusions of these results are discussed in Section 6.2 and 6.3 in this chapter.

6.1.2. Conclusions of the Case Study Model Calibration

Results from the DOE-2 basecase model simulation were calibrated with the data obtained from the case study site. The calibrations focused on two areas: zone temperature and monthly energy use calibrations. To simulate the basecase building using the DOE-2 program, input variables were adjusted so that the results of the zone temperatures and monthly energy use matched the case study site's data. The study found 2 primary factors which affected the DOE-2 simulation results, namely the setting of space FLOOR-WEIGHT (which activated the Custom-Weighting Factors), and the use of ground temperatures in the simulation. Results from the study pointed out that modeling the basecase building for this study was substantially improved by using Custom Weighting Factors and ground temperatures collected from the site data (i.e., the site data ground temperatures were used in place of the ground temperatures recorded in the TMY2 weather tape).

The calibration results were evaluated based on the standard statistical measures of the coefficient of variation (CV) and mean bias error (MBE), as defined by Kreider and Haberl (1994). The final calibration in this study presented an acceptable DOE-2 basecase model, based on monthly energy use. However, further research is needed to study the temperature and energy calibrations based on the CV and MBE standards.

The DOE-2 calibrated model represented the case study building in terms of its environmental conditions and energy consumption. The model was used to study and evaluate the effectiveness of proposed daylighting designs regarding their contributions to daylight in building and energy savings that resulted from the use of daylight.

6.2. CONCLUSIONS OF DAYLIGHT FACTOR EVALUATIONS

This section discusses the conclusions of Daylight Factor measurements and the proposed shading evaluations. The measurement results discussed in the previous chapters were quantitative studies. The study analyzed the Daylight Factors obtained from the measurements under the overcast sky, from the case study building and from the DOE-2 daylighting simulations. Additional results including Daylight Factor measurements which were conducted in the College of Architecture's daylighting laboratory. The laboratory results were qualitatively evaluated and presented in Appendix D.

The use of the physical scale model in this research provided a means to study the proposed designs regarding their contributions to interior Daylight Factors and window shading from solar beam radiation. The proposed designs are expected to provide solar shading, to enhance the room brightness and reduce the use of artificial lighting, as well as reducing the solar heat gains, which contributed to the energy savings in an air-conditioning system.

6.2.1. Conclusions of Shading Property Evaluation

The study of shading properties was conducted in the daylighting laboratory, using the simulation of direct sunlight on windows as measured by a heliodon. Results obtained from the model experiments suggested that the maximum 6-foot overhang with a vertical fin shadings offered complete solar shading on the windows throughout the day during fall/spring and summer seasons, and yet allowed useful solar in the winter.

6.2.2. Conclusions of Daylight Factor Evaluation

Results of the DOE-2 simulations and the model measurements, both from the laboratory and the overcast sky experiments, suggested the changes in Daylight Factors due to shading applications. The application of exterior shading devices on the window, despite offering a window solar shading, obstructed the contribution of exterior illuminance to the space and resulted in the reduction in interior illuminance. Lightshelf daylighting system proved to be effective in gaining the benefit of daylight, while shielding the window from solar beam radiation. Considering the application of the 18-inch combined lightshelf, the measurement and the DOE-2 simulation results showed improvement on interior Daylight Factors, compared to the application of the maximum 6-foot overhang and the maximum 6-foot overhang with a vertical fin shading systems. In conclusion, the combined lightshelf system was considered the most effective, due to its contribution to interior illuminance, and was recommended as a final design in this study.

6.2.3. Conclusions of Daylight Factor Comparison

In the basecase study, the Daylight Factors obtained from the case study site, the basecase model measurements, and the basecase DOE-2 daylighting simulation results were compared. The study found that Daylight Factors obtained from the model measurements appeared to be the most reliable, while the DOE-2 presented the lowest values.

Considering the comparison of Daylight Factors obtained from the studies and from the actual building, the study showed that window transmittance of the case study building was responsible for a large portion of the disagreement of the results. As each of the actual building's windows had a screen layer on half of the window area, the transmission of light through the windows was reduced up to 80%. Future study on the physical scale model and DOE-2 calibration with the actual building requires a consideration on window glazing composition and its transmittance property.

6.3. CONCLUSIONS OF DOE-2 DAYLIGHTING AND ENERGY SIMULATIONS

This section summarizes the results from DOE-2 daylighting and energy simulations and provides discussion on the proposed shading designs regarding their contribution to daylight distribution and energy savings from using daylighting.

6.3.1. Conclusions of Daylighting Analysis on Vernal Equinox

This section concluded the analysis of the proposed daylighting designs concerning the DOE-2 daylighting and energy simulations on vernal equinox (March 21). March 21st was selected to study the effect of daylight and energy use resulting from shading applications since this day represented the clear sky condition and had the highest daylight availability. Results from the vernal equinox study included the evaluations of window conduction and solar heat gain, space temperature, building cooling load, and building energy use.

6.3.1.1. Conclusions of window conduction and solar heat gain evaluation

In the analysis of window thermal loads, two windows facing southeast and southwest were selected for the study. Results from the DOE-2 simulations suggested that using shadings resulted in the reduction in solar heat gain through the windows. According to the simulations, the basecase model had the highest solar heat gain through the windows while the model with the maximum 6-foot overhang with vertical fin gained the lowest. The solar heat gain through the bare window of the basecase model accounted for 5 – 8 times the gain through the window with the 6-foot overhang and vertical fin, and accounted for 1.5 times the gain through the window with combined lightshelf.

Regarding the conduction through the windows, the applications of the different proposed shadings barely affected the changes in window conduction. The study suggested that heat gain and loss through windows depended on the temperature deviation between the indoor and outdoor.

In conclusion, although results from the study showed that window shadings hardly had benefit on window conduction, they were considered effective in lessening the solar heat gain through window glazing. However, this study focused on the simulation of vernal equinox only. The simulations focusing on other seasonal days are recommended for future study in order to gain a better understanding of the effect of shadings on window conduction.

6.3.1.2. Conclusions of building cooling load evaluation

The study analyzed building cooling loads from window conduction and solar radiation of the basecase model compared with the models with proposed designs. The simulation reports of March 21st indicated that the model with maximum 6-foot overhang with vertical fin provided the lowest building cooling load from window solar radiation, but caused the highest window conduction heat loss. The heating load from window conduction in the model with maximum 6-foot overhang with vertical fin was

37% more than that in the basecase model. However, this maximum overhang with vertical fin model produced the reduction in building cooling load from window solar radiation up to 55% and contributed to 79% in total cooling load decrease.

The model with a final design, the 18-inch combined lightshelf system, produced a 25% higher window conduction heat loss compared to the basecase model. Nevertheless, this final model produced an 11% decrease in cooling load from window solar radiation, and promoted a total reduction in building cooling load up to 22%.

Results from the analysis of building cooling load on March 21st suggested that adding shading on window, despite producing conduction heat loss, could reduce the heat gain from solar radiation significantly and contributed to the energy savings in building cooling load.

6.3.1.3. Conclusions of building energy use evaluation

The study of building energy use and the evaluation of energy savings resulting from the use of daylighting covered both lighting and overall building electricity consumption. Results from the DOE-2 simulation on March 21 showed that the basecase model consumed the highest lighting electricity. The study also suggested that the use of proposed daylighting designs could contribute to the reduction in lighting energy use. The comparison of the three proposed models indicated that maximum lighting energy saving was best achieved in the model with 18-inch combined lightshelf (28.7%), followed by the model with maximum 6-foot overhang (26.7%), while the model with maximum 6-foot overhang with vertical fin offered the least lighting electricity saving (25.6%).

Concerning the total building energy uses on March 21, the DOE-2 simulation reports indicated that the basecase model consumed the highest energy use during the day. The maximum energy saving was achieved from the use of daylighting in the model with maximum 6-foot overhang with vertical fin, which accounted for a 16.5% daily saving. In addition, the model with maximum 6-foot overhang and the model with 18-inch combined lightshelf offered a 15% and 12.2% energy saving respectively.

This section provides conclusions from the DOE-2 simulations on March 21st only. The summaries of DOE-2 daylighting energy simulation, the annual energy consumption and the annual energy savings obtained from the use of daylighting are discussed in the following section.

6.3.2. Conclusions of DOE-2 Daylighting Energy Simulation

The conclusions of DOE-2 simulations in this study covered the calibration of monthly energy uses of the basecase model with and without daylighting, the summary of annual energy use, and total energy savings obtained from the use of daylighting.

6.3.2.1. Conclusions of the monthly energy use calibration

To acquire the basecase daylighting model, results from the DOE-2 simulation of the multi-zone model with daylighting needed to be calibrated with the one-zone model without daylighting. The calibration focused on a correspondence of monthly energy use between the basecase models with and without daylighting. Regarding the lighting energy use calibration, the study found that the setting of interior light levels needed to be high enough, otherwise the DOE-2 would consider daylight as the lighting source and disregard the use of artificial lighting. The appropriate value of the light set point would subsequently cause the DOE-2 to use the electrical lighting to maintain the predetermined illuminance levels.

6.3.2.2. Conclusions of monthly energy use evaluation

Results from the study suggested that in terms of the electricity use, the basecase model consumed the highest monthly energy. However, there was little difference in monthly natural gas use between the basecase model and the models with proposed designs. From the analysis, the monthly energy consumption of the basecase model was the highest especially in ventilation fan, space cooling, and lighting. For the space heating, the models with maximum 6-foot overhang and maximum 6-foot overhang with vertical fin consumed the most heating energy, compared to the basecase model and the model with final design. It can be concluded that the application of maximum overhang and vertical fin, despite preventing the solar radiation, which resulted in the cooling energy reduction, lost the opportunity to gain the benefit of sunlight in heating season. Future study is needed to explore the effective daylight designs that offer the supreme savings in cooling and lighting energy uses after compensating for the heating energy needed.

6.3.2.3. Conclusions of energy saving evaluation

Results from the study supported the idea of using daylighting in a building to increase savings on lighting electricity. The study found that the proposed designs offered lighting electricity savings as much as 22% in the model with maximum 6-foot overhang with vertical fin, 25% in the model with maximum 6-foot overhang, and up to 28% in the model with 18-inch combined lightshelf.

Regarding the cooling energy use, an application of maximum 6-foot overhang with vertical shading on the model contributed to the 10% reduction in annual cooling electricity consumption, which was considered the most saving among all the three proposed models. The annual cooling energy savings achieved from the model with maximum 6-foot overhang and the model with 18-inch combined lightshelf accounted for 8% and 6% respectively.

Results from the study also suggested that in the heating season, heat loss occurred in the model with maximum 6-foot overhang and the model with maximum 6-foot overhang with vertical fin. As a consequence, these 2 models consumed 4% more of heating energy than the basecase model did. However, around 4% of heating energy savings were gained in the model with 18-inch combined lightshelf.

Annually, the electricity consumption of the proposed daylighting models were around 10% less than the basecase model. The summary showed that for the total energy use, the maximum energy saving was achieved in the model with 18-inch combined lightshelf, which accounted for an 8% saving. The other 2 proposed models offered a 6% reduction in total building energy use.

In conclusion, the use of daylighting design in building contributes not only to the increase in Daylight Factors in a building interior but also the reduction in solar radiation and conduction heat gain through building, which resulted in savings on cooling, lighting, and total building energy uses.

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APPENDIX A

DATA COLLECTED FROM THE CASE STUDY SITE DATA LOGGERS

This chapter presents the plots of hourly data representing the energy use and thermal conditions of the case study building during January to December 1999. The case study house's data was measured by using the 50-channel data logger installed during the building construction. Data obtained was recorded as 15-minute data and was converted into an hourly format that depicted thermal conditions and energy use patterns of the house during the 1999 occupancy (Kootin-Sanwu 2003). There were 27 channels of recorded data which indicated electricity uses in various categories, outdoor environmental conditions, indoor thermal conditions, flow metering, including natural gas use. Each channel was assigned an identification number and description. This stored data was acquired with the permission of the Energy Systems Laboratory at Texas A&M University.

Figure A1 presents the plot of hourly outdoor temperature, obtained from the data recorded in channel I.D. 3810: TEMP-OUTDOOR. Figures A2 – A3 illustrated the case study house's indoor conditions during the year 1999. Presented in Figure A2 is the HVAC supply temperature plot obtained from the channel I.D. 3802: TEMP-SUPPLY, while the HVAC return temperature plot from the channel I.D. 3804: TEMP-RETURN is shown in Figure A3. The plots of building energy use are presented in Figures A4 – A6, which include whole-building electricity, equipment electricity, and lighting and receptacle electricity use respectively. The plot of whole-building electricity use presented in Figure A4 was the sum of recorded data from two channels, namely channel I.D. 3789: WHL HSE ELE-L1 and channel I.D. 3790: WHL HSE ELE-L2. Figure A5 presents the equipment electricity use, which was the sum of electricity uses from various appliance categories derived from the data recorded in channel I.D. 3791 and 4151: DRYER, 3792 and 4152: A/C, 3793 and 4153: A/C BLOWER, 3794: REFRIGERATOR, 3795 and 4154: FREEZER, 3796: WASHER, and 3797: DISHWASHER. Finally, Figure A6 displays the plot of lighting and receptacle electricity use, which was the difference between the whole building electricity use and the total equipment electricity use.

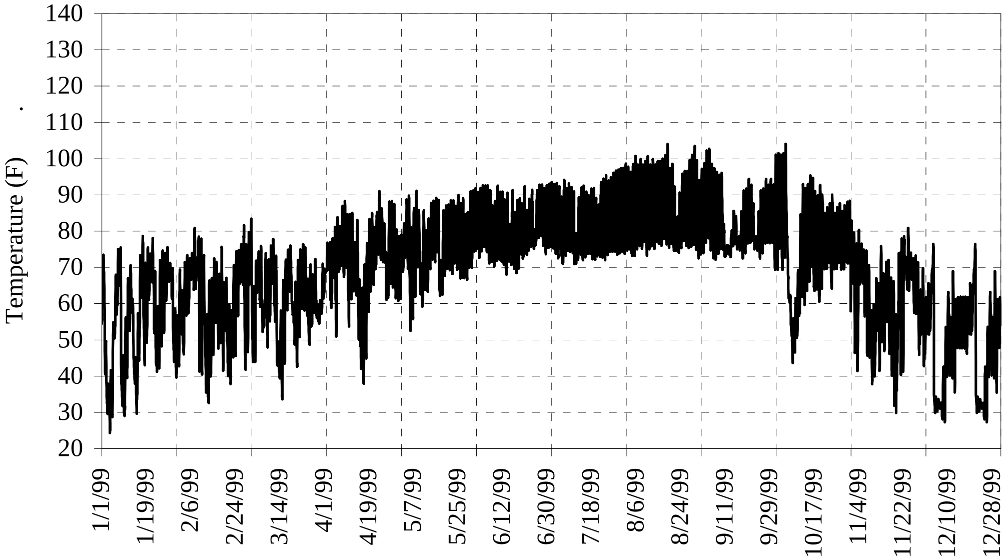


Figure A1 – Measured hourly ambient temperature at the case study site from January to December 1999.

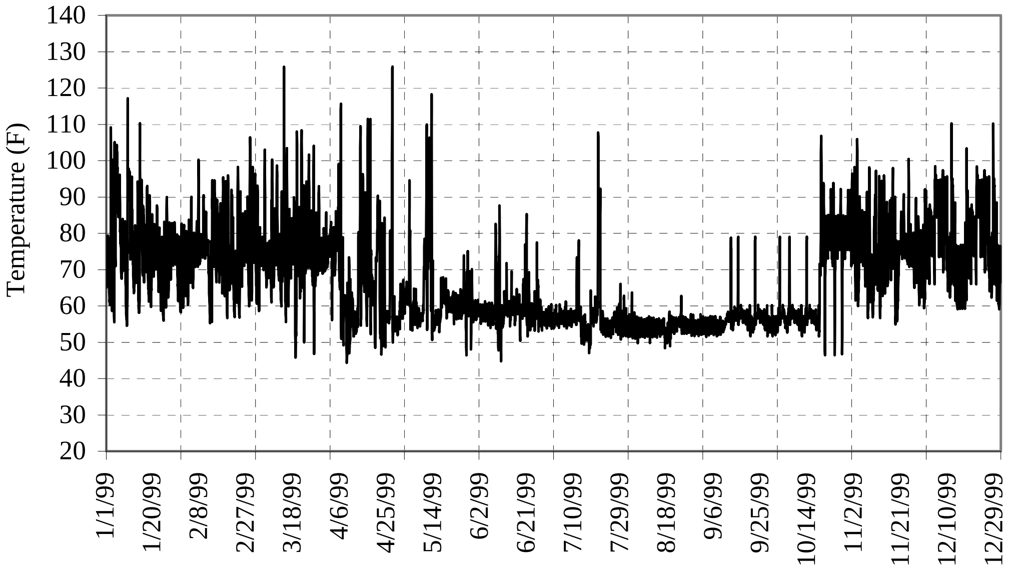


Figure A2 – Measured hourly supply temperature of the case study house from January to December 1999.

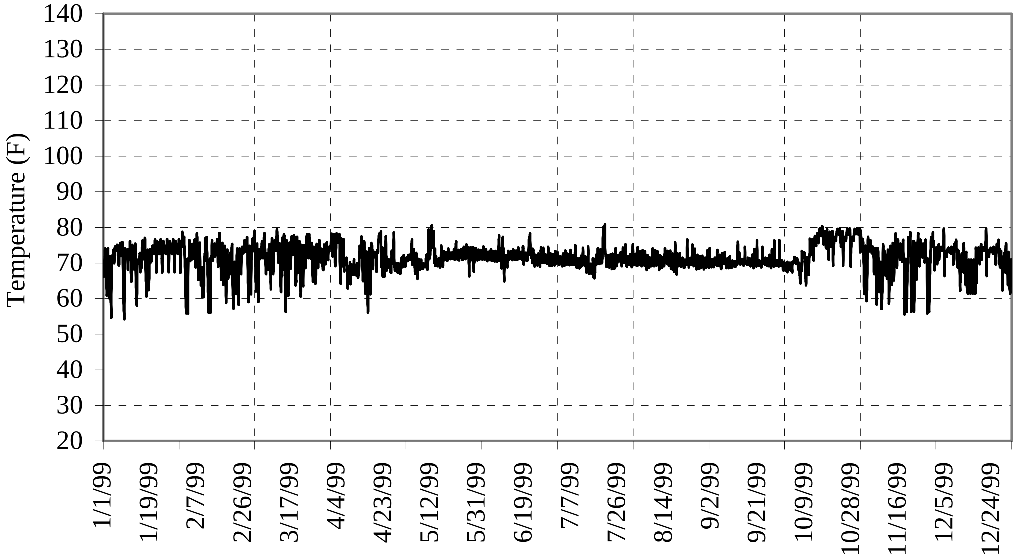


Figure A3 – Measured hourly return temperature of the case study house from January to December 1999.

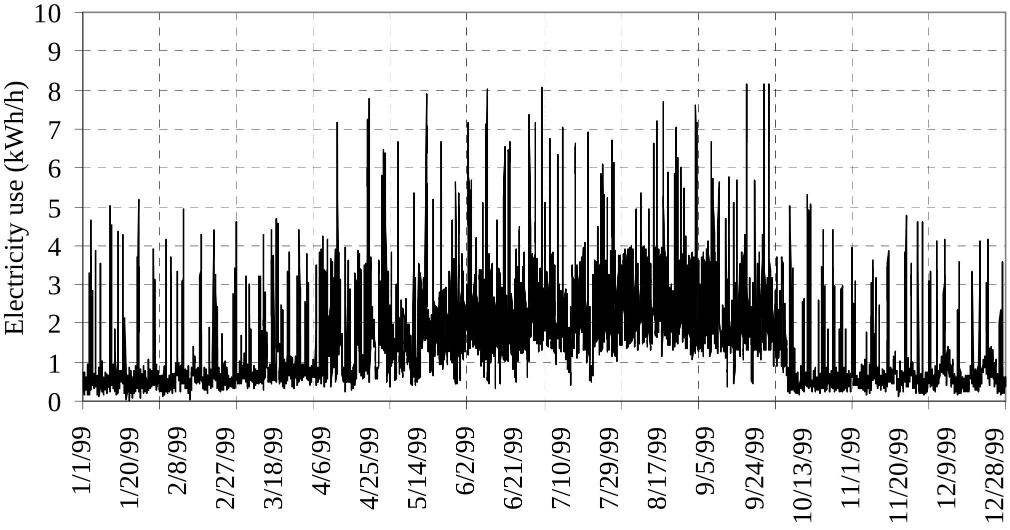


Figure A4 – Measured hourly whole building electricity use of the case study house from January to December 1999.

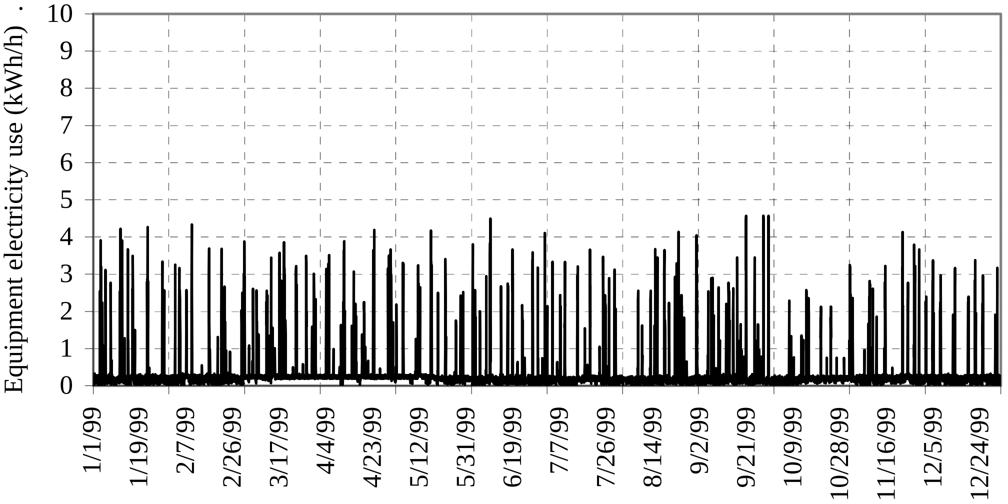


Figure A5 – Measured hourly equipment electricity use of the case study house from January to December 1999.

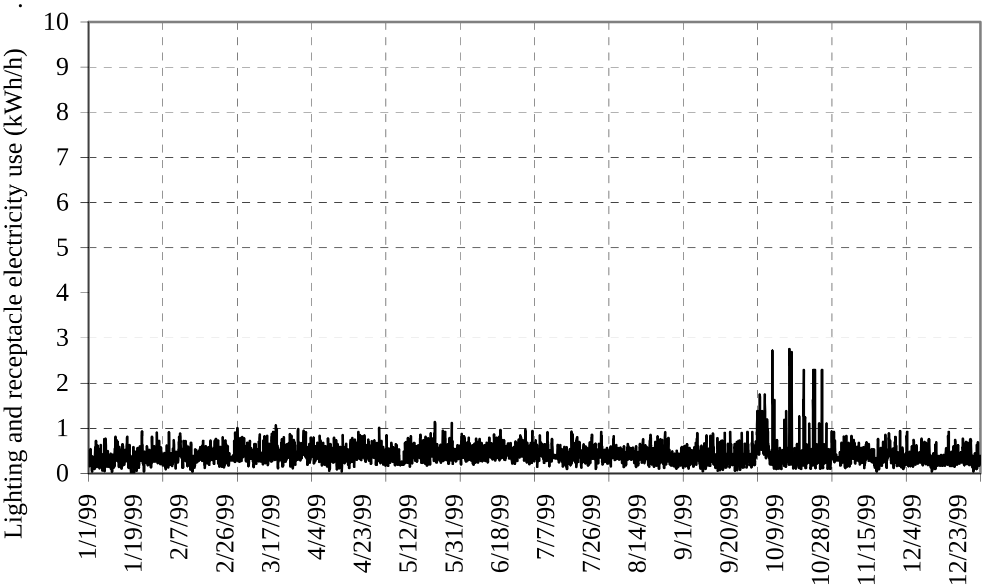


Figure A6 – Measured hourly light and receptacle electricity use of the case study house from January to December 1999.

APPENDIX B

LIGHTING AND RECEPTACLE AND EQUIPMENT ELECTRICITY USE HOURLY PROFILES

HOURLY PROFILES DETAILS

The profiles of lighting and receptacle and equipment electricity use were previously mentioned in Section 4.1 of Chapter IV. Hourly data for these electricity use profiles were collected from the case study site and converted for input into DOE-2 as schedule profiles. The hourly profiles presented in this appendix show the analysis of the 24-hour profiles of lighting and receptacle and equipment electricity uses, illustrated in average one daily schedule (one schedule for each day: Monday, Tuesday, etc.).

Figures B1 – B7 present hourly profiles of average lighting and receptacle electricity uses.

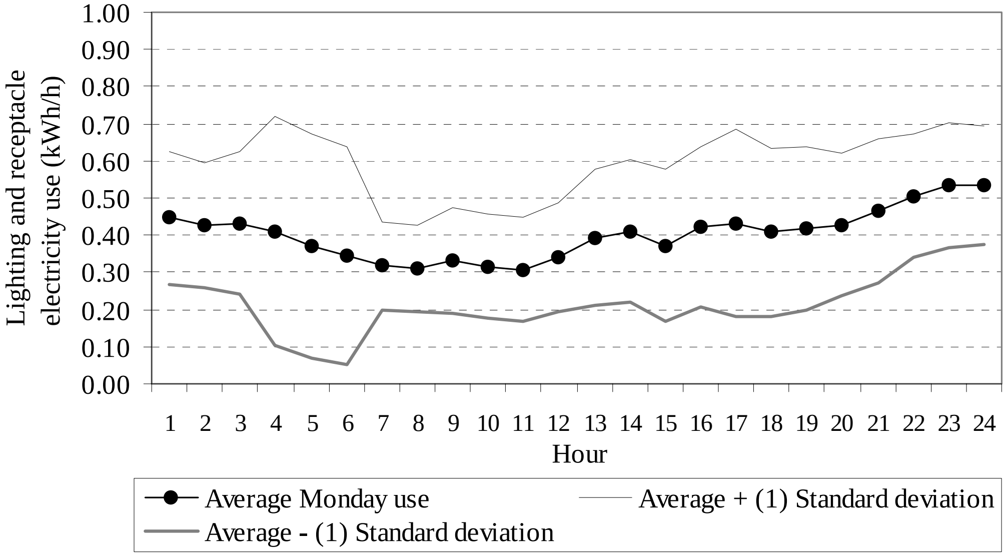


Figure B1 – Average Monday lighting and receptacle electricity use.

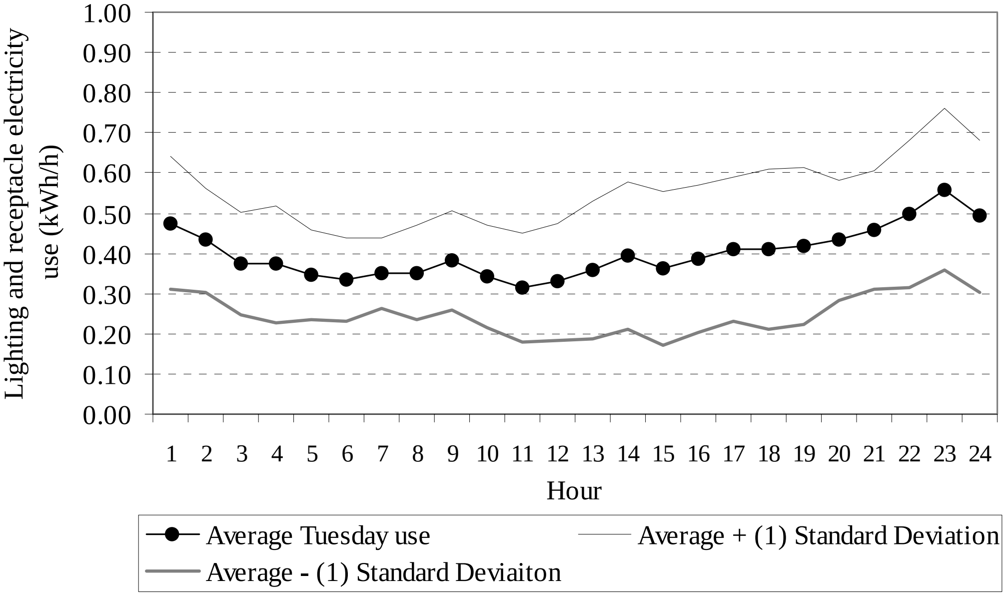


Figure B2 – Average Tuesday lighting and receptacle electricity use.

