THERMAL AND DAYLIGHTING PERFORMANCE OF AUTOMATED SPLIT-CONTROLLED BLINDS

By

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A THESIS PRESENTED TO THE GRADUATE SCHOOL
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To my family and friends, for all the support and guidance they provided throughout my student life

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TABLE OF CONTENTS

APPENDIX

LIST OF TABLES

LIST OF FIGURES

Abstract of Thesis Presented to the Graduate School
of the University of Florida in Partial Fulfillment of the
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This research dealt with the study of thermal and daylighting performance of the proposed split-controlled blind system, as compared to a conventional Venetian blind system commonly used in commercial offices. Conventional blinds are most commonly used for the purpose of blocking direct sunlight and preventing glare to the occupants. Conventional blinds are not efficiently used to maximize daylight once the direct light is no longer available. Also, keeping the blinds open for longer periods with direct light coming inside the building increases the cooling loads for the building. The proposed split-controlled blinds consist of multiple sections of blinds, each section with a separate blind angle to allow sufficient daylight inside the building, prevent glare to the occupants and reduce cooling loads for the office building. The case study for this research comprised of a simple office room with a south facing window and interior blinds system installed. EnergyPlus, thermal and energy simulation software and Radiance, daylighting analysis software were used as tools to simulate the office room. Seven static blind angle settings in conventional blinds as a base case and 29 split blind angle settings as a prototype case were simulated by EnergyPlus (EP) and Radiance, to study

the thermal and daylighting performance of the proposed split-controlled blind system. Conservative energy savings were observed for the split-blinds system for the three days of energy simulations. Within the comfort range between 500 lux and 2000 lux, higher average illuminance values with less daylighting fluctuation were observed during the course of the entire year as a result of using the split-blinds system. No observable difference in Useful Daylight Illuminances (UDI) performance was observed between the split-controlled blind system and conventional blind system.

CHAPTER 1
INTRODUCTION

Blinds are the most commonly used shading devices in commercial and residential buildings. Blinds consist of slats of wood, fabric, or metal which are made to overlap one another to cover the window. They are operated by rotating the slats from an open position to a closed position by making them overlap each other.

Venetian blinds consist of horizontal slats connected by cloth stripes called tapes or chords which help in rotating all the slats in unison from 0 to 180 degrees. In general, split blinds were defined as conventional Venetian blinds divided into multiple sections. Each section of the split-controlled blinds would perform a specific function. In this research, split blinds were divided into three sections. Each section of the split-controlled blind system had different slat angle covering different sections of the window.

Figure 1-1 shows split-controlled blind system in which each section performs different functions:

- The top section performs the function of transmission of low angled daylight so that light penetrates into the remote part of the room.
- The middle section performs the function of allowing all the daylight to come in, and at the same time preventing direct sunlight, which causes glare, thus creating discomfort for occupants.
- The lower section performs the function of not allowing too much heat to come inside and thus prevents overheating of the room.

Problem Statement

Buildings in United States account for 40% of the total energy consumption. Substantial research has been carried out in the field of sustainable construction to reduce the amount of energy consumed in buildings. “Research studies related to advanced glazings and daylighting systems have been made to maximize daylighting and reduce glare inside the buildings” (Tzempelikos et al.2007). Venetian blinds are one of the most common shading devices used in most commercial and residential buildings. Conventional Venetian blinds are most commonly used to block direct sunlight and prevent glare. Conventional Venetian blinds are rarely used to maximize daylight penetration into the building. Significant electric lighting energy savings can be obtained by proper use of daylighting in buildings (Lee et al.1998a). In regions dominated by warm weather, keeping blinds open for longer periods allows excess heat inside the building and thus increases the cooling load. A more efficient blind system, which prevents glare to the occupants and reduces energy consumption in buildings, is a necessity. The proposed split-controlled blind system performs the function of providing better daylighting into the building. Split-controlled blind system also reduces the Heating Ventilation and Air Conditioning (HVAC) load by preventing excess heat entering the room and allowing sufficient daylighting, which, in turn, reduces the use of electric lighting.

Research Objectives

The objective of this research was to study thermal and daylighting performance of a new shading device system, the split-controlled blind system. The thermal and daylighting performances of split-controlled blinds were compared to the performance of conventional blinds. This research determined energy savings and useful daylight illuminance as a result of using the split-controlled blinds.

Thus this research tried to answer the following questions:

- Does split-controlled blind system give higher energy savings and perform better thermally as compared to the conventional blind system?

- Does split-controlled blind system provide higher daylighting levels?

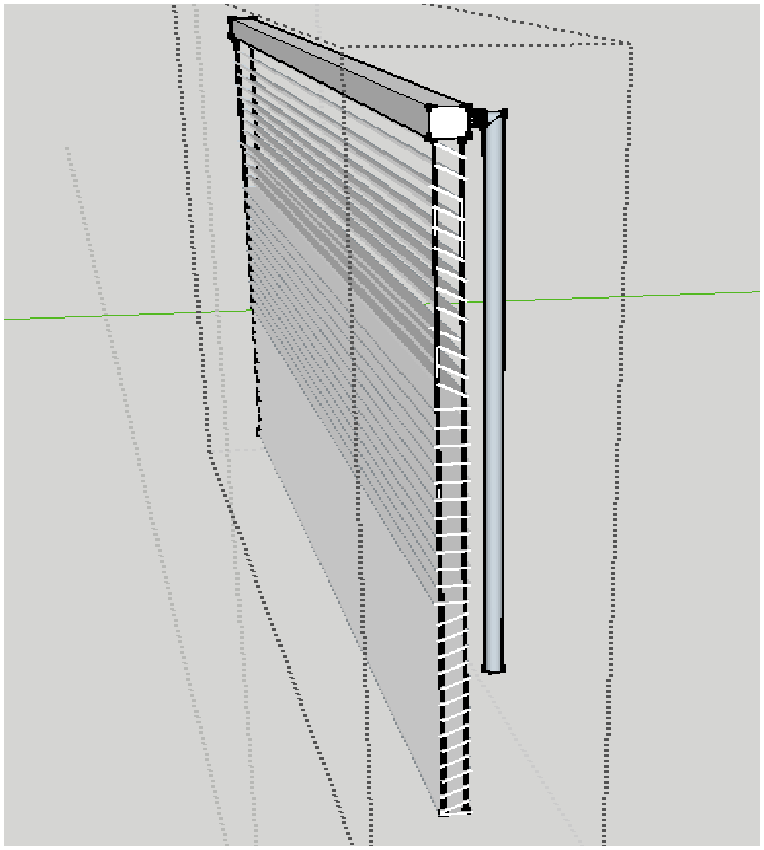

Figure 1-1. A three-dimensional view of a Google SketchUp image for the proposed split controlled blind system. The split blinds system is divided into three sections: Top section, Middle section, and Bottom section

Limitations of Research

The test facility for this experiment was a small office room 3 m x 3.5 m x 5 m in size located in Gainesville, Florida. This research was validated by testing the proposed split-controlled blind system by using two simulation software tools: EnergyPlus and Radiance. However, it should be noted that this experiment did not take into consideration other possible external conditions such as a presence of trees and other sources of shade. The performance of proposed split-controlled blinds is yet to be tested in complex building systems.

The ability of the software tools used to accurately simulate the desired conditions is a factor to be considered while validating these theoretical results. Radiance is considered a highly accurate software program for simulating lighting conditions for three-dimensional models of buildings, but Radiance requires a high amount of computing power, as well as a thorough knowledge of daylighting and optics. EnergyPlus (EP) is considered to be one of the best software engines for energy simulations of buildings, but it is not the best software to be considered for daylighting analysis.

CHAPTER 2
LITERATURE REVIEW

The function of a shading device is to prevent glare caused by direct sunlight, as well as to prevent excess heat entering into the building. Venetian blinds are one of the most commonly used shading devices in office buildings. Heating/cooling energy consumption, along with the thermal and visual comfort, is highly affected by the type of shading device used (Tzempelikos et al. 2007).

Manually Controlled Blinds

Manually controlled blinds perform the function of blocking excess direct light coming into the building and preventing glare. Excess heat entering through the fenestration leads to an increase in cooling load for the building (Tzempelikos et al. 2007). The process of manually operating blinds by the occupant is often found to be cumbersome. Most of the time the user tends to leave the blinds open all day, which leads to excessive heat coming into the building, thus increasing the cooling load for the building.

Just the presence of blinds can affect the illuminance level inside the room, when compared with blinds totally retracted. The horizontal blind slats reduced the illuminance at a photosensor on the ceiling by 30% to 50% for about eight hours between 6 a.m. to 6 p.m. in September and May, which increased the lighting consumption of the test room by approximately 30% (Galasiu et al. 2004).

Positioning the blinds with the slats at a 45° upward angle reduced the total illuminance at the ceiling on average by 45% to 60% in both September and May for about 8 to 10 hours a day. Results showed that blinds positioned with their slats at a 45°

downward angle reduced the total illuminance at the ceiling photosensor by 40% to 45% for 7 hours in the spring, and 10 hours in the fall (Galasiu et al. 2004).

Automated blinds

In the case of automated blinds, the slat angle of the blinds is controlled by a computer program. Dynamic blinds are controlled automatically with the help of a motor or mechanized system to make the blinds system perform a particular task, such as block direct sunlight or to maintain a particular illuminance level inside the room.

> The category of ‘dynamic’ window technologies encompasses numerous conventional components, such as motorized louvers, venetian blinds, and shades, as well as more advanced glazing systems, such as switchable electrochromics, photochromics, thermochromics, polymer-dispersed liquid crystal glazings, and electrically-heated glazings (Lee et al. 1998b).

However, the potential for a dynamic operation of shading devices through a building automation system is generally neglected. The impact of shading design and control on building performance is not taken into account at the design stage, although an optimum cooling and lighting energy balance between fenestration and lighting may be identified and utilized (Tzempelikos et al. 2006).

As a result of the dynamic systems control over solar heat gain, reductions in cooling load were observed. Also lighting energy savings were observed as a result of dynamic systems ability to control the illuminance levels inside the room. Dynamic blinds were found to perform better than the static blind system in terms of cooling load reductions and peak load reduction (Lee et al. 1998b). “Total annual energy savings of 16-26% were attained with the automated blind compared to an unshaded low-E spectrally-selective window system with the same daylighting controls in Los Angeles, California” (Lee et al.1998a).

> Field data indicated that an automated interior blind with spectrally selective glazing and a less than optimal control algorithm was more than twice as effective at reducing peak solar gains under clear sky conditions as a static unshaded bronze glazing with the same daylighting control system, while providing the same level of useful daylight (Lee et al. 1998b).

Energy Analysis

One of the main purposes of using Venetian blinds as a shading device is to avoid the flow of excess heat coming into the room, thus increasing the cooling load for the building.

> Even in heating-dominated climates, cooling is important for perimeter spaces with high solar gains. Shading provision is necessary; the properties and control of shading have to be taken into account from the early design stage, since they have a significant impact on peak thermal loads, energy consumption for heating, cooling and lighting, as well as on human comfort (Tzempelikos et al. 2006).

One quarter of total energy usage in the commercial sector is accounted by lighting energy consumption in buildings, followed by heating, cooling, office equipment and water heating (Koomey et al. 2001). In one comparative study by Lee et al. (1998a) the base case was defined as automated blinds with static positions, divided into two cases, one with daylighting control and one without daylighting control. The prototype case consisted of automated blinds activated every 30 seconds to maintain illuminance of 540-700 lux. The same ballast system was used for lighting control in both cases.

Average cooling reductions of 6% to 15% (for 45˚ blind angle) and 17% to 32% (for 0˚ blind angle) were achieved by the dynamic blinds compared to the static blinds. Average peak load reductions were 6% to 15% by dynamic blinds as compared to static blinds (for 45˚blind angle) and 18% to 32% by dynamic blinds as compared to static blinds (for 0˚ static angle). For the base case without daylighting controls, daily lighting energy savings by dynamic blinds were 22% to 86% for any static blind angle. Cooling load reductions for dynamic blinds were on the order of 28 ± 5% as compared to the static blinds for 0˚ blind angle for clear days in July.

In the case of the static system, an imbalance occurred between cooling load reductions and lighting energy savings for closed and horizontal position of the blinds. This balance was achieved in case of the dynamic system. The dynamic system always blocked direct sunlight and provided view for a maximum of 50% of the day throughout the year, thus reducing the occupant's discomfort considerably (Lee et al. 1998a).

Blinds Control Strategies

For climates with moderate daylight availability and for a building type that is cooling-load dominated, dynamic window technologies can be coupled with daylighting controls to actively optimize daylight and its respective solar heat gains at the perimeter zone of commercial buildings (Lee et al. 1998). If automated blinds were interconnected to a lighting system, such that the amount of electric lighting used was linked with the daylight available inside the building, sufficient energy savings could be observed. A variety of control alternatives have been suggested to reduce lighting energy consumption. Daylight dimming control systems save lighting energy most effectively since they use daylight as an alternative light source (Kim and Kim, 2007). "The dimming system had the potential to save between 50% and 60% lighting energy over the 12-hour period considered (6 a.m. to 6 p.m.) compared to the electric lights being fully on during the same time interval" (Galasiu et al. 2004). Approximately 20% to 40% of lighting energy consumption in buildings can be reduced by using daylight dimming control systems (Kim et al. 2007). However, daylight dimming systems have not been widely applied to buildings due to the visual problems associated with fluctuating electric light outputs under varying sky and cloud conditions.

Use of off-the-shelf technology can be made to promote efficient window systems. For example, (Lee et al. 2004) attempted to develop a low cost networking system for dynamic window, lighting and sensors devices. Lawrence Berkeley National Laboratory (LBNL) developed a building communication network, known as the Integral Building Environment Communication System (IBECS). This system was found to be cheaper due to a low per point networking cost. This cost-effective network interface for AC/DC motorized shading and a switchable electrochromic window system was developed by using a microlan bridge to couple the various devices and sensors in a building with the existing Ethernet Network. The IBECS achieved significant reductions in per point networking costs. By making some modifications to the interface between the motor and the shading devices, such a system can also be applied to all types of motorized window shading systems (Lee et al. 2004).

In another experiment by Galasiu et al. (2004), 15 photometric sensors were positioned for measuring exterior as well as interior illuminance levels; three of them were at the center of the ceiling. These three sensors were set to have partially shielded, fully shielded and no shielded conditions. The sky conditions were classified into clear sky conditions and partly cloudy sky conditions. Three blind conditions: no blind condition, horizontal blinds, and blinds at a 35˚ angle were used in the study. The shielding conditions used in the photo sensors significantly controlled the daylight fluctuations caused by the partly cloudy sky conditions. The slat angle of the Venetian blind used was not a significant factor in controlling or determining the interior illuminance level. The altitude and azimuth angles were important factors under partly cloudy sky conditions for causing the change in fluctuations (Galasiu et al. 2004).

EnergyPlus and Radiance

EnergyPlus (EP)

EnergyPlus is a building energy simulation program. Various components of building dynamics such as heating, cooling, lighting, ventilation, and energy flows, can be modeled in EnergyPlus. EnergyPlus is a standalone simulation program without a graphical user interface (GUI). A number of GUIs are being developed to make the software user friendly. Some of the commonly used GUIs are Open Studio, EnergyPlugged, DesignBuilder, and ECOTECT.

Building Loads Analysis and System Thermodynamics (BLAST) and DOE-2 are computer programs used to perform the heating and cooling load calculations for buildings. Their origins date from the early 1970s. They are primarily used to investigate the energy performance of new as well as retrofit building design options. They possess different capabilities, such as peak load calculation and annual energy performance of building facilities of any size and type.

EnergyPlus was built on the platform of BLAST and DOE-2. EnergyPlus possesses many of their capabilities with many innovative simulation capabilities, such as time-step less than an hour, modular systems, and plant integration with heat balance-based simulation, Multizone airflow, thermal comfort, water use, and natural ventilation.

The disadvantages of EnergyPlus include:

- EnergyPlus does not have a Graphical User Interface (GUI). Though a number of third party interfaces are being developed, EP is a simulation engine.
- EP is not a life cycle assessment program. EP cannot be used as a Life Cycle Costing (LCC) tool.

- EnergyPlus also cannot be considered as a replacement for an architect or a design engineer. EP inputs and outputs have to be monitored by an engineer or an architect to correctly interpret the results (EnergyPlus Documentation 2008).

Radiance

Radiance is software tool to simulate various lighting conditions. Radiance makes visualization of lighting effortless in a virtual environment because of the endless possibilities that arise from its 50 or so tools. These tools can be used to produce realistic and natural renderings of complex building systems with complex lightings.

Radiance synthesizes images from three-dimensional geometric models. The model consists of the description of the surface's shape, size, location, and composition. Generally, simple surfaces, such as polygons, spheres, and cones, can be directly modeled in Radiance. A number of other generator programs can be used to produce more complex shapes, such as boxes, prisms, and surfaces of revolution. More complex structures, consisting of thousands of surfaces, can be produced separately by Computer Aided Design (CAD) programs (Larson 1991).

Radiance is UNIX-based software, thus familiarity with the UNIX operating system is necessary in order to use Radiance.

Radiance performs five main functions:

- Produces shapes of objects in an environment by entering and compiling information by various methods described in Larson and Shakespeare's book Rendering with Radiance.
- Characterizes the light's interaction with the surfaces using various mathematical models described in the book.
- Simulates and renders lighting, certain techniques can calculate the propagation of light in an environment, as well as the nature of the values computed.
- Analyzes and manipulates images, the image processing and conversion.

- Creates interactions between automation of rendering and analysis processes and facilitates links to other systems and computing environments (Larson and Shakespeare 1998).

CHAPTER 3
METHODOLOGY

Introduction

This research evaluated the performance of split-controlled blind system by comparing its thermal and daylighting performance with conventional Venetian blind system. Two building simulation tools, EnergyPlus (EP) and Radiance, were used to validate the proposed split-controlled blind system. In EnergyPlus, simulations were performed for three days: March 21, June 21, and December 21.

Daylighting assessment was done using the software, Radiance. Simulations were performed for every occupied hour for the entire year to obtain illuminance values for four sensor points placed one meter from each other. The first sensor point was placed one meter from the window.

Description of Case Study

The case study involved a small 3 m x 3.5 m x 5 m office room in Gainesville, Florida. The office room was fitted with a 1.83 m x 1.83 m (6’ x 6’) window (U-factor=2.69, visible transmittance=0.744) on the south side. The window was glazed with double insulated glass that consisted of: a 6 mm interior glass (Low emittance glass (Low-E), conductivity=0.6 W/m-K, thickness=0.006 m, solar transmittance=0.6, solar reflectance on front side=0.22, solar reflectance on back side=0.17), 13 mm air space, and a 6 mm Low-E exterior glass. No frame was used for the window.

The wall surface consisted of three layers: concrete with steel connectors on the outside (thickness=0.15 m, conductivity=1.078 W/m-k, density=2185.44 kg/m^3, specific heat=1173 J/kg-K), an insulation in the middle (thickness=0.1 m, conductivity=0.499 W/m-K, density=1552 kg/ m^3, specific heat=880 J/kg-k), and concrete with steel connectors on the inside (thickness=0.1 m, conductivity=1.329 W/m-k, density=2213 kg/ m^3, specific heat=964 J/kg-K). Blinds with high reflective slats were used. Slat width was 0.025 m; slat separation was 0.0187 m and slat conductivity of 0.9 W/m-K.

EnergyPlus simulations were performed for three days of the year, March 21 (maximum dry-bulb temperature equal to 31.7˚ C, barometric pressure equal to 101217, wind speed equal to 12.9 m/s), June 21 (maximum dry-bulb temperature equal to 34.4˚ C, barometric pressure equal to 101217, wind speed equal to 9.3 m/s) and December 21 (maximum dry-bulb temperature equal to 27.2˚ C, barometric pressure equal to 101217, wind speed equal to 8.8 m/s).

Figure 3-1 shows the three-dimensional model of the office room described in the case study. This Google SketchUp model was imported into EP using the Plug-in, OpenStudio.

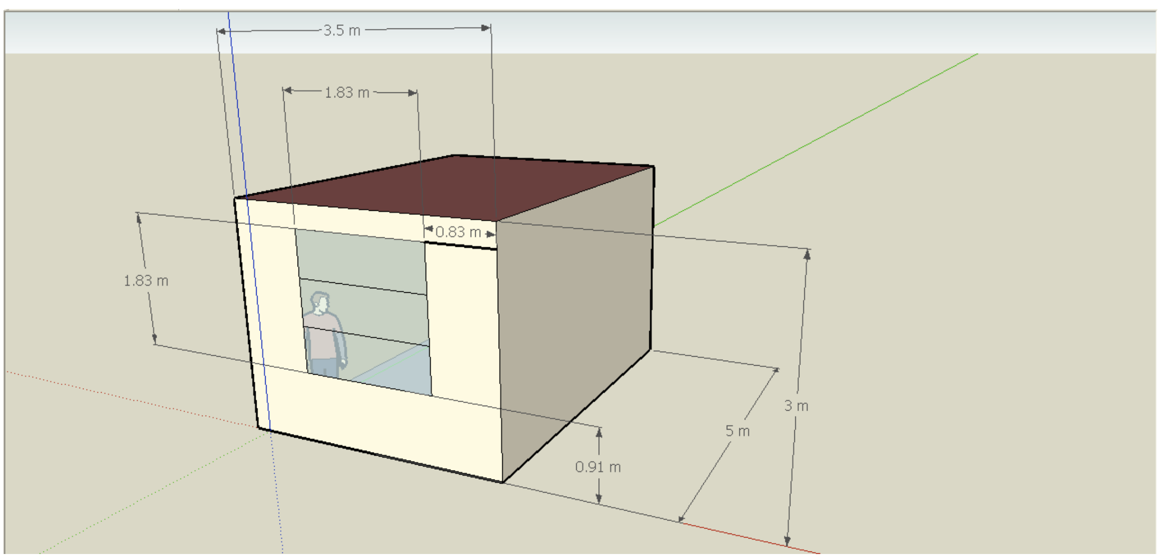

Figure 3-1. Three-dimensional Google SketchUp view of the office room.