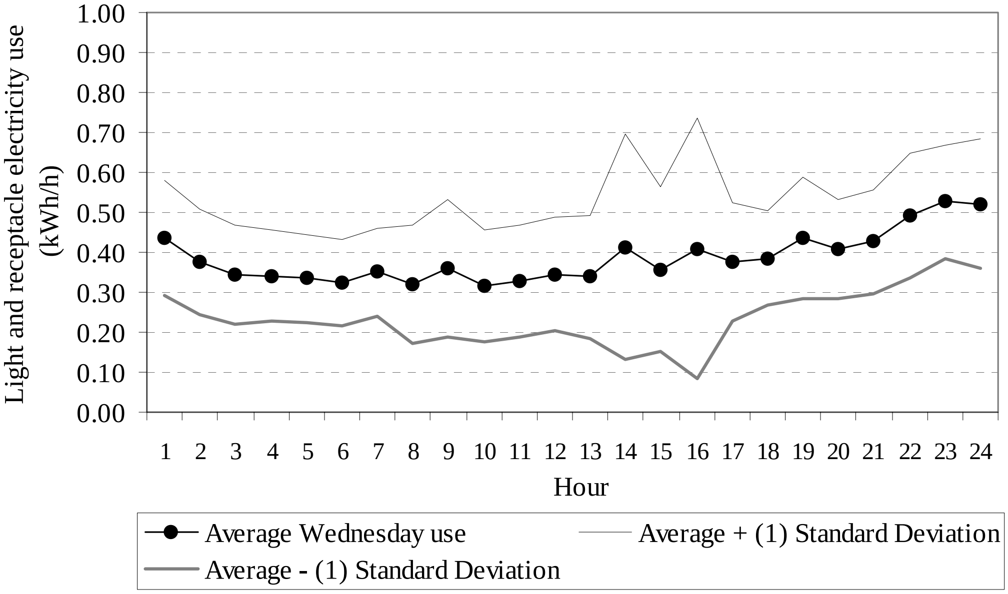


Figure B3 – Average Wednesday lighting and receptacle electricity use.

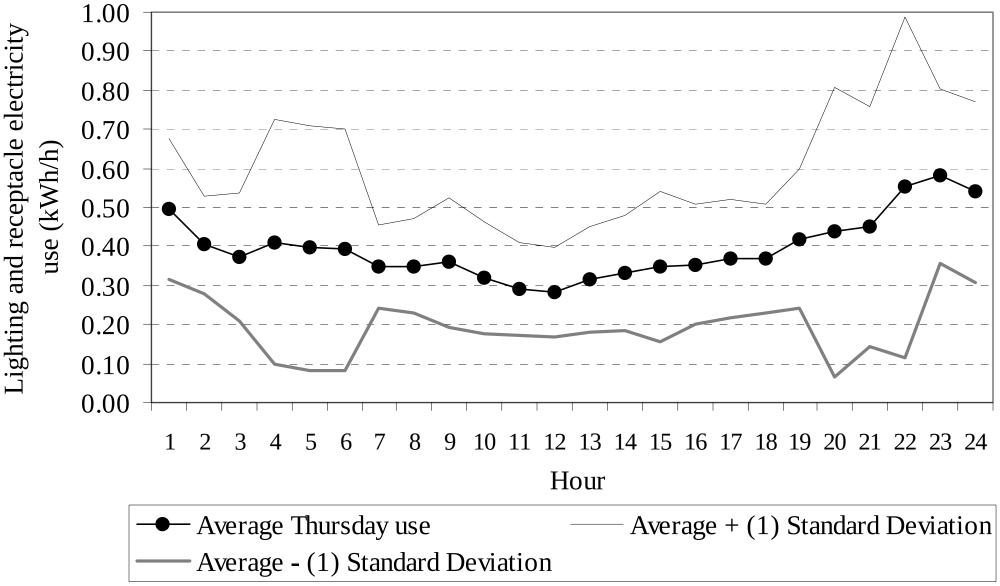


Figure B4 – Average Thursday lighting and receptacle electricity use.

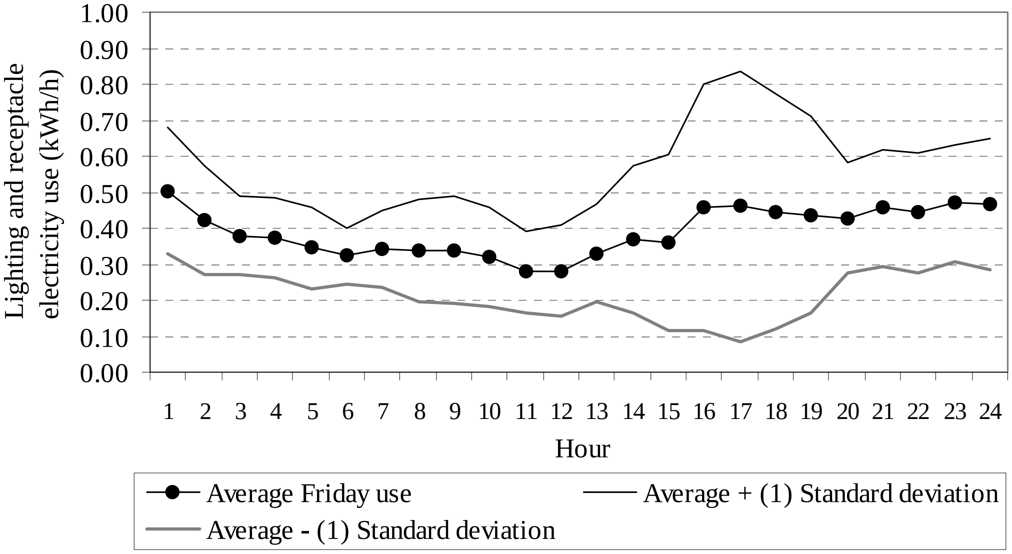


Figure B5 – Average Friday lighting and receptacle electricity use.

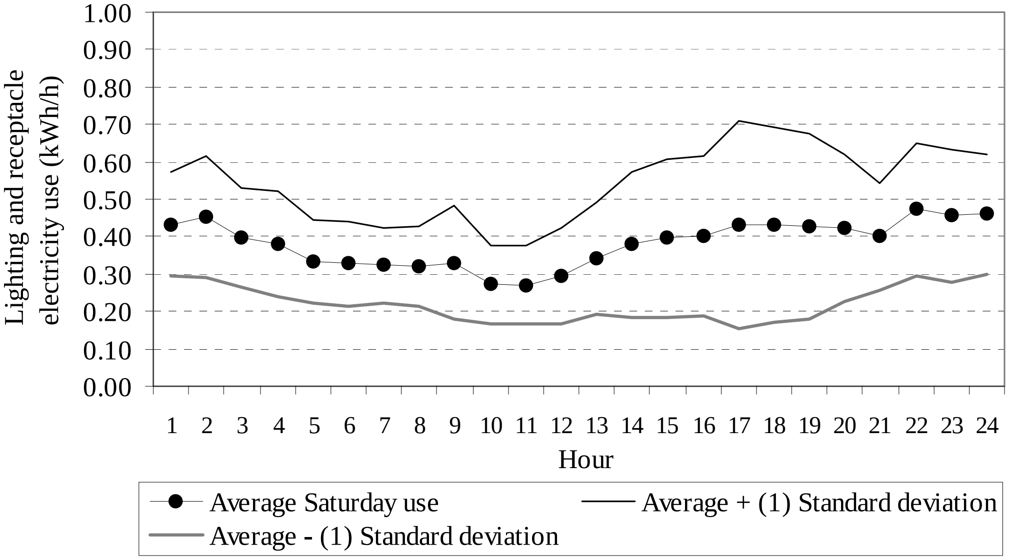


Figure B6 – Average Saturday lighting and receptacle electricity use.

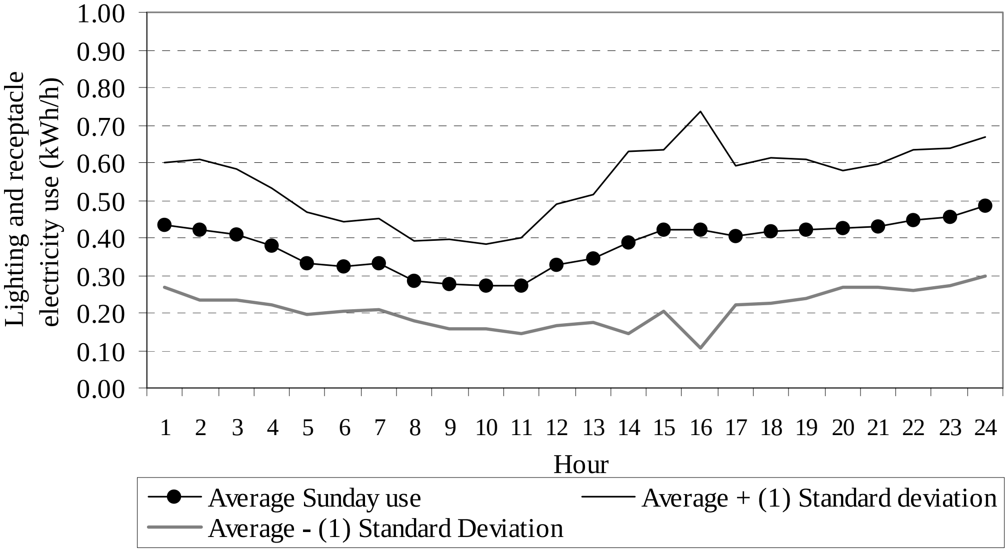


Figure B7 – Average Sunday lighting and receptacle electricity use.

Figure B9 – B15 presents hourly profiles of average equipment electricity uses.

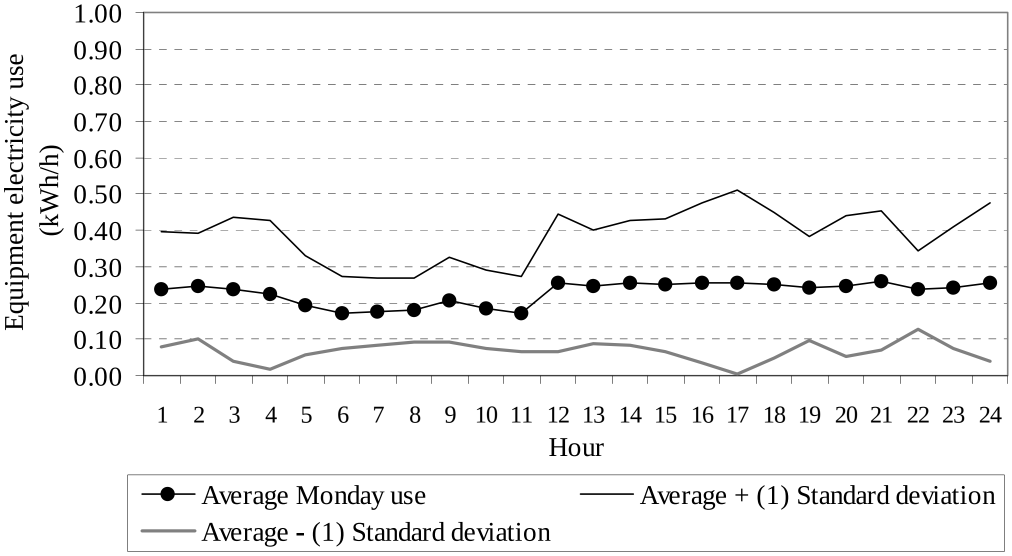


Figure B9 – Average Monday equipment electricity use.

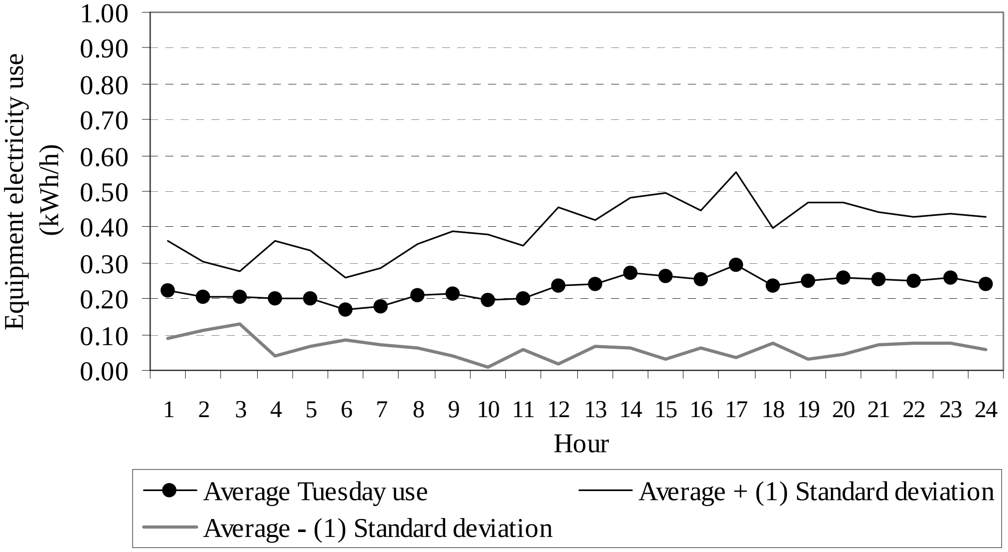


Figure B10 – Average Tuesday equipment electricity use.

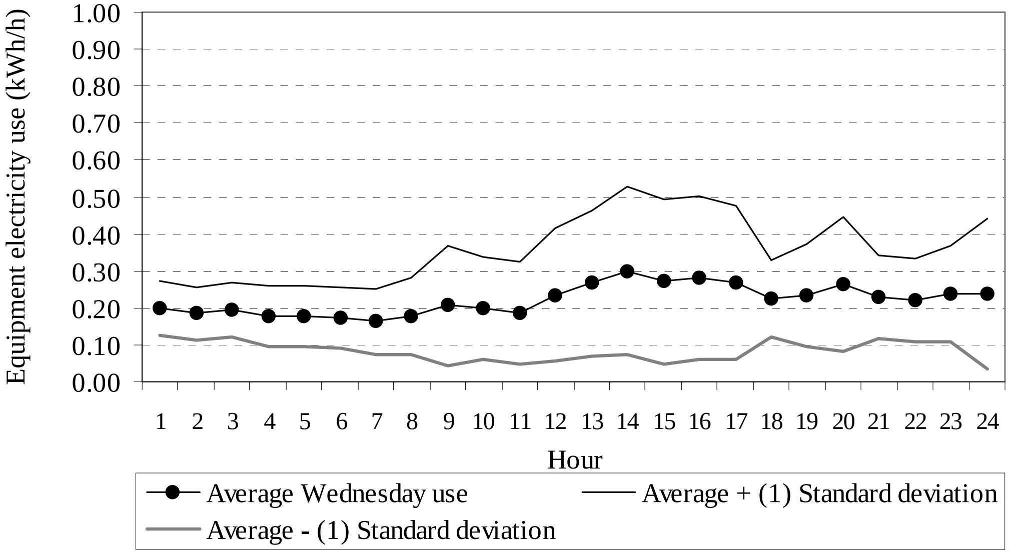


Figure B11 – Average Wednesday equipment electricity use.

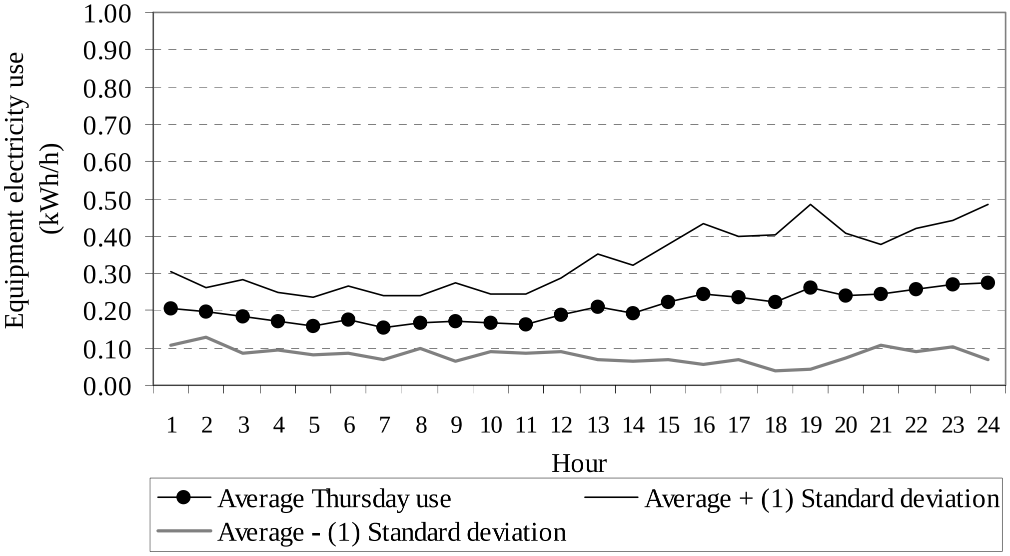


Figure B12 – Average Thursday equipment electricity use.

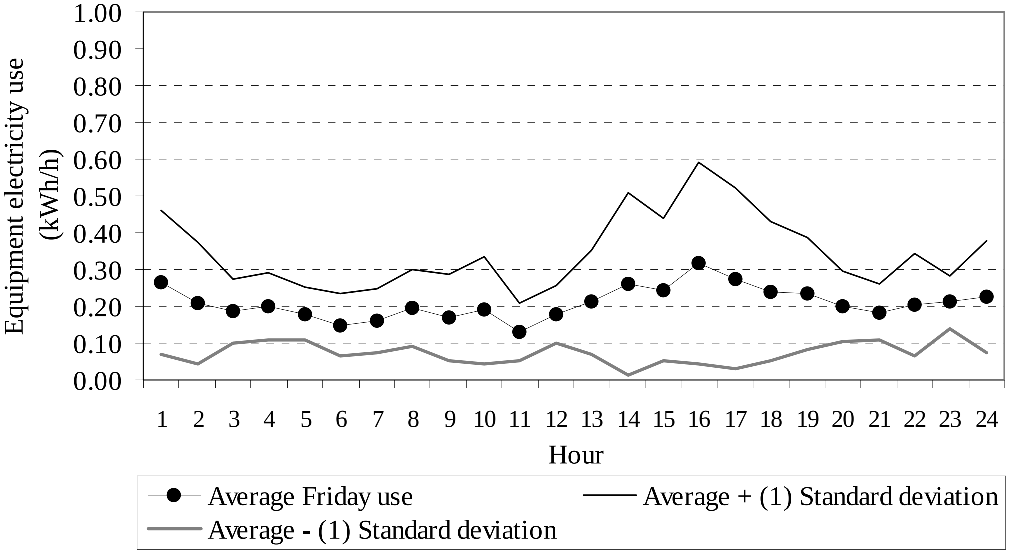


Figure B13 – Average Friday equipment electricity use.

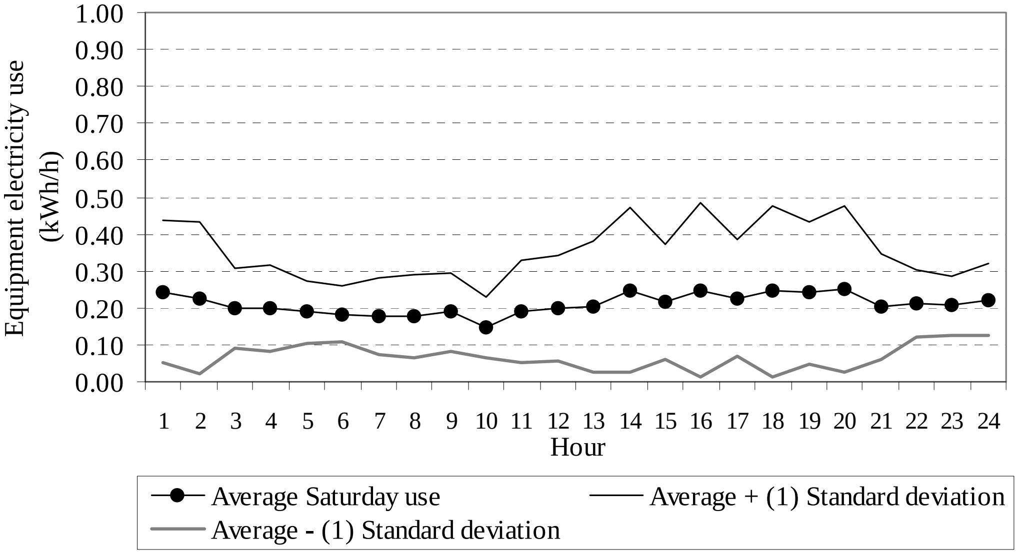


Figure B14 – Average Saturday equipment electricity use.

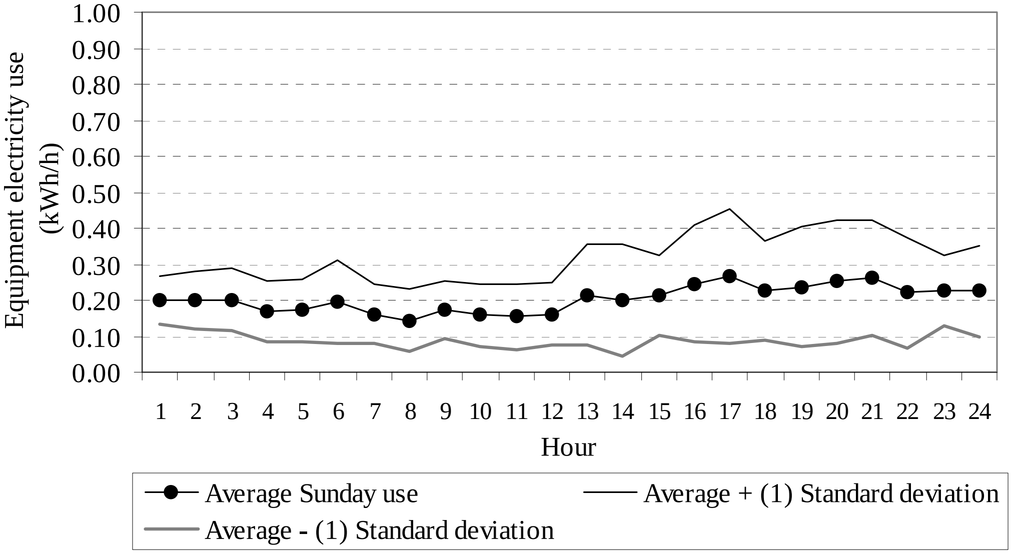


Figure B15 – Average Sunday equipment electricity use.

APPENDIX C

CASE STUDY HOUSE DOE-2 INPUT FILE

CASE STUDY HOUSE DOE-2 INPUT FILE

This study used the DOE-2.1e Program for energy simulations. This section of the appendix covers the DOE-2 input file of the basecase model. The input file presented in this section includes three primary DOE-2 commands, namely 1) LOADS, 2) SYSTEMS, and 3) PLANT.

```
********************** INPUT FILE THE FOR DOE-2 SIMULATION ******************
                  THE HABITAT FOR THE HUMANITY HOUSE, BRYAN, TEXAS
                                                 BY NAYARAT RUNGCHAREONRAT
*****************************************************************************
INPUT LOADS  ..

TITLE   LINE-1 *HABITAT FOR HUMANITY HOUSE, BRYAN,TEXAS *
        LINE-2 *COPYRIGHT 2003 *
        LINE-3 *MASTER THESIS *
        LINE-4 *NAYARAT RUNGCHAREONRAT *  ..

        RUN-PERIOD          JAN 1 1999 THRU DEC 31 1999  ..

        ABORT               ERRORS  ..
        DIAGNOSTIC          WARNINGS  ..
        LOADS-REPORT        VERIFICATION=(ALL-VERIFICATION)
                            SUMMARY=(ALL-SUMMARY)  ..

$ VERIFICATION REPORT
$        LV-A               GENERAL PROJECT AND BUILDING INPUT
$        LV-B               SUMMARY OF SPACES OCCURRING IN THE PROJECT
$        LV-C               DETAILS OF SPACE
$        LV-D               DETAILS OF EXTERIOR SURFACES
$        LV-E               DETAILS OF UNDERGROUND SURFACE
$        LV-F               DETAILS OF INTERIOR SURFACES
$        LV-G               DETAILS OF SCHEDULE
$        LV-H               DETAILS OF WINDOWS
$        LV-I               DETAILS OF CONSTRUCTION
$        LV-J               DETAILS OF BUILDING SHADES
$        LV-K               WEIGHTING FACTOR SUMMARY
$        LV-N               SURFACE VERTEX VERIFICATION REPORT

$ SUMMARY REPORT
$        LS-A               SPACE PEAK LOADS SUMMARY
$        LS-B               SPACE PEAK LOAD COMPONENTS
$        LS-C               BUILDING PEAK LOAD COMPONENTS
$        LS-D               BUILDING MONTHLY LOADS SUMMARY
$        LS-E               SPACE MONTHLY LOAD COMPONENTS
$        LS-F               BUILDING MONTHLY LOAD COMPONENTS

$HOUSTON DESIGN DAYS

$ SUMMER1 = DESIGN-DAY                        ALL VALUES ARBITRARY
$        DRYBULB-HI = 97                      UNUSED,(DEG F)
$        DRYBULB-LO = 42                      UNUSED,(DEG F)
```

```
$        HOUR-HI = 13                     UNUSED,(HOURS)
$        HOUR-LO = 6                      UNUSED,(HOURS)
$        DEWPT-HI = 70                    UNUSED,(DEG F)
$        DEWPT-LO = 72                    UNUSED,(DEG F)
$        DHOUR-HI = 15                    UNUSED,(HOURS)
$        DHOUR-LO = 5                     UNUSED,(HOURS)
$        WIND-SPEED = 5                   UNUSED,(KNOTS)
$        WIND-DIR = 8                     0=NORTH,1=NNE ...
$        CLOUD-AMOUNT = 4                 0=CLEAR,10=OVERCAST
$        CLOUD-TYPE = 0                   0=SUMMER,2=FALL/SPRING,
$                                         1=WINTER
$        CLEARNESS = 0.6                  VARIES FROM 0.5 TO 1.2
$        GROUND-T = 65  ..                UNUSED,(DEG F)
$        WINTER1 = DESIGN-DAY             ALL VALUES ARBITRARY
$        DRYBULB-HI = 85                  UNUSED,(DEG F)
$        DRYBULB-LO = 14                  UNUSED,(DEG F)
$        HOUR-HI = 14                     UNUSED,(HOURS)
$        HOUR-LO = 8                      UNUSED,(HOURS)
$        DEWPT-HI = 38                    UNUSED,(DEG F)
$        DEWPT-LO =19                     UNUSED,(DEG F)
$        DHOUR-HI = 15                    UNUSED,(HOURS)
$        DHOUR-LO =3                      UNUSED,(HOURS)
$        WIND-SPEED = 7                   UNUSED,(KNOTS)
$        WIND-DIR = 0                     0=NORTH,1=NNE ...
$        CLOUD-AMOUNT = 4                 0=CLEAR,10=OVERCAST
$        CLOUD-TYPE = 1                   0=SUMMER,2=FALL/SPRING,
$                                         1=WINTER
$        CLEARNESS = 0.6                  VARIES FROM 0.5 TO 1.2
$        GROUND-T = 60  ..                UNUSED,(DEG F)

         BUILDING-LOCATION
         LATITUDE = 30
         LONGITUDE = 96
         ALTITUDE = 108
         TIME-ZONE = 6
         DAYLIGHT-SAVINGS = YES
         AZIMUTH = 225
         HOLIDAY = YES
         GROUND-T = (70.35, 72.22, 73.38, $CASE STUDY SITE DATA
                     74.61, 75.72, 77.46,
                     77.48, 77.54, 76.24,
                     77.01, 72.26, 71.09) ..
$        CLEARNESS-NUMBER = ()            UNUSED
$        HEAT-PEAK-PERIOD = (1,24)        DOE-2 DEFAULT,UNUSED
$        COOL-PEAK-PERIOD = (1,24)        UNUSED
$        ATM-MOISTURE = (0.7,0.7,0.7,0.7, DEFAULT
$                        0.7,0.7,0.7,0.7,
$                        0.7,0.7,0.7,0.7)
$        ATM-TURBIDITY =(0.1, 0.1, 0.11,  DOE2.1E-COLLEGE STATION
$                        0.12,0.13, 0.08,
$                        0.15, 0.12, 0.11,
$                        0.09, 0.08, 0.07)
```

```
$BUILDING MATERIAL DESCRIPTION

$WALL STUDS$

WA-2-2 = LAYERS
         MATERIAL = (AV01,BP01,PW03,WD05,GP01)  ..

$         AV01 = ASBESTOS-VINYL TILE
$         BP01 = BUILDING PAPER PERMEABLE FELT, RESISTANCE =0.06
$         PW03 = PLYWOOD 1/2", RESISTANCE =0.63$
$         WD05 = WOOD 4 INCH
$         GP01 = GYPSUM BOARD 1/2", RESISTANCE =0.45


$WALL BETWEEN THE STUDS$

WA-1-1 = LAYERS
         MATERIAL = (AV01,BP01,PW03,IN13,GP01)  ..

$         AV01 = ASBESTOS-VINYL TILE
$         BP01 = BUILDING PAPER PERMEABLE FELT, RESISTANCE =0.06
$         PW03 = PLYWOOD 1/2", RESISTANCE =0.63
$         IN13 = R-13 BATT INSULATION, RESISTANCE =12.96
$         GP01 = GYPSUM BOARD 1/2", RESISTANCE =0.45

$ROOF CONSTRUCTION MATERIAL

$ROOF DESCRIPTION

RB-1-1 = LAYERS
          MATERIAL = (AR02,BP03,PW04)  ..

$         AR02 = ASPHALT SHINGLE, RESISTANCE =0.44
$         BP03 = PLASTIC FILM SEAL, RESISTANCE =0.01
$         PW04 = PLYWOOD 5/8", RESISTANCE=0.78

$ROOF STUDS

RB-1-2 = LAYERS
          MATERIAL = (AR02,PW04,WD05)  ..

$         AR02 = ASPHALT SHINGLE, RESISTANCE =0.44
$        PW04 = PLYWOOD 5/8", RESISTANCE=0.78
$        WD05 = WOOD 4 INCH

$ROOF WALL

WR-1-1 = LAYERS
          MATERIAL =(AV01,BP03,PW04)  ..

$         AV01 = ASBESTOS-VINYL TILE
$         BP03 = PLASTIC FILM SEAL, RESISTANCE =0.01
$         PW04 = PLYWOOD 5/8", RESISTANCE=0.78
```

```
$ATTIC CEILING DESCRIPTION

$ATTIC CEILING

CL-1-1 = LAYERS
          MATERIAL = (PW04,IN12)
          I-F-R = 0.92  ..                $INSIDE-FILM-RES,HEAT
                                          $FLOWING DOWNWARD

$         PW04 = PLYWOOD 5/8", RESISTANCE=0.78
$         IN12 = R-19 BATT INSULATION, RESISTANCE=16.97

$ATTIC CEILING STUDS

CL-1-3 = LAYERS
          MATERIAL = (PW04,WD02)
          I-F-R = 0.92  ..

$         PW04 = PLYWOOD 5/8", RESISTANCE = 0.78
$         WD02 = WOOD 1.5", RESISTANCE = 1.87

$SPACE CEILING DESCRIPTION

$SPACE CEILING

CL-1-2 = LAYERS
          MATERIAL = (IN12,GP02)
          I-F-R = 0.92  ..                $INSIDE-FILM-RES, HEAT
                                          $FLOWING DOWNWARD

$         IN12 = R-19 BATT INSULATION, RESISTANCE=16.97
$         GP02 = GYPSUM BOARD 5/8", RESISTANCE =0.56

$SPACE CEILING STUDS

CL-1-4 = LAYERS
          MATERIAL = (WD02,GP02)
          I-F-R = 0.92  ..

$         WD02 = WOOD 1.5", RESISTANCE = 1.87
$         GP02 = GYPSUM BOARD 5/8", RESISTANCE = 0.56

$FLOOR CONSTRUCTION TYPES

FL-1-1 = LAYERS
          MATERIAL = (CC03,LT01)
          I-F-R = 0.61  ..                 $DEFAULT,HEAT FLOWING UPWARD

$         CC03 = CONCRETE 4", HEAVY WEIGHT, RESISTANCE =0.44
$         LT01 = LINOLEUM TILE, RESISTANCE =0.05


$WINDOW GLASS CONSTRUCTION TYPE

GT-1      = GLASS-TYPE
         GLASS-TYPE-CODE = 2000           $DOUBLE CLEAR
         SPACER-TYPE-CODE = 0             $TAKEN FROM WINDOW LIBRARY
         FRAME-CONDUCTANCE = 0.434        $WOOD WITH CLADDING
         FRAME-ABS = 0.7 ..               $FRAME ABSORPTIVITY
```

```
$DOOR CONSTRUCTION TYPES

DOOR-1 = LAYERS
        MATERIAL = (WD02)  ..             $WOOD 1.5 INCH

$CONSTRUCTIONS

ROOF-1   = CONSTRUCTION
          LAYERS = RB-1-1                 $ROOF
         U-VALUE = 0.813
         ABSORPTANCE = 0.7
         ROUGHNESS = 1  ..
ROOF-2   = CONSTRUCTION
          LAYERS = RB-1-2                 $ROOF STUDS
         U-VALUE = 0.161
         ABSORPTANCE = 0.7
         ROUGHNESS = 1  ..
CEILING-1 = CONSTRUCTION LAYERS = CL-1-1  .. $ATTIC CEILING
CEILING-2 = CONSTRUCTION LAYERS = CL-1-2  .. $SPACE CEILING
CEILING-3 = CONSTRUCTION LAYERS = CL-1-3  .. $ATTIC CEILING STUDS
CEILING-4 = CONSTRUCTION LAYERS = CL-1-4  .. $SPACE CEILING STUDS
WALL-1    = CONSTRUCTION LAYERS = WA-1-1  .. $WALL
WALL-2    = CONSTRUCTION LAYERS = WA-2-2  .. $WALL STUDS
WALL-3    = CONSTRUCTION LAYERS = WR-1-1  .. $ROOF WALLS
FLOOR-1   = CONSTRUCTION LAYERS = FL-1-1  .. $INTERIOR FLOOR
DOORS     = CONSTRUCTION LAYERS = DOOR-1  ..

$SCHEDULE

$OCCUPANCY SCHEDULE

OC-1     = DAY-SCHEDULE
          (1,8)  (1.0)
         (9,15) (0)
         (16,24) (1)  ..
OC-WEEK1  = WEEK-SCHEDULE DAYS (ALL) DAY-SCHEDULE = OC-1 ..
OCCUPY-1  = SCHEDULE THRU DEC 31 OC-WEEK1  ..

$LIGHTING SCHEDULE

LT-1 = DAY-SCHEDULE(1) (0.461)            $LIGHTING SCHEDULE
                   (2) (0.419)
                   (3) (0.387)
                   (4) (0.381)
                   (5) (0.351)
                   (6) (0.339)
                   (7) (0.338)
                   (8) (0.325)
                   (9) (0.340)
                   (10) (0.308)
                   (11) (0.295)
                   (12) (0.314)
                   (13) (0.346)
                   (14) (0.384)
                   (15) (0.373)
                   (16) (0.408)
                   (17) (0.413)
                   (18) (0.410)
                   (19) (0.425)
                    (20) (0.426)
```

```
                    (21) (0.441)
                    (22) (0.487)
                    (23) (0.512)
                    (24) (0.500)  ..

LT-WEEK = WEEK-SCHEDULE DAYS (ALL) DAY-SCHEDULE = LT-1  ..

LIGHTS-1 = SCHEDULE   THRU DEC 31 LT-WEEK  ..

$EQUIPMENT SCHEDULES

EQ-1 = DAY-SCHEDULE(1) (0.269)            $EQUIPMENT SCHEDULE
                   (2) (0.265)
                   (3) (0.225)
                   (4) (0.216)
                   (5) (0.187)
                   (6) (0.188)
                   (7) (0.185)
                   (8) (0.206)
                   (9) (0.231)
                   (10) (0.213)
                   (11) (0.224)
                   (12) (0.272)
                   (13) (0.411)
                   (14,15) (0.486)
                   (16) (0.480)
                   (17) (0.437)
                   (18) (0.408)
                   (19) (0.390)
                   (20) (0.344)
                   (21) (0.330)
                   (22) (0.303)
                   (23) (0.333)
                   (24) (0.313)  ..

EQ-WEEK = WEEK-SCHEDULE DAYS (ALL) DAY-SCHEDULE = EQ-1  ..

EQUIP-1 = SCHEDULE THRU DEC 31 EQ-WEEK  ..

$SET DEFAULT VALUES

SET-DEFAULT FOR EXTERIOR-WALL
SHADING-SURFACE = YES
GND-REFLECTANCE = 0.20 ..                 $GRASS SURFACE

$ZONE DESCRIPTION

$ATTIC SPACE

ATTIC-1  = SPACE
         AREA = 1209                      $FT2
         VOLUME = 4473.34                 $FT3
         TEMPERATURE = (80)               $AVERAGE VALUE
$        PEOPLE-SCHEDULE =                UNUSED
$        NUMBER-OF-PEOPLE =               INUSED
$        PEOPLE-HEAT-GAIN = 400          ASHRAE STANDAR (BTU/HR)
$        PEOPLE-HG-LAT = 200              ASHRAE STANDARD(BTU/HR)
$        PEOPLE-HG-SENS = 200             ASHRAE STANDARD(BTU/HR)
$        LIGHTING-SCHEDULE               UNUSED
$        LIGHTING-TYPE                    UNUSED
```

```
$        LIGHT-TO-SPACE =                 UNUSED
$        LIGHTING-W/SQFT =                UNUSED
$        LIGHTING-KW =                    UNUSED
$        LIGHT-HEAT-TO =                  UNUSED
$        LIGHT-TO-RETURN =                UNUSED
$        LIGHT-RAD-FRAC=                  UNUSED
$        TASK-LIGHT-SCH =                 UNUSED
$        TASK-LT-W/SQFT =                 UNUSED
$        TASK-LIGHTING-KW =               UNUSED
$        EQUIP-SCHEDULE =                 UNUSED
$        EQUIPMENT-W/SQFT=                UNUSED
$        EQUIPMENT-KW =                   UNUSED
$        EQUIP-SENSIBLE =                 UNUSED
$        EQUIP-LATENT =                   UNUSED
$        SOURCE-TYPE =                    UNUSED
$        SOURCE-SCHEDULE =                UNUSED
$        SOURCE-BTU/HR =                  UNUSED
$        SOURCE-SENSIBLE =                UNUSED
$        SOURCE-LATENT =                  UNUSED
          INF-METHOD = AIR-CHANGE        DEFAULT=NONE,CRACK,RESIDENTIAL
         AIR-CHANGES/HR = 0.2             $APPROXIMATE VALUE
$        INF-SCHEDULE  =                  UNUSED
         FLOOR-WEIGHT = 0                 $USE AUTOMATIC CUSTOM W-F
$        WEIGHTING-FACTOR =               ALTERNATE FOR FLOOR WEIGHT
         ZONE-TYPE  = UNCONDITIONED  ..

CEIL-2 = EXTERIOR-WALL
         X = 0 Y = 0 Z = 8.125            $COORDINATES
         AZIMUTH = 0                      $FACING SOUTH
         TILT = 0                         $HORIZONTAL SURFACE
         HEIGHT = 0.8                     $FT
         WIDTH = 7                        $FT
         CONSTRUCTION = CEILING-3         $ATTIC CEILING STUDS
         GND-REFLECTANCE = 0.30  ..       $CONCRETE FLOOR
$        SKY-FORM-FACTOR =                USE DEFAULT
$        GND-FORM-FACTOR =                USE DEFAULT
$        INF-COEF =                       USE ONLY INF-METH.=CRACK
$        SHADING-SURFACE = YES
$        SHADING-DIVISION =               USE DEFAULT
$        MULTIPLIER = 1
$        SOLAR-FRACTION =                 USE DEFAULT
$        INSIDE-VIS-REFL = 0.7            CEILING, TILT<10
$        INSIDE-SOL-ABS = 0.3             CEILING, TILT<10

CEIL-1 = EXTERIOR-WALL
         X = 0 Y = -0.8 Z = 8.125         $COORDINATES
         AZIMUTH = 0                      $FACING SOUTH
         TILT = 0                         $HORIZONTAL SURFACE
         HEIGHT = 11.7                    $FT.
         WIDTH = 7                        $FT.
         CONSTRUCTION = CEILING-1         $ATTIC CEILING
         GND-REFLECTANCE = 0.30  ..       $CONCRETE FLOOR
$        SKY-FORM-FACTOR =                USE DEFAULT
$        GND-FORM-FACTOR =                USE DEFAULT
$        INF-COEF =                       USE ONLY INF-METH.=CRACK
$        SHADING-SURFACE = YES
$        SHADING-DIVISION =               USE DEFAULT
$        MULTIPLIER = 1
$        SOLAR-FRACTION =                 USE DEFAULT
$        INSIDE-VIS-REFL = 0.7            CEILING, TILT<10
```

```
$        INSIDE-SOL-ABS = 0.3             CEILING, TILT<10

TOP-RIGHT-1 = ROOF
         X = 1.5 Y = -39.4 Z = 8.125      $COORDINATES
         HEIGHT = 19.4                    $FT.
         WIDTH = 1.25                     $FT.
         AZIMUTH = 90                     $FACING WEST
         TILT = 23                        $SLOPED SURFACE
         CONSTRUCTION = ROOF-2  ..        $ROOF STUDS
$        SKY-FORM-FACTOR =                USE DEFAULT
$        GND-FORM-FACTOR =                USE DEFAULT
$        INF-COEF =                       USE ONLY INF-METH.=CRACK
$        SHADING-SURFACE = YES
$        SHADING-DIVISION =               USE DEFAULT
$        MULTIPLIER = 1
$        SOLAR-FRACTION =                 USE DEFAULT
$        INSIDE-VIS-REFL = 0.5            10<TILT<170
$        INSIDE-SOL-ABS = 0.5             10<TILT<170

TOP-RIGHT-2 = ROOF
         X = 1.5 Y = -38.15 Z = 8.125     $COORDINARES
         HEIGHT = 19.4                    $FT.
         WIDTH = 38.4                     $FT.
         AZIMUTH = 90                     $FACING WEST
         TILT = 23                        $SLOPED SURFACE
         CONSTRUCTION = ROOF-1  ..        $ROOF
$        SKY-FORM-FACTOR =                USE DEFAULT
$        GND-FORM-FACTOR =                USE DEFAULT
$        INF-COEF =                       USE ONLY INF-METH.=CRACK
$        SHADING-SURFACE = YES
$        SHADING-DIVISION =               USE DEFAULT
$        MULTIPLIER = 1
$        SOLAR-FRACTION =                 USE DEFAULT
$        INSIDE-VIS-REFL = 0.5            10<TILT<170
$        INSIDE-SOL-ABS = 0.5             10<TILT<170

TOP-RIGHT-3 = ROOF
         X = 1.5 Y = 0.25 Z = 8.125       $COORDINATES
         HEIGHT = 19.4                    $FT.
         WIDTH = 1.25                     $FT.
         AZIMUTH = 90                     $FACING WEST
         TILT = 23                        $SLOPED SURFACE
         CONSTRUCTION = ROOF-2  ..        $ROOF STUDS
$        SKY-FORM-FACTOR =               USE DEFAULT
$        GND-FORM-FACTOR =                USE DEFAULT
$        INF-COEF =                       USE ONLY INF-METH.=CRACK
$        SHADING-SURFACE = YES
$        SHADING-DIVISION =               USE DEFAULT
$        MULTIPLIER = 1
$        SOLAR-FRACTION =                 USE DEFAULT
$        INSIDE-VIS-REFL = 0.5            10<TILT<170
$        INSIDE-SOL-ABS = 0.5             10<TILT<170

TOP-LEFT-1 = ROOF
         X = -33.4 Y = 1.5 Z = 8.125      $COORDINATES
         HEIGHT = 19.4                    $FT.
         WIDTH = 1.25                     $FT.
         AZIMUTH = 270                    $FACING EAST
         TILT = 23                        $SLOPED SURFACE
         CONSTRUCTION = ROOF-2  ..        $ROOF STUDS
```

```
$        SKY-FORM-FACTOR =                USE DEFAULT
$        GND-FORM-FACTOR =                USE DEFAULT
$        INF-COEF =                       USE ONLY INF-METH.=CRACK
$        SHADING-SURFACE = YES
$        SHADING-DIVISION =               USE DEFAULT
$        MULTIPLIER = 1
$        SOLAR-FRACTION =                 USE DEFAULT
$        INSIDE-VIS-REFL = 0.5            10<TILT<170
$        INSIDE-SOL-ABS = 0.5             10<TILT<170

TOP-LEFT-2 = ROOF
         X = -33.4 Y = 0.25 Z = 8.125     $COORDINATES
         HEIGHT = 19.4                    $FT.
         WIDTH = 38.4                     $FT.
         AZIMUTH = 270                    $FACING EAST
         TILT = 23                        $SLOPED SURFACE
         CONSTRUCTION = ROOF-1  ..        $ROOF
$        SKY-FORM-FACTOR =                USE DEFAULT
$        GND-FORM-FACTOR =                USE DEFAULT
$        INF-COEF =                       USE ONLY INF-METH.=CRACK
$        SHADING-SURFACE = YES
$        SHADING-DIVISION =               USE DEFAULT
$        MULTIPLIER = 1
$        SOLAR-FRACTION =                 USE DEFAULT
$        INSIDE-VIS-REFL = 0.5            10<TILT<170
$        INSIDE-SOL-ABS = 0.5             10<TILT<170

TOP-LEFT-3 = ROOF
         X = -33.4 Y = -38.15 Z = 8.125   $COORDINATES
         HEIGHT = 19.4                    $FT.
         WIDTH = 1.25                     $FT.
         AZIMUTH = 270                    $FACING EAST
         TILT = 23                        $SLOPED SURFACE
         CONSTRUCTION = ROOF-2  ..        $ROOF STUDS
$        SKY-FORM-FACTOR =                USE DEFAULT
$        GND-FORM-FACTOR =                USE DEFAULT
$        INF-COEF =                      USE ONLY INF-METH.=CRACK
$        SHADING-SURFACE = YES
$        SHADING-DIVISION =               USE DEFAULT
$        MULTIPLIER = 1
$        SOLAR-FRACTION =                 USE DEFAULT
$        INSIDE-VIS-REFL = 0.5            10<TILT<170
$        INSIDE-SOL-ABS = 0.5             10<TILT<170

TRIANG-1 = POLYGON (-31.9,-37.9,8.125)   $POLYGON'S LOCAL COORDINATES
                 (0,-37.9,8.125)
                 (-15.95,-37.9,15.525) ..

ROOF-N = EXTERIOR-WALL
         POLYGON = TRIANG-1
         CONSTRUCTION = WALL-3            $NORTH GABLE WALL
         GND-REFLECTANCE = 0.20 ..
$        SKY-FORM-FACTOR =                USE DEFAULT
$        GND-FORM-FACTOR =                USE DEFAULT
$        INF-COEF =                       USE ONLY INF-METH.=CRACK
$        SHADING-SURFACE = YES
$        SHADING-DIVISION =               USE DEFAULT
$        MULTIPLIER = 1
$        SOLAR-FRACTION =                 USE DEFAULT
$        INSIDE-VIS-REFL = 0.5            10<TILT<170
```

```
$        INSIDE-SOL-ABS = 0.5             10<TILT<170

TRIANG-2 = POLYGON (0,0,8.125)           $POLYGON'S COORDINATES
                 (-31.9,0,8.125)
                 (-15.95,0,15.252)  ..

ROOF-S = EXTERIOR-WALL
         POLYGON = TRIANG-2
         CONSTRUCTION = WALL-3            $SOUTH GABLE WALL
         GND-REFLECTANCE = 0.20 ..
$        SKY-FORM-FACTOR =                USE DEFAULT
$        GND-FORM-FACTOR =                USE DEFAULT
$        INF-COEF =                       USE ONLY INF-METH.=CRACK
$        SHADING-SURFACE = YES
$        SHADING-DIVISION =               USE DEFAULT
$        MULTIPLIER = 1
$        SOLAR-FRACTION =                 USE DEFAULT
$        INSIDE-VIS-REFL = 0.5            10<TILT<170
$        INSIDE-SOL-ABS = 0.5             10<TILT<170

$ LIVING SPACE$
RESIDENCE = SPACE
$        AREA = 1121.5                    FT2
$        VOLUME = 9112.27                 FT3
         SHAPE = BOX
         HEIGHT = 8.125
         WIDTH = 31.9
         DEPTH = 35.157
         TEMPERATURE =(70.5)              $MID POINT OF DESIGN HEAT T
                                         $AND DESIGN COOL T
         PEOPLE-SCHEDULE = OCCUPY-1
         NUMBER-OF-PEOPLE = 3
         PEOPLE-HEAT-GAIN = 400           $ASHRAE STANDARD(BTU/HR/P)
         PEOPLE-HG-LAT = 150             $ASHRAE STANDARD(BTU/HR/P)
         PEOPLE-HG-SENS = 250             $ASHRAE STANDARD(BTU/HR/P)
         LIGHTING-SCHEDULE = LIGHTS-1
         LIGHTING-TYPE = INCAND
$        LIGHTING-KW =                     UNUSED
         LIGHTING-W/SQFT = 0.892
         LIGHT-TO-SPACE = 1
$        LIGHT-HEAT-TO =                  UNUSED
$        LIGHT-TO-RETURN =                UNUSED
$        LIGHT-RAD-FRAC =                 UNUSED
$        TASK-LIGHT-SCH =                 UNUSED
$        TASK-LT-W/SQFT=                  UNUSED
$        TASK-LIGHTING-KW =               UNUSED
         EQUIP-SCHEDULE = EQUIP-1
         EQUIPMENT-W/SQFT = 0.892
$        EQUIPMENT-KW =                   UNUSED
$        EQUIP-SENSIBLE =                 UNUSED
$        EQUIP-LATENT =                   UNUSED
$        SOURCE-SCHEDULE =                UNUSED
$        SOURCE-TYPE =                    UNUSED
$        SOURCE-BTU/HR =                  UNUSED
$        SOURCE-SENSIBLE =                UNUSED
$        SOURCE-LATENT =                  UNUSED
$        INF-SCHEDULE =                   UNUSED
         INF-METHOD = AIR-CHANGE
         AIR-CHANGES/HR = 0.32            $KOOTIN SANWU'S DISSERTATION
         FLOOR-WEIGHT = 0                 $USE CUSTOM W-F
```

```
         ZONE-TYPE = CONDITIONED  ..

$NORTH-EAST FACING WALL

NORTH-1  = EXTERIOR-WALL
         HEIGHT = 8.125
         WIDTH = 1.50
         X = -31.9  Y = -37.9  Z = 0
         AZIMUTH = 180
         CONSTRUCTION = WALL-2           $STUDS
         GND-REFLECTANCE = 0.20 ..
$        SKY-FORM-FACTOR =                USE DEFAULT
$        GND-FORM-FACTOR =                USE DEFAULT
$        INF-COEF =                       USE ONLY INF-METH.=CRACK
$        SHADING-SURFACE = YES
$        SHADING-DIVISION =               USE DEFAULT
$        MULTIPLIER = 1
$        SOLAR-FRACTION =                 USE DEFAULT
$        INSIDE-VIS-REFL = 0.5            10<TILT<170
$        INSIDE-SOL-ABS = 0.5             10<TILT<170

NORTH-2 = EXTERIOR-WALL
         HEIGHT = 8.125
         WIDTH = 28.9
         X = -30.4 Y = -37.9 Z = 0
         AZIMUTH = 180
         CONSTRUCTION = WALL-1              $ WALL
         GND-REFLECTANCE = 0.20 ..
$        SKY-FORM-FACTOR =                USE DEFAULT
$        GND-FORM-FACTOR =                USE DEFAULT
$        INF-COEF =                       USE ONLY INF-METH.=CRACK
$        SHADING-SURFACE = YES
$        SHADING-DIVISION =               USE DEFAULT
$        MULTIPLIER = 1
$        SOLAR-FRACTION =                 USE DEFAULT
$        INSIDE-VIS-REFL = 0.5            10<TILT<170
$        INSIDE-SOL-ABS = 0.5             10<TILT<170

WN-1 = WINDOW
         HEIGHT = 5
         WIDTH = 6
         X = 1.5 Y = 2
         GLASS-TYPE = GT-1
         FRAME-WIDTH = 0.21  ..
$        SETBACK = 0                      DEAFULT
$        SHADING-SCHEDULE =
$        MAX-SOLAR-SCH =
$        SUN-CTRL-PROB = 1.0              DEFAULT
$        OPEN-SHADE-SCH =
$        WIN-SHADE-TYPE = MOVABLE-INTERIOR DEFAULT
$        CONDUCT-SCHEDULE =
$        CONDUCT-TMIN-SCH =               SCHED VALUES OF OA DRY BULB
$        SKY-FORM-FACTOR =                USE DEFAULT
$        GND-FORM-FACTOR =                USE DEFAULT
$        SHADING-SURFACE = YES
$        SHADING-DIVISION = 10            DEFAULT
$        INF-COEF =                       USE ONLY INF-METH.=CRACK
$        SOL-TRANS-SCH =                  USE ONLY FOR A SUNSPACE
$        VIS-TRANS-SCH =                  DAYLIGHT TRANSMITTANCE VALUE
$        GLARE-CTRL-PROB = 1.0            DEFAULT
```

```
$        INSIDE-VIS-REFL = 0.15           DEFAULT

DN-1 = DOOR
         HEIGHT = 6.8
         WIDTH = 3
         X = 9.5 Y = 0
         CONSTRUCTION = DOORS  ..
$        SETBACK = 0                      DEFAULT
$        SKY-FORM-FACTOR =                USE DEFAULT
$        GND-FORM-FACTOR =                USE DEFAULT
$        SHADING-SURFACE = YES
$        SHADING-DIVISION = 10            DEFAULT
$        INF-COEF =                       USE ONLY INF-METH.=CRACK
$        INSIDE-VIS-REFL = 0.5            10<TILT<170

WN-2 = WINDOW
         HEIGHT = 5
         WIDTH = 3
         X = 16.15 Y = 2
         GLASS-TYPE = GT-1
         FRAME-WIDTH = 0.21  ..
$        SETBACK = 0                     DEAFULT
$        SHADING-SCHEDULE =
$        MAX-SOLAR-SCH =
$        SUN-CTRL-PROB = 1.0              DEFAULT
$        OPEN-SHADE-SCH =
$        WIN-SHADE-TYPE = MOVABLE-INTERIOR DEFAULT
$        CONDUCT-SCHEDULE =
$        CONDUCT-TMIN-SCH =               SCHED VALUES OF OA  DRY BULB
$        SKY-FORM-FACTOR =                USE DEFAULT
$        GND-FORM-FACTOR =                USE DEFAULT
$        SHADING-SURFACE = YES
$        SHADING-DIVISION = 10            DEFAULT
$        INF-COEF =                       USE ONLY INF-METH.=CRACK
$        SOL-TRANS-SCH =                  USE ONLY FOR A SUNSPACE
$        VIS-TRANS-SCH =                  DAYLIGHT TRANSMITTANCE VALUE
$        GLARE-CTRL-PROB = 1.0            DEFAULT
$        INSIDE-VIS-REFL = 0.15           DEFAULT

WN-3 = WINDOW
         HEIGHT = 3
         WIDTH = 3
         X = 24.9 Y = 4
         GLASS-TYPE = GT-1
         FRAME-WIDTH = 0.21  ..
$        SETBACK = 0                     DEAFULT
$        SHADING-SCHEDULE =
$        MAX-SOLAR-SCH =
$        SUN-CTRL-PROB = 1.0              DEFAULT
$        OPEN-SHADE-SCH =
$        WIN-SHADE-TYPE = MOVABLE-INTERIOR DEFAULT
$        CONDUCT-SCHEDULE =
$        CONDUCT-TMIN-SCH =               SCHED VALUES OF OA  DRY BULB
$        SKY-FORM-FACTOR =                USE DEFAULT
$        GND-FORM-FACTOR =                USE DEFAULT
$        SHADING-SURFACE = YES
$        SHADING-DIVISION = 10            DEFAULT
$        INF-COEF =                       USE ONLY INF-METH.=CRACK
$        SOL-TRANS-SCH =                  USE ONLY FOR A SUNSPACE
$        VIS-TRANS-SCH =                  DAYLIGHT TRANSMITTANCE VALUE
```

```
$        GLARE-CTRL-PROB = 1.0            DEFAULT
$        INSIDE-VIS-REFL = 0.15           DEFAULT

NORTH-3 = EXTERIOR-WALL
         HEIGHT = 8.125
         WIDTH = 1.5
         X = -1.5  Y = -37.9  Z = 0
         AZIMUTH = 180
         CONSTRUCTION = WALL-2            $STUDS
         GND-REFLECTANCE = 0.20 ..
$        SKY-FORM-FACTOR =                USE DEFAULT
$        GND-FORM-FACTOR =                USE DEFAULT
$        INF-COEF =                       USE ONLY INF-METH.=CRACK