Figure 3-2 shows the top view of the office room. The two sensor points used in EP were collinearly placed at distance of 0.75 m and 3.5 m with the window's midpoint at a height of 0.76 m above the ground level.

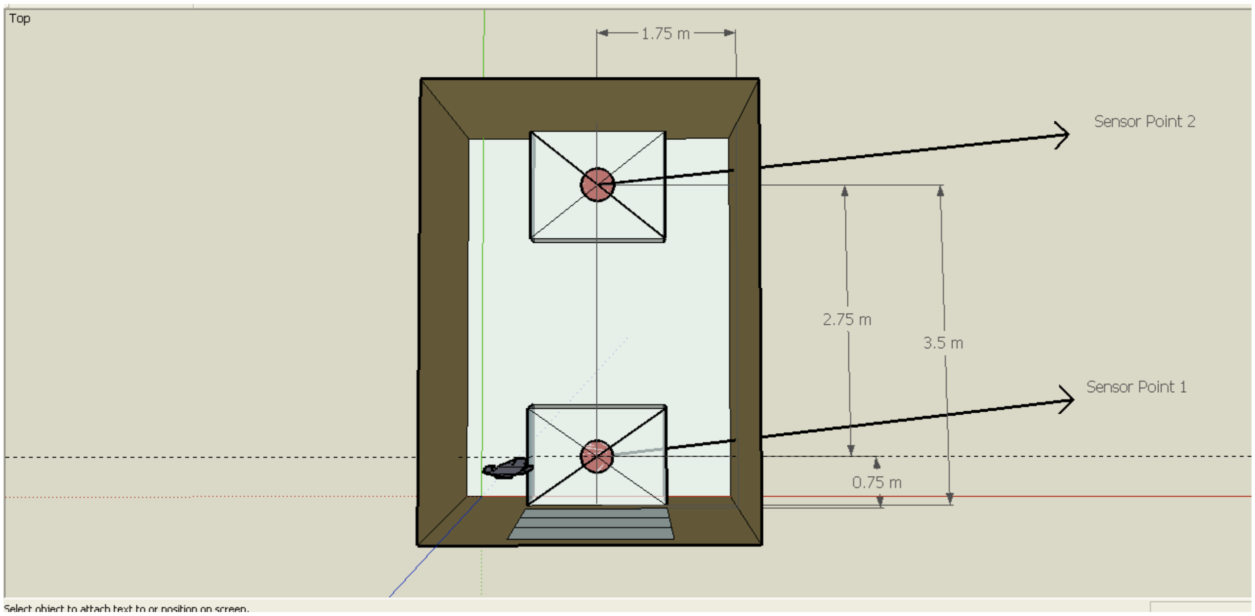

Figure 3-2. Top view the office building with the two sensor points positioned on two office desks.

Location and Weather Data:

The weather file for the Gainesville region was obtained from the U.S Department of Energy (DOE) Building Technologies (BT) Program website. Elevation of the building is 41 m above sea level and standard pressure was 100833 Pa. (EnergyPlus Weather file, 2008).

HVAC

The HVAC system used for the EnergyPlus simulation was Packaged Terminal: Air Conditioner (PTAC). The PTAC consists of an outside air mixer, direct Expansion (DX) cooling coil, and a heating coil, which may be run by gas, electricity, hot water, steam and a supply air fan (EnergyPlus Documentation, 2008).

Simulations

Simulations were conducted for seven different static slat angles (0˚, 15˚, 30˚, 45˚, 60˚, 75˚, and 90˚) in the case of conventional blinds. In the case of split blinds, the following 29 sets of split angles were tested: 0˚-0˚-0˚, 0˚-0˚-80˚, 0˚-0˚-45˚, 10˚-0˚-0˚, 10˚-0˚-45˚, 10˚-0˚-80˚, -37˚-45˚-45˚, -37˚-45˚-80˚, -37˚-45˚-0˚, -37˚-45˚-10˚, -37˚-0˚-0˚, -37˚-0˚-80˚, -37˚-0˚-45˚, 0˚-45˚-0˚, 0˚-45˚-0˚, 0˚-45˚-45˚, 0˚-45˚-80˚, 0˚-80˚-0˚, 0˚-80˚-45˚, 0˚-80˚-80˚, 10˚-45˚-0˚, 10˚-45˚-45˚, 10˚-45˚-80˚, 10˚-80˚-0˚, 10˚-80˚-45˚, 10˚-80˚-80˚, -37˚-80˚-80˚, -37˚-80˚-45˚, and -37˚-80˚-0˚. For split blinds, the angles are specified in the order from the top section to the bottom section. For example, 10˚-0˚-45˚ means, the top blinds would be 10˚ closed downwards, the middle angle would be totally open at 0˚ angles, and the bottom section would have an angle of 45˚ closed downwards. The -37˚ slat angle indicated the slat angle rotation of 37˚ inwards facing the room allowing for more daylight penetration at the backend of the room.

The office room had two sensor points, each placed at a height of 0.76 m above the ground level. The first sensor point was placed 0.75 m from the window, and the second sensor point was placed 3.5 m from the window. The following variables were measured at the two sensor points: Average Illuminance (lux), Glare Index, Average hourly lighting load (W), Average hourly HVAC load (W), Average Total Energy Consumption (W) for three days of the year: March 21, June 21, and December 21 for every occupied hour, from 8 a.m. to 5 p.m.

June 21 is one of two solstices. On this day, the rays of the sun directly strike the Tropic of Cancer at 23°30' north latitude. On June 21 the summer solstice marks the beginning of summer in the Northern Hemisphere and subsequently marks winter in the Southern Hemisphere. On December 21, the winter solstice marks the beginning of winter in the Northern Hemisphere and marks summer in the Southern Hemisphere.

Therefore March 21, June 21, and December 21 become important days for performing simulations.

EnergyPlus Inputs

The IDF editor is the interface used by the user to define all the parameters required to run the simulation. The three-dimentional model created in Google SketchUp was imported in EnergyPlus using IDF Editor. The graphical interface for IDF Editor is shown in Figure 3-3. The IDF Editor lists all the input parameters as objects to be defined by the user. The value to be inputted is defined briefly in the box named “comments section” on the right side of the checklist. The important parameters that need to be defined before running the simulations are as follows:

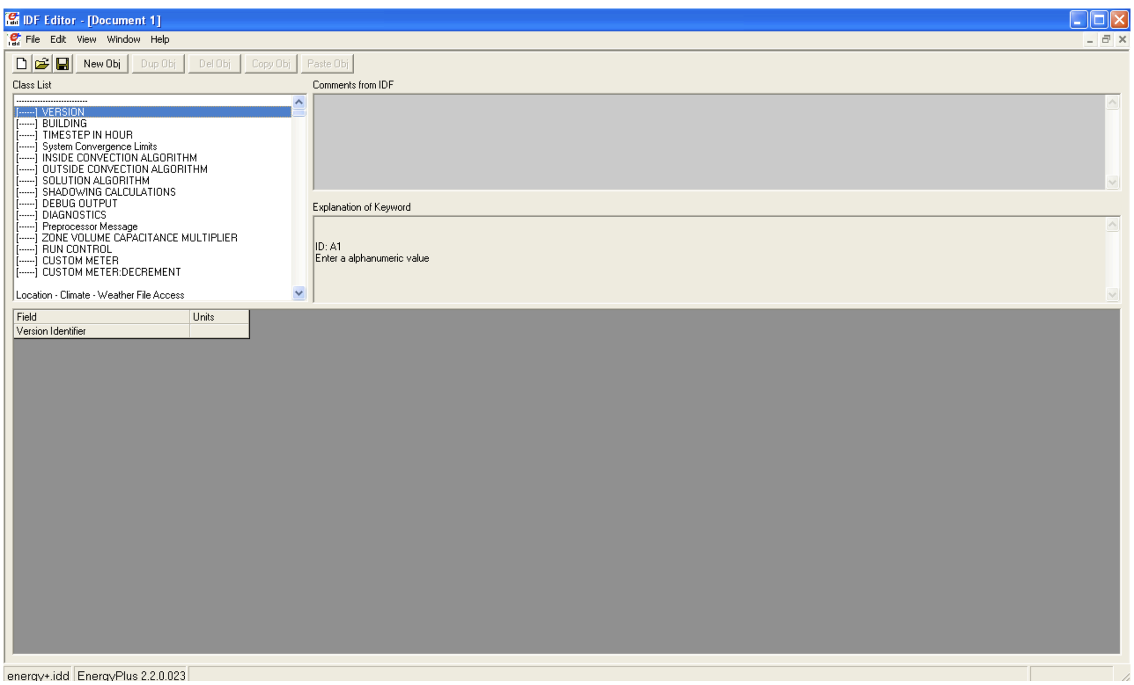

Figure 3-3. The input for EnergyPlus was done through the IDF-Editor interface.

Selecting the walls and windows

The parameter surface construction was used to describe the physical properties and the configuration for the building envelope and the interior elements.

Material Regular

This parameter was used to define the four main thermal properties of the material: thickness, conductivity, density, and specific heat. Appendix A contains all the values assigned for each of the required variables for the definition of the parameter.

Design Day

Figure 3-4 shows the object Design day, this parameter defines all the variables for the day required to run the simulation. The day of the month and month of the year for which the simulations are to be run are defined here. Others prominent variables, such as maximum Drybulb temperature and Windspeed, are defined here.

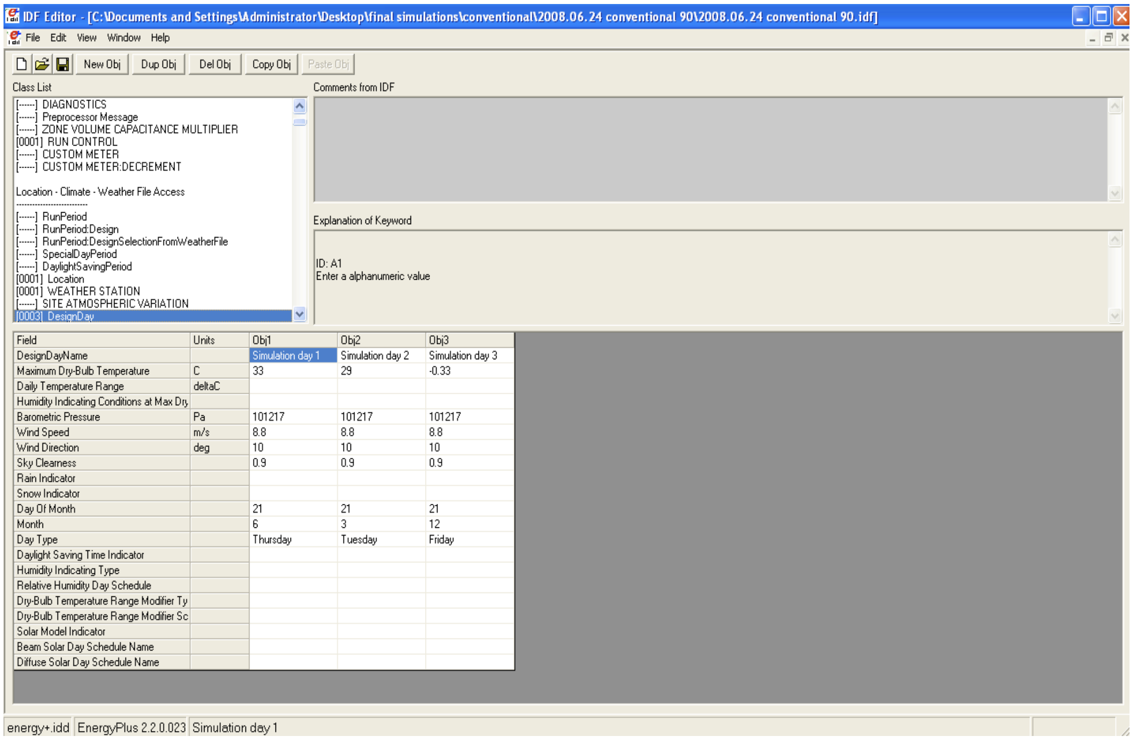

Figure 3-4. The IDF interface for Design Day Input.

Construction

Once all the materials are defined in the parameter Material Regular, all the elements of the building such as walls, floors, windows, and doors are "built" in this parameter from the materials defined. From the most exterior layers, up to 10 layers can be specified.

Material: Blinds

This parameter defines all the dimensions of the blinds, as well as material properties of the blinds. Blinds can be placed either inside of the window, on the outside of the window, or between two layers of glass. For this case study, the blinds are placed inside the window. The blinds are assumed to cover all the glazed part of the window.

Surface(s)

The parameter Surface heat transfer was used to define all the geometric specifications for all the building elements, walls, window, slab, and roof. This parameter not only defines the important elements of the building but also the interaction between all the building surfaces.

Figure 3-5 shows the parameter surface heat transfer selected in the Thermal Zone Description Geometry section. This parameter consists of the variables, Surface Type, Sun Exposure, Wind Exposure, and the coordinates for each surface vertex of the surface selected.

Lights

The parameter Lights gives the option to define the type and intensity of the interior lights used. This case study used 256 W of interior lighting for the office building.

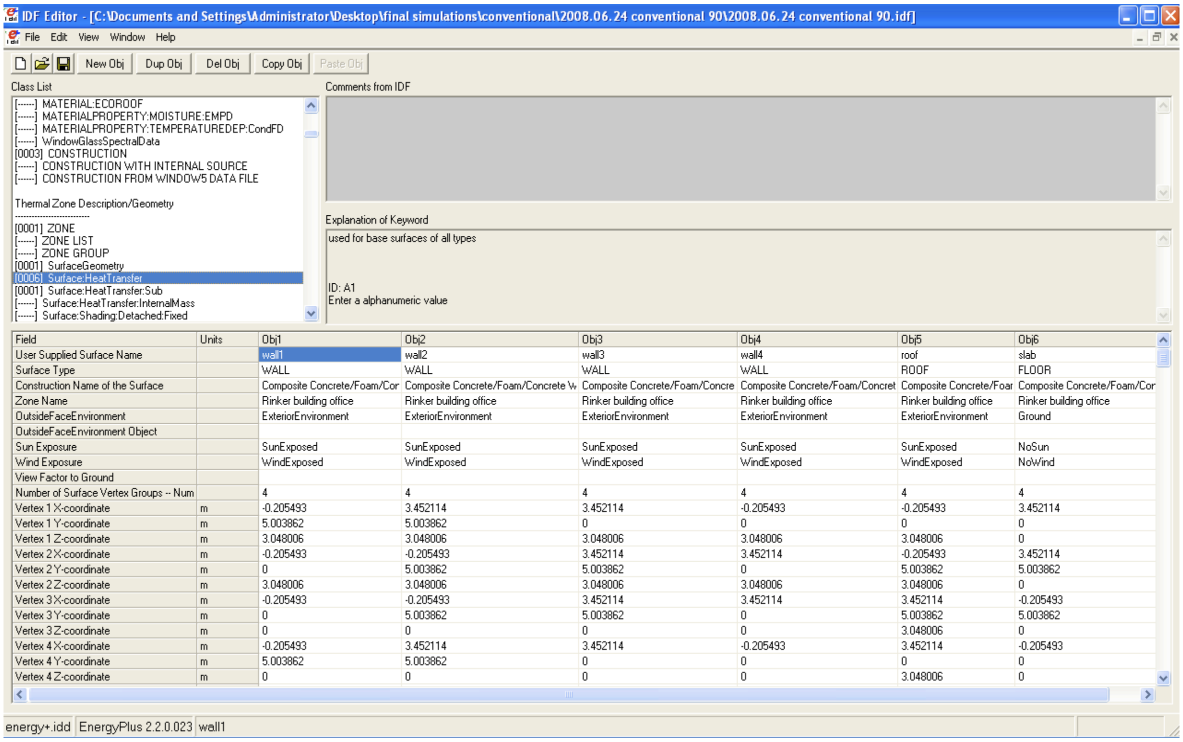

Figure 3-5. Screen shot showing all the necessary variables for the object surface heat transfer.

Schedule

Electrical equipment, such as Heating Ventilation and Air Conditioning (HVAC), and lights can be set on schedule by using the parameter schedule compact. The parameter schedule compact defines the time period of the day for which the electric appliance was in use.

Daylighting: Detailed

The parameter Daylighting: Detailed defines all the necessary variables required to calculate illuminance levels at the required sensor points. Many variables, such as sky condition, sun position, calculation point (sensor point), location of the sensor point, and transmittance value of the windows, were defined here. The dimming strategy used to control lighting depended on the illuminance set point that was chosen, the fraction of the zone that the set point controls, and the type of lighting control used (EnergyPlus Documentation, Version 2.2, 2008).

Lighting Control Type

EnergyPlus has two types of lighting control mechanisms. In the first mechanism, the overhead lights dim continuously and linearly from maximum electric power and maximum light output to minimum electric power and minimum light output as the daylight illuminance increases inside the room. The lights stay on at the minimum point with further increase in the daylight illuminance. In the second mechanism, known as stepped control of lighting, the electric power input and light output vary in discrete, equally spaced steps (EnergyPlus Documentation, 2008). For this case study, the stepped control of lighting was used. For the two sensor points in the model, the illuminance setpoint was 500 lux. The stepped control of light works in the following manner:

For an illuminance value of less than one-third of the set point value (i.e, 500/3=167 lux), the fraction of light to be switched ON is equal to one. For illuminance values between one-third and two-thirds of 500 (i.e., 167-333 lux), the fraction of light to be switched ON is equal to two-thirds. This means if the light level in the room was between 167 and 333 lux, two-thirds of the lights were be switched ON. If the illuminance value in the room was between 333 and 500 lux, then one-thirds of the lighting was switched ON. Finally, if the illuminance value in the room is more than 500 lux, all the lights were switched OFF. Table 3-1 describes the fractional distribution of electric lighting used, depending on the illuminance values in the room.

Selecting Input and Weather Files

As shown in Figure 3-6, the input file and weather files can be selected from the "Single Simulation" tab from the two pull-down lists. The "Browse…" option can be used to locate an input or weather file that was created or downloaded from the website.

Table 3-1. Example of a Stepped Lighting Control System with Three Steps

Daylight illuminance (lux)	Fraction of lights that are ON
0-167	1.0
167-233	2/3
233-500	1/3
500	0.0

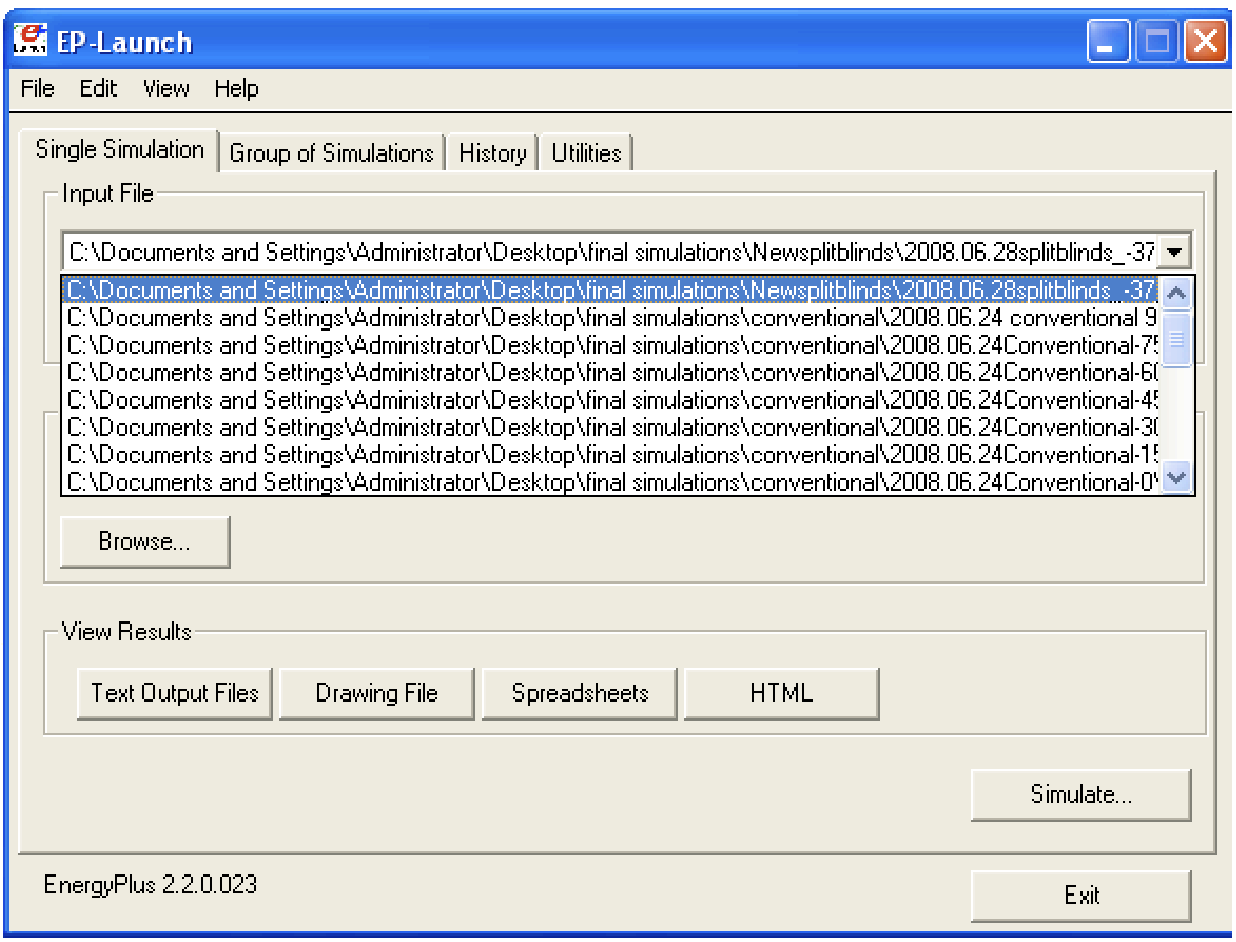

Figure 3-6. The first drop-down menu is used for selecting the input file (IDF editor file) created using IDF Editor.