$        SHADING-SURFACE = YES
$        SHADING-DIVISION =               USE DEFAULT
$        MULTIPLIER = 1
$        SOLAR-FRACTION =                 USE DEFAULT
$        INSIDE-VIS-REFL = 0.5            10<TILT<170
$        INSIDE-SOL-ABS = 0.5             10<TILT<170

$NORTH-WEST FACING WALL

WEST-1 = EXTERIOR-WALL
         HEIGHT = 8.125
         WIDTH = 1.5
         X = 0 Y = -37.9 Z = 0
         AZIMUTH = 90
         CONSTRUCTION = WALL-2            $STUDS
         GND-REFLECTANCE = 0.20 ..
$        SKY-FORM-FACTOR =                USE DEFAULT
$        GND-FORM-FACTOR =                USE DEFAULT
$        INF-COEF =                       USE ONLY INF-METH.=CRACK
$        SHADING-SURFACE = YES
$        SHADING-DIVISION =               USE DEFAULT
$        MULTIPLIER = 1
$        SOLAR-FRACTION =                 USE DEFAULT
$        INSIDE-VIS-REFL = 0.5            10<TILT<170
$        INSIDE-SOL-ABS = 0.5             10<TILT<170

WEST-2 = EXTERIOR-WALL
         HEIGHT = 8.125
         WIDTH = 11.5
         X = 0 Y = -36.4 Z = 0
         AZIMUTH = 90
         CONSTRUCTION = WALL-1            $ WALL
         GND-REFLECTANCE = 0.20 ..
$        SKY-FORM-FACTOR =                USE DEFAULT
$        GND-FORM-FACTOR =                USE DEFAULT
$        INF-COEF =                       USE ONLY INF-METH.=CRACK
$        SHADING-SURFACE = YES
$        SHADING-DIVISION =               USE DEFAULT
$        MULTIPLIER = 1
$        SOLAR-FRACTION =                 USE DEFAULT
$        INSIDE-VIS-REFL = 0.5            10<TILT<170
$        INSIDE-SOL-ABS = 0.5             10<TILT<170

WW-1 = WINDOW
         HEIGHT = 3
         WIDTH = 3
         X = 2 Y = 4
```

```
         GLASS-TYPE = GT-1
         FRAME-WIDTH = 0.21  ..
$        SETBACK = 0                       DEAFULT
$        SHADING-SCHEDULE =
$        MAX-SOLAR-SCH =
$        SUN-CTRL-PROB = 1.0               DEFAULT
$        OPEN-SHADE-SCH =
$        WIN-SHADE-TYPE = MOVABLE-INTERIOR DEFAULT
$        CONDUCT-SCHEDULE =
$        CONDUCT-TMIN-SCH =                SCHED VALUES OF OA  DRY BULB
$        SKY-FORM-FACTOR =                 USE DEFAULT
$        GND-FORM-FACTOR =                 USE DEFAULT
$        SHADING-SURFACE = YES
$        SHADING-DIVISION = 10             DEFAULT
$        INF-COEF =                        USE ONLY INF-METH.=CRACK
$        SOL-TRANS-SCH =                   USE ONLY FOR A SUNSPACE
$        VIS-TRANS-SCH =                   DAYLIGHT TRANSMITTANCE VALUE
$        GLARE-CTRL-PROB = 1.0             DEFAULT
$        INSIDE-VIS-REFL = 0.15            DEFAULT

WEST-3 = EXTERIOR-WALL
         HEIGHT = 8.125
         WIDTH = 1.5
         X = 0 Y = -24.9 Z = 0
         AZIMUTH = 90
         CONSTRUCTION = WALL-2             $STUDS
         GND-REFLECTANCE = 0.20 ..
$        SKY-FORM-FACTOR =                 USE DEFAULT
$        GND-FORM-FACTOR =                 USE DEFAULT
$        INF-COEF =                        USE ONLY INF-METH.=CRACK
$        SHADING-SURFACE = YES
$        SHADING-DIVISION =                USE DEFAULT
$        MULTIPLIER = 1
$        SOLAR-FRACTION =                  USE DEFAULT
$        INSIDE-VIS-REFL = 0.5             10<TILT<170
$        INSIDE-SOL-ABS = 0.5              10<TILT<170

WEST-4 = EXTERIOR-WALL
         HEIGHT = 8.125
         WIDTH = 9.4
         X = 0 Y = -23.4 Z = 0
         AZIMUTH = 90
         CONSTRUCTION = WALL-1             $ WALL
         GND-REFLECTANCE = 0.20 ..
$        SKY-FORM-FACTOR =                 USE DEFAULT
$        GND-FORM-FACTOR =                 USE DEFAULT
$        INF-COEF =                        USE ONLY INF-METH.=CRACK
$        SHADING-SURFACE = YES
$        SHADING-DIVISION =                USE DEFAULT
$        MULTIPLIER = 1
$        SOLAR-FRACTION =                  USE DEFAULT
$        INSIDE-VIS-REFL = 0.5             10<TILT<170
$        INSIDE-SOL-ABS = 0.5              10<TILT<170

WEST-5 = EXTERIOR-WALL
         HEIGHT = 8.125
         WIDTH = 1.5
         X = 0 Y = -14 Z =0
         AZIMUTH = 90
         CONSTRUCTION = WALL-2             $ STUDS
```

```
         GND-REFLECTANCE = 0.20 ..
$        SKY-FORM-FACTOR =                USE DEFAULT
$        GND-FORM-FACTOR =                USE DEFAULT
$        INF-COEF =                       USE ONLY INF-METH.=CRACK
$        SHADING-SURFACE = YES
$        SHADING-DIVISION =               USE DEFAULT
$        MULTIPLIER = 1
$        SOLAR-FRACTION =                 USE DEFAULT
$        INSIDE-VIS-REFL = 0.5            10<TILT<170
$        INSIDE-SOL-ABS = 0.5             10<TILT<170

WEST-6 = EXTERIOR-WALL
         HEIGHT = 8.125
         WIDTH = 12.5
         X = -7 Y = -12.5 Z = 0
         AZIMUTH = 90
         CONSTRUCTION = WALL-1            $ WALL
         GND-REFLECTANCE = 0.20 ..
$        SKY-FORM-FACTOR =                USE DEFAULT
$        GND-FORM-FACTOR =                USE DEFAULT
$        INF-COEF =                       USE ONLY INF-METH.=CRACK
$        SHADING-SURFACE = YES
$        SHADING-DIVISION =               USE DEFAULT
$        MULTIPLIER = 1
$        SOLAR-FRACTION =                 USE DEFAULT
$        INSIDE-VIS-REFL = 0.5            10<TILT<170
$        INSIDE-SOL-ABS = 0.5             10<TILT<170

WW-2 = WINDOW
         HEIGHT = 5
         WIDTH = 3
         X = 4.25 Y = 2
         GLASS-TYPE = GT-1
         FRAME-WIDTH = 0.21  ..
$        SETBACK = 0                      DEAFULT
$        SHADING-SCHEDULE =
$        MAX-SOLAR-SCH =
$        SUN-CTRL-PROB = 1.0              DEFAULT
$        OPEN-SHADE-SCH =
$        WIN-SHADE-TYPE = MOVABLE-INTERIOR DEFAULT
$        CONDUCT-SCHEDULE =
$        CONDUCT-TMIN-SCH =               SCHED VALUES OF OA  DRY BULB
$        SKY-FORM-FACTOR =                USE DEFAULT
$        GND-FORM-FACTOR =                USE DEFAULT
$        SHADING-SURFACE = YES
$        SHADING-DIVISION = 10            DEFAULT
$        INF-COEF =                       USE ONLY INF-METH.=CRACK
$        SOL-TRANS-SCH =                  USE ONLY FOR A SUNSPACE
$        VIS-TRANS-SCH =                  DAYLIGHT TRANSMITTANCE VALUE
$        GLARE-CTRL-PROB = 1.0            DEFAULT
$        INSIDE-VIS-REFL = 0.15           DEFAULT

$ SOUTH-WEST FACING WALL
SOUTH-1 = EXTERIOR-WALL
         HEIGHT = 8.125
         WIDTH = 7
         X = 0 Y = -12.5
         AZIMUTH = 0
         CONSTRUCTION = WALL-1            $WALL
         GND-REFLECTANCE = 0.20 ..
```

```
$        SKY-FORM-FACTOR =                 USE DEFAULT
$        GND-FORM-FACTOR =                 USE DEFAULT
$        INF-COEF =                        USE ONLY INF-METH.=CRACK
$        SHADING-SURFACE = YES
$        SHADING-DIVISION =                USE DEFAULT
$        MULTIPLIER = 1
$        SOLAR-FRACTION =                  USE DEFAULT
$        INSIDE-VIS-REFL = 0.5             10<TILT<170
$        INSIDE-SOL-ABS = 0.5              10<TILT<170

DS-1 = DOOR
         HEIGHT = 6.8
         WIDTH = 3
         X = 3 Y = 0
         CONSTRUCTION = DOORS  ..
$        SETBACK = 0                       DEFAULT
$        SKY-FORM-FACTOR =                 USE DEFAULT
$        GND-FORM-FACTOR =                 USE DEFAULT
$        SHADING-SURFACE = YES
$        SHADING-DIVISION = 10             DEFAULT
$        INF-COEF =                        USE ONLY INF-METH.=CRACK
$        INSIDE-VIS-REFL = 0.5             10<TILT<170

SOUTH-2 = EXTERIOR-WALL
         HEIGHT = 8.125
         WIDTH = 1.5
         X = -7 Y = 0 Z = 0
         AZIMUTH = 0
         CONSTRUCTION = WALL-2             $STUDS
         GND-REFLECTANCE = 0.20 ..
$        SKY-FORM-FACTOR =                 USE DEFAULT
$        GND-FORM-FACTOR =                 USE DEFAULT
$        INF-COEF =                        USE ONLY INF-METH.=CRACK
$        SHADING-SURFACE = YES
$        SHADING-DIVISION =                USE DEFAULT
$        MULTIPLIER = 1
$        SOLAR-FRACTION =                  USE DEFAULT
$        INSIDE-VIS-REFL = 0.5             10<TILT<170
$        INSIDE-SOL-ABS = 0.5              10<TILT<170

SOUTH-3 = EXTERIOR-WALL
         HEIGHT = 8.125
         WIDTH = 21.9
         X = -8.5 Y = 0 Z = 0
         AZIMUTH = 0
         CONSTRUCTION = WALL-1             $WALL
         GND-REFLECTANCE = 0.20 ..
$        SKY-FORM-FACTOR =                 USE DEFAULT
$        GND-FORM-FACTOR =                 USE DEFAULT
$        INF-COEF =                        USE ONLY INF-METH.=CRACK
$        SHADING-SURFACE = YES
$        SHADING-DIVISION =                USE DEFAULT
$        MULTIPLIER = 1
$        SOLAR-FRACTION =                  USE DEFAULT
$        INSIDE-VIS-REFL = 0.5             10<TILT<170
$        INSIDE-SOL-ABS = 0.5              10<TILT<170

WS-1 = WINDOW
         HEIGHT = 5
         WIDTH = 3
```

```
         X = 2.4 Y = 2
         GLASS-TYPE = GT-1
         FRAME-WIDTH = 0.21  ..
$        SETBACK = 0                     DEAFULT
$        SHADING-SCHEDULE =
$        MAX-SOLAR-SCH =
$        SUN-CTRL-PROB = 1.0             DEFAULT
$        OPEN-SHADE-SCH =
$        WIN-SHADE-TYPE = MOVABLE-INTERIOR DEFAULT
$        CONDUCT-SCHEDULE =
$        CONDUCT-TMIN-SCH =              SCHED VALUES OF OA  DRY BULB
$        SKY-FORM-FACTOR =               USE DEFAULT
$        GND-FORM-FACTOR =               USE DEFAULT
$        SHADING-SURFACE = YES
$        SHADING-DIVISION = 10           DEFAULT
$        INF-COEF =                      USE ONLY INF-METH.=CRACK
$        SOL-TRANS-SCH =                 USE ONLY FOR A SUNSPACE
$        VIS-TRANS-SCH =                 DAYLIGHT TRANSMITTANCE VALUE
$        GLARE-CTRL-PROB = 1.0           DEFAULT
$        INSIDE-VIS-REFL = 0.15          DEFAULT

WS-2 = WINDOW
         HEIGHT = 5
         WIDTH = 3
         X = 16.3 Y = 2
         GLASS-TYPE = GT-1
         FRAME-WIDTH = 0.21  ..
$        SETBACK = 0                     DEAFULT
$        SHADING-SCHEDULE =
$        MAX-SOLAR-SCH =
$        SUN-CTRL-PROB = 1.0             DEFAULT
$        OPEN-SHADE-SCH =
$        WIN-SHADE-TYPE = MOVABLE-INTERIOR DEFAULT
$        CONDUCT-SCHEDULE =
$        CONDUCT-TMIN-SCH =              SCHED VALUES OF OA  DRY BULB
$        SKY-FORM-FACTOR =               USE DEFAULT
$        GND-FORM-FACTOR =               USE DEFAULT
$        SHADING-SURFACE = YES
$        SHADING-DIVISION = 10           DEFAULT
$        INF-COEF =                      USE ONLY INF-METH.=CRACK
$        SOL-TRANS-SCH =                 USE ONLY FOR A SUNSPACE
$        VIS-TRANS-SCH =                 DAYLIGHT TRANSMITTANCE VALUE
$        GLARE-CTRL-PROB = 1.0           DEFAULT
$        INSIDE-VIS-REFL = 0.15          DEFAULT

SOUTH-4  = EXTERIOR-WALL
         HEIGHT = 8.125
         WIDTH = 1.5
         X = -30.4 Y = 0 Z = 0
         AZIMUTH = 0
         CONSTRUCTION = WALL-2           $STUDS
         GND-REFLECTANCE = 0.20 ..
$        SKY-FORM-FACTOR =               USE DEFAULT
$        GND-FORM-FACTOR =               USE DEFAULT
$        INF-COEF =                      USE ONLY INF-METH.=CRACK
$        SHADING-SURFACE = YES
$        SHADING-DIVISION =              USE DEFAULT
$        MULTIPLIER = 1
$        SOLAR-FRACTION =                USE DEFAULT
$        INSIDE-VIS-REFL = 0.5           10<TILT<170
```

```
$        INSIDE-SOL-ABS = 0.5             10<TILT<170

$ SOUTH-EAST FACING WALL

EAST-1 = EXTERIOR-WALL
         HEIGHT = 8.125
         WIDTH = 1.5
         X = -31.9 Y = 0 Z = 0
         AZIMUTH = 270
         CONSTRUCTION = WALL-2            $STUDS
         GND-REFLECTANCE = 0.20 ..
$        SKY-FORM-FACTOR =                USE DEFAULT
$        GND-FORM-FACTOR =                USE DEFAULT
$        INF-COEF =                       USE ONLY INF-METH.=CRACK
$        SHADING-SURFACE = YES
$        SHADING-DIVISION =               USE DEFAULT
$        MULTIPLIER = 1
$        SOLAR-FRACTION =                 USE DEFAULT
$        INSIDE-VIS-REFL = 0.5            10<TILT<170
$        INSIDE-SOL-ABS = 0.5             10<TILT<170


EAST-2 = EXTERIOR-WALL
         HEIGHT = 8.125
         WIDTH = 11.9
         X = -31.9 Y = -1.5 Z = 0
         AZIMUTH = 270
         CONSTRUCTION = WALL-1            $ WALL
         GND-REFLECTANCE = 0.20 ..
$        SKY-FORM-FACTOR =                USE DEFAULT
$        GND-FORM-FACTOR =                USE DEFAULT
$        INF-COEF =                       USE ONLY INF-METH.=CRACK
$        SHADING-SURFACE = YES
$        SHADING-DIVISION =               USE DEFAULT
$         MULTIPLIER = 1
$        SOLAR-FRACTION =                 USE DEFAULT
$        INSIDE-VIS-REFL = 0.5            10<TILT<170
$        INSIDE-SOL-ABS = 0.5             10<TILT<170

WE-1 = WINDOW
         HEIGHT = 5
         WIDTH = 3
         X = 3 Y = 2
         GLASS-TYPE = GT-1
         FRAME-WIDTH = 0.21  ..
$        SETBACK = 0                      DEAFULT
$        SHADING-SCHEDULE =
$        MAX-SOLAR-SCH =
$        SUN-CTRL-PROB = 1.0              DEFAULT
$        OPEN-SHADE-SCH =
$        WIN-SHADE-TYPE = MOVABLE-INTERIOR DEFAULT
$        CONDUCT-SCHEDULE =
$        CONDUCT-TMIN-SCH =               SCHED VALUES OF OA  DRY BULB
$        SKY-FORM-FACTOR =                USE DEFAULT
$        GND-FORM-FACTOR =                USE DEFAULT
$        SHADING-SURFACE = YES
$        SHADING-DIVISION = 10            DEFAULT
$        INF-COEF =                       USE ONLY INF-METH.=CRACK
$        SOL-TRANS-SCH =                  USE ONLY FOR A SUNSPACE
$        VIS-TRANS-SCH =                  DAYLIGHT TRANSMITTANCE VALUE
```

```
$        GLARE-CTRL-PROB = 1.0            DEFAULT
$        INSIDE-VIS-REFL = 0.15           DEFAULT

EAST-3 = EXTERIOR-WALL
         HEIGHT = 8.125
         WIDTH = 1.5
         X = -31.9 Y = -13.4 Z = 0
         AZIMUTH = 270
         CONSTRUCTION = WALL-2            $STUDS
         GND-REFLECTANCE = 0.20 ..
$        SKY-FORM-FACTOR =                USE DEFAULT
$        GND-FORM-FACTOR =                USE DEFAULT
$        INF-COEF =                       USE ONLY INF-METH.=CRACK
$        SHADING-SURFACE = YES
$        SHADING-DIVISION =               USE DEFAULT
$        MULTIPLIER = 1
$        SOLAR-FRACTION =                 USE DEFAULT
$        INSIDE-VIS-REFL = 0.5            10<TILT<170
$        INSIDE-SOL-ABS = 0.5             10<TILT<170

EAST-4 = EXTERIOR-WALL
         HEIGHT = 8.125
         WIDTH = 8.5
         X = -31.9 Y = -14.9 Z = 0
         AZIMUTH = 270
         CONSTRUCTION = WALL-1           $WALL
         GND-REFLECTANCE = 0.20 ..
$        SKY-FORM-FACTOR =               USE DEFAULT
$        GND-FORM-FACTOR =                USE DEFAULT
$        INF-COEF =                       USE ONLY INF-METH.=CRACK
$        SHADING-SURFACE = YES
$        SHADING-DIVISION =               USE DEFAULT
$        MULTIPLIER = 1
$        SOLAR-FRACTION =                 USE DEFAULT
$        INSIDE-VIS-REFL = 0.5            10<TILT<170
$        INSIDE-SOL-ABS = 0.5             10<TILT<170

WE-2 = WINDOW
         HEIGHT = 5
         WIDTH = 3
         X = 3 Y = 2
         GLASS-TYPE = GT-1
         FRAME-WIDTH = 0.21  ..
$        SETBACK = 0                      DEAFULT
$        SHADING-SCHEDULE =
$        MAX-SOLAR-SCH =
$        SUN-CTRL-PROB = 1.0              DEFAULT
$        OPEN-SHADE-SCH =
$        WIN-SHADE-TYPE = MOVABLE-INTERIOR DEFAULT
$        CONDUCT-SCHEDULE =
$        CONDUCT-TMIN-SCH =               SCHED VALUES OF OA  DRY BULB
$        SKY-FORM-FACTOR =                USE DEFAULT
$        GND-FORM-FACTOR =                USE DEFAULT
$        SHADING-SURFACE = YES
$        SHADING-DIVISION = 10            DEFAULT
$        INF-COEF =                       USE ONLY INF-METH.=CRACK
$        SOL-TRANS-SCH =                  USE ONLY FOR A SUNSPACE
$        VIS-TRANS-SCH =                  DAYLIGHT TRANSMITTANCE VALUE
$        GLARE-CTRL-PROB = 1.0            DEFAULT
$        INSIDE-VIS-REFL = 0.15           DEFAULT
```

```
EAST-5 = EXTERIOR-WALL
         HEIGHT = 8.125
         WIDTH = 1.5
         X = -31.9 Y = -23.4 Z = 0
         AZIMUTH = 270
         CONSTRUCTION = WALL-2            $STUDS
         GND-REFLECTANCE = 0.20 ..
$        SKY-FORM-FACTOR =                USE DEFAULT
$        GND-FORM-FACTOR =                USE DEFAULT
$        INF-COEF =                       USE ONLY INF-METH.=CRACK
$        SHADING-SURFACE = YES
$        SHADING-DIVISION =               USE DEFAULT
$        MULTIPLIER = 1
$        SOLAR-FRACTION =                 USE DEFAULT
$        INSIDE-VIS-REFL = 0.5            10<TILT<170
$        INSIDE-SOL-ABS = 0.5             10<TILT<170

EAST-6 = EXTERIOR-WALL
         HEIGHT = 8.125
         WIDTH = 11.5
         X = -31.9 Y = -24.9 Z = 0
         AZIMUTH = 270
         CONSTRUCTION = WALL-1            $WALL
         GND-REFLECTANCE = 0.20 ..
$        SKY-FORM-FACTOR =                USE DEFAULT
$        GND-FORM-FACTOR =                USE DEFAULT
$        INF-COEF =                       USE ONLY INF-METH.=CRACK
$        SHADING-SURFACE = YES
$        SHADING-DIVISION =               USE DEFAULT
$        MULTIPLIER = 1
$        SOLAR-FRACTION =                 USE DEFAULT
$        INSIDE-VIS-REFL = 0.5            10<TILT<170
$        INSIDE-SOL-ABS = 0.5             10<TILT<170

WE-3 = WINDOW
         HEIGHT = 5
         WIDTH = 6
         X = 3 Y = 2
         GLASS-TYPE = GT-1
         FRAME-WIDTH = 0.21  ..
$        SETBACK = 0                      DEAFULT
$        SHADING-SCHEDULE =
$        MAX-SOLAR-SCH =
$        SUN-CTRL-PROB = 1.0              DEFAULT
$        OPEN-SHADE-SCH =
$        WIN-SHADE-TYPE = MOVABLE-INTERIOR DEFAULT
$        CONDUCT-SCHEDULE =
$        CONDUCT-TMIN-SCH =               SCHED VALUES OF OA  DRY BULB
$        SKY-FORM-FACTOR =                USE DEFAULT
$        GND-FORM-FACTOR =                USE DEFAULT
$        SHADING-SURFACE = YES
$        SHADING-DIVISION = 10            DEFAULT
$        INF-COEF =                       USE ONLY INF-METH.=CRACK
$        SOL-TRANS-SCH =                  USE ONLY FOR A SUNSPACE
$        VIS-TRANS-SCH =                  DAYLIGHT TRANSMITTANCE VALUE
$        GLARE-CTRL-PROB = 1.0            DEFAULT
$        INSIDE-VIS-REFL = 0.15           DEFAULT

EAST-7 = EXTERIOR-WALL
```

```
         HEIGHT = 8.125
         WIDTH = 1.5
         X = -31.9 Y = -36.4 Z = 0
         AZIMUTH = 270
         CONSTRUCTION = WALL-2            $STUDS
         GND-REFLECTANCE = 0.20 ..
$        SKY-FORM-FACTOR =                USE DEFAULT
$        GND-FORM-FACTOR =                USE DEFAULT
$        INF-COEF =                       USE ONLY INF-METH.=CRACK
$        SHADING-SURFACE = YES
$        SHADING-DIVISION =               USE DEFAULT
$        MULTIPLIER = 1
$        SOLAR-FRACTION =                 USE DEFAULT
$        INSIDE-VIS-REFL = 0.5            10<TILT<170
$        INSIDE-SOL-ABS = 0.5             10<TILT<170

SCEIL-1 = INTERIOR-WALL
         AREA = 55.825
         X = -31.9 Y = -37.9 Z = 8.125
         AZIMUTH = 180
         TILT = 0
         HEIGHT = 1.75
         WIDTH = 31.9
         INT-WALL-TYPE = STANDARD
         NEXT-TO ATTIC-1
         CONSTRUCTION = CEILING-4  ..     $LIVING ROOM CEILING STUDS
$        SOLAR-FRACTION =                 LIST OF TWO
$        INSIDE-VIS-REFL =                LIST OF TWO
$        INSIDE-SOL-ABS =                 LIST OF TWO

SCEIL-2 = INTERIOR-WALL
         AREA = 810.26
         X = -31.9 Y = -36.15  Z = 8.125
         AZIMUTH = 180
         TILT = 0
         HEIGHT = 23.65
         WIDTH = 31.9
         INT-WALL-TYPE = STANDARD
         NEXT-TO ATTIC-1
         CONSTRUCTION = CEILING-2  ..     $LIVING ROOM PART CEILING
$        SOLAR-FRACTION =                 LIST OF TWO
$        INSIDE-VIS-REFL =                LIST OF TWO
$        INSIDE-SOL-ABS =                 LIST OF TWO


SCEIL-3 = INTERIOR-WALL
         AREA = 22.41
         X = -7 Y = 0 Z = 8.125
         AZIMUTH = 0
         TILT = 0
         HEIGHT = 0.875
         WIDTH = 24.9
         INT-WALL-TYPE = STANDARD
         NEXT-TO ATTIC-1
         CONSTRUCTION = CEILING-4  ..     $BEDROOM PART CEILING STUDS
$        SOLAR-FRACTION =                 LIST OF TWO
$        INSIDE-VIS-REFL =                LIST OF TWO
$        INSIDE-SOL-ABS =                 LIST OF TWO

SCEIL-4 = INTERIOR-WALL
```

```
         AREA = 311.25
         X = -7 Y = -0.875 Z = 8.125
         AZIMUTH = 0
         TILT = 0
         HEIGHT = 11.625
         WIDTH = 24.9
         INT-WALL-TYPE = STANDARD
         NEXT-TO ATTIC-1
         CONSTRUCTION = CEILING-2  ..     $BEDROOM PART CEILING
$        SOLAR-FRACTION =                 LIST OF TWO
$        INSIDE-VIS-REFL =                LIST OF TWO
$        INSIDE-SOL-ABS =                 LIST OF TWO

U-F      CONS = FLOOR-1
         AREA = 1209
         TILT = 180  ..
$        SOLAR-FRACTION =                 ONLY IF CWF TO BE CALCULATED
$        INSIDE-VIS-REFL = 0.2            DEFAULT FOR FLOOR
$        INSIDE-SOL-ABS =  0.8            DEFAULT FOR FLOOR

EAVE-FRONT = BUILDING-SHADE
         HEIGHT = 4
         WIDTH = 16
         TRANSMITTANCE = 0
         X = -31.9 Y = -37.9 Z = 8.125
         TILT = 180
         AZIMUTH = 180 ..
$        SHADE-VIS-REFL = 0.5             DEFAULT
$        SHADE-GND-REFL = 0.2             DEFAULT

OTHER-HOUSE = BUILDING-SHADE
         HEIGHT = 10
         WIDTH = 41.8
         TRANSMITTANCE = 0
         X = -45.55 Y = 0
         AZIMUTH = 270 ..
$        SHADE-VIS-REFL = 0.5             DEFAULT
$        SHADE-GND-REFL = 0.2             DEFAULT

$HOURLY REPORT

$HR-SCH-1 =S CHEDULE THRU DEC 31 (ALL) (1,24) (1) ..

$LRB-1 = REPORT-BLOCK
$         VARIABLE-TYPE=GLOBAL
$         VARIABLE-LIST=(2) ..
$         2 = GROUND TEMPERATURE (RANKINE)

$LDS-REP-1 = HOURLY-REPORT
$         REPORT-SCHEDULE=HR-SCH-1
$         REPORT-BLOCK=(LRB-1) ..

END ..
COMPUTE LOADS ..

INPUT SYSTEMS ..

SYSTEMS-REPORT  VERIFICATION = (SV-A)
                SUMMARY = (ALL-SUMMARY) ..
```

```
$         SV-A    SYSTEM DESIGN PARAMETER

$SUMMARY
$     SS-A    SYSTEM MONTHLY LOADS SUMMARY-CONSUMPTION OF EACH TOTAL
               SYSTEM
$     SS-B    SYSTEM MONTHLY LOADS SUMMARY-CONSUMPTION OF THE HVAC
               EQUIPMENT
$     SS-C    SYSTEM MONTHLY LOAD HOURS
$     SS-D    PLANT MONTHLY LOADS SUMMARY -CONSUMPTION OF ALL SYSTEMS
$             ASSOCIATED WITH THE PLANT
$     SS-E    PLANT MONTHLY LOAD HOURS
$     SS-F    ZONE MONTHLY DEMAND SUPPLY
$     SS-G    ZONE MONTHLY LOADS SUMMARY
$     SS-H    SYSTEM MONTHLY LOADS SUMMARY
$     SS-I    SYSTEM MONTHLY COOLING LOAD SUMMARY
$     SS-J    SYSTEM PEAK HEATING AND COOLING DAYS

$SYSTEMS SCHEDULE

FAN-1     = DAY-SCHEDULE (1,24) (1) ..
FAN-WEEK = WEEK-SCHEDULE DAYS (ALL)
           DAY-SCHEDULE=FAN-1 ..
FAN-SCHED = SCHEDULE  THRU DEC 31 FAN-WEEK ..

HEAT-1    = DAY-SCHEDULE
          (1)(70.25)
         (2)(69.87)
          (3)(69.69)
          (4)(69.63)
          (5)(69.53)
          (6)(69.38)
          (7)(69.27)
          (8)(69.17)
          (9)(69.22)
          (10)(69.30)
          (11)(69.95)
          (12)(70.61)
          (13)(71.32)
          (14)(71.93)
          (15)(72.13)
          (16)(72.25)
          (17)(72.44)
          (18)(72.59)
          (19)(72.50)
          (20)(72.14)
          (21)(71.83)
          (22)(71.37)
          (23)(70.83)
          (24)(70.32)  ..


HEAT-WEEK = WEEK-SCHEDULE DAYS (ALL)
            DAY-SCHEDULE =HEAT-1  ..

HEAT-SCHED = SCHEDULE THRU DEC 31 HEAT-WEEK ..

HEATING-1  = SCHEDULE THRU DEC 31 (ALL)(1,24)(1.0)  ..

COOL-1    = DAY-SCHEDULE
          (1)(71.48)
```

```
          (2)(71.35)
          (3)(71.15)
          (4)(70.95)
          (5)(70.80)
          (6)(70.65)
          (7)(70.55)
          (8)(70.51)
          (9)(70.50)
          (10)(70.65)
          (11)(70.98)
          (12)(71.52)
          (13)(72.10)
          (14)(72.49)
          (15)(72.74)
          (16)(72.96)
          (17)(73.13)
          (18)(73.21)
          (19)(73.13)
          (20)(72.94)
          (21)(72.58)
          (22)(72.30)
          (23)(72.05)
          (24)(71.81) ..


COOL-WEEK = WEEK-SCHEDULE DAYS (ALL)
            DAY-SCHEDULE =COOL-1  ..

COOL-SCHED = SCHEDULE THRU DEC 31 COOL-WEEK ..

COOLING-1  = SCHEDULE THRU DEC 31 (ALL)(1,24)(1) ..

$HEATOFF   = SCHEDULE THRU DEC 31 (ALL)(1,24)(69) ..
$COOLOFF   = SCHEDULE THRU DEC 31 (ALL)(1,24)(65) ..

$SYSTEM DESCRIPTION

CONTROL  = ZONE-CONTROL
          DESIGN-HEAT-T=73                $DEGREE F
         HEAT-TEMP-SCH=HEAT-SCHED
         DESIGN-COOL-T=68
         COOL-TEMP-SCH=COOL-SCHED
         THERMOSTAT-TYPE = PROPORTIONAL
         THROTTLING-RANGE = 2  ..

ZAIR      = ZONE-AIR
         CFM/SQFT = 0.82  ..

RESIDENCE = ZONE
          ZONE-CONTROL=CONTROL
          ZONE-AIR=ZAIR
          ZONE-TYPE=CONDITIONED
          SIZING-OPTION=ADJUST-LOADS ..   $OR FROM LOADS

ATTIC-1  = ZONE
         ZONE-TYPE=UNCONDITIONED ..

S-CONT   = SYSTEM-CONTROL
         COOLING-SCHEDULE=COOLING-1
         HEATING-SCHEDULE=HEATING-1
```

```
         MAX-SUPPLY-T=130                 $APPROXIMATE VALUE
         MIN-SUPPLY-T=50 ..               $APPROXIMATE VALUE

S-AIR    = SYSTEM-AIR   SUPPLY-CFM=992  ..

S-FAN    = SYSTEM-FANS
         SUPPLY-DELTA-T=2                 $KOOTIN SANWU'S DISSERTATION
         SUPPLY-KW=0.000128               $DEFAULT-KW/CFM
         FAN-SCHEDULE=FAN-SCHED ..

S-EQUIP  = SYSTEM-EQUIPMENT
$        COOLING-CAPACITY=25000            KOOTIN SANWU'S DISSERTATION
         COMPRESSOR-TYPE=SINGLE-SPEED
         COOLING-EIR=0.341                 $EQUIV. TO 10 SEERS
$        HEATING-CAPACITY=-22000           FROM PEAK LOADS REPORT
         FURNACE-HIR=1.1765 ..
$         DEFAULT:HEAT-SOURCE=HEAT-PUMP

SYST-1   = SYSTEM  SYSTEM-TYPE=RESYS
         ZONE-NAMES=(RESIDENCE,ATTIC-1)
         SYSTEM-CONTROL=S-CONT
         SYSTEM-AIR=S-AIR
         SYSTEM-FANS=S-FAN
         SYSTEM-EQUIPMENT=S-EQUIP ..

PLANT-1  = PLANT-ASSIGNMENT SYSTEM-NAMES =(SYST-1)  ..


$HOURLY-REPORT

HR-SCH-3 = SCHEDULE THRU DEC 31 (ALL) (1,24) (1) ..

LRB-3    = REPORT-BLOCK
         VARIABLE-TYPE=RESIDENCE
         VARIABLE-LIST=(6) ..
$         6 =CURRENT HOUR ZONE TEMPERATURE (F)

LRB-4    = REPORT-BLOCK
         VARIABLE-TYPE=ATTIC-1
         VARIABLE-LIST=(6)  ..

LRB-5    = REPORT-BLOCK
         VARIABLE-TYPE=GLOBAL
         VARIABLE-LIST=(8)  ..
$         8 =OUTDOOR DRY BULB TEMPERATURE

LDS-REP-3 = HOURLY-REPORT
          REPORT-SCHEDULE=HR-SCH-3
          REPORT-BLOCK=(LRB-3,LRB-4,LRB-5)  ..

END ..
COMPUTE SYSTEMS ..

INPUT PLANT ..

PLANT-REPORT VERIFICATION=(ALL-VERIFICATION)
             SUMMARY =(ALL-SUMMARY) ..

$VERIFICATION
$         PV-A    EQUIPMENT SIZE
```

```
$         PV-B    COST REFERENCE DATA
$         PV-C    EQUIPMENT COSTS
$         PV-D    COST OF UTILITIES
$         PV-E    EQUIPMENT LOAD RATIOS
$         PV-G    EQUIPMENT QUADRATICS
$         PV-H    LIFE-CYCLE PARAMETERS

$SUMMARY
$         PS-A    PLANT ENERGY UTILIZATION SUMMARY
$         PS-B    MONTHLY PEAK AND TOTAL ENERGY USE
$         PS-C    EQUIPMENT PART LOAD OPERATION
$         PS-D    PLANT LOAD SATISFIED
$         PS-E    MONTHLY ENERGY END-USE SUMMARY
$         PS-G    ELECTRIC LOADS SCATTER PLOT
$         PS-H    EQUIPMENT USE STATISTICS
$         PS-I    EQUIPMENT LIFE-CYCLE COST
$         PS-J    PLANT LIFE-CYCLE COST SUMMARY
$         BEPS    ESTIMATES BUILDING ENERGY PERFORMANCE

PLANT-1  = PLANT-ASSIGNMENT  ..

DHW-1    = PLANT-EQUIPMENT
         TYPE =DHW-HEATER
         SIZE =0.056  ..

$         WATER HEATER: RHEEM, MODEL # 21V40-7,INPUT 34,000 BTU,
$         40 GALLON

DHW-2    = DAY-SCHEDULE
        (1,7) (0.1)
        (8,9) (0.8)
        (10,12) (0.3)
        (13,14) (0.3)
        (15,17) (0.3)
        (18,21) (0.8)
        (22,24) (0) ..

DHW-WEEK = WEEK-SCHEDULE DAYS (ALL)
         DAY-SCHEDULE =DHW-2 ..

DHWSCH-1 = SCHEDULE THRU DEC 31 DHW-WEEK ..

ENERGY-RESOURCE
RESOURCE = NATURAL-GAS  ..

END ..
COMPUTE PLANT ..

STOP ..
```