Figure 3-7 shows the drop-down menu to select the weather file for the city for which the simulation was run. The weather files can be downloaded from the website for the Building Technologies Program of the U.S Department of Energy: Energy Efficiency and Renewable Energy. The simulate option at the bottom of the interface is used to run the simulations.

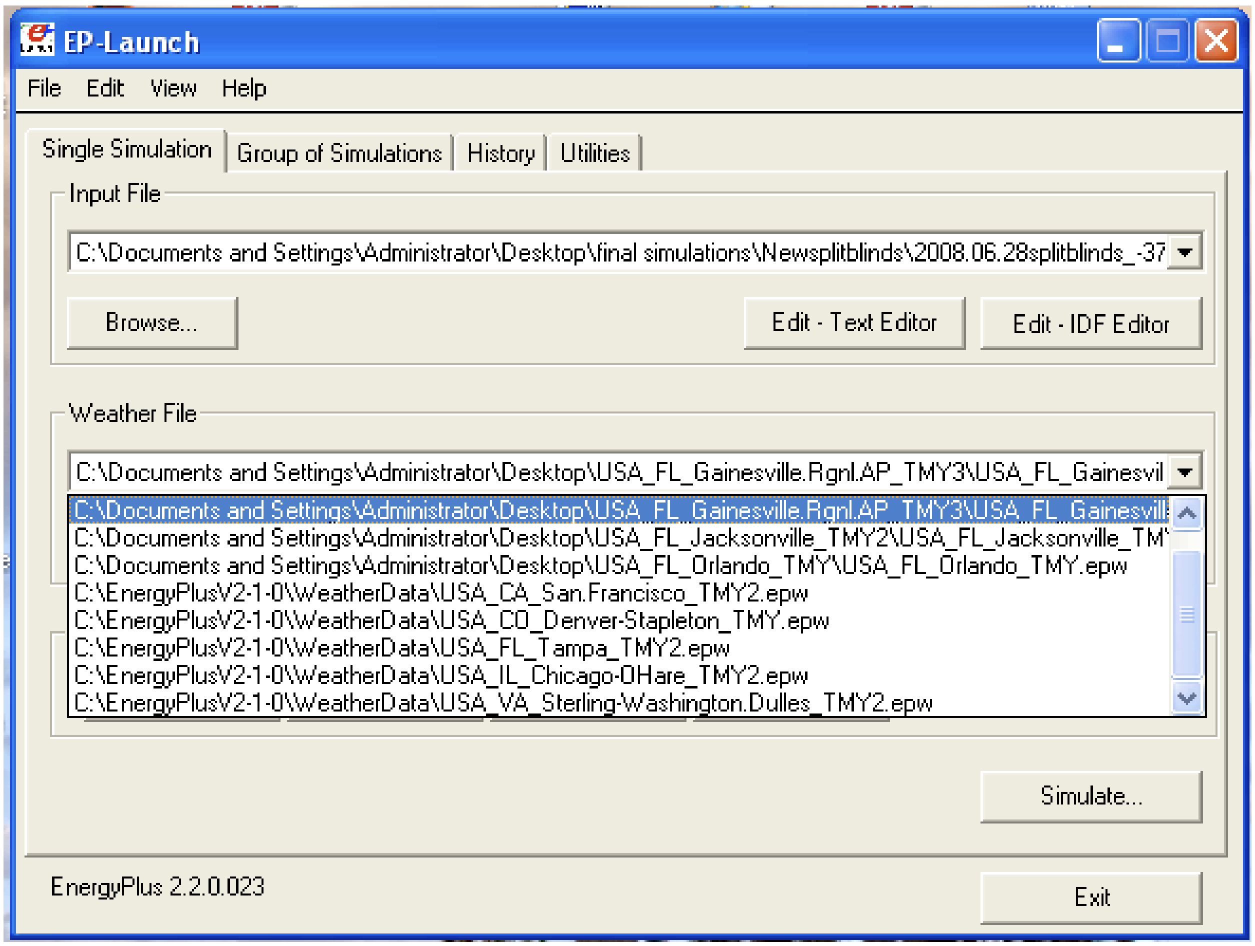

Figure 3-7. The second drop-down menu is used for selecting the weather file.

Radiance

The Radiance program was developed as a research tool for predicting the distribution of visible radiation in illuminated spaces. Radiance takes as input a three-dimensional geometric model of the physical environment and produces a map of spectral radiance values in a color image. The technique of ray tracing follows light backwards from the image plane to the source(s). Because Radiance can produce realistic images from a simple description, it has a wide range of applications in graphic arts, lighting design, Computer-Aided Design (CAD), and architecture (Larson and Shakespeare 1998).

The simulation tool Radiance uses a light-backwards ray tracing method with extensions to efficiently solve the rendering equation for specular, diffuse and directional-diffuse reflection, and transmission in any combination to any level in any environment, including complicated, curved geometries. The simulation blends deterministic and stochastic ray tracing techniques to achieve the best balance between speed and accuracy in its local and global illumination methods (Larson 1991).

The building blocks for any Radiance input file are the primitives. All the materials that were used, along with all the surfaces that described the objects in the scene, need to be described as primitives.

The scene description for Radiance is in three-dimensional Cartesian (X, Y, Z rectilinear) coordinates, which lists all the materials and surfaces used to create the scene. The scene description file is stored in American Standard Code for Information Interchange (ASCII) text.

Modifiers are either the word "void," which indicates no modifier, or some previously defined primitive identifier. The type can be the material type (e.g., plastic, metal or glass) or surface type (e.g., sphere, polygon, cone, or cylinder), as well as one of a few other type categories (pattern, texture, or mixture), and the identifier is the name of the primitive being described.

Figure 3-8 shows a fish-eye image of the office room used in this case study. This image was generated by the software Radiance. This is a high resolution fish-eye image of the office room used in the case study. This image was rendered in Radiance using the command Rpict (Appendix B). The walls of the office room are gray, the floor was green, and the two furniture tables shown are made of wood.

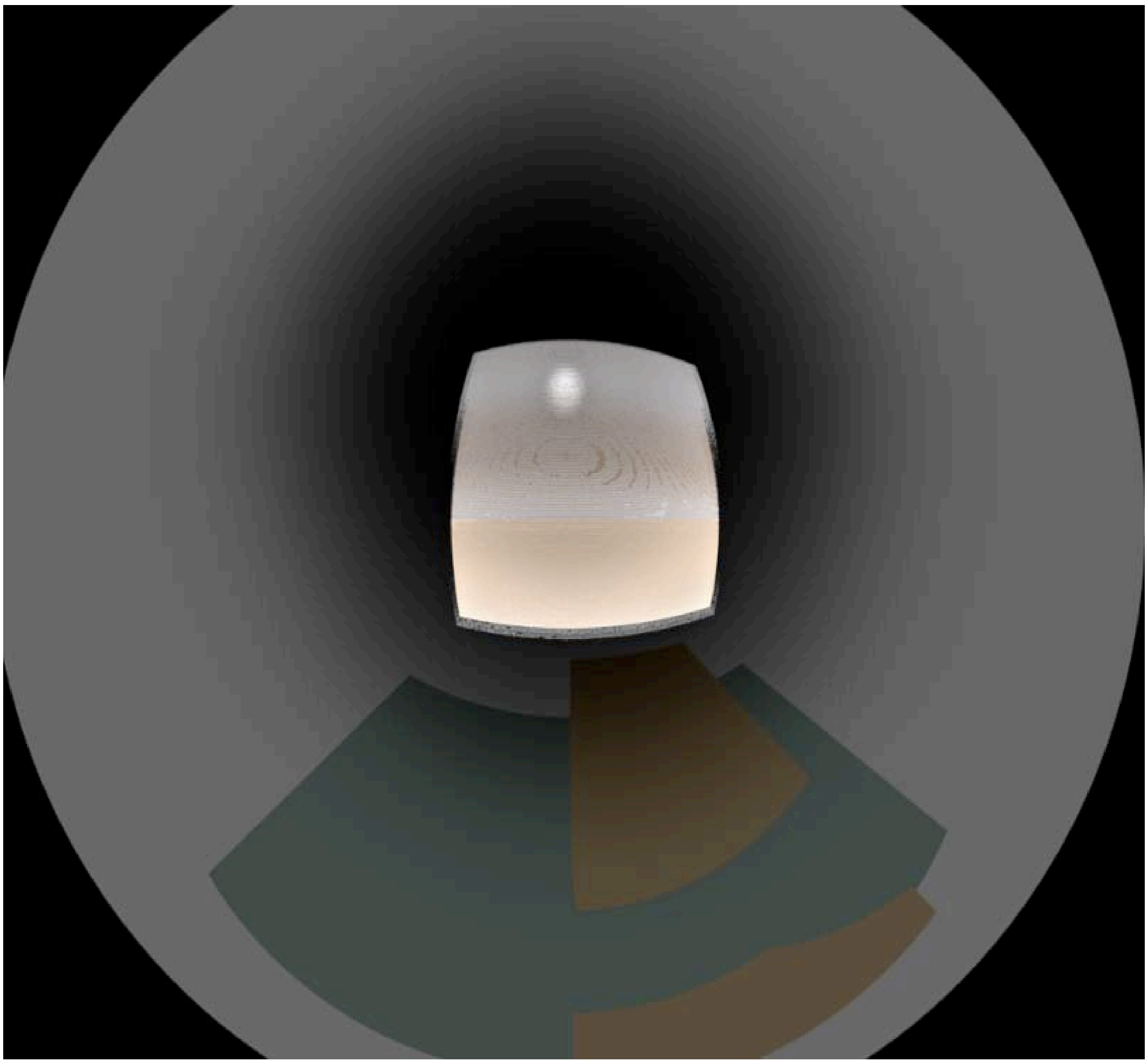

Figure 3-8. Fish-eye view of a Radiance-rendered image of the office room.

Figure 3-9 shows a closer view of the office room. The Venetian blinds covering the window can be observed in the image.

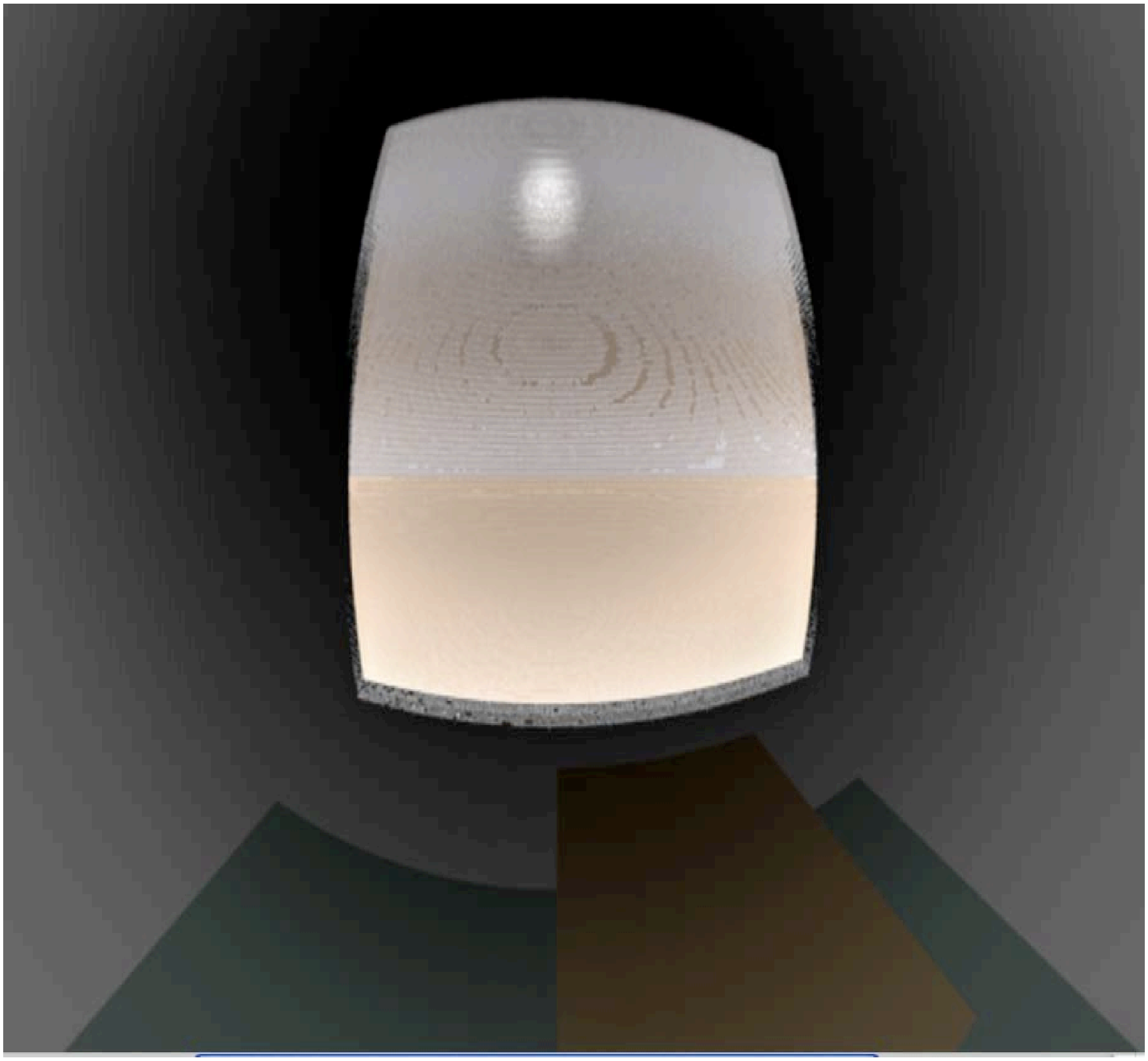

Figure 3-9. Close-up view of the office room.

Quality settings

To obtain meaningful quantitative results and maintain the photometric accuracy, the Radiance quality setting needs to be configured correctly. The following three main ambient parameters were considered for this research to calculate the illuminance values at the four sensor points.

1) Ambient bounces (-ab)
2) Ambient value (-av)
3) Ambient divisions (-ad)

Ambient bounces (-ab):

This parameter sets the number of inter-reflections between the surfaces that the program should calculate before reverting to the ambient value. For example, if the ambient bounce (–ab) was set to 4, then the sampling of the ray occurs on four different surfaces after leaving the source. Thus, as the -ab value increases, the ambient bounce increases and the accuracy of the quantitative results increases. Concurrently, the time taken to run the simulations also increases. Due to the large quantity of the data desired a low value of ambient bounce (-ab) was assumed for this research.

Ambient value (-av):

The ambient value is the average radiance in all directions of the visible scene, and it is to be defined by the user as an RGB value. Setting an ambient value may be useful for visualization, where adding a constant radiance to a scene may save on computational effort by maybe achieving a similar appearance using less ambient bounces. Where "absolute" quantitative accuracy is required, the ambient value should be set at zero, and all simulated lighting should be a result of the indirect calculation.

Ambient Divisions (-ad)

Monte Carlo sampling takes place in cosine-weighted hemispheres at selected points within the model, with interpolation occurring between these points. The number of ambient divisions sets the number of samples sent out from each sample hemisphere. The error in the Monte Carlo calculation of indirect illuminance is inversely proportional to the square root of this number. In other words, the higher the value for -ad, more accurate the results are. The –ad value of 4096 was used in this research. Conventionally, -ad value is expressed as a factor of 2 (2n).

In conclusion, an appropriate setting of the ambient parameters was one of the challenging aspects of using Radiance. The need for realistic and meaningful results necessitates higher settings of ambient parameters. Higher ambient parameters demand for high computer a processing capability, which means higher investments in computer infrastructure. It was important to maintain a balance between the research costs and time required for running the simulations. Time constraints, as well as low computer processing capabilities, meant a compromise with the ambient settings of the software (Larson and Shakespeare 1998).

CHAPTER 4
RESULTS AND ANALYSIS

Introduction

Simulations were performed by EnergyPlus (EP) and Radiance to assess the thermal and daylighting performance of the proposed split-controlled blind system. The simulations were carried out for seven different static slat angles (0˚, 15˚, 30˚, 45˚, 60˚, 75˚, and 90˚) in the case of conventional blinds. In the case of split-controlled blinds 29 sets of split angles were tested. The parameters average hourly lighting load (W), average hourly HVAC load (W), and average total energy consumption (W) were obtained from EnergyPlus for three days of the year: March 21, June 21, and December 21. A comparative study was conducted for the results obtained from EnergyPlus and Radiance to assess the performance of the two blind systems. Illuminance values were obtained at the four sensor points by from the Radiance simulations conducted for the entire year. The four sensor points were placed one meter from each other with the first sensor point placed one meter from the window.

EnergyPlus Results Analysis

Energy consumption results were obtained from the software EnergyPlus. Simulations were performed for the three days of the year, March 21, June 21 and December 21 for each occupied hour from 8 a.m. to 5 p.m. The results obtained are tabulated in Table 4-1. The hourly lighting energy consumption, HVAC consumption, and as the total energy consumption were used as criteria for selection of the best blind angle for that hour (refer to “choosing angle” for best angle).

Table 4-1 gives the energy consumption for lighting, HVAC, and the total electric demand for the three days March 21, June 21, and December 21 for each occupied hour from 8 a.m. to 5 p.m. The results are shown for the best possible angle for each hour. For example, if 30˚ is the best angle for conventional blinds at 9 a.m. on March 21 and 10˚-0˚-45˚ is the best angle for split blinds for the same hour and day, then the Lighting consumption, HVAC and Total electric demand for that hour for that day were chosen.

Table 4-2 shows the comparative study of split-controlled blinds and conventional blinds. The three columns give the difference in percentage for the lighting energy consumption, HVAC and total electric consumption between the split-controlled blinds and conventional blinds. A positive difference would mean split-controlled blinds work better than conventional blinds, and a negative difference would infer otherwise.

Figures 4-1 through 4-3 show the percentage of energy savings as a result of using split-controlled blinds. The x axis represents the office hours from 9 a.m. to 5 p.m. The y axis represents the percentage values. A positive difference indicates energy savings as a result of using split-controlled blinds. A negative difference indicates energy savings as a result of using conventional blind system blind system.

On March 21 (Figure 4-1), 11 a.m. lighting energy consumption for the split-controlled blinds angle was 50% more than for conventional blinds, and the HVAC consumption was 2.83% more than that of conventional blinds. The total energy consumption for that hour was 14.81% more in the case of split-controlled blinds as compared to conventional blinds. At 1 p.m., the split-controlled blind system was 50% more efficient in terms of lighting energy consumption and 1.44% more efficient in terms of HVAC consumption. Overall, at 1 p.m., the split-controlled blinds were 13.22% more efficient than conventional blinds. Considering the results for the entire day, a marginal difference of 1% occurred between the two systems with split-controlled blinds being more efficient.

For June 21 at noon (Figure 4-2), the split-controlled blinds had 33.33% lower electric lighting energy consumption and 20.81% lower HVAC consumption, thus total energy consumption for split controlled blinds was 24.41% lower as compared to conventional blinds. On average for the entire day, split-controlled blinds caused 3.10% less energy consumption, as compared to conventional blinds.

For December 21 (Figure 4-3), the average energy consumption in the case of the split-controlled blind system was 1.85% less than the conventional blinds. Thus, on average the split-controlled blind system worked slightly better than the conventional blind system in terms of lighting and HVAC electric energy consumption.

Daylighting Analysis

Evaluating the performance of blinds was one of the important tasks of this research. Dynamic daylighting performance parameter such as Useful Daylight Illuminance (UDI) was recommended by Mardaljevic et al. (2006). The UDI may be defined as the percentage of time per year when useful daylight (i.e., between 100 lux and 2000 lux) is available to the occupant. If illuminance value in the room is less than 100 lux, the room becomes too dark and when greater than 2000 lux, the excess daylight can cause glare and thus discomfort to the occupant (Mardaljevic et al. 2006). Once the illuminance values on a work plane are obtained, the next challenge was to quantify these results for comparative study. The Daylight Autonomy (DA) is the percentage of time per year when the minimum required illuminance at the sensor point is met by daylight alone (Mardaljevic et al. 2006).