APPENDIX D

RESULTS OF DAYLIGHT FACTOR MEASUREMENTS OBTAINED FROM THE COLLEGE OF ARCHITECTURE'S ARTIFICIAL SKY DOME AT TEXAS A&M UNIVERSITY

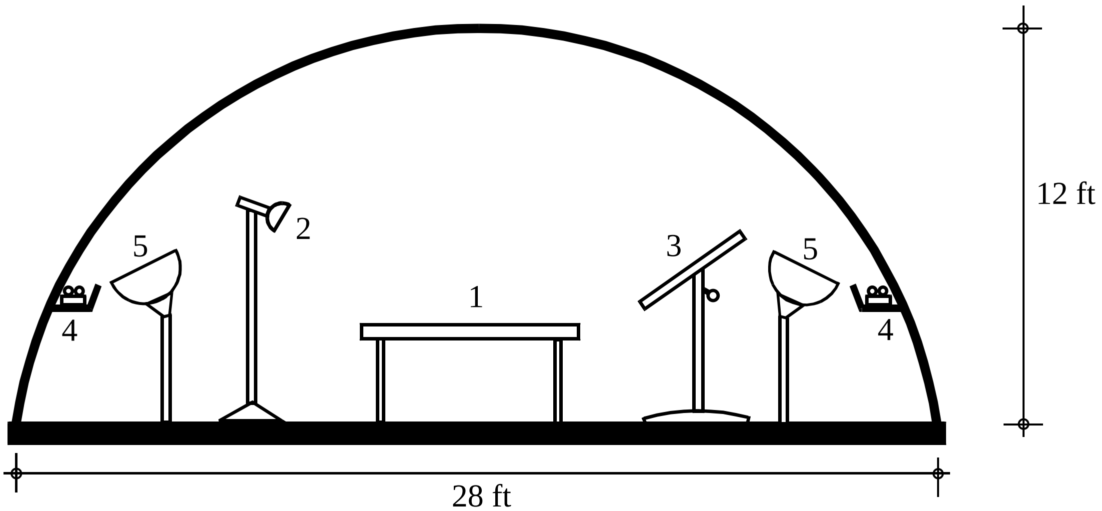
THE USE OF A DAYLIGHTING LABORATORY: THE ARTIFICIAL SKY DOME

Physical scale model testing can be conducted either in a daylighting laboratory or under actual sky conditions. However, model testing under real overcast sky conditions often experiences problems of unpredictable sky luminance distribution as well as uncontrollable daily or seasonal events. Therefore, the development of artificial sky simulators provided a means to overcome these problems. There are two basic types of artificial sky simulators (Spitzglas 1983): the hemispherical dome structure and the rectangular-shaped structure (the mirror type). The mirror type is a rectangular box with a luminous ceiling plane, surrounded by vertical mirrors on its four sides. The hemispherical sky is a dome structure with an opaque white interior and diffusive surface, illuminated by light sources located around the periphery of the base. Preliminary model testing in this study was conducted using the College of Architecture ’s Artificial Daylighting Sky Dome.

The sky simulator located at Texas A&M university is an insulated, aluminium-skinned dome attached to a steel-frame structure (Abdulmohsen 1995). The dome has a diameter of 28 feet at its base, and a height of 12 feet. The interior surface is covered with rough matte sprayed-on insulation material. Figure D1 presents an illustration of the sky dome in cross section.

The light source for this sky simulator includes two types of luminaires: 1000-watt, high pressure sodium HID lamps, and 110-watt, cool white fluorescent lamps. The artificial sun source is a 650-watt, cool beam PAR lamp. The laboratory contains a model table which is located in the middle of the room, and a heliodon table opposite to the artificial sun source. The laboratory is thermally controlled by three 3-ton fan coil units served by hot and cold water system from the building’s utility plant.

This chapter presents the results of Daylight Factors obtained from the measurements of the physical scale model under the daylighting laboratory. The results presented in this chapter include Daylight Factors measured from the basecase model and the three proposed models, namely the model with maximum 6-foot overhang, the model with maximum 6-foot overhang with vertical fin, and the model with 18-inch combined lightshelf. This chapter also discusses the measurement results from the study of the living room with and without the combination designs of clerestory window, high windows, and exterior and interior lightshelves.



(1) Model table
(2) Artificial sun source (650-watt, cool beam PAR lamp) for sun simulator
(3) Heliodon table
(4) Sky simulator light source (110-watt cool white fluorescent lamps)
(5) Sky simulator light source (1000-watt high pressure sodium HID lamps)

Figure D1 – Illustration of a cross section of the College of Architecture's Daylighting Laboratory at TAMU.

As seen in Figure D2, Daylight Factors of the three proposed models and the basecase model were compared. The graph illustrated that the applications of maximum overhang and maximum overhang with vertical fin shading systems reduced the interior Daylight Factors. According to the study objective, the use of lightshelf system aimed to increase interior illuminance while shading the windows from the direct sun. Figure D2 shows that the use of lightshelf, as the proposed final design, did increase Daylight Factors of the Bedroom-1 (southeast bedroom) and the Bedroom-M (southwest bedroom), but failed to achieve its goal of enhancing the illuminance of the living, dining, and the bedroom-2. Further studies are needed to resolve the problems found in this result disagreement.

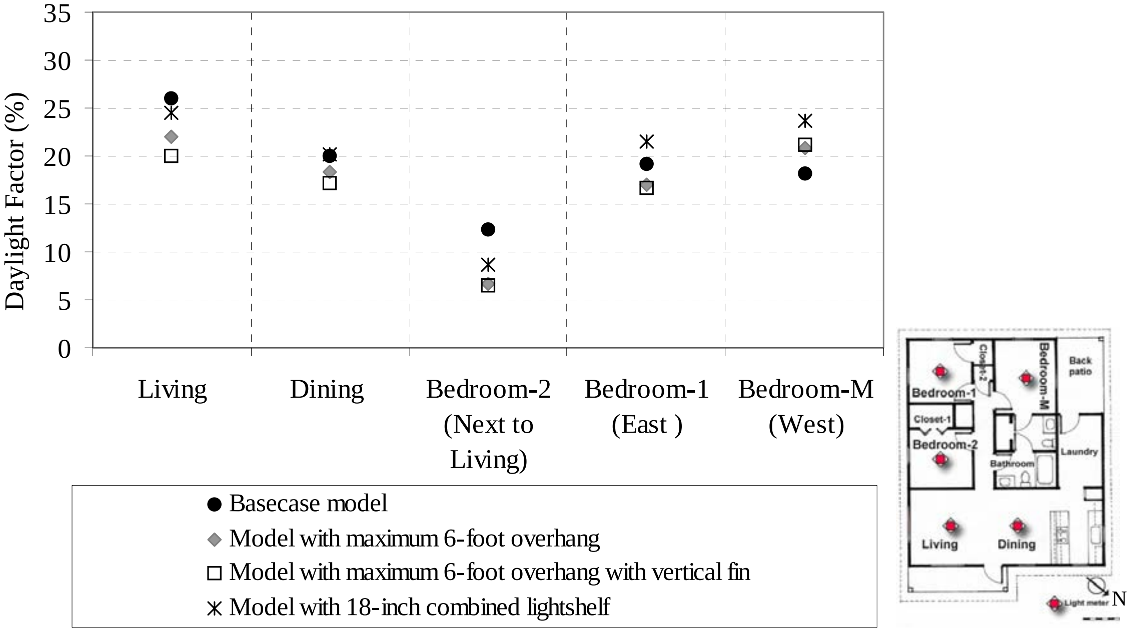
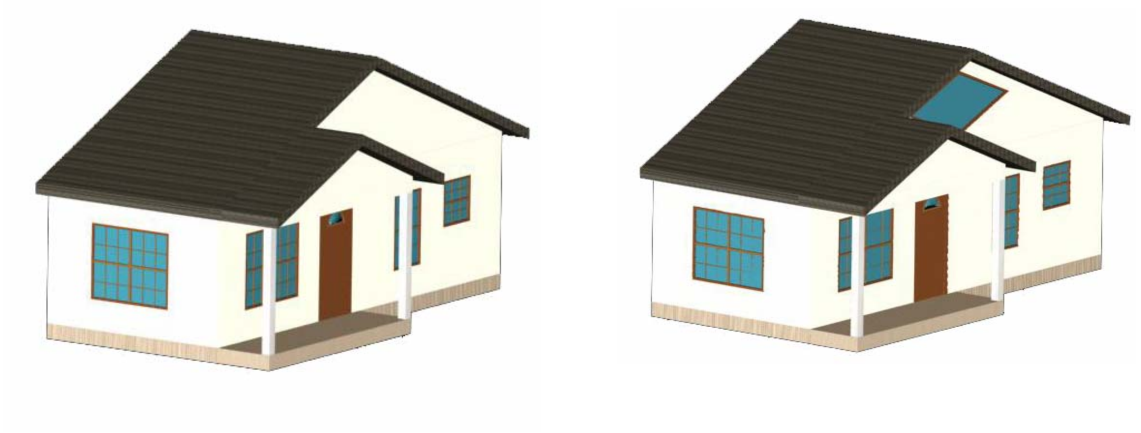


Figure D2 – Daylight Factor comparison of the basecase and the three proposed models. The physical scale model measurements were undertaken in the Daylighting sky dome.

The final proposed design included both the applications of a combined lightshelf with high window and a clerestory window. The clerestory window was a 26.5-ft^2 trapezoid-shape window added on the northeast wall of the living room. The application of the clerestory window together with the lightshelf aimed to introduce daylight into the living area. The comparison of Daylight Factors resulting from the design combinations of the clerestory window, the high window, the exterior shading, and the combined lightshelf illustrated the effect of each combination design on interior illuminance. Figure D3 presents 12 cases of the design combinations of the living room openings, and Figure D4 presents the results from Daylight Factor measurements in the living and dining area.



1L – Basecase

2L – Basecase with clerestory window

3L – Maximum 6-foot overhang

4L – Maximum 6-foot overhang with clerestory window

5L –Maximum 6-foot overhang with vertical fin

6L – Maximum 6-foot overhang with vertical fin and with clerestory window

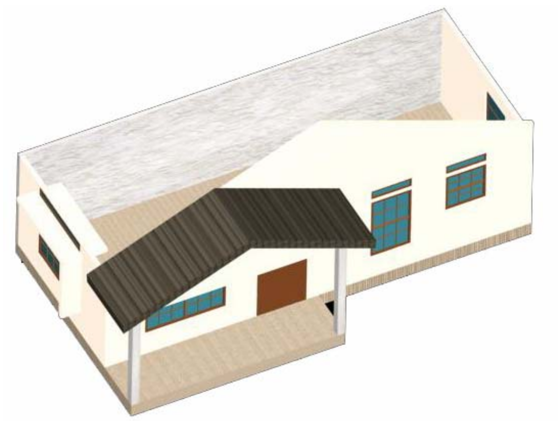
Figure D3 – Renderings of the living room model with design combinations of the clerestory window and the shadings.

7L – High window

8L – High window with clerestory window

9L – High window with 18-inch overhang with vertical fin

10L – High window with 18-inch overhang with vertical fin and with clerestory window



11L – 18-inch combined lightshelf

12L – 18-inch combined lightshelf with clerestory window

Figure D3 – Continued.

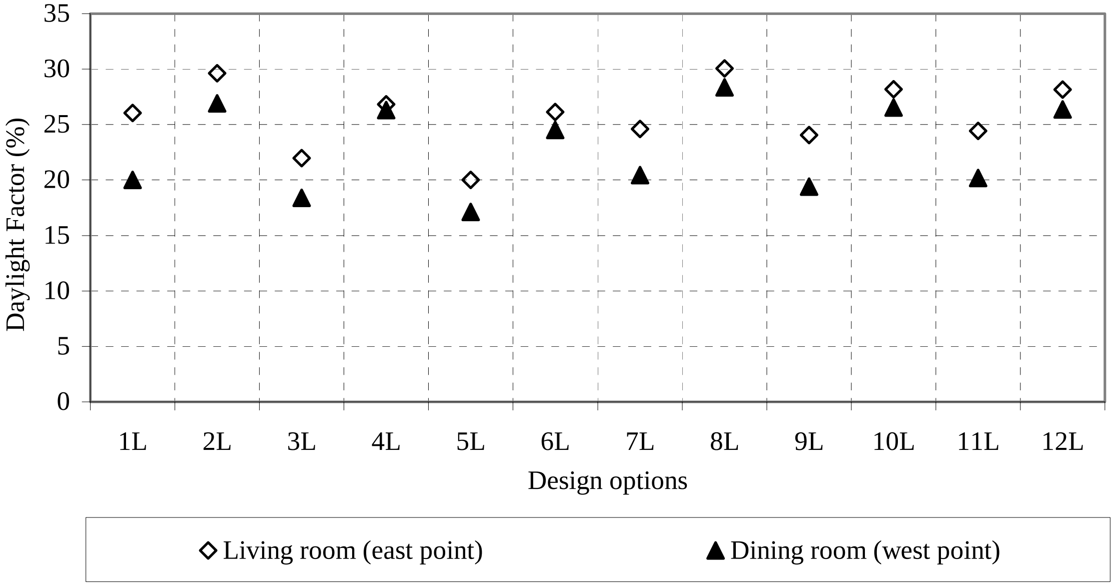


Figure D4 – Daylight Factors measurements from the living room of the physical scale model. The measurements were undertaken in the Daylighting sky dome. The living room model was proposed with the combined designs of the clerestory window and the lightshelves.

Results from the model measurements, as seen in Figure D4, suggested that adding the clerestory window on the living room northeast wall could enhance interior Daylight factors (i.e., design option 2L, 4L, 6L, 8L, 10L, and 12L), when compared to the Daylight factors of the model with the same proposed shading without the clerestory window (i.e., design options 1L, 3L, 5L, 7L, 9L, and 11L). The results also proved an effective use of the lightshelf system, as proposed in the final design model: the model with 18-inch combined lightshelf and with the clerestory window. The use of the clerestory window together with the combined lightshelf system offered an increase in interior illuminance and resulted in the improvement of Daylight factors in the living area compared to the basecase room.

The study of the living room suggested that the clerestory window allowed more daylight into space and significantly enhanced the room brightness. However, care should be taken in using the clerestory window for daylight introduction because it can lead to the penetration of sunlight into the space as well as the increase in building heat gain. Therefore, for buildings in hot and humid climates in the north latitudes where cooling is considered critical than heating loads, the clerestory window should be used only on the north side to avoid the penetration of direct solar beam radiation.

APPENDIX E

SELECTED DOE-2 INPUT FILES FOR DAYLIGHTING AND ENERGY SIMULATIONS

Results of DOE-2 Daylighting and energy simulations were discussed in Section 4.3 of Chapter IV. Evaluation of the proposed design options, which included the model with maximum 6-foot overhang, the model with maximum 6-foot overhang with vertical fin, and the model with 18-inch combined lightshelf, were demonstrated by comparing the DOE-2 simulation results of each design option in terms of the Daylight Factor contribution and energy savings in building. The DOE-2 daylighting simulation data were primarily input in LOADS command. Table E1 presents the summary of DOE-2 daylighting subcommands input in SPACE-CONDITIONS.

In addition to the subcommands which were input in SPACE-CONDITIONS of each simulated space, data input for DOE-2 daylighting models also include the description of building shades, window shades and glazing visible properties, and inside visible reflectance of interior surfaces. Selected details of the DOE-2 input data of each model with proposed design, which are portion of the whole input file, are presented in this Appendix.

Table E1 – DOE-2 daylighting simulation input data. The data was input in LOADS under SPACE-CONDITIONS subcommand of each simulated space.