Table 4-1. Energy consumption for lighting (W), HVAC (W) and Total Electric Demand (W) for March 21, June 21 and December 21

Conventional Blinds

21-Mar	Angle	Hour	Lighting Demand	HVAC Demand	Total Electric Demand
	30	9	162	263	425
	30	10	115	282	398
	30	11	102	301	403
	30	12	102	312	415
	30	13	102	320	422
	30	14	102	318	420
	30	15	102	309	411
	0	16	102	294	397
	0	17	141	279	420

21-Jun	Angle	Hour	Lighting Demand	HVAC Demand	Total Electric Demand
	15	9	188	390	578
	15	10	188	393	581
	15	11	162	394	557
	30	12	154	395	549
	15	13	154	397	551
	15	14	154	397	551
	15	15	162	397	559
	15	16	188	399	587
	15	17	188	400	588

21-Dec	Angle	Hour	Lighting Demand	HVAC Demand	Total Electric Demand
	60	9	162	1455	1618
	60	10	115	1342	1457
	60	11	102	1261	1363
	60	12	102	1212	1314
	60	13	102	1186	1288
	60	14	102	1194	1296
	60	15	102	1230	1333
	0	16	13	1286	1299
	0	17	85	1352	1437

Split blinds

Angle	Hour	Lighting Demand	HVAC Demand	Total Electric Demand
10-0-45	9	162	263	425
10-45-45	10	128	284	412
80-80-80	11	154	309	463
80-80-80	12	102	317	419
37-45-45	13	51	315	366
37-45-45	14	77	315	392
10-45-45	15	102	308	411
10-0-0	16	102	294	397
0-0-0	17	141	246	387

Angle	Hour	Lighting Demand	HVAC Demand	Total Electric Demand
10-0-0	9	188	390	578
10-0-0	10	188	393	581
10-0-0	11	154	394	547
10-45-0	12	102	313	415
10-0-0	13	154	397	551
10-0-0	14	154	397	551
10-0-0	15	154	396	550
10-0-0	16	188	399	587
10-0-0	17	188	399	587

Angle	Hour	Lighting Demand	HVAC Demand	Total Electric Demand
0-80-80	9	196	1452	1648
37-80-0	10	64	1361	1425
0-80-80	11	102	1244	1346
0-80-80	12	51	1209	1260
37-45-80	13	51	1228	1279
0-80-80	14	0	1195	1195
0-80-45	15	51	1232	1283
0-0-45	16	26	1286	1311
0-0-45	17	90	1353	1442

Table 4-2. EnergyPlus Comparison Results

Simulation day	Hours	Lighting energy consumption (Difference in percentage)	HVAC electric demand (Difference in percentage)	Total Electric Demand (Difference in percentage)
21-Mar	9	0.00	0.04	0.02
	10	-11.11	-0.47	-3.56
	11	-50.00	-2.83	-14.81
	12	0.00	-1.38	-1.04
	13	50.00	1.44	13.22
	14	25.00	0.94	6.80
	15	0.00	0.08	0.06
	16	0.00	0.08	0.06
	17	0.00	11.67	7.76
Average		1.54	1.06	0.95
21-Jun				
	9	0.00	0.05	0.03
	10	0.00	0.02	0.02
	11	5.26	0.20	1.68
	12	33.33	20.81	24.31
	13	0.00	0.00	0.00
	14	0.00	0.02	0.02
	15	5.26	0.22	1.68
	16	0.00	0.10	0.07
	17	0.00	0.11	0.07
Average		4.87	2.39	3.10
21-Dec	9	-21.05	0.27	-1.87
	10	44.44	-1.39	2.24
	11	0.00	1.34	1.24
	12	50.00	0.28	4.16
	13	50.00	-3.60	0.66
	14	100.00	-0.12	7.79
	15	50.00	-0.11	3.74
	16	-100.00	0.01	-0.97
	17	-5.00	-0.08	-0.37
Average		18.71	-0.38	1.85

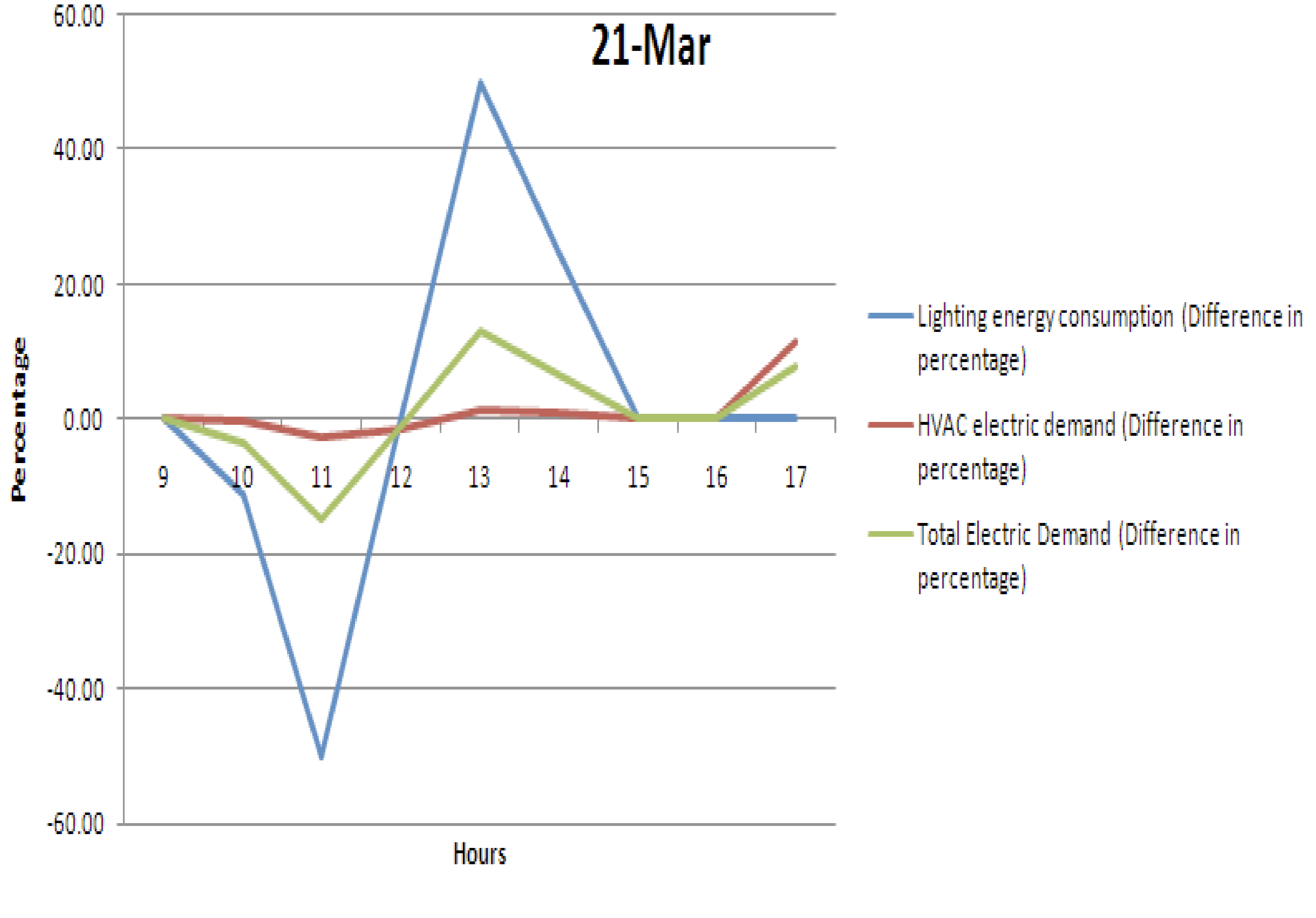

Figure 4-1. Energy consumption differences between split-controlled blinds and conventional blinds for March 21st

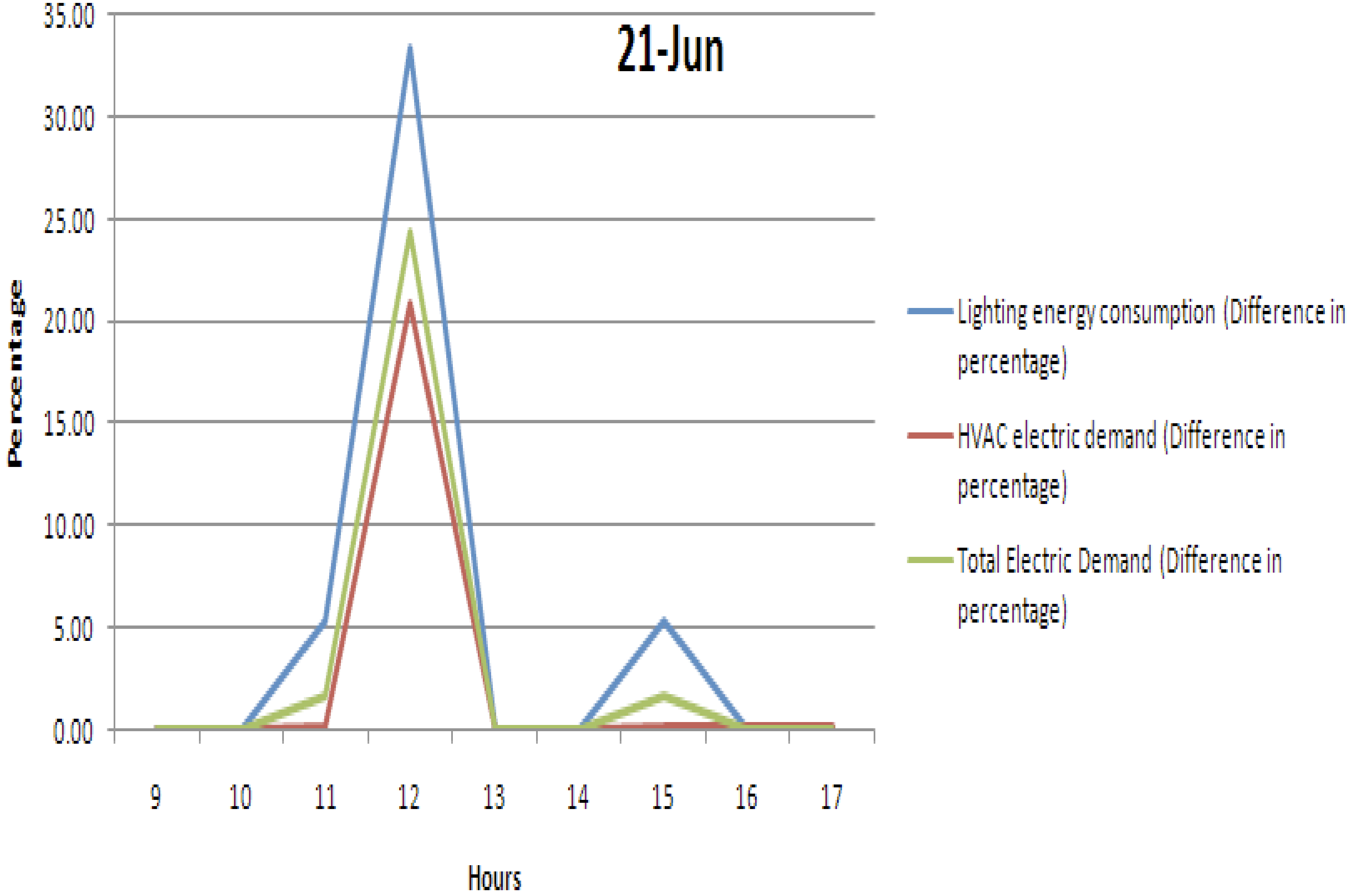

Figure 4-2. Energy consumption differences between split-controlled blinds and conventional blinds for June 21st.

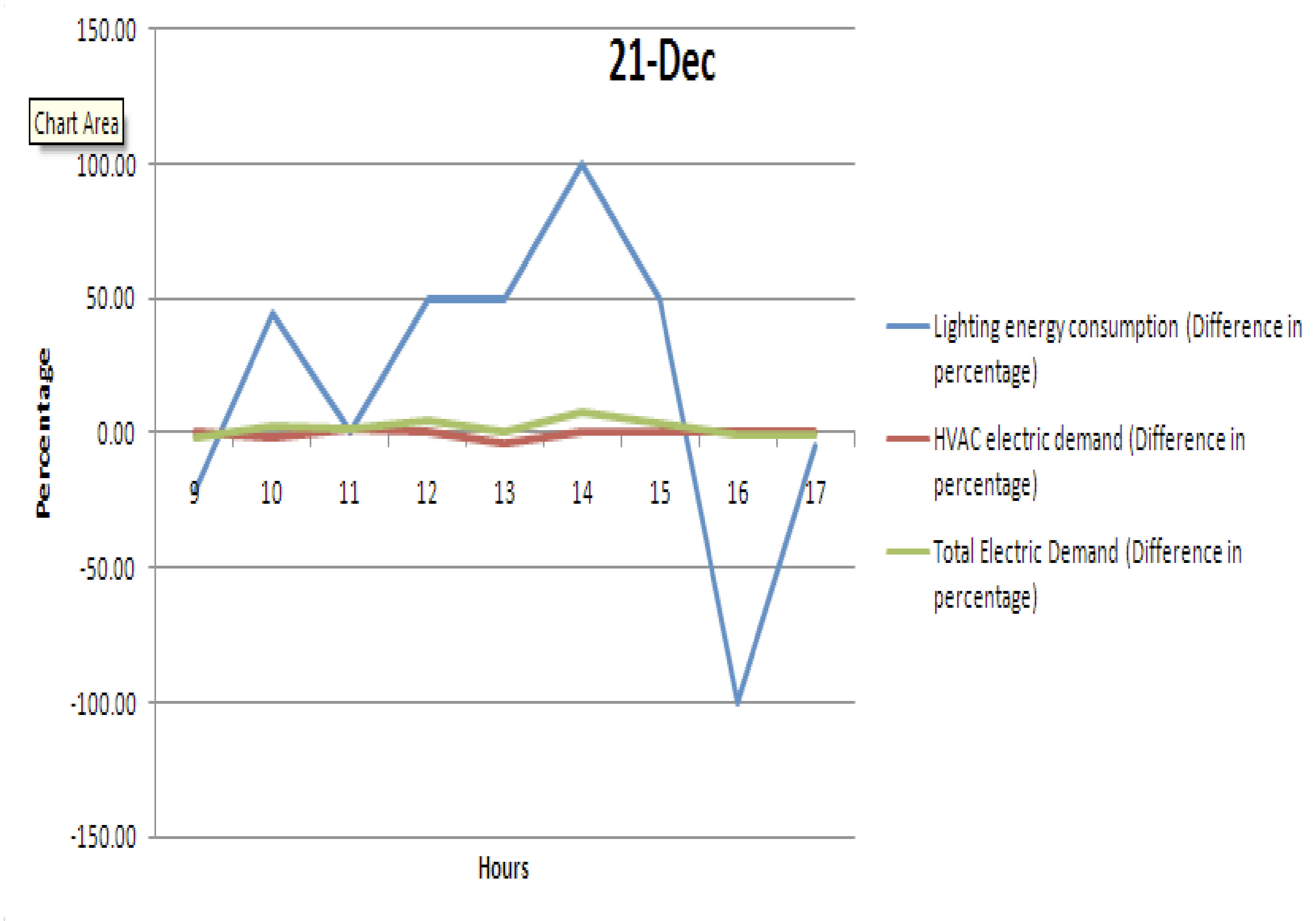

Figure 4-3. Energy consumption differences between split-controlled blinds and conventional blinds for December 21

Mardaljevic et al. (2006) suggested that the useful daylight illuminance can be divided into two ranges, UDI between 100 lux and 500 lux can be considered as supplementary daylight, which meant, depending on user preference, electric lighting could be used to supplement daylight required in the room. The second range was named as autonomous UDI for illuminance values between 500 lux and 2000 lux. This range of daylighting would not require any artificial electric lighting.

Choosing Blind Angle

One of the objectives of choosing the blinds' best possible slat angle was to make sure sufficient useful daylight was available at each sensor point. The angle of the blinds' setting, which gave maximum illuminance levels on all four sensor points was considered the best angle for the blinds' setting. Thus, the basic algorithm for selecting the best angle was as follows:

- Select all the angles at the first sensor point, which have illuminance levels in the autonomous UDI range (500-2000 lux).
- Then select the same angles for the fourth sensor point.
- Choose the angle that gives maximum illuminance value for the fourth sensor point.
- Then select the angle among the points chosen from the first sensor point which has given the highest illuminance value for the fourth sensor point.

This way the blind angle for each hour was chosen. Then the UDI was classified for each sensor point, depending on the value of illuminance at each sensor point. For example, if the first sensor point gave an illuminance value between 500 lux and 2000 lux; it was classified into the 500 lux to 2000 lux UDI range. Similarly, if a sensor point gave an illuminance value between 100 lux and 500 lux, then it was classified as the UDI in the 100 lux to 500 lux range. For an illuminance value between 100 lux and 500 lux, the value 100% was assigned to the corresponding UDI range, and a value of zero was assigned to the remaining UDI ranges. For each hour, the UDI was defined and the average for each day was calculated. Similarly, the average for each month was calculated and tabulated into the following results.

Tables 4-3 through 4-7 show the UDI results for each month of the year, and are tabulated for each of the four sensor points. The UDI is divided into four sections: UDI<100 lx, UDI-100-500lx, UDI-500-2000lx, and UDI>2000 lx. The values in Tables 4-3 through 4-7 show the average UDI values for each month.

Radiance Results Analysis

Figures 4-4 through 4-7 show UDI distribution for the four sensor points in the form of stacked column charts. The x axis represents the months and the y axis represents the percentages (i.e. values of UDI). Different UDI ranges are represented by different colors.

At the first sensor point (Figure 4-4), for the month of February, the UDI (500-2000 lux) decreases to 92% and for the month of March, it decreases to 84% in the case of split-controlled blinds. In the case of conventional blinds, the UDI remains almost constant throughout the year except for the month of October, when the UDI (500-2000 lux) decreases to 93% Thus, in this case for the first sensor point, the conventional blinds have an upper edge over the blinds in terms of daylighting performance.

At the second sensor point (Figure 4-5), for the month of March, the UDI (500-2000 lux) decreases to 77% and for the month of October, it decreases to 80% while maintaining a constant value between 90% to 96% for the rest of the year in the case of split-controlled blinds. In the case of conventional blinds, the UDI remains almost

Table 4-3. UDI values for Sensor Point 1

SPLIT-CONTROLLED BLINDS

	SENSOR POINT 1			
	UDI <100lx	UDI =100lx-5(	UDI =500-20(	UDI >2000lx
jan	0.00	0.32	99.68	0.00
feb	0.00	7.24	92.76	0.00
mar	0.00	15.31	84.69	0.00
apr	0.00	0.00	100.00	0.00
may	0.00	0.00	100.00	0.00
jun	0.00	0.00	100.00	0.00
jul	0.00	0.00	100.00	0.00
aug	0.00	0.00	100.00	0.00
sep	0.00	3.33	96.67	0.00
oct	0.00	9.35	90.65	0.00
nov	0.00	0.33	99.67	0.00
dec	0.00	0.32	99.68	0.00
Average	0.00	3.02	96.98	0.00

CONVENTIONAL BLINDS

	SENSOR POINT 1			
	UDI <100lx	UDI =100lx-5(	UDI =500-20(	UDI >2000lx
jan	0.00	0.00	98.39	1.61
feb	0.00	0.00	100.00	0.00
mar	0.00	0.00	100.00	0.00
apr	0.00	0.00	100.00	0.00
may	0.00	0.00	100.00	0.00
jun	0.00	0.00	100.00	0.00
jul	0.00	0.00	100.00	0.00
aug	0.00	0.00	100.00	0.00
sep	0.00	0.00	100.00	0.00
oct	0.00	6.77	93.23	0.00
nov	0.00	0.00	100.00	0.00
dec	0.00	0.00	98.39	1.61
Average	0.00	0.56	99.17	0.27

Table 4-4. UDI values for Sensor Point 2

SPLIT-CONTROLLED BLINDS

		SENSOR POINT 2		
	UDI <100lx	UDI =100lx-5(	UDI =500-20(	UDI >2000lx
jan	0	3.55	96.45	0
feb	0	10.00	90.00	0
mar	0	22.81	77.19	0
apr	0	10.00	90.00	0
may	0	10.00	90.00	0
jun	0	10.00	90.00	0
jul	0	10.00	90.00	0
aug	0	10.00	90.00	0
sep	0	13.33	86.67	0
oct	0	19.35	80.65	0
nov	0	9.00	91.00	0
dec	0	6.45	93.55	0
Average	0.00	11.21	88.79	0.00

CONVENTIONAL BLINDS

		SENSOR POINT 2		
	UDI <100lx	UDI =100lx-5(	UDI =500-20(	UDI >2000lx
jan	0.00	15.16	84.84	0.00
feb	0.00	3.10	96.90	0.00
mar	0.00	8.13	91.88	0.00
apr	0.00	10.00	90.00	0.00
may	0.00	10.00	90.00	0.00
jun	0.00	10.00	90.00	0.00
jul	0.00	8.71	91.29	0.00
aug	0.00	10.00	90.00	0.00
sep	0.00	10.00	90.00	0.00
oct	0.00	10.00	90.00	0.00
nov	0.00	10.33	89.67	0.00
dec	0.00	23.23	76.77	0.00
Average	0.00	10.72	89.28	0.00

Table 4-5. UDI values for Sensor Point 3

SPLIT-CONTROLLED BLINDS

	SENSOR POINT 3			
	UDI <100lx	UDI =100lx-50(	UDI =500-200(	UDI >2000lx
jan	0.32	14.52	85.16	0.00
feb	7.24	17.24	75.52	0.00
mar	15.31	22.19	59.69	2.81
apr	0.00	30.00	70.00	0.00
may	0.00	48.06	51.94	0.00
jun	0.00	49.00	51.00	0.00
jul	0.00	40.00	60.00	0.00
aug	0.00	36.45	63.55	0.00
sep	3.33	29.00	64.67	3.00
oct	9.35	20.00	70.65	0.00
nov	0.33	14.33	85.33	0.00
dec	0.32	17.74	81.94	0.00
Average	3.02	28.21	68.29	0.48

CONVENTIONAL BLINDS

	SENSOR POINT 3			
	UDI <100lx	UDI =100lx-50(	UDI =500-200(	UDI >2000lx
jan	0.00	50.00	50.00	0.00
feb	0.00	20.34	79.66	0.00
mar	0.00	25.63	74.38	0.00
apr	0.00	31.00	69.00	0.00
may	0.00	43.23	56.77	0.00
jun	0.00	40.33	59.67	0.00
jul	0.00	40.00	60.00	0.00
aug	0.00	38.06	61.94	0.00
sep	0.00	29.67	70.33	0.00
oct	0.00	20.00	80.00	0.00
nov	0.00	29.33	70.67	0.00
dec	0.00	71.94	28.06	0.00
Average	0.00	36.63	63.37	0.00

Table 4-6. UDI values for Sensor Point 4

SPLIT-CONTROLLED BLINDS

		SENSOR POINT 4		
	UDI <100lx	UDI =100lx-50(	UDI =500-2000	UDI >2000lx
jan	0.32	94.52	5.16	0.00
feb	7.24	92.76	0.00	0.00
mar	15.31	71.25	10.94	2.50
apr	0.00	77.67	22.33	0.00
may	0.00	86.13	13.87	0.00
jun	0.00	90.00	10.00	0.00
jul	0.00	87.42	12.58	0.00
aug	0.00	84.19	15.81	0.00
sep	3.33	79.00	14.67	3.00
oct	9.35	81.94	8.71	0.00
nov	0.33	97.67	2.00	0.00
dec	0.32	86.13	13.55	0.00
Average	3.02	85.72	10.80	0.46

CONVENTIONAL BLINDS

		SENSOR POINT 4		
	UDI <100lx	UDI =100lx-50(	UDI =500-2000	UDI >2000lx
jan	0.32	74.52	25.16	0.00
feb	0.00	67.59	32.41	0.00
mar	0.00	63.75	36.25	0.00
apr	0.00	73.00	27.00	0.00
may	0.00	89.68	10.32	0.00
jun	0.00	90.00	10.00	0.00
jul	0.00	90.00	10.00	0.00
aug	0.00	82.26	17.74	0.00
sep	0.00	62.00	38.00	0.00
oct	0.32	70.65	29.03	0.00
nov	0.00	62.33	37.67	0.00
dec	0.00	94.84	5.16	0.00
Average	0.05	76.72	23.23	0.00

constant throughout the year except for the month of December, where it falls to 76%. Thus, in this case for the second sensor point, both blind systems perform equally well.