SPACE-CONDITION Subcommand	**LIVING**	**BEDROOM-2**	**BEDROOM-1**	**BEDROOM-M**
LIGHT-REF-POINT1	(-25.7,-31.4,2)	(-26.7,-19.9,2)	(-26.7,-5.45,2)	(-12.1,-6.25,2)
LIGHT-REF-POINT2	(-10.25,-31.4,2)			
Note: Position of reference point in the room middle, at window sill level				
ZONE-FRACTION1	0.5	1	1	1
ZONE-FRACTION2	0.5			
Note: Fraction of the floor area which is controlled by LIGHT-REF-POINT, only the living room area was divided into 2 fractions				
LIGHT-SET-POINT1	500 or 30 FC	500 or 30 FC	500 or 30 FC	500 or 30 FC
LIGHT-SET-POINT2	500 or 35 FC			
Note: LIGHT-SET-POINT = 500 FC for basecase simulation, with the assumption of maximum lighting electricity consumption. Other values are from IESNA Recommendation for residential lighting				
LIGHT-CTRL-TYPE1	Stepped	Stepped	Stepped	Stepped
LIGHT-CTRL-TYPE2	Stepped			
Note: The lighting control system which its power input and light output vary in discrete (Source: DOE-21E Reference Manual)				
MIN-POWER-FRAC	0	0	0	0
MIN-LIGHT-FRAC	0	0	0	0
Note: Specification of the minimum power input and light output fraction for a continuously dimmable lighting control system, which are all zero for this study				
LIGHT-CTRL-STEPS	1	1	1	1
Note: On/Off steps for this study				
VIEW-AZIMUTH	180	270	0	90
Note: The direction of occupant view measured clockwise from the space y-axis (Source: DOE-21E Reference Manual)				
MAX-GLARE	22	22	22	22
Note: Window shading will be deployed to reduce daylight glare according to the maximum set point. Daylight Glare Index (DGI) = 22 is considered just acceptable Daylight Glare Index (DGI) = 22 is considered just acceptable (Source: Chauvel et al. 1982)				

1. DETAILS OF DOE-2 SIMULATION INPUT DATA FOR THE MODEL WITH MAXIMUM 6-FOOT OVERHANG

1.1. Living Room

1.1.1. SPACE-CONDITIONS of living room

```
$ LIVING ROOM $
LIVING = SPACE
       AREA = 578.47                       $FT2
      VOLUME = 4700.07                    $FT3
      TEMPERATURE = (70.5)                $MID POINT OF DESIGN
                                          $HEAT-T AND COOL-T
      PEOPLE-SCHEDULE = OCCUPY-1
      NUMBER-OF-PEOPLE = 3
      PEOPLE-HEAT-GAIN = 400              $ASHRAE STANDARD(BTU/HR/P)
      PEOPLE-HG-LAT = 150                 $ASHRAE STANDARD(BTU/HR/P)
      PEOPLE-HG-SENS = 250                $ASHRAE STANDARD(BTU/HR/P)
      LIGHTING-SCHEDULE = LIGHTS-1
      LIGHTING-TYPE = INCAND
$     LIGHTING-KW =                       UNUSED
      LIGHTING-W/SQFT = 0.892
      LIGHT-TO-SPACE = 1
$     LIGHT-HEAT-TO =                     UNUSED
$     LIGHT-TO-RETURN =                   UNUSED
$     LIGHT-RAD-FRAC =                    UNUSED
$     TASK-LIGHT-SCH =                    UNUSED
$     TASK-LT-W/SQFT=                     UNUSED
$     TASK-LIGHTING-KW =                  UNUSED
      EQUIP-SCHEDULE=EQUIP-1
      EQUIPMENT-W/SQFT = 0.892
$     EQUIPMENT-KW =                      UNUSED
$     EQUIP-SENSIBLE =                    UNUSED
$     EQUIP-LATENT =                      UNUSED
$     SOURCE-SCHEDULE =                   UNUSED
$     SOURCE-TYPE =                       UNUSED
$     SOURCE-BTU/HR =                     UNUSED
$     SOURCE-SENSIBLE =                   UNUSED
$     SOURCE-LATENT =                     UNUSED
$     INF-SCHEDULE =                      UNUSED
      INF-METHOD=AIR-CHANGE
      AIR-CHANGES/HR = 0.32               $KOOTIN SANWU'S DISSERTATION
      FLOOR-WEIGHT = 0                    $AUTOMATIC USING CUSTOM W-F
      ZONE-TYPE = CONDITIONED
      DAYLIGHTING = YES
      LIGHT-REF-POINT1 = (-25.7,-31.4,2)  $POSITION IN X,Y,Z AXIS
      LIGHT-REF-POINT2 = (-10.25,-31.4,2) $POSITION IN X,Y,Z AXIS
      ZONE-FRACTION1 = 0.5
      ZONE-FRACTION2 = 0.5
      LIGHT-SET-POINT1 = 30               $IESNA RECOMMENDATION
      LIGHT-SET-POINT2 = 35               $IESNA RECOMMENDATION
      LIGHT-CTRL-TYPE1 = STEPPED
      LIGHT-CTRL-TYPE2 = STEPPED
      MIN-POWER-FRAC = 0
      MIN-LIGHT-FRAC = 0
      LIGHT-CTRL-STEPS = 1
$     LIGHT-CTRL-PROB =                   UNUSED
$     DAYLIGHT-REP-SCH =                  UNUSED
```

```
      VIEW-AZIMUTH = 180                  $FACING NORTH SIDE
      MAX-GLARE = 22  ..                  $GENERAL WORK,DOE-2 INDEX
```

1.1.2. Exterior wall description: northeast wall

```
$ LIVING ROOM FACING WALLS
LIVNORTH-1 = EXTERIOR-WALL
      HEIGHT=8.125
      WIDTH=1.50
      X=-31.9  Y=-37.9  Z=0
      AZIMUTH=180
      CONSTRUCTION=WALL-2                 $STUDS
      GND-REFLECTANCE = 0.20             $GRASS
$     SKY-FORM-FACTOR =                   USE DOE-2 DEFAULT
$     GND-FORM-FACTOR =                   USE DOE-2 DEFAULT
$     INF-COEF =                          USE ONLY INF-METH.=CRACK
      SHADING-SURFACE =YES
      SHADING-DIVISION = 10
$     MULTIPLIER =1
$     SOLAR-FRACTION =                    USE DOE-2 DEFAULT
      INSIDE-VIS-REFL = 0.7               $PAINTING REFLECTIVITY VALUE
      INSIDE-SOL-ABS = 0.3  ..            $WHITE SEMI-GLOSS PAINT
```

Gable-end wall: northeast wall

```
TRIANG-1 = POLYGON
       (-31.9,-37.9,8.125)               $POLYGON'S LOCAL COORDINATES
      (0,-37.9,8.125)
       (-15.95,-37.9,15.525) ..


ROOF-N = EXTERIOR-WALL
       POLYGON=TRIANG-1
      CONSTRUCTION=WALL-R                 $NORTH GABLE WALL
      GND-REFLECTANCE = 0.20 ..
$     SKY-FORM-FACTOR =                   USE DEFAULT
$     GND-FORM-FACTOR =                   USE DEFAULT
$     INF-COEF =                          USE ONLY INF-METH.=CRACK
$     SHADING-SURFACE =YES
$     SHADING-DIVISION =                  USE DEFAULT
$     MULTIPLIER =1
$     SOLAR-FRACTION =                    USE DEFAULT
$     INSIDE-VIS-REFL = 0.5               10<TILT<170
$     INSIDE-SOL-ABS = 0.5                10<TILT<170
```

Gable-end wall: southwest wall

```
TRIANG-2=POLYGON
       (0,0,8.125)                       $POLYGON'S COORDINATES
      (-31.9,0,8.125)
      (-15.95,0,15.252)  ..


ROOF-S = EXTERIOR-WALL
       POLYGON=TRIANG-2
      CONSTRUCTION=WALL-R                 $SOUTH GABLE WALL
      GND-REFLECTANCE = 0.20 ..
```

```
$     SKY-FORM-FACTOR =                   USE DEFAULT
$     GND-FORM-FACTOR =                   USE DEFAULT
$     INF-COEF =                          USE ONLY INF-METH.=CRACK
$     SHADING-SURFACE =YES
$     SHADING-DIVISION =                  USE DEFAULT
$     MULTIPLIER =1
$     SOLAR-FRACTION =                    USE DEFAULT
$     INSIDE-VIS-REFL = 0.5               10<TILT<170
$     INSIDE-SOL-ABS = 0.5                10<TILT<170
```

1.1.3. Window description: northeast facing window

```
LWN-1=WINDOW
      HEIGHT=5
      WIDTH=6
      X=1.5 Y=2
      GLASS-TYPE=GT-1
      FRAME-WIDTH=0.21
$     SETBACK =0                          DEAFULT
$     SHADING-SCHEDULE =                  UNUSED
$     MAX-SOLAR-SCH =                     UNUSED
$     SUN-CTRL-PROB = 1.0                 DEFAULT
$     OPEN-SHADE-SCH =                    UNUSED
$     WIN-SHADE-TYPE = MOVABLE-INTERIOR   DOE-2 DEFAULT
$     CONDUCT-SCHEDULE =                  UNUSED
$     CONDUCT-TMIN-SCH =                  SCHED VALUES OF OA DRY BULB
$     SKY-FORM-FACTOR =                   USE DOE-2 DEFAULT
$     GND-FORM-FACTOR =                   USE DOE-2 DEFAULT
$     SHADING-SURFACE = YES
      SHADING-DIVISION = 10               $DOE-2DEFAULT
$     INF-COEF =                          USE ONLY INF-METH.=CRACK
$     SOL-TRANS-SCH =                     USE ONLY FOR A SUNSPACE
$     VIS-TRANS-SCH =                     DAYLIGHT TRANSMITTANCE VALUE
      GLARE-CTRL-PROB = 1.0               $DOE-2 DEFAULT
      INSIDE-VIS-REFL = 0.15  ..          $DOE-2 WINDOW LIBRARY
```

1.1.4. Window and shading description: northwest facing window

```
LWW-1=WINDOW
      HEIGHT=3
      WIDTH=3
      X=2 Y=4
      GLASS-TYPE=GT-1
      FRAME-WIDTH=0.21
$     SETBACK =0                          DEAFULT
$     SHADING-SCHEDULE =
$     MAX-SOLAR-SCH =
$     SUN-CTRL-PROB = 1.0                 DEFAULT
$     OPEN-SHADE-SCH =
$     WIN-SHADE-TYPE = MOVABLE-INTERIOR   DEFAULT
$     CONDUCT-SCHEDULE =
$     CONDUCT-TMIN-SCH =                  SCHED VALUES OF OA  DRY BULB
      OVERHANG-A = 0.5                    $FEET
      OVERHANG-B = 0                      $FEET
      OVERHANG-W = 4                      $FEET
      OVERHANG-D = 1.5                    $FEET
      OVERHANG-ANGLE = 90                 $PERPENDICULAR TO WINDOW
$     SKY-FORM-FACTOR =                   USE DEFAULT
```

```
$      GND-FORM-FACTOR =                    USE DEFAULT
$      SHADING-SURFACE = YES
       SHADING-DIVISION = 10                $DOE-2 DEFAULT
$      INF-COEF =                           USE ONLY INF-METH.=CRACK
$      SOL-TRANS-SCH =                      USE ONLY FOR A SUNSPACE
$      VIS-TRANS-SCH =                      DAYLIGHT TRANSMITTANCE VALUE
       GLARE-CTRL-PROB = 1.0                $DOE-2 DEFAULT
       INSIDE-VIS-REFL = 0.15  ..           $DOE-2 WINDOW LIBRARY
```

Southeast facing window

```
LIVWE-1 =WINDOW
       HEIGHT=5
       WIDTH=6
       X=3 Y=2
       GLASS-TYPE=GT-1
       FRAME-WIDTH=0.21
$      SETBACK =0                           DEAFULT
$      SHADING-SCHEDULE =
$      MAX-SOLAR-SCH =
$      SUN-CTRL-PROB = 1.0                  DEFAULT
$      OPEN-SHADE-SCH =
$      WIN-SHADE-TYPE = MOVABLE-INTERIOR    DEFAULT
$      CONDUCT-SCHEDULE =
$      CONDUCT-TMIN-SCH =                   SCHED VALUES OF OA  DRY BULB
       OVERHANG-A = 0.5                     $FEET
       OVERHANG-B = 0                       $FEET
       OVERHANG-W = 7                       $FEET
       OVERHANG-D = 6                       $FEET
       OVERHANG-ANGLE = 90                  $PERPENDICULAR TO WINDOW
$      SKY-FORM-FACTOR =                    USE DEFAULT
$      GND-FORM-FACTOR =                    USE DEFAULT
$      SHADING-SURFACE = YES
       SHADING-DIVISION = 10                $DOE-2 DEFAULT
$      INF-COEF =                           USE ONLY INF-METH.=CRACK
$      SOL-TRANS-SCH =                      USE ONLY FOR A SUNSPACE
$      VIS-TRANS-SCH =                      DAYLIGHT TRANSMITTANCE VALUE
       GLARE-CTRL-PROB = 1.0                $DOE-2 DEFAULT
       INSIDE-VIS-REFL = 0.15  ..           $DOE-2 WINDOW LIBRARY
```

1.1.5. Living room floor description

```
$LIVING ROOM FLOOR
LIVFL-1 = UNDERGROUND-FLOOR
       CONSTRUCTION =FLOOR-1
       AREA =578.47
       TILT =180
$      SOLAR-FRACTION =                     ONLY IF CWF TO BE CALCULATED
       INSIDE-VIS-REFL = 0.5               $VINYL TILE REFELCTIVITY VALUE
       INSIDE-SOL-ABS =  0.8  ..           $MEDIUM LIGHT BROWN COLOR
```

1.1.6. Living room ceiling description

```
$LIVING ROOM CEILING
LIVCL-2 =INTERIOR-WALL
       AREA =371.954
```

```
      X =-31.9 Y =-36.56 Z =8.125
      AZIMUTH =180
      TILT =0
      HEIGHT =11.66
      WIDTH =31.9
      INT-WALL-TYPE =STANDARD
      NEXT-TO ATTIC-1
      CONSTRUCTION=CEILING-2              $LIVING ROOM CEILING
$     SOLAR-FRACTION =                    LIST OF TWO
      INSIDE-VIS-REFL = (0.7,0.7)         $PAINTING REFLECTIVITY VALUE
      INSIDE-SOL-ABS = (0.3,0.8)  ..      $WHITE SEMI-GLOSS PAINT
```

1.1.7. Living room interior wall description

```
$LIVING ROOM INTERIOR WALL
LIVINT-1 = INTERIOR-WALL
      AREA =76.375
      X =-31.9 Y=-24.9 Z=0
      AZIMUTH =180
      TILT =90
      HEIGHT =8.125
      WIDTH =9.4
      INT-WALL-TYPE =STANDARD
      NEXT-TO BEDROOM-2
      CONSTRUCTION =WALL-3                $INTERIOR WALL
$     SOLAR-FRACTION =                    LIST OF TWO
      INSIDE-VIS-REFL = (0.7,0.7)         $PAINTING REFLECTIVITY VALUE
      INSIDE-SOL-ABS = (0.3,0.3)  ..      $WHITE SEMI-GLOSS PAINT
```

1.2. Bedroom-2 (Bedroom Next to Living Room)

1.2.1. SPACE-CONDITIONS of bedroom-2

```
$BEDROOM NEXT TO LIVING ROOM
BEDROOM-2 =SPACE
      AREA =104
      VOLUME =845
      TEMPERATURE = (70.5)               $MID POINT OF DESIGN
                                         $HEAT-T AND COOL-T
      PEOPLE-SCHEDULE = OCCUPY-1
      NUMBER-OF-PEOPLE = 1
      PEOPLE-HEAT-GAIN = 400              $ASHRAE STANDARD(BTU/HR/P)
      PEOPLE-HG-LAT = 150                 $ASHRAE STANDARD(BTU/HR/P)
      PEOPLE-HG-SENS = 250                $ASHRAE STANDARD(BTU/HR/P)
      LIGHTING-SCHEDULE = LIGHTS-1
      LIGHTING-TYPE = INCAND
$     LIGHTING-KW =                       UNUSED
      LIGHTING-W/SQFT = 0.892
      LIGHT-TO-SPACE = 1
$     LIGHT-HEAT-TO =                     UNUSED
$     LIGHT-TO-RETURN =                   UNUSED
$     LIGHT-RAD-FRAC =                    UNUSED
$     TASK-LIGHT-SCH =                    UNUSED
$     TASK-LT-W/SQFT=                     UNUSED
$     TASK-LIGHTING-KW =                  UNUSED
      EQUIP-SCHEDULE=EQUIP-1
      EQUIPMENT-W/SQFT = 0.892
```

```
$     EQUIPMENT-KW =                    UNUSED
$     EQUIP-SENSIBLE =                  UNUSED
$     EQUIP-LATENT =                    UNUSED
$     SOURCE-SCHEDULE =                 UNUSED
$     SOURCE-TYPE =                     UNUSED
$     SOURCE-BTU/HR =                   UNUSED
$     SOURCE-SENSIBLE =                 UNUSED
$     SOURCE-LATENT =                   UNUSED
$     INF-SCHEDULE =                    UNUSED
      INF-METHOD=AIR-CHANGE
      AIR-CHANGES/HR = 0.32             $KOOTIN SANWU'S DISSERTATION
      FLOOR-WEIGHT = 0                  $AUTOMATIC USING CUSTOM W-F
      ZONE-TYPE = CONDITIONED
      DAYLIGHTING = YES
      LIGHT-REF-POINT1 = (-26.7,-19.9,2)
$     LIGHT-REF-POINT2 =
      ZONE-FRACTION1 = 1
$     ZONE-FRACTION2 =
      LIGHT-SET-POINT1 = 30            $IESNA RECOMMENDATION
      LIGHT-CTRL-TYPE1 = STEPPED
      MIN-POWER-FRAC = 0
      MIN-LIGHT-FRAC = 0
      LIGHT-CTRL-STEPS = 1
$     LIGHT-CTRL-PROB =
$     DAYLIGHT-REP-SCH =
      VIEW-AZIMUTH = 270
      MAX-GLARE = 22  ..                $IF WIN-SHADE-TYPE=MOVABLE
```

1.2.2. Exterior wall description: southeast wall

```
BD2EAST-2 =EXTERIOR-WALL
      HEIGHT =8.125
      WIDTH =8.5
      X =-31.9 Y =-14.9 Z =0
      AZIMUTH =270
      CONSTRUCTION =WALL-1              $WALL
      GND-REFLECTANCE = 0.20
$     SKY-FORM-FACTOR =                 USE DEFAULT
$     GND-FORM-FACTOR =                 USE DEFAULT
$     INF-COEF =                        USE ONLY INF-METH.=CRACK
      SHADING-SURFACE =YES
      SHADING-DIVISION = 10             $DOE-2 DEFAULT
$     MULTIPLIER =1
$     SOLAR-FRACTION =                  USE DEFAULT
      INSIDE-VIS-REFL = 0.7             $PAINTING REFLECTIVITY VALUE
      INSIDE-SOL-ABS = 0.3  ..          $WHITE SEMI-GLOSS PAINT
```

1.2.3. Window and shading description: southeast facing window

```
BD2WE-1 =WINDOW
      HEIGHT=5
      WIDTH=3
      X=3 Y=2
      GLASS-TYPE=GT-1
      FRAME-WIDTH=0.21
$     SETBACK =0                        DEAFULT
$     SHADING-SCHEDULE =
```

```
$     MAX-SOLAR-SCH =
$     SUN-CTRL-PROB = 1.0                 DEFAULT
$     OPEN-SHADE-SCH =
$     WIN-SHADE-TYPE = MOVABLE-INTERIOR   DEFAULT
$     CONDUCT-SCHEDULE =
$     CONDUCT-TMIN-SCH =                  SCHED VALUES OF OA  DRY BULB
      OVERHANG-A = 0.5                    $FEET
      OVERHANG-B = 0                      $FEET
      OVERHANG-W = 4                      $FEET
      OVERHANG-D = 6                      $FEET
      OVERHANG-ANGLE = 90                 $PERPENDICULAR TO WINDOW
$     SKY-FORM-FACTOR =                   USE DEFAULT
$     GND-FORM-FACTOR =                   USE DEFAULT
$     SHADING-SURFACE = YES
      SHADING-DIVISION = 10               $DOE-2 DEFAULT
$     INF-COEF =                          USE ONLY INF-METH.=CRACK
$     SOL-TRANS-SCH =                     USE ONLY FOR A SUNSPACE
$     VIS-TRANS-SCH =                     DAYLIGHT TRANSMITTANCE VALUE
      GLARE-CTRL-PROB = 1.0               $DOE-2 DEFAULT
      INSIDE-VIS-REFL = 0.15  ..          $DOE-2 WINDOW LIBRARY
```

1.2.4. Bedroom-2 floor description

```
$BEDROOM-2 FLOOR
BD2FL-1 = UNDERGROUND-FLOOR
      CONSTRUCTION =FLOOR-1
      AREA =104
      TILT =180
$     SOLAR-FRACTION =                    ONLY IF CWF TO BE CALCULATED
      INSIDE-VIS-REFL = 0.5               $VINYL TILE REFLECTIVITY VALUE
      INSIDE-SOL-ABS =  0.8  ..           $MEDIUM LIGHT BROWN COLOR
```

1.2.5. Bedroom-2 ceiling description

```
$BEDROOM-2 CEILING
BD2CL-2 =INTERIOR-WALL
      AREA =93.6
      X =-31.9 Y =-23.9 Z =8.125
      AZIMUTH =180
      TILT =0
      HEIGHT =9
      WIDTH =10.4
      INT-WALL-TYPE =STANDARD
      NEXT-TO ATTIC-1
      CONSTRUCTION=CEILING-2              $BEDROOM-2 CEILING
$     SOLAR-FRACTION =                    LIST OF TWO
      INSIDE-VIS-REFL = (0.7,0.7)         $PAINTING REFLECTIVITY VALUE
      INSIDE-SOL-ABS = (0.3,0.8)  ..      $WHITE SEMI-GLOSS PAINT
```

1.2.6. Bedroom-2 interior wall description

```
$BEDROOM-2 INTERIOR WALL
BD2INT-2 =INTERIOR-WALL
      AREA =73.125
      X =-21.5 Y=-15.9 Z=0
      AZIMUTH =270
```

```
      TILT =90
      HEIGHT =8.125
      WIDTH =9
      INT-WALL-TYPE =STANDARD
      NEXT-TO LIVING
      CONSTRUCTION =WALL-3                $INTERIOR WALL
$     SOLAR-FRACTION =                    LIST OF TWO
      INSIDE-VIS-REFL = (0.7,0.7)         $PAINTING REFLECTIVITY VALUE
      INSIDE-SOL-ABS = (0.3,0.3)  ..      $WHITE SEMI-GLOSS PAINT
```

1.3. Bedroom-1 (Southeast Bedroom)

1.3.1. SPACE-CONDITIONS of bedroom-1

```
$BEDROOM-1
BEDROOM-1 = SPACE
      AREA =113.36
      VOLUME =921.05
      TEMPERATURE = (70.5)               $MID POINT OF DESIGN
                                         $HEAT-T AND COOL-T
      PEOPLE-SCHEDULE = OCCUPY-1
      NUMBER-OF-PEOPLE = 1
      PEOPLE-HEAT-GAIN = 400              $ASHRAE STANDARD(BTU/HR/P)
      PEOPLE-HG-LAT = 150                 $ASHRAE STANDARD(BTU/HR/P)
      PEOPLE-HG-SENS = 250                $ASHRAE STANDARD(BTU/HR/P)
      LIGHTING-SCHEDULE = LIGHTS-1
      LIGHTING-TYPE = INCAND
$     LIGHTING-KW =                       UNUSED
      LIGHTING-W/SQFT = 0.892
      LIGHT-TO-SPACE = 1
$     LIGHT-HEAT-TO =                     UNUSED
$     LIGHT-TO-RETURN =                   UNUSED
$     LIGHT-RAD-FRAC =                    UNUSED
$     TASK-LIGHT-SCH =                    UNUSED
$     TASK-LT-W/SQFT=                     UNUSED
$     TASK-LIGHTING-KW =                  UNUSED
      EQUIP-SCHEDULE=EQUIP-1
      EQUIPMENT-W/SQFT = 0.892
$     EQUIPMENT-KW =                      UNUSED
$     EQUIP-SENSIBLE =                    UNUSED
$     EQUIP-LATENT =                      UNUSED
$     SOURCE-SCHEDULE =                   UNUSED
$     SOURCE-TYPE =                       UNUSED
$     SOURCE-BTU/HR =                     UNUSED
$     SOURCE-SENSIBLE =                   UNUSED
$     SOURCE-LATENT =                     UNUSED
$     INF-SCHEDULE =                      UNUSED
      INF-METHOD=AIR-CHANGE
      AIR-CHANGES/HR = 0.32               $KOOTIN SANWU'S DISSERTATION
      FLOOR-WEIGHT = 0                    $AUTOMATIC USING CUSTOM W-F
      ZONE-TYPE = CONDITIONED
      DAYLIGHTING = YES
      LIGHT-REF-POINT1 = (-26.7,-5.45,2)
$     LIGHT-REF-POINT2 =
      ZONE-FRACTION1 = 1
$     ZONE-FRACTION2 =
      LIGHT-SET-POINT1 = 30              $IESNA RECOMMENDATION
      LIGHT-CTRL-TYPE1 = STEPPED
```

```
      MIN-POWER-FRAC = 0
      MIN-LIGHT-FRAC = 0
      LIGHT-CTRL-STEPS = 1
$     LIGHT-CTRL-PROB =
$     DAYLIGHT-REP-SCH =
      VIEW-AZIMUTH = 0
      MAX-GLARE = 22  ..                  $GENERAL WORK,DOE-2 INDEX
```

1.3.2. Exterior wall description: southeast wall

```
$BEDROOM-1 SOUTH-EAST FACING WALL
BD1EAST-1 = EXTERIOR-WALL
       HEIGHT =8.125
      WIDTH =9.4
      X =-31.9 Y =-1.5 Z =0
      AZIMUTH =270
      CONSTRUCTION =WALL-1                 $WALL
      GND-REFLECTANCE = 0.20
$     SKY-FORM-FACTOR =                    USE DEFAULT
$     GND-FORM-FACTOR =                    USE DEFAULT
$     INF-COEF =                           USE ONLY INF-METH.=CRACK
      SHADING-SURFACE =YES
      SHADING-DIVISION = 10                $DOE-2 DEFAULT
$     MULTIPLIER =1
$     SOLAR-FRACTION =                     USE DEFAULT
      INSIDE-VIS-REFL = 0.7                $PAINTING REFLECTIVITY VALUE
      INSIDE-SOL-ABS = 0.3  ..             $WHITE SEMI-GLOSS PAINT
```

1.3.3. Window and shading description: southeast facing window

```
BD1WE-1 =WINDOW
      HEIGHT=5
      WIDTH=3
      X=3.125 Y=2
      GLASS-TYPE=GT-1
      FRAME-WIDTH=0.21
$     SETBACK =0                          DEAFULT
$     SHADING-SCHEDULE =                  UNUSED
$     MAX-SOLAR-SCH =                     UNUSED
$     SUN-CTRL-PROB = 1.0                  DEFAULT
$     OPEN-SHADE-SCH =                    UNUSED
$     WIN-SHADE-TYPE = MOVABLE-INTERIOR    DEFAULT
$     CONDUCT-SCHEDULE =                  UNUSED
$     CONDUCT-TMIN-SCH =                   SCHED VALUES OF OA  DRY BULB
      OVERHANG-A = 0.5                     $FEET
      OVERHANG-B = 0                       $FEET
      OVERHANG-W = 4                       $FEET
      OVERHANG-D = 6                       $FEET
      OVERHANG-ANGLE = 90                  $PERPENDICULAR TO WINDOW
$     SKY-FORM-FACTOR =                    USE DEFAULT
$     GND-FORM-FACTOR =                    USE DEFAULT
$     SHADING-SURFACE = YES
      SHADING-DIVISION = 10                $DOE-2 DEFAULT
$     INF-COEF =                           USE ONLY INF-METH.=CRACK
$     SOL-TRANS-SCH =                      USE ONLY FOR A SUNSPACE
$     VIS-TRANS-SCH =                      DAYLIGHT TRANSMITTANCE VALUE
      GLARE-CTRL-PROB = 1.0                $DOE-2 DEFAULT
```

```
      INSIDE-VIS-REFL = 0.15  ..          $DOE-2 WINDOW LIBRARY
```

Southwest facing window

```
BD1WS-1 =WINDOW
      HEIGHT=5
      WIDTH=3
      X=3.275 Y=2
      GLASS-TYPE=GT-1
      FRAME-WIDTH=0.21
$     SETBACK =0                          DEAFULT
$     SHADING-SCHEDULE =                 UNUSED
$     MAX-SOLAR-SCH =                    UNUSED
$     SUN-CTRL-PROB = 1.0                 DEFAULT
$     OPEN-SHADE-SCH =                   UNUSED
$     WIN-SHADE-TYPE = MOVABLE-INTERIOR   DEFAULT
$     CONDUCT-SCHEDULE =                 UNUSED
$     CONDUCT-TMIN-SCH =                  SCHED VALUES OF OA  DRY BULB
      OVERHANG-A = 0.5                    $FEET
      OVERHANG-B = 0                      $FEET
      OVERHANG-W = 4                      $FEET
      OVERHANG-D = 6                      $FEET
      OVERHANG-ANGLE = 90                 $PERPENDICULAR TO WINDOW
$     SKY-FORM-FACTOR =                   USE DEFAULT
$     GND-FORM-FACTOR =                   USE DEFAULT
$     SHADING-SURFACE = YES
      SHADING-DIVISION = 10               $DOE-2 DEFAULT
$     INF-COEF =                          USE ONLY INF-METH.=CRACK
$     SOL-TRANS-SCH =                     USE ONLY FOR A SUNSPACE
$     VIS-TRANS-SCH =                     DAYLIGHT TRANSMITTANCE VALUE
      GLARE-CTRL-PROB = 1.0               $DOE-2 DEFAULT
      INSIDE-VIS-REFL = 0.15  ..          $DOE-2 WINDOW LIBRARY
```