For the third sensor point (Figure 4-6), the UDI (500-2000 lux) for split-controlled blinds for the month of January was 85%, as compared to 50% for conventional blinds. For the month of November, the UDI for split-controlled blinds was 85%, as compared to 70% for conventional blinds. Similarly for the month of December, the UDI for split-controlled blinds was 81%, as compared to 28% in the case of conventional blind system. Overall, for 68% time of the year, useful daylight was available at the third sensor point in the case of split-controlled blinds, as compared to 63% of time for conventional blinds.

Figure 4-7 shows, at the fourth sensor point, that split-controlled blind have a lower annual average UDI (500-2000 lux) with the value of 10%, as compared to 23% for conventional blinds. Supplementary UDI (100-500 lux) was 88% for split blinds, as compared to 76% for conventional blinds, which means that the need for supplementary electric lighting would be required at the fourth sensor point for most of the year.

By analyzing the UDI for both split and conventional blind systems, it can be concluded that both blind systems seem to perform equally well. It was proposed that split-controlled blinds would perform better than conventional blinds due to the different functions that the split sections would tend to perform. It cannot be determined why the proposed hypothesis was not true. It can be concluded that for the given set of split angles discussed in this research, both split-controlled blinds and conventional blinds would perform equally well. Simulations performed with more varied set of angles can

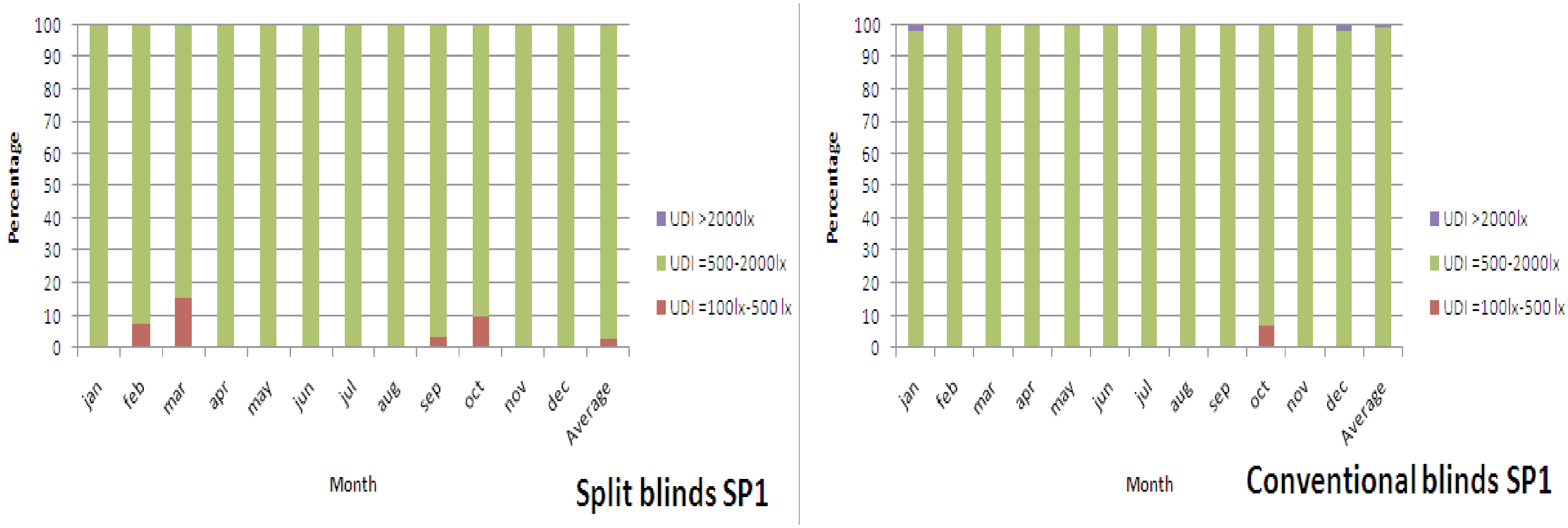

Figure 4-4. UDI comparison for Sensor Point 1(SP1).

Figure 4-5. UDI comparison for Sensor Point 2 (SP2).

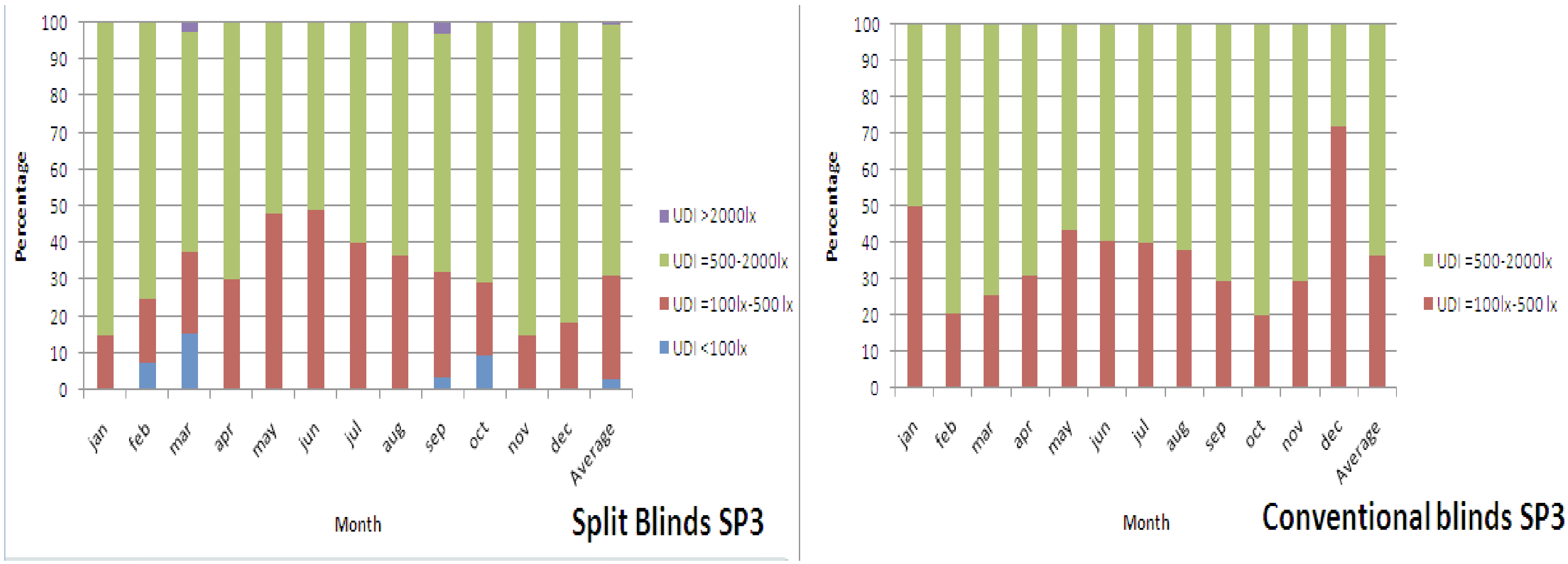

Figure 4-6. UDI comparison for Sensor Point 3 (SP3).

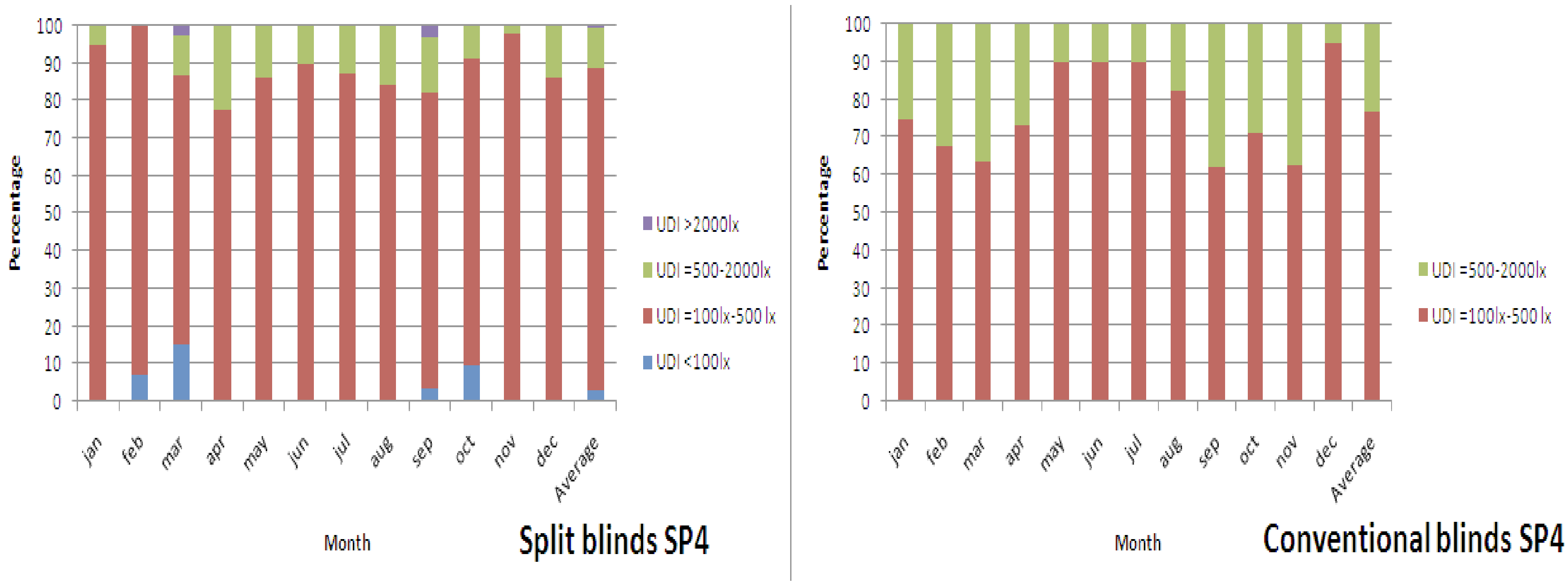

Figure 4-7. UDI comparison for Sensor Point 4 (SP4).

perhaps shed more light on the performance of these split-controlled blinds, as compared to conventional blinds.

Figures 4-8 and 4-9 show the frequency distribution in percentage of total illuminance values for the entire year at the first sensor point for split-controlled blinds and conventional blinds. X axis represents the illuminance values in range intervals of 100 lux and the y axis represents percentages of total illuminance values.

For histograms shown in Figures 4-8 and 4-9, the illuminance values at the first sensor point are plotted for the entire year. In the case of conventional blinds a wide distribution of values falls in the range between 500 lux and 2000 lux. The illuminance values obtained for split-controlled blinds vary in a range of 600 lux to 2000 lux with almost 70% values falling in the range between 1400 lux and 2000 lux, thus showing less variation in illuminance values for split-controlled blinds.

Figure 4-10 shows the illuminance values at the first sensor point on January 1st at 8 a.m. The x axis represents the 29 split blind angles simulated, and the y axis represents the illuminance values obtained at the first sensor point for each of the split blind angles.

For split blind angles -37˚-80˚-80˚, -37˚-80˚-45˚, where the top blinds are tilted downwards towards the interior at -37˚,illuminance values of 574 lux and 858 lux were obtained at the first sensor point respectively. This demonstrates the ability of the top blinds to deflect daylight into the room, even when the middle and bottom blinds are almost closed. For the angles 0˚-80˚-0˚, 0˚-80˚-45˚, 0˚-80˚-80˚, illuminance values of 851 lux, 849 lux, and 599 lux were obtained at the first sensor point respectively.

With the middle blinds almost closed at 80˚, there is still sufficient daylight inside the room, which demonstrated the ability of the split blinds to prevent glare causing direct sunlight entering into the room at the eye level and concurrently have good daylighting inside the room.

Figure 4-11 shows the average illuminance values at all four sensor points in the office room. The x axis represents the four sensor points, and y axis represents the illuminance values in lux.

Average illuminance value for split-controlled blinds at the first sensor point is 1542 lux as compared to 1251 lux for conventional blinds. Average illuminance value for spilt-controlled blinds at the first sensor point is 19% higher than the average illuminance value for conventional blinds. Similarly, at the second sensor point, the illuminance value for split-controlled blinds is 924 lux, as compared to 857 lux, for conventional blinds. Considering the comfort zone between 500 lux and 2000 lux, higher illuminance values were obtained at all four sensor points as a result of using split-controlled blinds.

Figures 4-12 through 4-15 show yearly illuminance (lux) distribution at the four sensor points respectively. The x axis represents months and y axis represents the illuminance values in lux. Figures 4-12 and 4-13 show that, from May 1st to September 1st, split-controlled blinds consistently gave higher illuminance values at the first sensor point as compared to illuminance values at the first sensor point for conventional blinds. Figures 4-14 and 4-15 show higher illuminance values for conventional blinds as compared to split-controlled blinds at the third and the fourth sensor point between April and September.

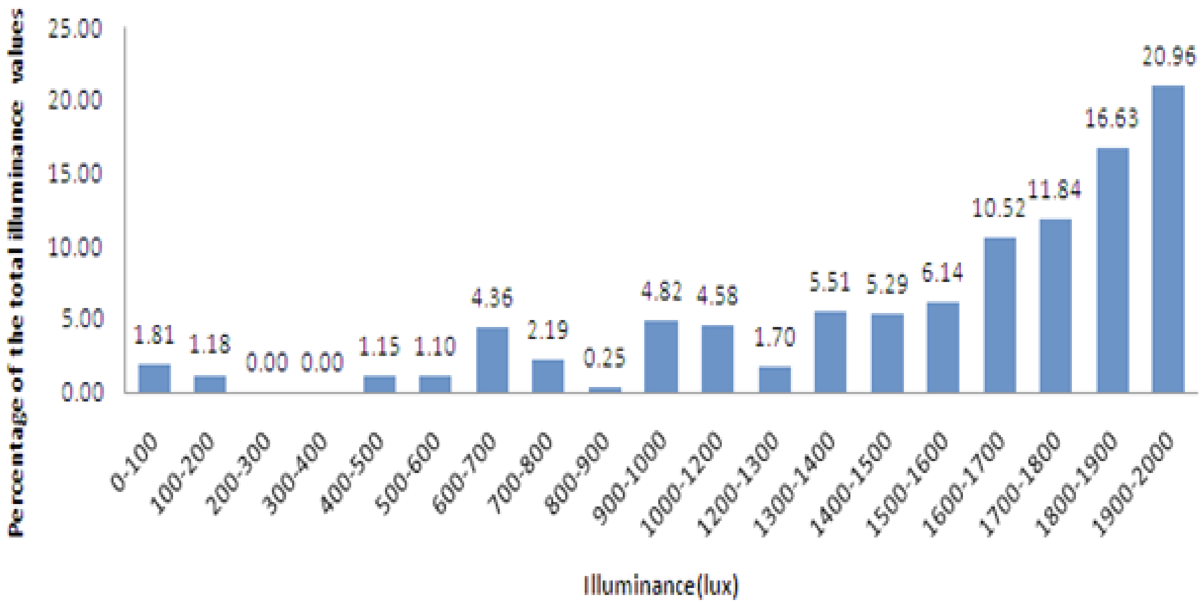

Figure 4-8. Frequency distribution of illuminance values from split-controlled blinds for sensor point 1.

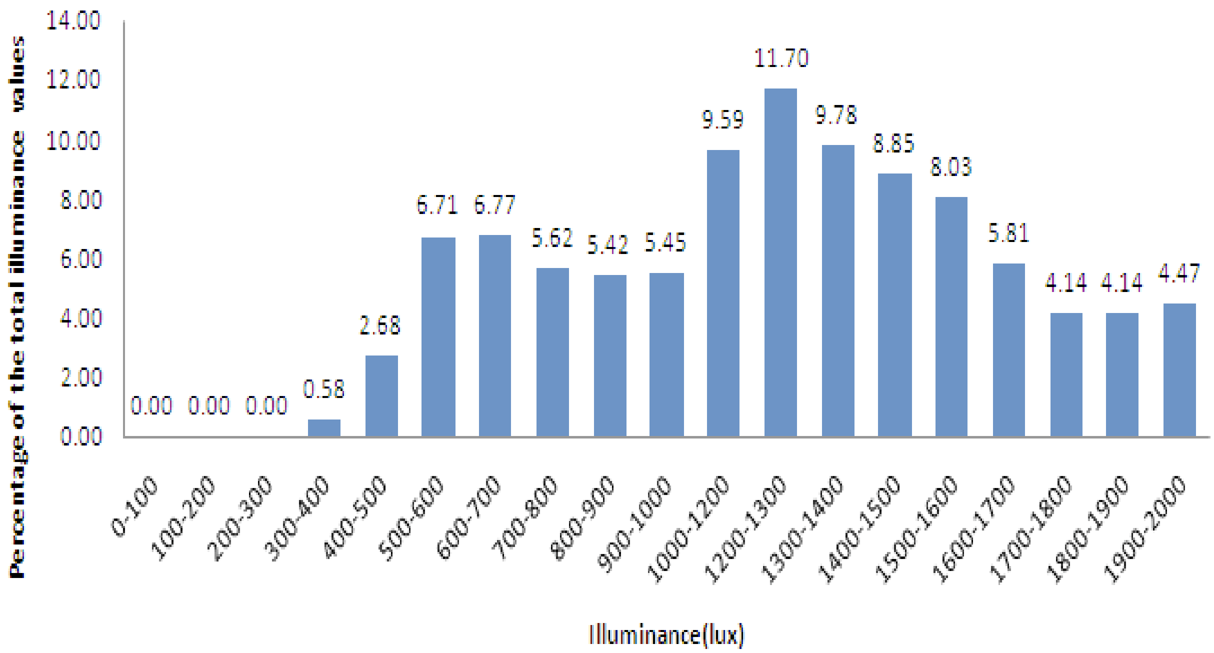

Figure 4-9. Frequency distribution of illuminance values from conventional blinds for the first sensor point.

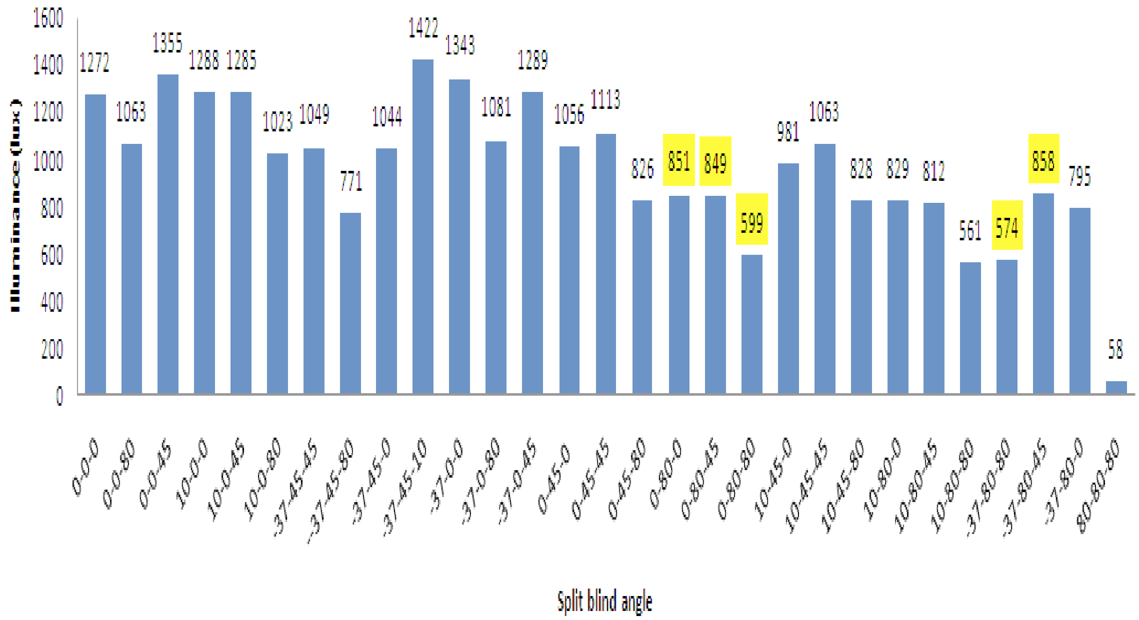

Figure 4-10. Illuminance values for all the split blind angles, at the first sensor point for January 1 at 8 a.m.