1.3.4. Bedroom-1 floor description

```
$BEDROOM-1 FLOOR
BD1FL-1 = UNDERGROUND-FLOOR
      CONSTRUCTION =FLOOR-1
      AREA =113.36
      TILT =180
$     SOLAR-FRACTION =                   ONLY IF CWF TO BE CALCULATED
      INSIDE-VIS-REFL = 0.5            $VINYL TILE REFLECTIVITY VALUE
      INSIDE-SOL-ABS =  0.8  ..           $MEDIUM LIGHT BROWN COLOR
```

1.3.5. Bedroom-1 ceiling description

```
$BEDROOM-1 CEILING
BD1CL-2 = INTERIOR-WALL
      AREA =102.96
      X =-31.9 Y =-9.9 Z =8.125
      AZIMUTH =180
      TILT =0
      HEIGHT =9.9
      WIDTH =10.4
      INT-WALL-TYPE =STANDARD
      NEXT-TO ATTIC-1
```

```
      CONSTRUCTION=CEILING-2             $CEILING
$     SOLAR-FRACTION =                   LIST OF TWO
      INSIDE-VIS-REFL = (0.7,0.7)        $PAINTING REFLECTIVITY VALUE
      INSIDE-SOL-ABS = (0.3,0.8)  ..     $WHITE SEMI-GLOSS PAINT
```

1.3.6. Bedroom-1 interior wall description

```
$BEDROOM-1 INTERIOR WALL
BD1INT-2 = INTERIOR-WALL
      AREA =76.375
      X =-22.5 Y=-10.9 Z=0
      AZIMUTH =0
      TILT =90
      HEIGHT =8.125
      WIDTH =9.4
      INT-WALL-TYPE =STANDARD
      NEXT-TO CLOSET-1
      CONSTRUCTION =WALL-3               $WALL
$     SOLAR-FRACTION =                   LIST OF TWO
      INSIDE-VIS-REFL = (0.7,0.7)        $PAINTING REFLECTIVITY VALUE
      INSIDE-SOL-ABS = (0.3,0.3)  ..     $WHITE SEMI-GLOSS PAINT
```

1.4. Bedroom-M (Southwest Bedroom)

1.4.1. SPACE-CONDITIONS of bedroom-M

```
$MASTER BEDROOM
BEDROOM-M =SPACE
      AREA =127.5
      VOLUME =1035.94
      TEMPERATURE = (70.5)               $MID POINT OF DESIGN
                                        $HEAT-T&COOL-T
      PEOPLE-SCHEDULE = OCCUPY-1
      NUMBER-OF-PEOPLE = 1
      PEOPLE-HEAT-GAIN = 400             $ASHRAE STANDARD(BTU/HR/P)
      PEOPLE-HG-LAT = 150                $ASHRAE STANDARD(BTU/HR/P)
      PEOPLE-HG-SENS = 250               $ASHRAE STANDARD(BTU/HR/P)
      LIGHTING-SCHEDULE = LIGHTS-1
      LIGHTING-TYPE = INCAND
$     LIGHTING-KW =                      UNUSED
      LIGHTING-W/SQFT = 0.892
      LIGHT-TO-SPACE = 1
$     LIGHT-HEAT-TO =                    UNUSED
$     LIGHT-TO-RETURN =                  UNUSED
$     LIGHT-RAD-FRAC =                   UNUSED
$     TASK-LIGHT-SCH =                   UNUSED
$     TASK-LT-W/SQFT=                    UNUSED
$     TASK-LIGHTING-KW =                 UNUSED
      EQUIP-SCHEDULE=EQUIP-1
      EQUIPMENT-W/SQFT = 0.892
$     EQUIPMENT-KW =                     UNUSED
$     EQUIP-SENSIBLE =                   UNUSED
$     EQUIP-LATENT =                     UNUSED
$     SOURCE-SCHEDULE =                  UNUSED
$     SOURCE-TYPE =                      UNUSED
$     SOURCE-BTU/HR =                    UNUSED
$     SOURCE-SENSIBLE =                  UNUSED
```

```
$     SOURCE-LATENT =                     UNUSED
$     INF-SCHEDULE =                      UNUSED
      INF-METHOD=AIR-CHANGE
      AIR-CHANGES/HR = 0.32               $KOOTIN SANWU'S DISSERTATION
      FLOOR-WEIGHT = 0                    $AUTOMATIC USING CUSTOM W-F
      ZONE-TYPE = CONDITIONED
      DAYLIGHTING = YES
      LIGHT-REF-POINT1 = (-12.1,-6.25,2)
$     LIGHT-REF-POINT2 =
      ZONE-FRACTION1 = 1
$     ZONE-FRACTION2 =
      LIGHT-SET-POINT1 = 30               $IESNA RECOMMENDATION
      LIGHT-CTRL-TYPE1 = STEPPED
      MIN-POWER-FRAC = 0
      MIN-LIGHT-FRAC = 0
      LIGHT-CTRL-STEPS = 1
$     LIGHT-CTRL-PROB =
$     DAYLIGHT-REP-SCH =
      VIEW-AZIMUTH = 90
      MAX-GLARE = 22  ..                   $GENERAL WORK, DOE-2 INDEX
```

1.4.2. Exterior wall description: southwest wall

```
$MASTER BEDROOM SOUTH-WEST FACING WALL
MBDSOUTH-2 = EXTERIOR-WALL
      HEIGHT =8.125
      WIDTH =8.7
      X =-8.5 Y =0 Z =0
      AZIMUTH =0
      CONSTRUCTION=WALL-1                 $WALL
      GND-REFLECTANCE = 0.20
$     SKY-FORM-FACTOR =                   USE DEFAULT
$     GND-FORM-FACTOR =                   USE DEFAULT
$     INF-COEF =                          USE ONLY INF-METH.=CRACK
      SHADING-SURFACE =YES
      SHADING-DIVISION = 10               $DOE-2 DEFAULT
$     MULTIPLIER =1
$     SOLAR-FRACTION =                    USE DEFAULT
      INSIDE-VIS-REFL = 0.7               $PAINTING REFLECTIVITY VALUE
      INSIDE-SOL-ABS = 0.3  ..            $WHITE SEMI-GLOSS PAINT
```

1.4.3. Window and shading description: southwest facing window

```
MBDWS-1 =WINDOW
      HEIGHT=5
      WIDTH=3
      X=2.375 Y=2
      GLASS-TYPE=GT-1
      FRAME-WIDTH=0.21
$     SETBACK =0                          DEAFULT
$     SHADING-SCHEDULE =                  UNUSED
$     MAX-SOLAR-SCH =                     UNUSED
$     SUN-CTRL-PROB = 1.0                 DEFAULT
$     OPEN-SHADE-SCH =                    UNUSED
$     WIN-SHADE-TYPE = MOVABLE-INTERIOR   DEFAULT
$     CONDUCT-SCHEDULE =                  UNUSED
$     CONDUCT-TMIN-SCH =                  SCHED VALUES OF OA  DRY BULB
```

```
      OVERHANG-A = 0.5                    $FEET
      OVERHANG-B = 0                      $FEET
      OVERHANG-W = 4                      $FEET
      OVERHANG-D = 6                      $FEET
      OVERHANG-ANGLE = 90                 $PERPENDICULAR TO WINDOW
$     SKY-FORM-FACTOR =                   USE DEFAULT
$     GND-FORM-FACTOR =                   USE DEFAULT
$     SHADING-SURFACE = YES
      SHADING-DIVISION = 10               $DOE-2 DEFAULT
$     INF-COEF =                          USE ONLY INF-METH.=CRACK
$     SOL-TRANS-SCH =                     USE ONLY FOR A SUNSPACE
$     VIS-TRANS-SCH =                     DAYLIGHT TRANSMITTANCE VALUE
      GLARE-CTRL-PROB = 1.0               $DOE-2 DEFAULT
      INSIDE-VIS-REFL = 0.15  ..          $DOE-2 WINDOW LIBRARY
```

1.4.4. Bedroom-M floor description

```
$MASTER BEDROOM FLOOR
MBDFL-1 = UNDERGROUND-FLOOR
      CONSTRUCTION =FLOOR-1
      AREA =127.5
      TILT =180
$     SOLAR-FRACTION =                   ONLY IF CWF TO BE CALCULATED
      INSIDE-VIS-REFL = 0.5              $VINYL TILE REFLECTIVITY VALUE
      INSIDE-SOL-ABS =  0.8  ..          $MEDIUM LIGHT BROWN COLOR
```

1.4.5. Bedroom-M ceiling description

```
$MASTER BEDROOM CEILING
MBDCL-2 =INTERIOR-WALL
       AREA =117.3
      X =-17.2 Y =-11.5 Z =8.125
      AZIMUTH =180
      TILT =0
      HEIGHT =11.5
      WIDTH =10.2
      INT-WALL-TYPE =STANDARD
      NEXT-TO ATTIC-1
      CONSTRUCTION=CEILING-2             $CEILING
$     SOLAR-FRACTION =                    LIST OF TWO
      INSIDE-VIS-REFL = (0.7,0.7)         $PAINTING REFLECTIVITY VALUE
      INSIDE-SOL-ABS = (0.3,0.8)  ..      $WHITE SEMI-GLOSS PAINT
```

1.4.6. Bedroom-M interior wall description

```
$MASTER BEDROOM INTERIOR WALL
MBDINT-1 = INTERIOR-WALL
      AREA =74.75
      X =-7 Y=-12.5 Z=0
      AZIMUTH =0
      TILT =90
      HEIGHT =8.125
      WIDTH =9.2
      INT-WALL-TYPE =STANDARD
      NEXT-TO BATHROOM
      CONSTRUCTION =WALL-3               $WALL
$     SOLAR-FRACTION =                    LIST OF TWO
      INSIDE-VIS-REFL = (0.7,0.7)         $PAINTING REFLECTIVITY VALUE
```

```
      INSIDE-SOL-ABS = (0.3,0.3)  ..      $WHITE SEMI-GLOSS PAINT
```

2. DETAILS OF DOE-2 SIMULATION INPUT DATA FOR THE MODEL WITH MAXIMUM 6-FOOT OVERHANG WITH A VERTICAL FIN

The DOE-2 input data for this proposed model was the same as that of the model with maximum 6-foot overhang. However, there were changes in window shading description since vertical fins were added as part of the proposed shadings. Descriptions of proposed window shadings proposed presented in this section are the examples of selected windows.

2.1. Living Room

2.1.1. Window and shading description: northwest facing window

```
LWW-1 = WINDOW
       HEIGHT = 3
      WIDTH = 3
      X = 2 Y = 4
      GLASS-TYPE = GT-1
      FRAME-WIDTH=0.21
$     SETBACK =0                       DEAFULT
$     SHADING-SCHEDULE =              UNUSED
$     MAX-SOLAR-SCH =                 UNUSED
$     SUN-CTRL-PROB = 1.0              DEFAULT
$     OPEN-SHADE-SCH =                UNUSED
$     WIN-SHADE-TYPE = MOVABLE-INTERIOR   DEFAULT
$     CONDUCT-SCHEDULE =              UNUSED
$     CONDUCT-TMIN-SCH =               SCHED VALUES OF OA  DRY BULB
      OVERHANG-A = 0.5                 $FEET
      OVERHANG-B = 0                   $FEET
      OVERHANG-W = 4                   $FEET
      OVERHANG-D = 1.5                 $FEET
      OVERHANG-ANGLE = 90              $PERPENDICULAR TO WINDOW
      RIGHT-FIN-A = 0                  $FEET
      RIGHT-FIN-B = 0                  $FEET
      RIGHT-FIN-H = 3                  $FEET
      RIGHT-FIN-D = 1.5                $FEET
$     SKY-FORM-FACTOR =                USE DEFAULT
$     GND-FORM-FACTOR =                USE DEFAULT
$     SHADING-SURFACE = YES
      SHADING-DIVISION = 10            $DOE-2 DEFAULT
$     INF-COEF =                       USE ONLY INF-METH.=CRACK
$     SOL-TRANS-SCH =                  USE ONLY FOR A SUNSPACE
$     VIS-TRANS-SCH =                  DAYLIGHT TRANSMITTANCE VALUE
      GLARE-CTRL-PROB = 1.0            $DOE-2 DEFAULT
      INSIDE-VIS-REFL = 0.15  ..       $DOE-2 WINDOW LIBRARY
```

Southeast facing window

```
LIVWE-1 =WINDOW
      HEIGHT=5
      WIDTH=6
```

```
      X=3 Y=2
      GLASS-TYPE=GT-1
      FRAME-WIDTH=0.21
$     SETBACK =0                          DEAFULT
$     SHADING-SCHEDULE =                  UNUSED
$     MAX-SOLAR-SCH =                     UNUSED
$     SUN-CTRL-PROB = 1.0                 DEFAULT
$     OPEN-SHADE-SCH =                    UNUSED
$     WIN-SHADE-TYPE = MOVABLE-INTERIOR   DEFAULT
$     CONDUCT-SCHEDULE =                  UNUSED
$     CONDUCT-TMIN-SCH =                  SCHED VALUES OF OA  DRY BULB
      OVERHANG-A = 0.5                    $FEET
      OVERHANG-B = 0                      $FEET
      OVERHANG-W = 7                      $FEET
      OVERHANG-D = 6                      $FEET
      RIGHT-FIN-A = 0                     $FEET
      RIGHT-FIN-B = 0                     $FEET
      RIGHT-FIN-H = 5                     $FEET
      RIGHT-FIN-D = 4                     $FEET
      OVERHANG-ANGLE = 90                 $PERPENDICULAR TO WINDOW
$     SKY-FORM-FACTOR =                   USE DEFAULT
$     GND-FORM-FACTOR =                   USE DEFAULT
$     SHADING-SURFACE = YES
      SHADING-DIVISION = 10               $DOE-2 DEFAULT
$     INF-COEF =                          USE ONLY INF-METH.=CRACK
$     SOL-TRANS-SCH =                     USE ONLY FOR A SUNSPACE
$     VIS-TRANS-SCH =                     DAYLIGHT TRANSMITTANCE VALUE
      GLARE-CTRL-PROB = 1.0               $DOE-2 DEFAULT
      INSIDE-VIS-REFL = 0.15  ..          $DOE-2 WINDOW LIBRARY
```

2.2. Bedroom-2 (Bedroom Next to Living Room)

2.2.1. Window and shading description (southeast facing window)

```
BD2WE-1 = WINDOW
       HEIGHT=5
      WIDTH=3
      X=3 Y=2
      GLASS-TYPE=GT-1
      FRAME-WIDTH=0.21
$     SETBACK =0                          DEAFULT
$     SHADING-SCHEDULE =                  UNUSED
$     MAX-SOLAR-SCH =                     UNUSED
$     SUN-CTRL-PROB = 1.0                 DEFAULT
$     OPEN-SHADE-SCH =                    UNUSED
$     WIN-SHADE-TYPE = MOVABLE-INTERIOR   DEFAULT
$     CONDUCT-SCHEDULE =                  UNUSED
$     CONDUCT-TMIN-SCH =                  SCHED VALUES OF OA  DRY BULB
      OVERHANG-A = 0.5                    $FEET
      OVERHANG-B = 0                      $FEET
      OVERHANG-W = 4                      $FEET
      OVERHANG-D = 6                      $FEET
      OVERHANG-ANGLE = 90                 $PERPENDICULAR TO WINDOW
      RIGHT-FIN-A = 0                     $FEET
      RIGHT-FIN-B = 0                     $FEET
      RIGHT-FIN-H = 5                     $FEET
      RIGHT-FIN-D = 4                     $FEET
$     SKY-FORM-FACTOR =                   USE DEFAULT
```

```
$     GND-FORM-FACTOR =                   USE DEFAULT
$     SHADING-SURFACE = YES
      SHADING-DIVISION = 10               $DOE-2 DEFAULT
$      INF-COEF =                        USE ONLY INF-METH.=CRACK
$     SOL-TRANS-SCH =                     USE ONLY FOR A SUNSPACE
$     VIS-TRANS-SCH =                     DAYLIGHT TRANSMITTANCE VALUE
      GLARE-CTRL-PROB = 1.0               $DOE-2 DEFAULT
      INSIDE-VIS-REFL = 0.15  ..          $DOE-2 WINDOW LIBRARY
```

2.3. Bedroom-1 (Southeast Bedroom)

2.3.1. Window and shading description (southeast facing window)

```
BD1WE-1 = WINDOW
      HEIGHT=5
      WIDTH=3
      X=3.125 Y=2
      GLASS-TYPE=GT-1
      FRAME-WIDTH=0.21
$     SETBACK =0                         DEAFULT
$     SHADING-SCHEDULE =                 UNUSED
$     MAX-SOLAR-SCH =                    UNUSED
$     SUN-CTRL-PROB = 1.0                 DEFAULT
$     OPEN-SHADE-SCH =                   UNUSED
$     WIN-SHADE-TYPE = MOVABLE-INTERIOR   DEFAULT
$     CONDUCT-SCHEDULE =                 UNUSED
$     CONDUCT-TMIN-SCH =                  SCHED VALUES OF OA  DRY BULB
      OVERHANG-A = 0.5                    $FEET
      OVERHANG-B = 0                      $FEET
      OVERHANG-W = 4                      $FEET
      OVERHANG-D = 6                      $FEET
      RIGHT-FIN-A = 0                     $FEET
      RIGHT-FIN-B = 0                     $FEET
      RIGHT-FIN-H = 5                     $FEET
      RIGHT-FIN-D = 4                     $FEET
      OVERHANG-ANGLE = 90                 $PERPENDICULAR TO WINDOW
$     SKY-FORM-FACTOR =                   USE DEFAULT
$     GND-FORM-FACTOR =                   USE DEFAULT
$     SHADING-SURFACE = YES
      SHADING-DIVISION = 10               $DOE-2 DEFAULT
$     INF-COEF =                          USE ONLY INF-METH.=CRACK
$     SOL-TRANS-SCH =                     USE ONLY FOR A SUNSPACE
$     VIS-TRANS-SCH =                     DAYLIGHT TRANSMITTANCE VALUE
      GLARE-CTRL-PROB = 1.0               $DOE-2 DEFAULT
      INSIDE-VIS-REFL = 0.15  ..          $DOE-2 WINDOW LIBRARY
```

Southwest facing window

```
BD1WS-1 = WINDOW
       HEIGHT=5
      WIDTH=3
      X=3.275 Y=2
      GLASS-TYPE=GT-1
      FRAME-WIDTH=0.21
$     SETBACK =0                         DEAFULT
$     SHADING-SCHEDULE =                 UNUSED
$     MAX-SOLAR-SCH =                    UNUSED
$     SUN-CTRL-PROB = 1.0                 DEFAULT
```

```
$     OPEN-SHADE-SCH =                    UNUSED
$     WIN-SHADE-TYPE = MOVABLE-INTERIOR   DEFAULT
$     CONDUCT-SCHEDULE =                  UNUSED
$     CONDUCT-TMIN-SCH =                  SCHED VALUES OF OA  DRY BULB
      OVERHANG-A = 0.5                    $FEET
      OVERHANG-B = 0                      $FEET
      OVERHANG-W = 4                      $FEET
      OVERHANG-D = 6                      $FEET
      OVERHANG-ANGLE = 90                 $PERPENDICULAR TO WINDOW
      LEFT-FIN-A = 0                      $FEET
      LEFT-FIN-B = 0                      $FEET
      LEFT-FIN-H = 5                      $FEET
      LEFT-FIN-D = 4                      $FEET
$     SKY-FORM-FACTOR =                   USE DEFAULT
$     GND-FORM-FACTOR =                   USE DEFAULT
$     SHADING-SURFACE = YES
      SHADING-DIVISION = 10               $DOE-2 DEFAULT
$     INF-COEF =                          USE ONLY INF-METH.=CRACK
$     SOL-TRANS-SCH =                     USE ONLY FOR A SUNSPACE
$     VIS-TRANS-SCH =                     DAYLIGHT TRANSMITTANCE VALUE
      GLARE-CTRL-PROB = 1.0               $DOE-2 DEFAULT
      INSIDE-VIS-REFL = 0.15  ..          $DOE-2 WINDOW LIBRARY
```

2.4. Bedroom-M (Southwest Bedroom)

2.4.1. Window and shading description (southwest facing window)

```
MBDWS-1 = WINDOW
       HEIGHT=5
       WIDTH=3
      X=2.375 Y=2
      GLASS-TYPE=GT-1
      FRAME-WIDTH=0.21
$     SETBACK =0                          DEAFULT
$     SHADING-SCHEDULE =                  UNUSED
$     MAX-SOLAR-SCH =                     UNUSED
$     SUN-CTRL-PROB = 1.0                 DEFAULT
$     OPEN-SHADE-SCH =                    UNUSED
$     WIN-SHADE-TYPE = MOVABLE-INTERIOR   DEFAULT
$     CONDUCT-SCHEDULE =                  UNUSED
$     CONDUCT-TMIN-SCH =                  SCHED VALUES OF OA  DRY BULB
      OVERHANG-A = 0.5                    $FEET
      OVERHANG-B = 0                      $FEET
      OVERHANG-W = 4                      $FEET
      OVERHANG-D = 6                      $FEET
      OVERHANG-ANGLE = 90                 $PERPENDICULAR TO WINDOW
      LEFT-FIN-A = 0                      $FEET
      LEFT-FIN-B = 0                      $FEET
      LEFT-FIN-H = 5                      $FEET
      LEFT-FIN-D = 4                      $FEET
$     SKY-FORM-FACTOR =                   USE DEFAULT
$     GND-FORM-FACTOR =                   USE DEFAULT
$     SHADING-SURFACE = YES
      SHADING-DIVISION = 10               $DOE-2 DEFAULT
$     INF-COEF =                          USE ONLY INF-METH.=CRACK
$     SOL-TRANS-SCH =                     USE ONLY FOR A SUNSPACE
$     VIS-TRANS-SCH =                     DAYLIGHT TRANSMITTANCE VALUE
      GLARE-CTRL-PROB = 1.0               $DOE-2 DEFAULT
```

```
      INSIDE-VIS-REFL = 0.15  ..          $DOE-2 WINDOW LIBRARY
```

3. DETAILS OF DOE-2 SIMULATION INPUT DATA FOR THE MODEL WITH 18-INCH COMBINED LIGHTSHELF WITH HIGH WINDOW

The model with 18-inch combined lightshelf with high window was proposed as the final design in this study. The DOE-2 input data for daylighting simulation, primarily in SPACE-CONDITIONS subcommands and the building descriptions, is similar to those of the 2 proposed models previously stated. However, there was a modification in the living room since the clerestory window was added onto the northeast wall for daylight introducing. There were also changes in window area and configuration since high windows were added according to the lightshelf daylighting system. Details of the portions of DOE-2 input file for this proposed model are presented below.

3.1. Living room

3.1.1. Exterior wall description: northeast wall

```
$ LIVING ROOM FACING WALLS
LIVNORTH-2 = EXTERIOR-WALL
      HEIGHT=8.125                        $FEET
      WIDTH=28.9                          $FEET
      X=-30.4 Y=-37.9 Z=0
      AZIMUTH=180
      CONSTRUCTION=WALL-1                 $ WALL
      GND-REFLECTANCE = 0.20
$     SKY-FORM-FACTOR =                   USE DOE-2 DEFAULT
$     GND-FORM-FACTOR =                   USE DOE-2 DEFAULT
$     INF-COEF =                          USE ONLY INF-METH.=CRACK
      SHADING-SURFACE =YES
      SHADING-DIVISION = 10               $DOE-2 DEFAULT
$     MULTIPLIER =1
$     SOLAR-FRACTION =                    DOE-2 DEFAULT
      INSIDE-VIS-REFL = 0.75              $PAINTING REFLECTIVITY VALUE
      INSIDE-SOL-ABS = 0.3 ..             $WHITE SEMI-GLOSS PAINT
```

Gable-end wall: northeast wall

```
TRIANG-1=POLYGON
       (-31.9,-37.9,8.125)               $POLYGON'S LOCAL COORDINATES
      (0,-37.9,8.125)
      (-15.95,-37.9,15.525) ..


ROOF-N = EXTERIOR-WALL
       POLYGON=TRIANG-1
      CONSTRUCTION=WALL-R                 $NORTH GABLE WALL
      GND-REFLECTANCE = 0.20 ..
$     SKY-FORM-FACTOR =                   USE DEFAULT
$     GND-FORM-FACTOR =                   USE DEFAULT
```

```
$     INF-COEF =                          USE ONLY INF-METH.=CRACK
$     SHADING-SURFACE =YES
$     SHADING-DIVISION =                  USE DEFAULT
$     MULTIPLIER =1
$     SOLAR-FRACTION =                    USE DEFAULT
$     INSIDE-VIS-REFL = 0.5               10<TILT<170
$     INSIDE-SOL-ABS = 0.5                10<TILT<170
```

3.1.2. Window description: northeast facing window

```
LWN-1 = WINDOW
     HEIGHT = 5                           $FEET
     WIDTH = 6                            $FEET
     X = 1.5 Y = 2
     GLASS-TYPE = GT-1
     FRAME-WIDTH = 0.21
$    SETBACK = 0                          DEAFULT
$    SHADING-SCHEDULE =
$    MAX-SOLAR-SCH =
$    SUN-CTRL-PROB = 1.0                  DEFAULT
$    OPEN-SHADE-SCH =
$    WIN-SHADE-TYPE = MOVABLE-INTERIOR    DOE-2 DEFAULT
$    CONDUCT-SCHEDULE =
$    CONDUCT-TMIN-SCH =                   SCHED VALUES OF OA  DRY BULB
$    SKY-FORM-FACTOR =                    USE DOE-2 DEFAULT
$    GND-FORM-FACTOR =                    USE DOE-2 DEFAULT
$    SHADING-SURFACE = YES
     SHADING-DIVISION = 10                $DOE-2DEFAULT
$    INF-COEF =                           USE ONLY INF-METH.=CRACK
$    SOL-TRANS-SCH =                      USE ONLY FOR A SUNSPACE
$    VIS-TRANS-SCH =                      DAYLIGHT TRANSMITTANCE VALUE
     GLARE-CTRL-PROB = 1.0                $DOE-2 DEFAULT
     INSIDE-VIS-REFL = 0.15  ..           $DOE-2 WINDOW LIBRARY


LHWN-1 = WINDOW                           $HIGH WINDOW
       HEIGHT = 0.7
      WIDTH = 6
      X = 1.5 Y = 7.2125
      GLASS-TYPE = GT-1
      FRAME-WIDTH = 0.21
$     SETBACK = 0                         DEAFULT
$     SHADING-SCHEDULE =                  UNUSED
$     MAX-SOLAR-SCH =                     UNUSED
$     SUN-CTRL-PROB = 1.0                 DEFAULT
$     OPEN-SHADE-SCH =                    UNUSED
$     WIN-SHADE-TYPE = MOVABLE-INTERIOR   DOE-2 DEFAULT
$     CONDUCT-SCHEDULE =                  UNUSED
$     CONDUCT-TMIN-SCH =                  SCHED VALUES OF OA  DRY BULB
$     SKY-FORM-FACTOR =                   USE DOE-2 DEFAULT
$     GND-FORM-FACTOR =                   USE DOE-2 DEFAULT
$     SHADING-SURFACE = YES
      SHADING-DIVISION = 10               $DOE-2DEFAULT
$     INF-COEF =                          USE ONLY INF-METH.=CRACK
$     SOL-TRANS-SCH =                     USE ONLY FOR A SUNSPACE
$     VIS-TRANS-SCH =                     DAYLIGHT TRANSMITTANCE VALUE
      GLARE-CTRL-PROB = 1.0               $DOE-2 DEFAULT
      INSIDE-VIS-REFL = 0.15  ..          $DOE-2 WINDOW LIBRARY
```