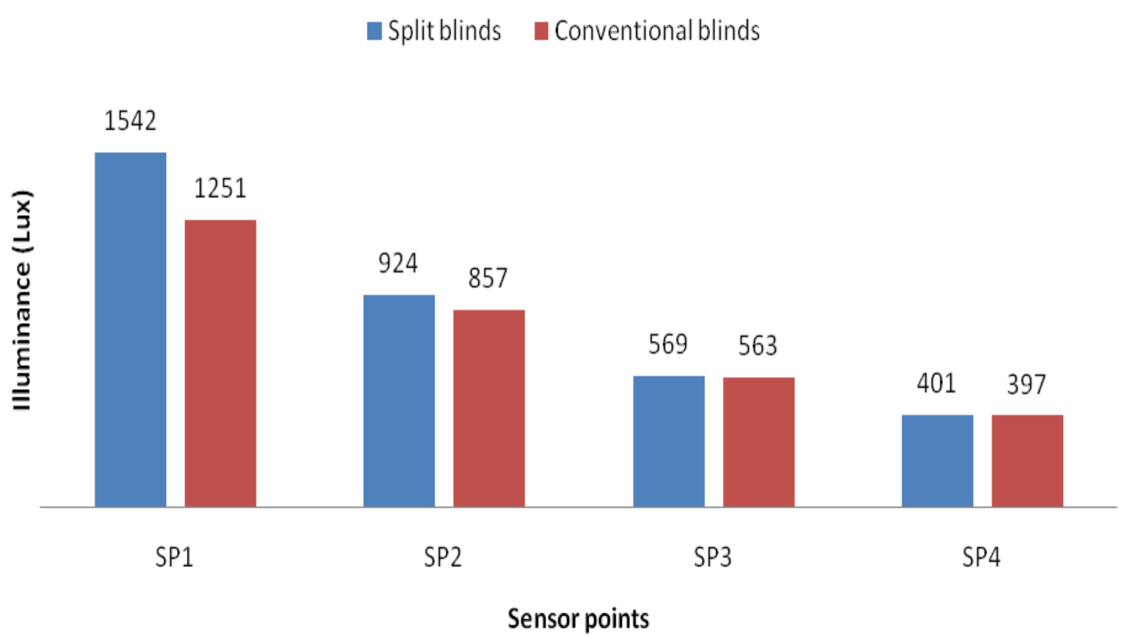

Figure 4-11. Average illuminance distribution at the four sensor points.

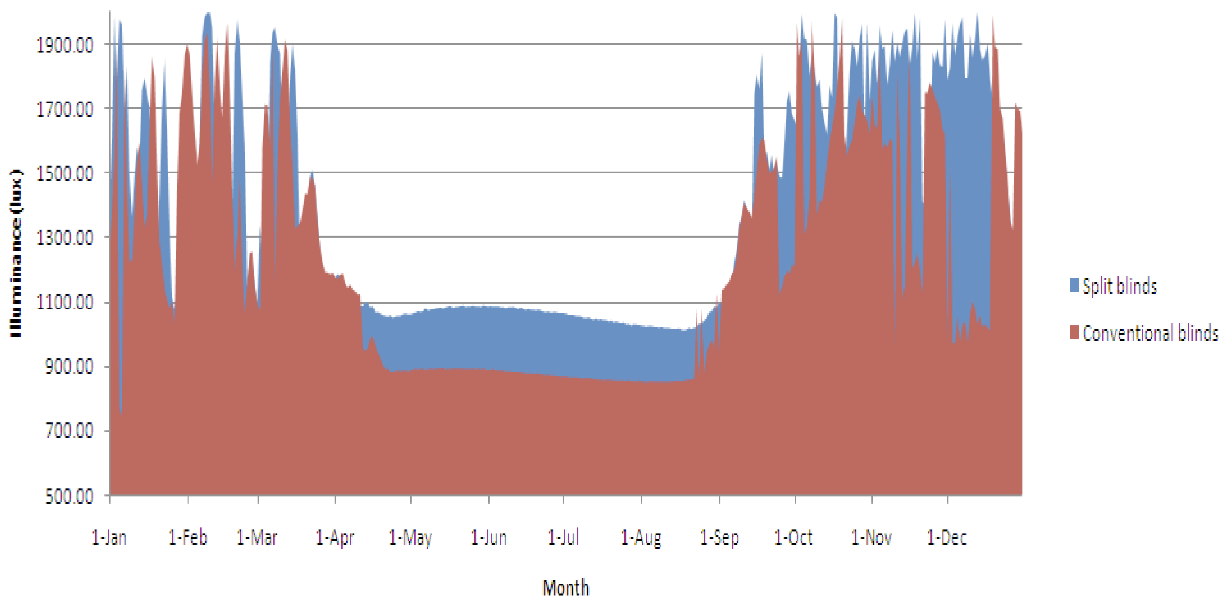

Figure 4-12. Yearly illuminance values at the first sensor point.

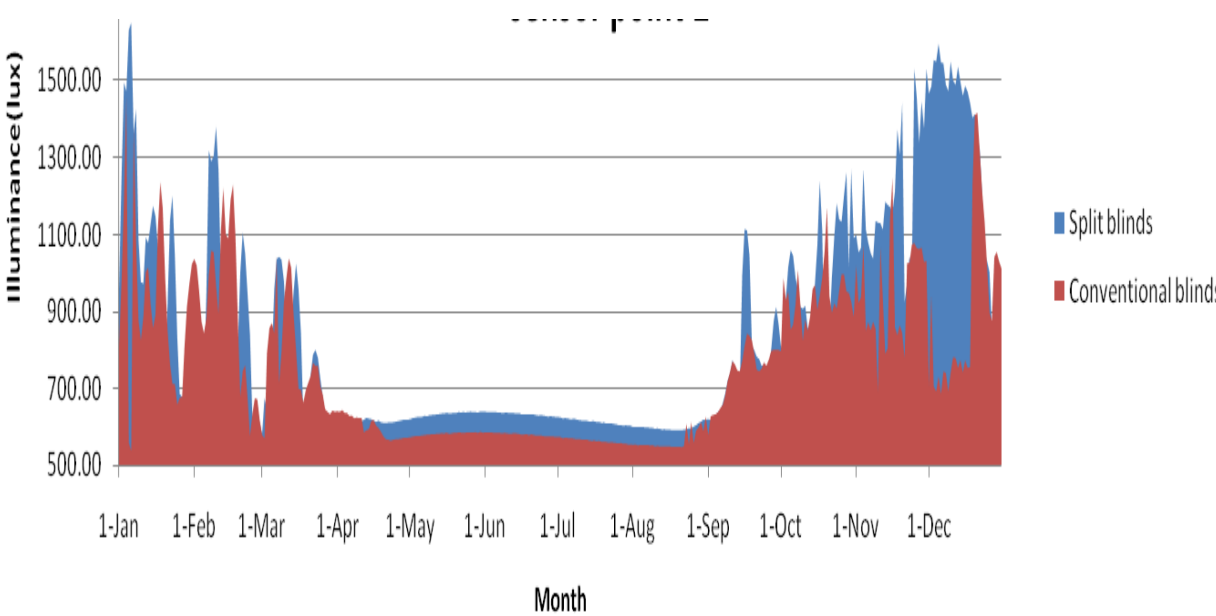

Figure 4-13. Yearly illuminance values at the second sensor point

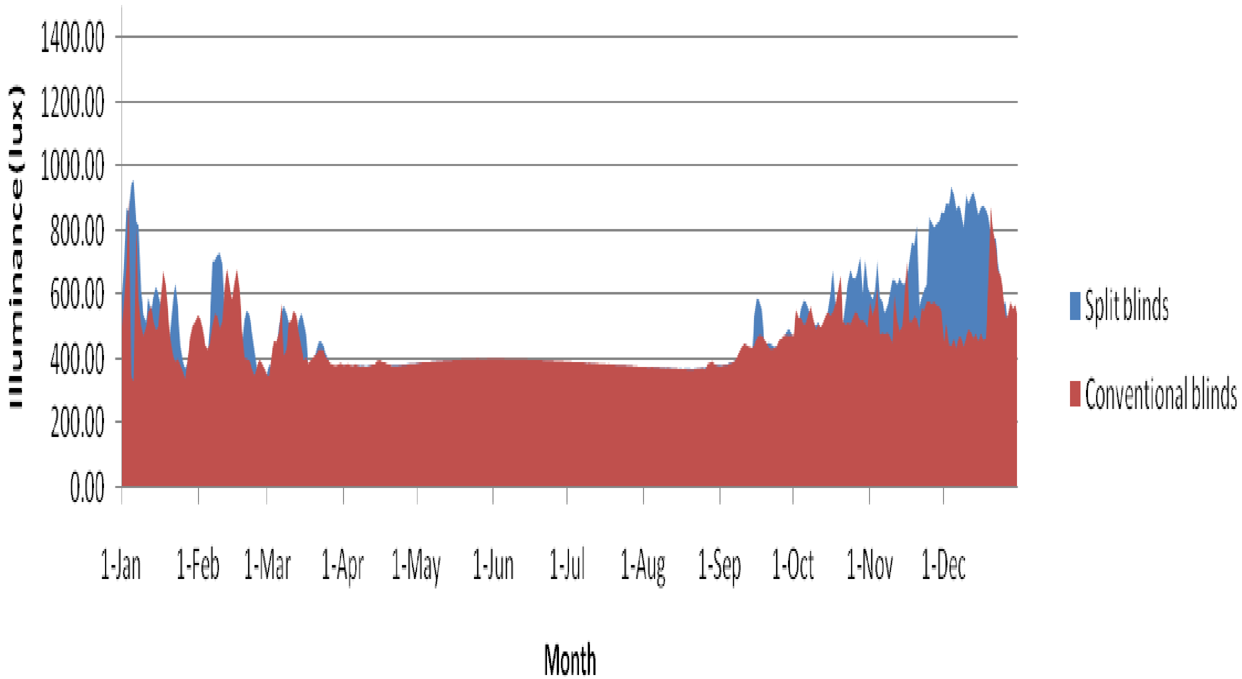

Figure 4-14. Yearly illuminance values at the first sensor point.

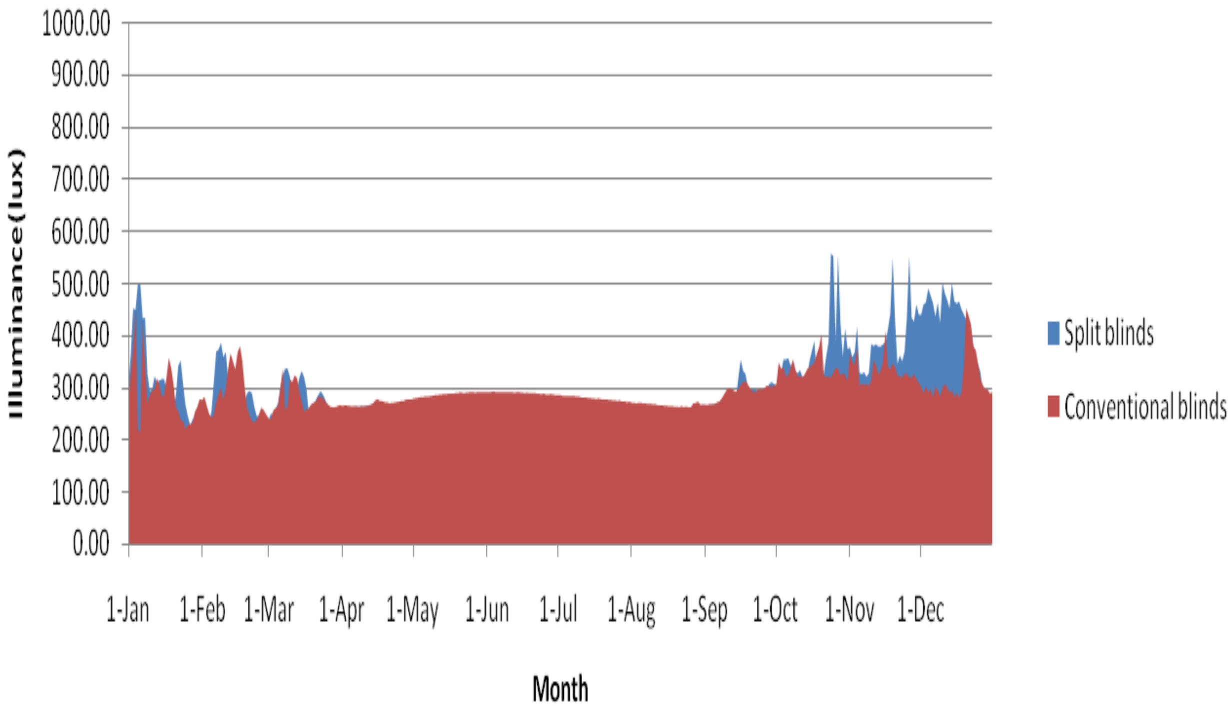

Figure 4-15. Yearly illuminance values at the first sensor point.

Automation Model

One of the aims of this research was to formulate a possible algorithm for the working of the split-controlled blind system in real time. Figure 4-16 shows a possible algorithm for real-time control of an automated split-controlled blind system. The automation model describes the functioning of each section of the split-control blind system with response to variation in illuminance levels inside the office room, as well as temperature variation.

In the first possible condition, if the illuminance level inside the room was greater than the maximum allowed illuminance of 2000 lux, the bottom blinds would be completely closed to prevent any excess heat coming into the building. Simultaneously, the middle section of the blinds would be closed by an angle β, and the top blind would be closed by an angle γ. This would naturally decrease the illuminance levels inside the room. The next step is to perform the illuminance check. In the second condition, if the illuminance level was less than 2000 lux, then the next illuminance check would be performed. Here the illuminance must be checked if it lies in the range between 500 lux and 2000 lux. If yes, no change in the blinds' angle is suggested. If no, proceed to the temperature check.

In the temperature check, if the temperature value is between the comfort ranges defined by the user, the bottom blinds are opened to allow light to come into the building until the illuminance value reaches the desired level. If the temperature is above the maximum allowed, the bottom blinds are closed, the middle section is closed by an angel β, and the top section is closed by an angle γ. If the temperature is below the minimum allowed, the top blinds are opened by γ, the middle blinds are opened by β, and the bottom blinds are opened by α.

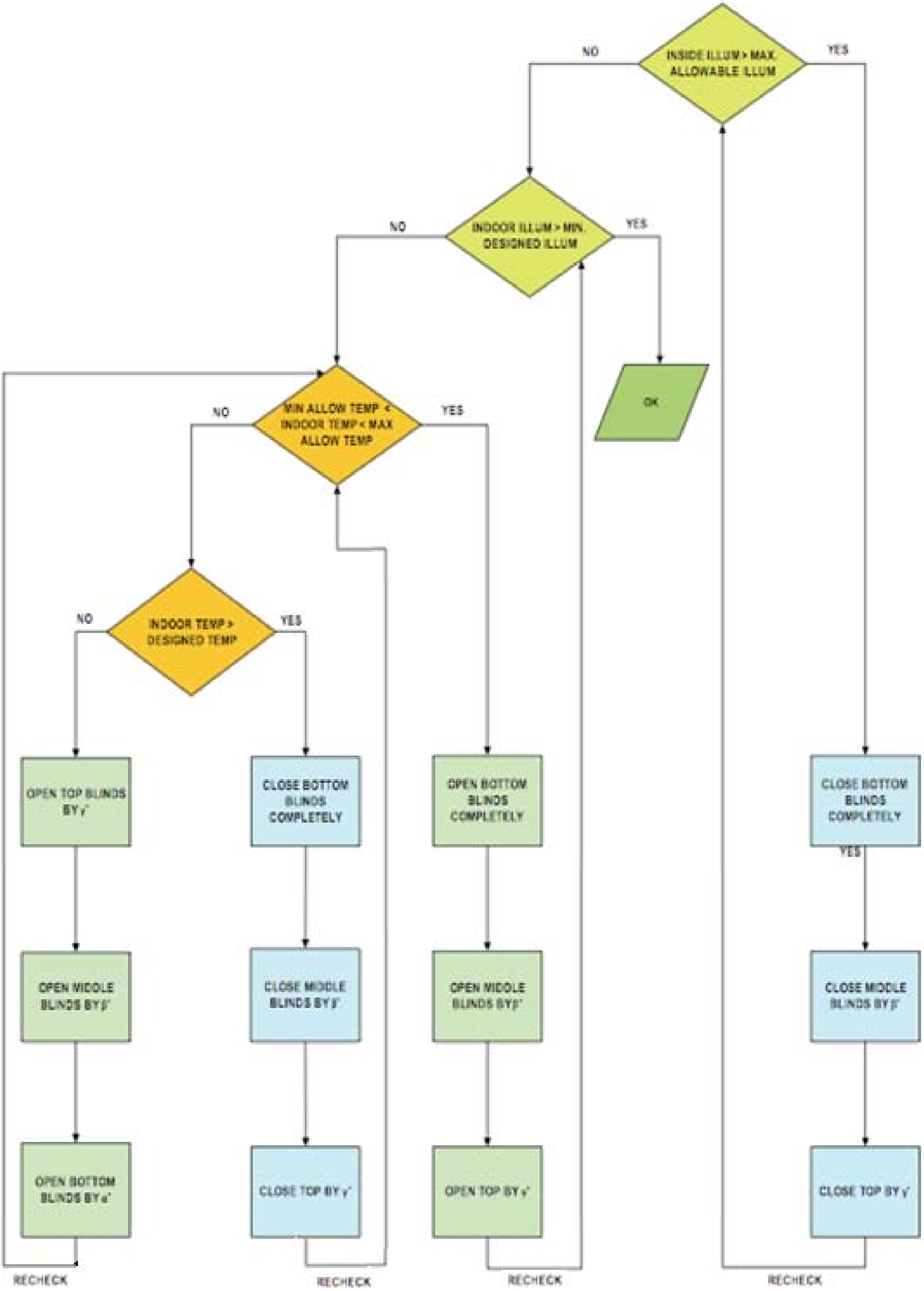

Figure 4-16. Automation algorithm for split-controlled blinds.

CHAPTER 6
CONCLUSIONS AND RECOMMENDATIONS

Conclusions

The main purpose of this research was to determine the ability of split-controlled blinds to provide better daylighting, as compared to the conventional Venetian blind system, and, as a result, to provide comfort to the occupants.

Energy Plus results showed lighting energy savings for the three days: March 21, June 21 and December 21. For certain periods of the day, lighting energy savings up to 50% were achieved by application of split controlled blind system. This results from the ability of split controlled blinds to provide better daylighting than the conventional blinds for the three days simulated.

Daylighting analysis showed that on average the split-controlled blind system provided higher illuminance at the sensor points compared to conventional blind system. Comparison of the UDI values for the two blind systems shows no significant difference among for the values for the four sensor points. It was observed that the average of all the illuminance values for the entire year at the four sensor points for the split controlled blinds were higher than those for the conventional blind system. From March to September, consistently higher illuminance values were obtained at the first and second sensor point in the case of split-controlled blind system. In the case of the split-controlled blinds, with the middle section of the blinds closed, sufficient daylight was obtained inside the room as a result of the ability of top section of the blinds to deflect light into the room. Thus, split-controlled blind system can provide sufficient level of daylight inside the room. For split-controlled blind system, 70% of the illuminance values obtained for the entire year at the first sensor point were within the range of

1400-2000 lux. Conventional blinds showed a wide distribution of illuminance values at the first sensor point with values ranging from 500 lux to 2000 lux.

Because of the constraints faced with running Radiance simulations, compromises were made on the quality settings that were chosen for running the simulation. Higher quality settings would provide more realistic results. For daylighting analysis involving complex fenestration systems, the ambient bounces (-ab) value to be chosen is on the order of 6 to 7. Running simulations with such high quality settings is not feasible with traditional personal computers.

Recommendations

It was observed that the proposed split-controlled blind system can be used to provide energy savings to the building. A wide range of split angles can be tested, which can verify the validity of split-control blinds. The best possible angles can then be chosen and an experimental setup can be tested to verify the validity of Radiance and EnergyPlus results. The results obtained from the simulation carried out for this research provide the benchmark for further research in this area, and they also provide an insight into the use of advanced daylighting and energy simulation tools, such as Radiance and EnergyPlus. This research can be extended by performing glare studies. Glare index values can be computed for the four sensor points using Radiance to analyze and assess the performance of split-controlled blinds in terms of occupancy comfort. This field of research contributes to the field of sustainable construction and can provide a valuable source of information for further research in this field. With an increased emphasis on “green” buildings, the need for more efficient building systems with advanced fenestration systems becomes a necessity.

APPENDIX A
ENERGYPLUS SPECIFICATIONS

Table A-1 shows the area distribution for each of the four walls along with their cardinal directions. The building envelope mainly comprises of concrete walls with insulation.

Table A-1. Window-Wall Ratio

	Total	North (315 to 45 deg)	East (45 to 135 deg)	South (135 to 225 deg)	West (225 to 315 deg)
Gross Wall Area (m2)	52.80	11.15	15.25	11.15	15.25
Window Opening Area (m2)	3.34	0.00	0.00	3.34	0.00
Window-Wall Ratio (%)	6.33	0.00	0.00	30.00	0.00

The rate of heat loss is indicated in terms of the U-factor (U-value) of a window assembly. The Insulating value is indicated by the R-value which is the inverse of the U-value. The lower the U-value, the greater a window's resistance to heat flow and the better its insulating value. Table A-2 gives the reflectance value, U-factor, gross area, azimuth angle, and the tilt angle for each of the surface elements of the office room.

Table A-2. The exterior of the room

	Construction	Reflectance	U-Factor with Film (W/m2-K)	U-Factor no Film (W/m2-K)	Gross Area (m2)	Azimuth (deg)	Tilt (deg)	CardinalDirection
WALL1	COMPOSITE CONCRETE/FOAM/CONCRETE WITH STEEL CONNECTORS	0.30	1.751	2.37	15.25	270.00	90.00	W
WALL2	COMPOSITE CONCRETE/FOAM/CONCRETE WITH STEEL CONNECTORS	0.30	1.751	2.37	11.15	0.00	90.00	N
WALL3	COMPOSITE CONCRETE/FOAM/CONCRETE WITH STEEL CONNECTORS	0.30	1.751	2.37	15.25	90.00	90.00	E

WALL4	COMPOSITE CONCRETE/FOAM/CONCRETE WITH STEEL CONNECTORS	0.30	1.751	2.37	11.15	180.00	90.00	S
SLAB	COMPOSITE CONCRETE/FOAM/CONCRETE WITH STEEL CONNECTORS	0.30	1.505	2.37	18.30	0.00	180.00	
ROOF	COMPOSITE CONCRETE/FOAM/CONCRETE WITH STEEL CONNECTORS	0.30	1.640	2.37	18.30	180.00	0.00	

Table A-3 shows the area, U-factor, and Visible transmittance value for the fenestration used in the EnergyPlus Model simulation model.

	Construction	Area of Opening (m2)	U-Factor	SHGC	Visible Transmittance	Shade Control	Parent Surface
WINDOW	DBL LOE (E2=.1) CLR 6MM/13MM AIR	3.34	2.69	0.567	0.744	Yes	WALL4

Table A-4 shows the various Air flow rates used for the HVAC system.

Table A-4. (PTAC) PACKAGED TERMINAL: AIRCONDITIONER

	maximum cooling air flow rate [m3/s]	maximum heating air flow rate [m3/s]	maximum air flow rate when compressor is off [m3/s]	maximum outside air flow rate in cooling [m3/s]	maximum outside air flow rate in heating [m3/s]	maximum outside air flow rate when compressor is off [m3/s]
RINKER BUILDING OFFICE PTAC	0.090848	0.090848	0.090848	0.000000	0.000000	0.000000

Tables A-5 and A-6 show the Rated Air Volume Flow, Rated Total Cooling Capacity, Rated Sensible Heating Ratio (SHR) value for the cooling coil and Nominal Capacity of the heating coil.

Table A-5. COIL: DX: COOLING BYPASS FACTOREMPIRICAL

	Rated Air Volume Flow Rate [m3/s]	Rated Total Cooling Capacity (gross) [W]	Rated SHR
RINKER BUILDING OFFICE PTAC COOLING COIL	0.090848	1503.86	0.798655

Table A-6. COIL: ELECTRIC: HEATING

	Nominal Capacity of the Coil [W]
RINKER BUILDING OFFICE PTAC HEATING COIL	1666.43

Table A-7 shows the Design load, Design air flow, Temperature at peak, Date /Time of the peak used for the cooling load.

Table A-7. HVAC Sizing Summary

Zone Cooling

	Design Load (W)	Calculated Design Air Flow (m3/s)	User Design Air Flow (m3/s)	Design Day Name	Date/Time Of Peak	Temperature at Peak (C)	Humidity Ratio at Peak (kgWater/kgAir)
RINKER BUILDING OFFICE	1108.53	0.091	0.091	SIMULATION DAY 1	6/21 13:30:00	33.00	0.00001

Table A-8 show the Design load, Design Air Flow, Temperature at peak, Date /Time of the peak used for the heating load.

Table A-8. Zone Heating

	Design Load (W)	Calculated Design Air Flow (m3/s)	User Design Air Flow (m3/s)	Design Day Name	Date/Time Of Peak	Temperature at Peak (C)	Humidity Ratio at Peak (kgWater/kgAir)
RINKER BUILDING OFFICE	1666.43	0.046	0.046	SIMULATION DAY 3	12/21 07:30:00	-0.33	0.00368

APPENDIX B:
RADIANCE GENERATORS

Generators

A generator is any program that produces a scene description as its output. They usually appear as commands in a scene description file. An example of a simple generator is genbox.

- **Genbox** takes the arguments of width, height and depth to produce a parallelepiped description.
- **Genprism** takes a list of 2-dimensional coordinates and extrudes them along a vector to produce a 3-dimensional prism.
- **Genrev** is a more sophisticated generator that produces an object of rotation from parametric functions for radius and axis position.
- **Gensurf** tessellates a surface defined by the parametric functions x(s, t), y(s, t), and z(s, t).
- **Genworm** links cylinders and spheres along a curve.
- **Gensky** produces a sun and sky distribution corresponding to a given time and date.
- **Xform** is a program that transforms a scene description from one coordinate space to another. Xform does rotation, translation, scaling, and mirroring. ry can be easily produced in RADIANCE, without the help of any CAD program.
- **Rview** is ray-tracing program for viewing a scene interactively. When the user specifies a new perspective, rview quickly displays a rough image on the terminal, and then progressively increases the resolution as the user looks on. The user can select a particular section of the image to improve, or move to a different view and start over. This mode of interaction is useful for debugging scenes as well as determining the best view for a final image.
- **Rpict** produces a high-resolution picture of a scene from a particular perspective. This program features adaptive sampling, crash recovery and progress reporting, all of which are important for time-consuming images.

APPENDIX C
RADIANCE SCRIPT

Appendix C shows the script used to run hourly simulations for each occupied hour from 8 a.m. to 5 p.m. for the 365 days of the year. Illuminance values were obtained at the four sensor points placed at a distance of 1 meter from each other with the first sensor point placed at a distance of 1 meter from the window at a height of 0.76 m from the floor level.

```
#!/bin/csh -f

set hr=$1
set day=$2
set mon=$3
#set filename="conv15"
if ($mon < 10) then
  set monname="0""$mon"
else
  set monname=$mon
endif

if ($#argv > 3) then
  set anglename=$4
else
  set anglename=""
endif
if ($#argv > 4) then
  set angle1=$5
else
  set angle1=""
endif
if ($#argv > 5) then
  set angle2=$6
else
  set angle2=""
endif
if ($#argv > 6) then
  set angle3=$7
else
  set angle3=""
endif
```

```
set month="$anglename""_""$monname""-""$day""-""$hr"
echo $month
set coord=(-a 30.00 -o 82.35 -m 84)
rm $month.out
echo "hr=$hr"
set skypar=($mon $day $hr $coord +s)
echo "$month/$day/$hr">>$month.out
gensky $mon $day $hr -a 29.69 -o -82.65 -m -84 +s>sky1.rad
oconv sky1.rad outside.rad room.rad window2.rad conv-45.rad>hr.oct
mkillum -ab 1 -ad 256 -as 128 -av 0 0 0 hr.oct "<" windowillum1.rad>illumination.rad
oconv -i hr.oct illumination.rad>hour.oct
rtrace -h -I -ab 1 -ad 4096 -as 128 -av 0 0 0 hour.oct<mainsamplesup1.inp|rcalc -e
'$1=47.4*$1+120*$2+11.6*$3'>>$month.out
echo " ">>$month.out
rm hr.oct
rm hour.oct
end
@ day++
echo "day=$day"
end
```

APPENDIX D
ENERGYPLUS INPUTS

Appendix D shows all the necessary inputs for running simulations inon EnergyPlus. All the data is obtained from **.audit** file, obtained as an output of EnergyPlus simulations. All the parameters and their assigned values, necessary to run the simulations can be seen here.

```
!-   ===========  ALL OBJECTS IN CLASS: BUILDING ===========

BUILDING,
    rinker building,         !- Building Name
    0,                       !- North Axis {deg}
    Urban,                   !- Terrain
    0.04,                    !- Loads Convergence Tolerance Value
    0.4,                     !- Temperature Convergence Tolerance Value {deltaC}
    FullInteriorAndExteriorWithReflections,  !- Solar Distribution
    25;                      !- Maximum Number of Warmup Days


!-   ===========  ALL OBJECTS IN CLASS: TIMESTEP IN HOUR ===========

TIMESTEP IN HOUR,
    4;                       !- Time Step in Hour


!-   ===========  ALL OBJECTS IN CLASS: INSIDE CONVECTION ALGORITHM ===========

INSIDE CONVECTION ALGORITHM,
    Detailed;                !- Algorithm


!-   ===========  ALL OBJECTS IN CLASS: OUTSIDE CONVECTION ALGORITHM ===========

OUTSIDE CONVECTION ALGORITHM,
    Detailed;                !- Algorithm


!-   ===========  ALL OBJECTS IN CLASS: SOLUTION ALGORITHM ===========

SOLUTION ALGORITHM,
    CTF,                     !- SolutionAlgo
    200;                     !- Max Surface Temperature Limit


!-   ===========  ALL OBJECTS IN CLASS: DIAGNOSTICS ===========