Clerestory window description: northeast facing window

```
SKYLIGHT = WINDOW
       HEIGHT = 4                          $FEET
       WIDTH = 6.6                         $FEET
       X = 12.65 Y = 0.6
       GLASS-TYPE = GT-1
       FRAME-WIDTH = 0.21
$      SETBACK = 0                         DEAFULT
$      SHADING-SCHEDULE =                  UNUSED
$      MAX-SOLAR-SCH =                     UNUSED
$      SUN-CTRL-PROB = 1.0                 DEFAULT
$      OPEN-SHADE-SCH =                    UNUSED
$      WIN-SHADE-TYPE = MOVABLE-INTERIOR   DOE-2 DEFAULT
$      CONDUCT-SCHEDULE =                  UNUSED
$      CONDUCT-TMIN-SCH =                  SCHED VALUES OF OA  DRY BULB
$      SKY-FORM-FACTOR =                   USE DOE-2 DEFAULT
$      GND-FORM-FACTOR =                   USE DOE-2 DEFAULT
$      SHADING-SURFACE = YES
       SHADING-DIVISION = 10               $DOE-2DEFAULT
$      INF-COEF =                          USE ONLY INF-METH.=CRACK
$      SOL-TRANS-SCH =                     USE ONLY FOR A SUNSPACE
$      VIS-TRANS-SCH =                     DAYLIGHT TRANSMITTANCE VALUE
       GLARE-CTRL-PROB = 1.0               $DOE-2 DEFAULT
       INSIDE-VIS-REFL = 0.15  ..          $DOE-2 WINDOW LIBRARY
```

3.1.3. Window and shading description: northwest facing window

```
LWW-1 = WINDOW
        HEIGHT = 3
       WIDTH = 3
       X = 2 Y = 4
       GLASS-TYPE = GT-1
       FRAME-WIDTH = 0.21
$      SETBACK = 0                         DEAFULT
$      SHADING-SCHEDULE =                  UNUSED
$      MAX-SOLAR-SCH =                     UNUSED
$      SUN-CTRL-PROB = 1.0                 DEFAULT
$      OPEN-SHADE-SCH =                    UNUSED
$      WIN-SHADE-TYPE = MOVABLE-INTERIOR   DEFAULT
$      CONDUCT-SCHEDULE =                  UNUSED
$      CONDUCT-TMIN-SCH =                  SCHED VALUES OF OA  DRY BULB
       OVERHANG-A = 0.5                    $FEET
       OVERHANG-B = 0                      $FEET
       OVERHANG-W = 4                      $FEET
       OVERHANG-D = 1.5                    $FEET
       OVERHANG-ANGLE = 90                 $PERPENDICULAR TO WINDOW
       RIGHT-FIN-A = 0                     $FEET
       RIGHT-FIN-B = 0                     $FEET
       RIGHT-FIN-H = 3                     $FEET
       RIGHT-FIN-D = 1.5                   $FEET
$      SKY-FORM-FACTOR =                   USE DEFAULT
$      GND-FORM-FACTOR =                   USE DEFAULT
$      SHADING-SURFACE = YES
       SHADING-DIVISION = 10               $DOE-2 DEFAULT
$      INF-COEF =                          USE ONLY INF-METH.=CRACK
```

```
$     SOL-TRANS-SCH =                     USE ONLY FOR A SUNSPACE
$     VIS-TRANS-SCH =                     DAYLIGHT TRANSMITTANCE VALUE
      GLARE-CTRL-PROB = 1.0               $DOE-2 DEFAULT
      INSIDE-VIS-REFL = 0.15  ..          $DOE-2 WINDOW LIBRARY

LHWW-1 = WINDOW                          $HIGH WINDOW
       HEIGHT = 0.7
      WIDTH = 3
      X = 2 Y = 7.2125
      GLASS-TYPE = GT-1
      FRAME-WIDTH = 0.21
$     SETBACK = 0                         DEAFULT
$     SHADING-SCHEDULE =                 UNUSED
$     MAX-SOLAR-SCH =                    UNUSED
$     SUN-CTRL-PROB = 1.0                 DEFAULT
$     OPEN-SHADE-SCH =                   UNUSED
$     WIN-SHADE-TYPE = MOVABLE-INTERIOR   DEFAULT
$     CONDUCT-SCHEDULE =                 UNUSED
$     CONDUCT-TMIN-SCH =                  SCHED VALUES OF OA  DRY BULB
$     SKY-FORM-FACTOR =                   USE DEFAULT
$     GND-FORM-FACTOR =                   USE DEFAULT
$     SHADING-SURFACE = YES
      SHADING-DIVISION = 10               $DOE-2 DEFAULT
$     INF-COEF =                          USE ONLY INF-METH.=CRACK
$     SOL-TRANS-SCH =                     USE ONLY FOR A SUNSPACE
$     VIS-TRANS-SCH =                     DAYLIGHT TRANSMITTANCE VALUE
      GLARE-CTRL-PROB = 1.0               $DOE-2 DEFAULT
      INSIDE-VIS-REFL = 0.15  ..          $DOE-2 WINDOW LIBRARY
```

3.2. Bedroom-2 (Bedroom Next to Living Room)

3.2.1. Window and shading description (southeast facing window)

```
BD2WE-1 = WINDOW
       HEIGHT = 5
      WIDTH = 3
      X = 3 Y = 2
      GLASS-TYPE = GT-1
      FRAME-WIDTH = 0.21
$     SETBACK = 0                        DEAFULT
$     SHADING-SCHEDULE =                 UNUSED
$     MAX-SOLAR-SCH =                    UNUSED
$     SUN-CTRL-PROB = 1.0                 DEFAULT
$     OPEN-SHADE-SCH =                   UNUSED
$     WIN-SHADE-TYPE = MOVABLE-INTERIOR   DEFAULT
$     CONDUCT-SCHEDULE =                 UNUSED
$     CONDUCT-TMIN-SCH =                  SCHED VALUES OF OA  DRY BULB
      OVERHANG-A = 0.5                    $FEET
      OVERHANG-B = 0                      $FEET
      OVERHANG-W = 4                      $FEET
      OVERHANG-D = 1.5                    $FEET
      OVERHANG-ANGLE = 90                 $PERPENDICULAR TO WINDOW
      RIGHT-FIN-A = 0                     $FEET
      RIGHT-FIN-B = 0                     $FEET
      RIGHT-FIN-H = 5                     $FEET
      RIGHT-FIN-D = 1.5                   $FEET
$     SKY-FORM-FACTOR =                   USE DEFAULT
$     GND-FORM-FACTOR =                   USE DEFAULT
```

```
$     SHADING-SURFACE = YES
      SHADING-DIVISION = 10               $DOE-2 DEFAULT
$     INF-COEF =                          USE ONLY INF-METH.=CRACK
$     SOL-TRANS-SCH =                     USE ONLY FOR A SUNSPACE
$     VIS-TRANS-SCH =                     DAYLIGHT TRANSMITTANCE VALUE
      GLARE-CTRL-PROB = 1.0               $DOE-2 DEFAULT
      INSIDE-VIS-REFL = 0.15  ..          $DOE-2 WINDOW LIBRARY

BD2HWE-1 = WINDOW                         $HIGH WINDOW
       HEIGHT = 0.7
      WIDTH = 3
      X = 3 Y = 7.2125
      GLASS-TYPE = GT-1
      FRAME-WIDTH = 0.21
$     SETBACK = 0                         DEAFULT
$     SHADING-SCHEDULE =                  UNUSED
$     MAX-SOLAR-SCH =                     UNUSED
$     SUN-CTRL-PROB = 1.0                 DEFAULT
$     OPEN-SHADE-SCH =                    UNUSED
$     WIN-SHADE-TYPE = MOVABLE-INTERIOR   DEFAULT
$     CONDUCT-SCHEDULE =                  UNUSED
$     CONDUCT-TMIN-SCH =                  SCHED VALUES OF OA  DRY BULB
$     SKY-FORM-FACTOR =                   USE DEFAULT
$     GND-FORM-FACTOR =                   USE DEFAULT
$      SHADING-SURFACE = YES
      SHADING-DIVISION = 10               $DOE-2 DEFAULT
$     INF-COEF =                          USE ONLY INF-METH.=CRACK
$     SOL-TRANS-SCH =                     USE ONLY FOR A SUNSPACE
$     VIS-TRANS-SCH =                     DAYLIGHT TRANSMITTANCE VALUE
      GLARE-CTRL-PROB = 1.0               $DOE-2 DEFAULT
      INSIDE-VIS-REFL = 0.15  ..          $DOE-2 WINDOW LIBRARY
```

3.3. Bedroom-1 (Southeast Bedroom)

3.3.1. Window and shading description (southeast facing window)

```
BD1WE-1 = WINDOW
       HEIGHT = 5
      WIDTH = 3
      X = 3.125 Y = 2
      GLASS-TYPE = GT-1
      FRAME-WIDTH = 0.21
$     SETBACK = 0                         DEAFULT
$     SHADING-SCHEDULE =                  UNUSED
$     MAX-SOLAR-SCH =                     UNUSED
$     SUN-CTRL-PROB = 1.0                 DEFAULT
$     OPEN-SHADE-SCH =                    UNUSED
$     WIN-SHADE-TYPE = MOVABLE-INTERIOR   DEFAULT
$     CONDUCT-SCHEDULE =                  UNUSED
$     CONDUCT-TMIN-SCH =                  SCHED VALUES OF OA  DRY BULB
      OVERHANG-A = 0.5                    $FEET
      OVERHANG-B = 0                      $FEET
      OVERHANG-W = 4                      $FEET
      OVERHANG-D = 1.5                    $FEET
      RIGHT-FIN-A = 0                     $FEET
      RIGHT-FIN-B = 0                     $FEET
      RIGHT-FIN-H = 5                     $FEET
      RIGHT-FIN-D = 1.5                   $FEET
```

```
      OVERHANG-ANGLE = 90                 $PERPENDICULAR TO WINDOW
$     SKY-FORM-FACTOR =                   USE DEFAULT
$     GND-FORM-FACTOR =                   USE DEFAULT
$     SHADING-SURFACE = YES
      SHADING-DIVISION = 10               $DOE-2 DEFAULT
$     INF-COEF =                          USE ONLY INF-METH.=CRACK
$     SOL-TRANS-SCH =                     USE ONLY FOR A SUNSPACE
$     VIS-TRANS-SCH =                     DAYLIGHT TRANSMITTANCE VALUE
      GLARE-CTRL-PROB = 1.0               $DOE-2 DEFAULT
      INSIDE-VIS-REFL = 0.15  ..          $DOE-2 WINDOW LIBRARY

BD1HWE-1 = WINDOW                         $HIGH WINDOW
       HEIGHT = 0.7
      WIDTH = 3
      X = 3.125 Y = 7.2125
      GLASS-TYPE = GT-1
      FRAME-WIDTH = 0.21
$     SETBACK = 0                         DEAFULT
$      SHADING-SCHEDULE =                 UNUSED
$     MAX-SOLAR-SCH =                     UNUSED
$     SUN-CTRL-PROB = 1.0                 DEFAULT
$     OPEN-SHADE-SCH =                    UNUSED
$     WIN-SHADE-TYPE = MOVABLE-INTERIOR   DEFAULT
$     CONDUCT-SCHEDULE =                  UNUSED
$     CONDUCT-TMIN-SCH =                  SCHED VALUES OF OA  DRY BULB
$     SKY-FORM-FACTOR =                   USE DEFAULT
$     GND-FORM-FACTOR =                   USE DEFAULT
$     SHADING-SURFACE = YES
      SHADING-DIVISION = 10               $DOE-2 DEFAULT
$     INF-COEF =                          USE ONLY INF-METH.=CRACK
$     SOL-TRANS-SCH =                     USE ONLY FOR A SUNSPACE
$     VIS-TRANS-SCH =                     DAYLIGHT TRANSMITTANCE VALUE
      GLARE-CTRL-PROB = 1.0               $DOE-2 DEFAULT
      INSIDE-VIS-REFL = 0.15  ..          $DOE-2 WINDOW LIBRARY
```

Southwest facing window

```
BD1WS-1 = WINDOW
       HEIGHT = 5
       WIDTH = 3
      X = 3.275 Y = 2
      GLASS-TYPE = GT-1
      FRAME-WIDTH = 0.21
$     SETBACK = 0                         DEAFULT
$     SHADING-SCHEDULE =                  UNUSED
$     MAX-SOLAR-SCH =                     UNUSED
$     SUN-CTRL-PROB = 1.0                 DEFAULT
$     OPEN-SHADE-SCH =                    UNUSED
$     WIN-SHADE-TYPE = MOVABLE-INTERIOR   DEFAULT
$     CONDUCT-SCHEDULE =                  UNUSED
$     CONDUCT-TMIN-SCH =                  SCHED VALUES OF OA  DRY BULB
      OVERHANG-A = 0.5                    $FEET
      OVERHANG-B = 0                      $FEET
      OVERHANG-W = 4                      $FEET
      OVERHANG-D = 1.5                    $FEET
      OVERHANG-ANGLE = 90                 $PERPENDICULAR TO WINDOW
      LEFT-FIN-A = 0                      $FEET
      LEFT-FIN-B = 0                      $FEET
```

```
      LEFT-FIN-H = 5                      $FEET
      LEFT-FIN-D = 1.5                    $FEET
$     SKY-FORM-FACTOR =                   USE DEFAULT
$     GND-FORM-FACTOR =                   USE DEFAULT
$     SHADING-SURFACE = YES
      SHADING-DIVISION = 10               $DOE-2 DEFAULT
$     INF-COEF =                          USE ONLY INF-METH.=CRACK
$     SOL-TRANS-SCH =                     USE ONLY FOR A SUNSPACE
$     VIS-TRANS-SCH =                     DAYLIGHT TRANSMITTANCE VALUE
      GLARE-CTRL-PROB = 1.0               $DOE-2 DEFAULT
      INSIDE-VIS-REFL = 0.15  ..          $DOE-2 WINDOW LIBRARY

BD1HWS-1 = WINDOW                        $HIGH WINDOW
       HEIGHT = 0.7
      WIDTH = 3
      X = 3.275 Y = 7.2125
      GLASS-TYPE = GT-1
      FRAME-WIDTH = 0.21
$     SETBACK = 0                         DEAFULT
$     SHADING-SCHEDULE =                 UNUSED
$     MAX-SOLAR-SCH =                    UNUSED
$     SUN-CTRL-PROB = 1.0                 DEFAULT
$     OPEN-SHADE-SCH =                   UNUSED
$     WIN-SHADE-TYPE = MOVABLE-INTERIOR   DEFAULT
$     CONDUCT-SCHEDULE =                 UNUSED
$     CONDUCT-TMIN-SCH =                  SCHED VALUES OF OA  DRY BULB
$     SKY-FORM-FACTOR =                   USE DEFAULT
$     GND-FORM-FACTOR =                   USE DEFAULT
$     SHADING-SURFACE = YES
      SHADING-DIVISION = 10               $DOE-2 DEFAULT
$     INF-COEF =                          USE ONLY INF-METH.=CRACK
$     SOL-TRANS-SCH =                     USE ONLY FOR A SUNSPACE
$     VIS-TRANS-SCH =                     DAYLIGHT TRANSMITTANCE VALUE
      GLARE-CTRL-PROB = 1.0               $DOE-2 DEFAULT
      INSIDE-VIS-REFL = 0.15  ..          $DOE-2 WINDOW LIBRARY
```

3.4. Bedroom-M (Southwest Bedroom)

3.4.1. Window and shading description (southwest facing window)

```
MBDWS-1 = WINDOW
      HEIGHT = 5
      WIDTH = 3
      X = 2.375 Y = 2
      GLASS-TYPE = GT-1
      FRAME-WIDTH = 0.21
$     SETBACK = 0                         DEAFULT
$     SHADING-SCHEDULE =                 UNUSED
$     MAX-SOLAR-SCH =                    UNUSED
$      SUN-CTRL-PROB = 1.0                 DEFAULT
$      OPEN-SHADE-SCH =                  UNUSED
$      WIN-SHADE-TYPE = MOVABLE-INTERIOR   DEFAULT
$      CONDUCT-SCHEDULE =                UNUSED
$      CONDUCT-TMIN-SCH =                  SCHED VALUES OF OA  DRY BULB
       OVERHANG-A = 0.5                    $FEET
       OVERHANG-B = 0                      $FEET
       OVERHANG-W = 4                      $FEET
       OVERHANG-D = 1.5                    $FEET
```

```
       OVERHANG-ANGLE = 90                 $PERPENDICULAR TO WINDOW
       LEFT-FIN-A = 0                      $FEET
       LEFT-FIN-B = 0                      $FEET
       LEFT-FIN-H = 5                      $FEET
       LEFT-FIN-D = 1.5                    $FEET
$      SKY-FORM-FACTOR =                   USE DEFAULT
$      GND-FORM-FACTOR =                   USE DEFAULT
$      SHADING-SURFACE = YES
       SHADING-DIVISION = 10               $DOE-2 DEFAULT
$      INF-COEF =                          USE ONLY INF-METH.=CRACK
$      SOL-TRANS-SCH =                     USE ONLY FOR A SUNSPACE
$      VIS-TRANS-SCH =                     DAYLIGHT TRANSMITTANCE VALUE
      GLARE-CTRL-PROB = 1.0               $DOE-2 DEFAULT
      INSIDE-VIS-REFL = 0.15  ..          $DOE-2 WINDOW LIBRARY

MBDHWS-1 = WINDOW                         $HIGH WINDOW
       HEIGHT = 0.7
      WIDTH = 3
      X = 2.375 Y = 7.2125
      GLASS-TYPE = GT-1
      FRAME-WIDTH = 0.21
$     SETBACK = 0                         DEAFULT
$     SHADING-SCHEDULE =                  UNUSED
$     MAX-SOLAR-SCH =                     UNUSED
$     SUN-CTRL-PROB = 1.0                 DEFAULT
$     OPEN-SHADE-SCH =                    UNUSED
$     WIN-SHADE-TYPE = MOVABLE-INTERIOR   DEFAULT
$     CONDUCT-SCHEDULE =                  UNUSED
$     CONDUCT-TMIN-SCH =                  SCHED VALUES OF OA  DRY BULB
$     SKY-FORM-FACTOR =                   USE DEFAULT
$     GND-FORM-FACTOR =                   USE DEFAULT
$     SHADING-SURFACE = YES
      SHADING-DIVISION = 10               $DOE-2 DEFAULT
$     INF-COEF =                          USE ONLY INF-METH.=CRACK
$     SOL-TRANS-SCH =                     USE ONLY FOR A SUNSPACE
$     VIS-TRANS-SCH =                     DAYLIGHT TRANSMITTANCE VALUE
      GLARE-CTRL-PROB = 1.0               $DOE-2 DEFAULT
      INSIDE-VIS-REFL = 0.15  ..          $DOE-2 WINDOW LIBRARY
```

3.5. Building Shade and Interior Lightshelf Description

3.5.1. Building shade description

```
$BUILDING SHADE EAST
EAST-EVE1 = BUILDING-SHADE
HEIGHT = 1.625
WIDTH = 32.9
TRANSMITTANCE = 0
X = 1.5
Y = -31.4
Z = 7.49
AZIMUTH = 90
TILT = 23  ..

EAST-EVE2 =BUILDING-SHADE
HEIGHT = 1.625
WIDTH = 3
TRANSMITTANCE = 1.0
```

```
X = 1.5
Y = -34.4
Z = 7.49
AZIMUTH = 90
TILT = 23  ..

EAST-EVE3 =BUILDING-SHADE
HEIGHT = 1.625
WIDTH = 5
TRANSMITTANCE = 0
X = 1.5
Y = -39.4
Z = 7.49
AZIMUTH = 90
TILT = 23  ..

$BUILDING SHADE WEST
WEST-EVE1 = BUILDING-SHADE
HEIGHT = 1.625
WIDTH = 6.13
TRANSMITTANCE = 0
X = -33.4
Y = 1.5
Z = 7.49
AZIMUTH = 270
TILT = 23  ..

WEST-EVE2 = BUILDING-SHADE
HEIGHT = 1.625
WIDTH = 3
TRANSMITTANCE = 1.0
X = -33.4
Y = -4.625
Z = 7.49
AZIMUTH = 270
TILT = 23  ..

WEST-EVE3 = BUILDING-SHADE
HEIGHT = 1.625
WIDTH = 10.27
TRANSMITTANCE = 0
X = -33.4
Y = -7.625
Z = 7.49
AZIMUTH = 270
TILT = 23  ..

WEST-EVE4 =BUILDING-SHADE
HEIGHT = 1.625
WIDTH = 3
TRANSMITTANCE =1.0
X = -33.4
Y = -17.895
Z = 7.49
AZIMUTH = 270
TILT = 23  ..

WEST-EVE5 = BUILDING-SHADE
HEIGHT = 1.625
WIDTH = 7
```

```
TRANSMITTANCE =0
X = -33.4
Y = -20.895
Z = 7.49
AZIMUTH = 270
TILT = 23  ..

WEST-EVE6 = BUILDING-SHADE
HEIGHT = 1.625
WIDTH = 6
TRANSMITTANCE = 1.0
X = -33.4
Y = -27.895
Z = 7.49
AZIMUTH = 270
TILT = 23  ..

WEST-EVE7 = BUILDING-SHADE
HEIGHT = 1.625
WIDTH = 5.5
TRANSMITTANCE = 0
X = -33.4
Y = -33.895
Z = 7.49
AZIMUTH = 270
TILT = 23  ..
```

3.5.2. Interior lightshelf description

Living room

```
$LIVING ROOM LIGHTSHELF
EAST-LS1 = BUILDING-SHADE
HEIGHT = 1.5
WIDTH = 4
TRANSMITTANCE =0
X = 0
Y = -34.9
Z = 7
AZIMUTH = 90
TILT = 0  ..

WEST-LS1 = BUILDING-SHADE
HEIGHT = 1.5
WIDTH = 7
TRANSMITTANCE = 0
X =-31.9
Y = -27.4
Z = 7
AZIMUTH = 270
TILT = 0 ..
```

Bedroom-2 (bedroom next to living room)

```
$BEDROOM-2 LIGHTSHELF
WEST-LS2 = BUILDING-SHADE
```

```
HEIGHT = 1.5
WIDTH = 4
TRANSMITTANCE = 0
X = -31.9
Y = -17.4
Z = 7
AZIMUTH = 270
TILT = 0  ..
```

Bedroom-1 (southeast bedroom)

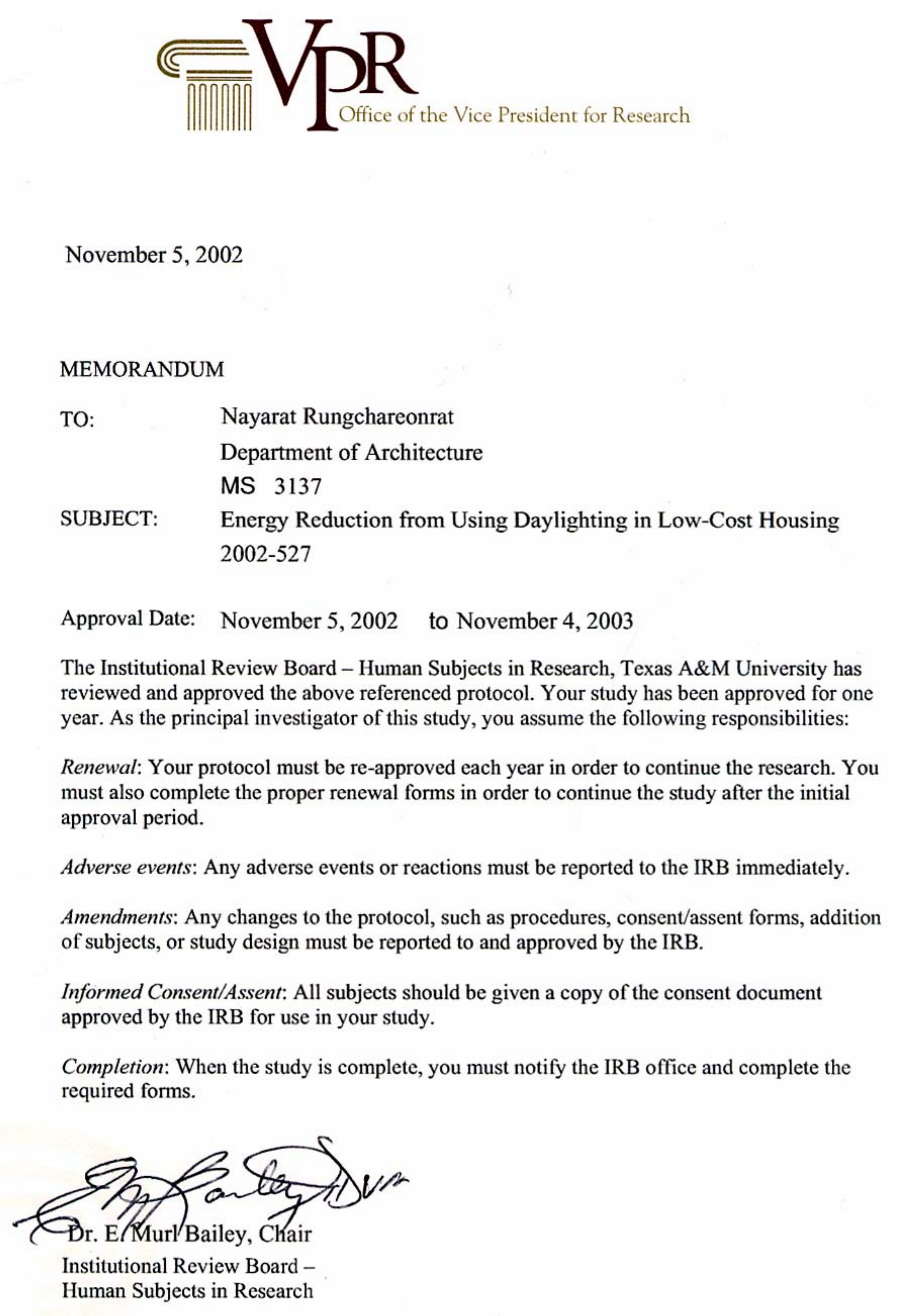
```
$BEDROOM-1 LIGHTSHELF
WEST-LS3 =BUILDING-SHADE
HEIGHT = 1.5
WIDTH = 4
TRANSMITTANCE =0
X = -31.9
Y = -4.125
Z = 7
AZIMUTH = 270
TILT = 0  ..

SOUTH-LS1 = BUILDING-SHADE
HEIGHT = 1.5
WIDTH = 4
TRANSMITTANCE = 0
X = -24.275
Y = 0
Z = 7
AZIMUTH = 0
TILT = 0  ..
```

Bedroom-M (southwest bedroom)

```
$MASTER BEDROOM LIGHTSHELF
SOUTH-LS2 = BUILDING-SHADE
HEIGHT = 1.5
WIDTH = 4
TRANSMITTANCE = 0
X = -10.375
Y = 0
Z = 7
AZIMUTH = 0
TILT = 0  ..
```

APPENDIX F

APPROVAL OF HUMAN SUBJECT COMPLIANCE



VPR
Office of the Vice President for Research

November 5, 2002

MEMORANDUM

TO: Nayarat Rungchareonrat
Department of Architecture
MS 3137

SUBJECT: Energy Reduction from Using Daylighting in Low-Cost Housing
2002-527

Approval Date: November 5, 2002 to November 4, 2003

The Institutional Review Board – Human Subjects in Research, Texas A&M University has reviewed and approved the above referenced protocol. Your study has been approved for one year. As the principal investigator of this study, you assume the following responsibilities:

Renewal: Your protocol must be re-approved each year in order to continue the research. You must also complete the proper renewal forms in order to continue the study after the initial approval period.

Adverse events: Any adverse events or reactions must be reported to the IRB immediately.

Amendments: Any changes to the protocol, such as procedures, consent/assent forms, addition of subjects, or study design must be reported to and approved by the IRB.

Informed Consent/Assent: All subjects should be given a copy of the consent document approved by the IRB for use in your study.

Completion: When the study is complete, you must notify the IRB office and complete the required forms.

Dr. E. Murl Bailey, Chair
Institutional Review Board –
Human Subjects in Research

VITA

Personal data:
Name: Nayarat Rungchareonrat
Place of Birth: Bangkok, Thailand
Date of Birth: November 29, 1974
Address: 107/2 Yenarekart Rd. Chongnonsee Yannawa
Bangkok, Thailand 10120

Education:
August 2003: Master of Science in Architecture
Texas A&M University
College Station, Texas

May 1997: Bachelor of Architecture
Chulalongkorn University
Bangkok, Thailand

Professional Experience:
1997-2000: Licensed Architect
Bangkok, Thailand

Research Interests:
Daylighting in Buildings
Sustainable Architecture
Environmental Systems and Energy Optimization in Building Designs