```

```
DIAGNOSTICS,
    DisplayExtraWarnings;    !- key1


!-   ===========  ALL OBJECTS IN CLASS: RUN CONTROL ===========

RUN CONTROL,
    Yes,                     !- Do the zone sizing calculation
    No,                      !- Do the system sizing calculation
    No,                      !- Do the plant sizing calculation
    Yes,                     !- Do the design day simulations
    Yes;                     !- Do the weather file simulation


!-   ===========  ALL OBJECTS IN CLASS: LOCATION ===========

Location,
    Gainesville,             !- LocationName
    30,                      !- Latitude {deg}
    -81.65,                  !- Longitude {deg}
    -5,                      !- TimeZone {hr}
    54;                      !- Elevation {m}


!-   ===========  ALL OBJECTS IN CLASS: WEATHER STATION ===========

WEATHER STATION,
    10.0,                    !- Wind Sensor Height Above Ground {m}
    0.14,                    !- Wind Speed Profile Exponent
    270.0,                   !- Wind Speed Profile Boundary Layer Thickness {m}
    1.5;                     !- Air Temperature Sensor Height Above Ground {m}


!-   ===========  ALL OBJECTS IN CLASS: DESIGNDAY ===========

DesignDay,
    Simulation day 1,        !- DesignDayName
    33,                      !- Maximum Dry-Bulb Temperature {C}
    ,                        !- Daily Temperature Range {deltaC}
    ,                        !- Humidity Indicating Conditions at Max Dry-Bulb
    101217,                  !- Barometric Pressure {Pa}
    8.8,                     !- Wind Speed {m/s}
    10,                      !- Wind Direction {deg}
    0.9,                     !- Sky Clearness
    ,                        !- Rain Indicator
    ,                        !- Snow Indicator
    21,                      !- Day Of Month
    6,                       !- Month
    Thursday,                !- Day Type
    ,                        !- Daylight Saving Time Indicator
    ;                        !- Humidity Indicating Type

DesignDay,
    Simulation day 2,        !- DesignDayName
```

```
    29,                         !- Maximum Dry-Bulb Temperature {C}
    ,                           !- Daily Temperature Range {deltaC}
    ,                           !- Humidity Indicating Conditions at Max Dry-Bulb
    101217,                     !- Barometric Pressure {Pa}
    8.8,                        !- Wind Speed {m/s}
    10,                         !- Wind Direction {deg}
    0.9,                        !- Sky Clearness
    ,                           !- Rain Indicator
    ,                           !- Snow Indicator
    21,                         !- Day Of Month
    3,                          !- Month
    Tuesday,                    !- Day Type
    ,                           !- Daylight Saving Time Indicator
    ;                           !- Humidity Indicating Type

DesignDay,
    Simulation day 3,           !- DesignDayName
    -.33,                       !- Maximum Dry-Bulb Temperature {C}
    ,                           !- Daily Temperature Range {deltaC}
    ,                           !- Humidity Indicating Conditions at Max Dry-Bulb
    101217,                     !- Barometric Pressure {Pa}
    8.8,                        !- Wind Speed {m/s}
    10,                         !- Wind Direction {deg}
    0.9,                        !- Sky Clearness
    ,                           !- Rain Indicator
    ,                           !- Snow Indicator
    21,                         !- Day Of Month
    12,                         !- Month
    Friday,                     !- Day Type
    ,                           !- Daylight Saving Time Indicator
    ;                           !- Humidity Indicating Type


!-   ===========  ALL OBJECTS IN CLASS: MATERIAL:REGULAR ===========

MATERIAL:REGULAR,
    Composite Concrete/Foam/Concrete With Steel Connectors #3,  !- Name
    Rough,                      !- Roughness
    0.15240030480061,           !- Thickness {m}
    1.078,                      !- Conductivity {W/m-K}
    2185.44,                    !- Density {kg/m3}
    1173,                       !- Specific Heat {J/kg-K}
    0.9,                        !- Absorptance:Thermal
    0.7,                        !- Absorptance:Solar
    0.7;                        !- Absorptance:Visible

MATERIAL:REGULAR,
    Composite Insulated Concrete Form Wall With Steel Ties #2,  !- Name
    Smooth,                     !- Roughness
    0.101600203200406,          !- Thickness {m}
    0.499,                      !- Conductivity {W/m-K}
    1552.01,                    !- Density {kg/m3}
    880,                        !- Specific Heat {J/kg-K}
```

```
    0.9,                       !- Absorptance:Thermal
    0.7,                       !- Absorptance:Solar
    0.7;                       !- Absorptance:Visible

MATERIAL:REGULAR,
    Composite Concrete/Foam/Concrete With Steel Connectors #1,  !- Name
    Rough,                     !- Roughness
    0.101600203200406,         !- Thickness {m}
    1.329,                     !- Conductivity {W/m-K}
    2213.25,                   !- Density {kg/m3}
    964,                       !- Specific Heat {J/kg-K}
    0.9,                       !- Absorptance:Thermal
    0.7,                       !- Absorptance:Solar
    0.7;                       !- Absorptance:Visible


!-   ===========  ALL OBJECTS IN CLASS: MATERIAL:WINDOWGLASS ===========

MATERIAL:WINDOWGLASS,
    LoE CLEAR 6MM Rev,         !- Name
    SpectralAverage,           !- Optical Data Type
    ,                          !- Name of Window Glass Spectral Data Set
    0.006,                     !- Thickness {m}
    0.600,                     !- Solar Transmittance at Normal Incidence
    0.220,                     !- Solar Reflectance at Normal Incidence: Front Side
    0.170,                     !- Solar Reflectance at Normal Incidence: Back Side
    0.840,                     !- Visible Transmittance at Normal Incidence
    0.078,                     !- Visible Reflectance at Normal Incidence: Front Side
    0.055,                     !- Visible Reflectance at Normal Incidence: Back Side
    0.0,                       !- IR Transmittance at Normal Incidence
    0.10,                      !- IR Hemispherical Emissivity: Front Side
    0.84,                      !- IR Hemispherical Emissivity: Back Side
    0.9;                       !- Conductivity {W/m-K}

MATERIAL:WINDOWGLASS,
    CLEAR 6MM,                 !- Name
    SpectralAverage,           !- Optical Data Type
    ,                          !- Name of Window Glass Spectral Data Set
    0.006,                     !- Thickness {m}
    0.775,                     !- Solar Transmittance at Normal Incidence
    0.071,                     !- Solar Reflectance at Normal Incidence: Front Side
    0.071,                     !- Solar Reflectance at Normal Incidence: Back Side
```

```
    0.881,                    !- Visible Transmittance at Normal Incidence
    0.080,                    !- Visible Reflectance at Normal Incidence: Front Side
    0.080,                    !- Visible Reflectance at Normal Incidence: Back Side
    0.0,                      !- IR Transmittance at Normal Incidence
    0.84,                     !- IR Hemispherical Emissivity: Front Side
    0.84,                     !- IR Hemispherical Emissivity: Back Side
    0.9;                      !- Conductivity {W/m-K}

!-   ===========  ALL OBJECTS IN CLASS: MATERIAL:WINDOWGAS ===========

MATERIAL:WINDOWGAS,
    AIR 13MM,                 !- Name
    Air,                      !- Gas Type
    0.0127;                   !- Thickness {m}

!-   ===========  ALL OBJECTS IN CLASS: MATERIAL:WINDOWBLIND ===========

MATERIAL:WINDOWBLIND,
    BLIND WITH HIGH REFLECTIVITY SLATS 1,  !- Name
    HORIZONTAL,               !- Slat orientation
    0.025,                    !- Slat width {m}
    0.01875,                  !- Slat separation {m}
    0.001,                    !- Slat thickness {m}
    90,                       !- Slat angle {deg}
    0.9,                      !- Slat conductivity {W/m-K}
    0.0,                      !- Slat beam solar transmittance
    0.8,                      !- Slat beam solar reflectance, front side
    0.8,                      !- Slat beam solar reflectance, back side
    0.0,                      !- Slat diffuse solar transmittance
    0.8,                      !- Slat diffuse solar reflectance, front side
    0.8,                      !- Slat diffuse solar reflectance, back side
    0.0,                      !- Slat beam visible transmittance
    0.8,                      !- Slat beam visible reflectance, front side
    0.8,                      !- Slat beam visible reflectance, back side
    0.0,                      !- Slat diffuse visible transmittance
    0.8,                      !- Slat diffuse visible reflectance, front side
    0.8,                      !- Slat diffuse visible reflectance, back side
    0.0,                      !- Slat IR (thermal) hemispherical transmittance
```

```
    0.9,                     !- Slat IR (thermal) hemispherical emissivity, front side
    0.9,                     !- Slat IR (thermal) hemispherical emissivity, back side
    0.050,                   !- Blind-to-glass distance {m}
    0.5,                     !- Blind top opening multiplier
    0.5,                     !- Blind bottom opening multiplier
    0.5,                     !- Blind left-side opening multiplier
    0.5,                     !- Blind right-side opening multiplier
    ,                        !- Minimum Slat Angle {deg}
    ;                        !- Maximum Slat Angle {deg}

MATERIAL:WINDOWBLIND,
    BLIND WITH HIGH REFLECTIVITY SLATS 2,  !- Name
    HORIZONTAL,              !- Slat orientation
    0.025,                   !- Slat width {m}
    0.01875,                 !- Slat separation {m}
    0.001,                   !- Slat thickness {m}
    90,                      !- Slat angle {deg}
    0.9,                     !- Slat conductivity {W/m-K}
    0.0,                     !- Slat beam solar transmittance
    0.8,                     !- Slat beam solar reflectance, front side
    0.8,                     !- Slat beam solar reflectance, back side
    0.0,                     !- Slat diffuse solar transmittance
    0.8,                     !- Slat diffuse solar reflectance, front side
    0.8,                     !- Slat diffuse solar reflectance, back side
    0.0,                     !- Slat beam visible transmittance
    0.8,                     !- Slat beam visible reflectance, front side
    0.8,                     !- Slat beam visible reflectance, back side
    0.0,                     !- Slat diffuse visible transmittance
    0.8,                     !- Slat diffuse visible reflectance, front side
    0.8,                     !- Slat diffuse visible reflectance, back side
    0.0,                     !- Slat IR (thermal) hemispherical transmittance
    0.9,                     !- Slat IR (thermal) hemispherical emissivity, front side
    0.9,                     !- Slat IR (thermal) hemispherical emissivity, back side
    0.050,                   !- Blind-to-glass distance {m}
    0.5,                     !- Blind top opening multiplier
    0.5,                     !- Blind bottom opening multiplier
    0.5,                     !- Blind left-side opening multiplier
    0.5,                     !- Blind right-side opening multiplier
    ,                        !- Minimum Slat Angle {deg}
    ;                        !- Maximum Slat Angle {deg}

MATERIAL:WINDOWBLIND,
    BLIND WITH HIGH REFLECTIVITY SLATS 3,  !- Name
    HORIZONTAL,              !- Slat orientation
```

```
    0.025,                     !- Slat width {m}
    0.01875,                   !- Slat separation {m}
    0.001,                     !- Slat thickness {m}
    90,                        !- Slat angle {deg}
    0.9,                       !- Slat conductivity {W/m-K}
    0.0,                       !- Slat beam solar transmittance
    0.8,                       !- Slat beam solar reflectance, front side
    0.8,                       !- Slat beam solar reflectance, back side
    0.0,                       !- Slat diffuse solar transmittance
    0.8,                       !- Slat diffuse solar reflectance, front side
    0.8,                       !- Slat diffuse solar reflectance, back side
    0.0,                       !- Slat beam visible transmittance
    0.8,                       !- Slat beam visible reflectance, front side
    0.8,                       !- Slat beam visible reflectance, back side
    0.0,                       !- Slat diffuse visible transmittance
    0.8,                       !- Slat diffuse visible reflectance, front side
    0.8,                       !- Slat diffuse visible reflectance, back side
    0.0,                       !- Slat IR (thermal) hemispherical transmittance
    0.9,                       !- Slat IR (thermal) hemispherical emissivity, front side
    0.9,                       !- Slat IR (thermal) hemispherical emissivity, back side
    0.050,                     !- Blind-to-glass distance {m}
    0.5,                       !- Blind top opening multiplier
    0.5,                       !- Blind bottom opening multiplier
    0.5,                       !- Blind left-side opening multiplier
    0.5,                       !- Blind right-side opening multiplier
    ,                          !- Minimum Slat Angle {deg}
    ;                          !- Maximum Slat Angle {deg}


!-   ===========  ALL OBJECTS IN CLASS: CONSTRUCTION ===========

CONSTRUCTION,
    Composite Concrete/Foam/Concrete With Steel Connectors,  !- Name
    Composite Concrete/Foam/Concrete With Steel Connectors #3,  !- Outside Layer
    Composite Insulated Concrete Form Wall With Steel Ties #2,  !- Layer #2
    Composite Concrete/Foam/Concrete With Steel Connectors #1;  !- Layer #3

CONSTRUCTION,
    Dbl LoE (e2=.1) Clr 6mm/13mm Air 1,  !- Name
    LoE CLEAR 6MM Rev,       !- Outside Layer
    AIR 13MM,                !- Layer #2
    CLEAR 6MM,               !- Layer #3
    BLIND WITH HIGH REFLECTIVITY SLATS 1;  !- Layer #4
```

```
CONSTRUCTION,
    Dbl LoE (e2=.1) Clr 6mm/13mm Air 2,  !- Name
    LoE CLEAR 6MM Rev,       !- Outside Layer
    AIR 13MM,                !- Layer #2
    CLEAR 6MM,               !- Layer #3
    BLIND WITH HIGH REFLECTIVITY SLATS 2;  !- Layer #4

CONSTRUCTION,
    Dbl LoE (e2=.1) Clr 6mm/13mm Air 3,  !- Name
    LoE CLEAR 6MM Rev,       !- Outside Layer
    AIR 13MM,                !- Layer #2
    CLEAR 6MM,               !- Layer #3
    BLIND WITH HIGH REFLECTIVITY SLATS 3;  !- Layer #4

CONSTRUCTION,
    Dbl LoE (e2=.1) Clr 6mm/13mm Air ,  !- Name
    LoE CLEAR 6MM Rev,       !- Outside Layer
    AIR 13MM,                !- Layer #2
    CLEAR 6MM;               !- Layer #3

!-   ===========  ALL OBJECTS IN CLASS: ZONE ===========

ZONE,
    Rinker building office,  !- Zone Name
    0,                       !- Relative North (to building) {deg}
    -0.203200406400813,      !- X Origin {m}
    0,                       !- Y Origin {m}
    0,                       !- Z Origin {m}
    1,                       !- Type
    1,                       !- Multiplier
    3.04785126485828,        !- Ceiling Height {m}
    autocalculate,           !- Volume {m3}
    Simple,                  !- Zone Inside Convection Algorithm
    Simple,                  !- Zone Outside Convection Algorithm
    Yes;                     !- Part of Total Floor Area

!-   ===========  ALL OBJECTS IN CLASS: SURFACEGEOMETRY ===========

SurfaceGeometry,
    LowerLeftCorner,         !- SurfaceStartingPosition
    ClockWise,               !- VertexEntry
    world;                   !- CoordinateSystem

!-   ===========  ALL OBJECTS IN CLASS: WINDOWSHADINGCONTROL ===========

WindowShadingControl,
    Normal 1,                !- User Supplied Shading Control Name
    InteriorBlind,           !- Shading Type
    Dbl LoE (e2=.1) Clr 6mm/13mm Air 1,  !- Name of construction with shading
    AlwaysOn,                !- Shading Control Type
```

```
    ,                        !- Schedule Name
    ,                        !- SetPoint {W/m2, W or deg C}
    Yes,                     !- Shading Control Is Scheduled
    Yes,                     !- Glare Control Is Active
    BLIND WITH HIGH REFLECTIVITY SLATS 1,  !- Material Name of Shading Device
    FixedSlatAngle,          !- Type of Slat Angle Control for Blinds
    ;                        !- Slat Angle Schedule Name

WindowShadingControl,
    Normal 2,                !- User Supplied Shading Control Name
    InteriorBlind,           !- Shading Type
    Dbl LoE (e2=.1) Clr 6mm/13mm Air 2,  !- Name of construction with shading
    AlwaysOn,                !- Shading Control Type
    ,                        !- Schedule Name
    ,                        !- SetPoint {W/m2, W or deg C}
    Yes,                     !- Shading Control Is Scheduled
    Yes,                     !- Glare Control Is Active
    BLIND WITH HIGH REFLECTIVITY SLATS 2,  !- Material Name of Shading Device
    FixedSlatAngle,          !- Type of Slat Angle Control for Blinds
    ;                        !- Slat Angle Schedule Name

WindowShadingControl,
    Normal 3,                !- User Supplied Shading Control Name
    InteriorBlind,           !- Shading Type
    Dbl LoE (e2=.1) Clr 6mm/13mm Air 3,  !- Name of construction with shading
    AlwaysOn,                !- Shading Control Type
    ,                        !- Schedule Name
    ,                        !- SetPoint {W/m2, W or deg C}
    Yes,                     !- Shading Control Is Scheduled
    Yes,                     !- Glare Control Is Active
    BLIND WITH HIGH REFLECTIVITY SLATS 3,  !- Material Name of Shading Device
    FixedSlatAngle,          !- Type of Slat Angle Control for Blinds
    ;                        !- Slat Angle Schedule Name


!-   ===========  ALL OBJECTS IN CLASS: SCHEDULETYPE ===========

ScheduleType,
    Fraction,                !- ScheduleType Name
    0.0 : 1.0,               !- range
    CONTINUOUS;              !- Numeric Type

ScheduleType,
    Any number;              !- ScheduleType Name


!-   ===========  ALL OBJECTS IN CLASS: SCHEDULE:COMPACT ===========

SCHEDULE:COMPACT,
    Office Lighting 2,       !- Name
    Fraction,                !- ScheduleType
    Through: 12/31,          !- Complex Field #1
```

```
    For: Weekdays SummerDesignDay,  !- Complex Field #2
    Until: 05:00,            !- Complex Field #3
    0,                       !- Complex Field #4
    Until: 07:00,            !- Complex Field #5
    0,                       !- Complex Field #6
    Until: 08:00,            !- Complex Field #7
    0,                       !- Complex Field #8
    Until: 17:00,            !- Complex Field #9
    1,                       !- Complex Field #10
    Until: 18:00,            !- Complex Field #11
    0,                       !- Complex Field #12
    Until: 20:00,            !- Complex Field #13
    0,                       !- Complex Field #14
    Until: 22:00,            !- Complex Field #15
    0,                       !- Complex Field #16
    Until: 23:00,            !- Complex Field #17
    0,                       !- Complex Field #18
    Until: 24:00,            !- Complex Field #19
    0,                       !- Complex Field #20
    For: Saturday,           !- Complex Field #21
    Until: 06:00,            !- Complex Field #22
    0.05,                    !- Complex Field #23
    Until: 08:00,            !- Complex Field #24
    0.1,                     !- Complex Field #25
    Until: 12:00,            !- Complex Field #26
    0.3,                     !- Complex Field #27
    Until: 17:00,            !- Complex Field #28
    0.15,                    !- Complex Field #29
    Until: 24:00,            !- Complex Field #30
    0.05,                    !- Complex Field #31
    For: WinterDesignDay,    !- Complex Field #32
    Until: 24:00,            !- Complex Field #33
    0.0,                     !- Complex Field #34
    For: Sunday Holidays AllOtherDays,  !- Complex Field #35
    Until: 24:00,            !- Complex Field #36
    0.05;                    !- Complex Field #37

SCHEDULE:COMPACT,
    Office HVAC,             !- Name
    on/off,                  !- ScheduleType
    Through: 12/31,          !- Complex Field #1
    For: Weekdays SummerDesignDay,  !- Complex Field #2
    Until: 06:00,            !- Complex Field #3
    0.0,                     !- Complex Field #4
    Until: 22:00,            !- Complex Field #5
    1.0,                     !- Complex Field #6
    Until: 24:00,            !- Complex Field #7
    0.0,                     !- Complex Field #8
    For: Saturday WinterDesignDay,  !- Complex Field #9
    Until: 06:00,            !- Complex Field #10
    0.0,                     !- Complex Field #11
    Until: 18:00,            !- Complex Field #12
    1.0,                     !- Complex Field #13
    Until: 24:00,            !- Complex Field #14
    0.0,                     !- Complex Field #15
    For: Sunday Holidays AllOtherDays,  !- Complex Field #16
    Until: 24:00,            !- Complex Field #17
```

```
    0.0;                      !- Complex Field #18

SCHEDULE:COMPACT,
    ALWAYS 4,                 !- Name
    Any number,               !- ScheduleType
    Through: 12/31,           !- Complex Field #1
    For: AllDays,             !- Complex Field #2
    Until: 24:00,             !- Complex Field #3
    4;                        !- Complex Field #4

SCHEDULE:COMPACT,
    ALWAYS 20,                !- Name
    Any number,               !- ScheduleType
    Through: 12/31,           !- Complex Field #1
    For: AllDays,             !- Complex Field #2
    Until: 24:00,             !- Complex Field #3
    20;                       !- Complex Field #4

SCHEDULE:COMPACT,
    ALWAYS 24,                !- Name
    Any number,               !- ScheduleType
    Through: 12/31,           !- Complex Field #1
    For: AllDays,             !- Complex Field #2
    Until: 24:00,             !- Complex Field #3
    24;                       !- Complex Field #4

SCHEDULE:COMPACT,
    OCCUPY-1,                 !- Name
    Fraction,                 !- ScheduleType
    Through: 12/31,           !- Complex Field #1
    For: WeekDays SummerDesignDay CustomDay1 CustomDay2,  !- Complex Field #2
    Until: 8:00,              !- Complex Field #3
    0.0,                      !- Complex Field #4
    Until: 11:00,             !- Complex Field #5
    1.00,                     !- Complex Field #6
    Until: 12:00,             !- Complex Field #7
    0.80,                     !- Complex Field #8
    Until: 13:00,             !- Complex Field #9
    1,                        !- Complex Field #10
    Until: 14:00,             !- Complex Field #11
    1,                        !- Complex Field #12
    Until: 18:00,             !- Complex Field #13
    1.00,                     !- Complex Field #14
    Until: 19:00,             !- Complex Field #15
    0.50,                     !- Complex Field #16
    Until: 21:00,             !- Complex Field #17
    0.10,                     !- Complex Field #18
    Until: 24:00,             !- Complex Field #19
    0.0,                      !- Complex Field #20
    For: Weekends WinterDesignDay Holiday,  !- Complex Field #21
    Until: 24:00,             !- Complex Field #22
    0.0;                      !- Complex Field #23

SCHEDULE:COMPACT,
    ActSchd,                  !- Name
    Any number,               !- ScheduleType
```

```
    Through: 12/31,          !- Complex Field #1
    For: AllDays,            !- Complex Field #2
    Until: 24:00,            !- Complex Field #3
    50;                      !- Complex Field #4


!-   ===========  ALL OBJECTS IN CLASS: PEOPLE ===========

PEOPLE,
    Occupancy,               !- Name
    Rinker building office,  !- Zone Name
    OCCUPY-1,                !- Number of People SCHEDULE Name
    people,                  !- Number of People calculation method
    2,                       !- Number of People
    ,                        !- People per Zone Area {person/m2}
    ,                        !- Zone area per person {m2/person}
    0.8,                     !- Fraction Radiant
    autocalculate,           !- user specified sensible fraction
    ActSchd,                 !- Activity level SCHEDULE Name
    No,                      !- Enable ASHRAE 55 comfort warnings
    ZoneAveraged;            !- MRT Calculation Type


!-   ===========  ALL OBJECTS IN CLASS: LIGHTS ===========

LIGHTS,
    PERIMETER Lights 1,      !- Name
    Rinker building office,  !- Zone Name
    Office Lighting 2,       !- SCHEDULE Name
    lighting level,          !- Design Level calculation method
    256,                     !- Lighting Level {W}
    20,                      !- Watts per Zone Area {W/m2}
    ,                        !- Watts per Person {W/person}
    0.2,                     !- Return Air Fraction
    0.59,                    !- Fraction Radiant
    0.2,                     !- Fraction Visible
    1,                       !- Fraction Replaceable
    GeneralLights;           !- End-Use Subcategory


!-   ===========  ALL OBJECTS IN CLASS: DAYLIGHTING:DETAILED ===========

DAYLIGHTING:DETAILED,
    Rinker building office,  !- Zone Name
    2,                       !- Total Daylighting Reference Points
    1.524,                   !- X-coordinate of first reference point {m}
    0.75,                    !- Y-coordinate of first reference point {m}
    0.762,                   !- Z-coordinate of first reference point {m}
    1.524,                   !- X-coordinate of second reference point {m}
    3.5,                     !- Y-coordinate of second reference point {m}
```

```
    0.762,                    !- Z-coordinate of second reference point {m}
    0.4,                      !- Fraction of zone controlled by first reference point
    0.6,                      !- Fraction of zone controlled by second reference point
    500,                      !- Illuminance setpoint at first reference point {lux}
    500,                      !- Illuminance setpoint at second reference point {lux}
    2,                        !- Lighting control type
    75,                       !- Azimuth angle of view direction clockwise from zone y-axis (for glare calculation) {deg}
    16,                       !- Maximum allowable discomfort glare index
    0.3,                      !- Minimum input power fraction for continuous dimming control
    0.3,                      !- Minimum light output fraction for continuous dimming control
    3,                        !- Number of steps (excluding off) for stepped control
    1;                        !- Probability lighting will be reset when needed in manual stepped control


!-   ===========  ALL OBJECTS IN CLASS: NODE LIST ===========

NODE LIST,
    zone node,                !- Node List Name
    one,                      !- Node_ID_1
    two;                      !- Node_ID_2


!-   ===========  ALL OBJECTS IN CLASS: SET POINT MANAGER:SINGLE ZONE HEATING ===========

SET POINT MANAGER:SINGLE ZONE HEATING,
    heat,                     !- Name
    TEMP,                     !- Control variable
    -99,                      !- minimum supply air temperature {C}
    99,                       !- maximum supply air temperature {C}
    Rinker building office,  !- zone name of the control zone
    one,                      !- node name of zone node
    two,                      !- node name of zone inlet node
    zone node;                !- Name of the set point Node or Node List


!-   ===========  ALL OBJECTS IN CLASS: SET POINT MANAGER:SINGLE ZONE COOLING ===========

SET POINT MANAGER:SINGLE ZONE COOLING,
    cooling,                  !- Name
    TEMP,                     !- Control variable
    -99,                      !- minimum supply air temperature {C}
    99,                       !- maximum supply air temperature {C}
    Rinker building office,  !- zone name of the control zone
```

```
    one,                        !- node name of zone node
    two,                        !- node name of zone inlet node
    zone node;                  !- Name of the set point Node or Node List
!-   ===========  ALL OBJECTS IN CLASS: ZONE CONTROL:THERMOSTATIC ===========
ZONE CONTROL:THERMOSTATIC,
    ZONE ONE Thermostat,      !- Thermostat Name
    Rinker building office,  !- Zone Name
    ALWAYS 4,                   !- Control Type SCHEDULE Name
    Dual Setpoint with Deadband,  !- Control Type #1
    Office Thermostat Dual SP Control;  !- Control Type Name #1
!-   ===========  ALL OBJECTS IN CLASS: DUAL SETPOINT WITH DEADBAND ===========
DUAL SETPOINT WITH DEADBAND,
    Office Thermostat Dual SP Control,  !- Name
    ALWAYS 20,                  !- Heating Setpoint Temperature SCHEDULE Name
    ALWAYS 24;                  !- Cooling Setpoint Temperature SCHEDULE Name
!
!
!-   ===========  ALL OBJECTS IN CLASS: COMPACT HVAC:THERMOSTAT ===========
!
! COMPACT HVAC:THERMOSTAT,
!     Rinker thermostat,        !- Thermostat Name
!     ALWAYS 20,                !- Thermostat Heating Setpoint Schedule
!     24,                       !- Thermostat Constant Heating Setpoint {C}
!     ALWAYS 24,                !- Thermostat Cooling Setpoint Schedule
!     20;                       !- Thermostat Constant Cooling Setpoint {C}
!
!
!-   ===========  ALL OBJECTS IN CLASS: COMPACT HVAC:ZONE:PTAC ===========
!
! COMPACT HVAC:ZONE:PTAC,
!     Rinker building office,  !- Zone Name
!     Rinker thermostat,        !- Thermostat Name
!     autosize,                 !- Zone Supply Air Cooling Flow Rate {m3/s}
!     autosize,                 !- Zone Supply Air Heating Flow Rate {m3/s}
!     autosize,                 !- Zone Supply Air No-Load Flow Rate {m3/s}
!     ,                         !- Zone Supply Air Sizing Factor
!     flow/zone,                !- Zone Outside Air Method
```

```
!     0.00944,                   !- Zone Outside Air Flow Rate per Person {m3/s}
!     ,                          !- Zone Outside Air Flow per Zone Area {m3/s-m2}
!     ,                          !- Zone Outside Air Flow per Zone {m3/s}
!     ,                          !- System Availability Schedule
!     Office HVAC,               !- Supply Fan Operating Mode Schedule Name
!     Draw Through,              !- Supply Fan Placement
!     0.7,                       !- Supply Fan Total Efficiency
!     75,                        !- Supply Fan Delta Pressure {Pa}
!     0.9,                       !- Supply Fan Motor Efficiency
!     Single-speed DX,           !- Cooling Coil Type
!     ,                          !- Cooling Coil Availability Schedule
!     autosize,                  !- Cooling Coil Rated Capacity {W}
!     autosize,                  !- Cooling Coil Rated SHR
!     3,                         !- Cooling Coil Rated COP
!     Electric,                  !- Heating Coil Type
!     ,                          !- Heating Coil Availability Schedule
!     autosize,                  !- Heating Coil Capacity {W}
!     0.8,                       !- Gas Heating Coil Efficiency
!     ;                          !- Gas Heating Coil Parasitic Electric Load {W}


!-   ===========  ALL OBJECTS IN CLASS: REPORT VARIABLE ===========

Report Variable,
    *,                         !- Key_Value
    Window Blind Slat Angle ,!- Variable_Name
    hourly;                    !- Reporting_Frequency

Report Variable,
    *,                         !- Key_Value
    Lights Electric Power,     !- Variable_Name
    hourly,                    !- Reporting_Frequency
    Office Lighting 2;         !- Schedule_Name

Report Variable,
    *,                         !- Key_Value
    Daylight Illum at Ref Point 1,  !- Variable_Name
    hourly;                    !- Reporting_Frequency

Report Variable,
    *,                         !- Key_Value
    Glare Index at Ref Point 1,  !- Variable_Name
    hourly;                    !- Reporting_Frequency

Report Variable,
    *,                         !- Key_Value
    Total Electric Power Purchased,  !- Variable_Name
    hourly;                    !- Reporting_Frequency

Report Variable,
    *,                         !- Key_Value
    Total Building Electric Demand,  !- Variable_Name
```

```
    hourly;                    !- Reporting_Frequency

Report Variable,
    *,                         !- Key_Value
    Total HVAC Electric Demand,  !- Variable_Name
    hourly;                    !- Reporting_Frequency

Report Variable,
    *,                         !- Key_Value
    Total Electric Demand,     !- Variable_Name
    hourly;                    !- Reporting_Frequency

Report Variable,
    *,                         !- Key_Value
    Daylight Illum at Ref Point 2,  !- Variable_Name
    hourly;                    !- Reporting_Frequency

Report Variable,
    *,                         !- Key_Value
    Glare Index at Ref Point 2,  !- Variable_Name
    hourly;                    !- Reporting_Frequency


!-   ===========  ALL OBJECTS IN CLASS: REPORT METER ===========

Report Meter,
    PurchasedHeating:Facility,  !- Meter_Name
    hourly;                    !- Reporting_Frequency

Report Meter,
    PurchasedCooling:Facility,  !- Meter_Name
    hourly;                    !- Reporting_Frequency


!-   ===========  ALL OBJECTS IN CLASS: REPORT CUMULATIVE METERFILEONLY ===========

Report Cumulative MeterFileOnly,
    Electricity:Zone:RINKER BUILDING OFFICE,  !- Meter_Name
    hourly;                    !- Reporting_Frequency

Report Cumulative MeterFileOnly,
    InteriorLights:Electricity,  !- Meter_Name
    hourly;                    !- Reporting_Frequency

Report Cumulative MeterFileOnly,
    EnergyTransfer:Zone:RINKER BUILDING OFFICE,  !- Meter_Name
    hourly;                    !- Reporting_Frequency

Report Cumulative MeterFileOnly,
    Heating:EnergyTransfer,  !- Meter_Name
    hourly;                    !- Reporting_Frequency

Report Cumulative MeterFileOnly,
    Heating:EnergyTransfer:Zone:RINKER BUILDING OFFICE,  !- Meter_Name
    hourly;                    !- Reporting_Frequency
```

```

Report Cumulative MeterFileOnly,
    EnergyTransfer:Zone:RINKER BUILDING OFFICE,  !- Meter_Name
    hourly;                  !- Reporting_Frequency


!-   ===========  ALL OBJECTS IN CLASS: REPORT ===========

Report,
    Variable Dictionary,     !- Type_of_Report
    DETAILS,                 !- Name_of_Report
    Lines;                   !- Specifications1_for_Report

Report,
    Construction;            !- Type_of_Report

Report,
    Surfaces,                !- Type_of_Report
    Details;                 !- Name_of_Report
```

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BIOGRAPHICAL SKETCH

Deepak V. Golasangimath was born in Bijapur, India. As a child, he excelled in mathematics and physics. This encouraged him to pursue an engineering career. Deepak earned his Master of Science (MS) degree in Building Construction from the M.E. Rinker, Sr. School of Building Construction at the University of Florida in Gainesville. While pursuing his master's degree in building construction, he worked as a research assistant with Dr. Svetlana Olbina. Prior to earning his M.S degree, he attended the National Institute of Technology in Warangal, India, to earn his Bachelor of Technology (B-Tech) degree in Civil Engineering. Deepak's research interests are in the field of sustainable construction, with emphasis on building technologies. He is also interested in Building Information Management (BIM) and implementation of BIM in the building industry. After graduation in December 2009, Deepak plans to work for a construction management firm in the United States to pursue a successful career in the field of construction.