Energy savings in a commercial building with daylighting controls: empirical study and DOE-2 validation

by

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CHAPTER 1. INTRODUCTION

Two of the main energy draws in contemporary commercial buildings are lighting and heating, ventilation, and air conditioning (HVAC) systems. In the early 1900's, commercial buildings were designed to maximize the amount of light in interior spaces because electric lighting was not yet widely available. With this design constraint, buildings were built with more exterior walls and large windows to ensure natural light in all of the rooms. As electricity use became widespread and air conditioning systems were installed, building design changed to reduce building interaction with the outside environment and increase the efficiency of HVAC systems. With these new design constraints, buildings were built in cubes with fewer exterior walls and small windows that reduced energy flows across the building envelope. Lighting was provided almost exclusively through electric means.

Rising energy prices and a renewed emphasis on reducing energy use to protect the environment has prompted building design professionals to reexamine standard commercial building design. Improvements in construction materials and a desire to make buildings aesthetically pleasing and not just functional have created new opportunities in lighting systems. One of these new opportunities is daylighting, a lighting control method developed to reduce the amount of electric light provided to a room in proportion to the amount of natural light without reducing overall light levels on a work plane. Daylighting uses light sensors and dimmable ballasts to maintain a defined minimum light level on a work plane.

Daylighting controls will save lighting energy by reducing the amount of power used by the lighting system. However, reducing the lighting power also reduces the heat given off by the lights to the workspace. This reduction acts to lessen the cooling load in warm climates but increase the heating load in cold climates. The increase in HVAC energy use during heating mode could act to cancel out energy savings realized through reducing the lighting power.

Daylighting is only an effective energy conservation method if all of the system interactions are accounted for in the energy comparison. Unfortunately, it is difficult to study the effects of daylighting on HVAC systems experimentally because it is impossible to control the heating and cooling loads and isolate daylighting effects in an operating commercial building. Computer simulation programs have been used to account for system interactions and attempt to predict overall energy savings. However, there are few studies that attempt to validate their ability to predict daylighting's effect on HVAC energy use with experimental data.

The Energy Resource Station (ERS) in Ankeny, IA was built to study side-by-side full-scale HVAC systems and allow control of internal loads. This thesis outlines the use of this facility to run experiments to determine the total energy savings realized in a commercial building using daylighting controls. A DOE-2.1E simulation was created to model the building with daylighting controls and the experimental data was used to validate the program's results. In addition, a new fenestration system, called MOLS (Mini Optical Light System) and developed specifically with daylighting in mind, was tested against mini blinds for increased energy savings.

LITERATURE REVIEW

It is difficult to fully judge the quality of a daylighting system using only quantitative measurements. The purpose of a lighting system is to ensure the proper amount of illumination that will allow needed activities to take place. It is difficult to determine exactly how much light is needed for every activity because lighting needs vary based on personal preference. Basic illumination levels have been determined as guidelines for various activities by the Illuminating Engineering Society and are widely used in lighting system design.

The quality of the light needs to be considered in addition to basic illumination. Too much glare, especially on a computer screen, will reduce productivity and compromise the quality of the lighting design. Although some parameters have been defined to estimate the amount of glare on a surface, it is difficult to measure quantitatively with a computer data acquisition system. In general, it is expected that increasing the direct light into a room will also increase the glare. More advanced daylighting systems include light shelves and other directional devices that are designed to increase illumination and reduce glare. Because of the importance of light quality, it is sometimes important to gather actual human input and impressions to fully determine the success of a lighting system design. In addition, systems that allow user adjustment, such as mini blinds, introduce an unpredictable element into the experiment that can drastically affect the amount of light incident on the interior and therefore affect the overall energy savings of the daylighting system.

Studying the effect of human interaction with the lighting system will reveal how much actual lighting energy savings can be realized with daylighting. However, allowing access to the test area removes the ability to study HVAC system energy consumption in addition to the lighting energy consumption. The presence of a human body changes the loads imposed on the HVAC system in an unpredictable way and prevents direct, side-by-side energy analysis studies in an occupied space. Therefore, experiments and simulations designed to study energy savings with daylighting generally address lighting energy and not the corresponding HVAC energy. This allows daylighting systems to be tested in full-scale occupied environments that bring with them all the additional human interactions.

The literature available on daylighting energy savings generally falls into three rough categories: the use or development of computer simulations to estimate illumination levels, lighting energy reductions, and/or HVAC energy reductions; experimental data collection and analysis to determine illumination levels, lighting energy reductions, and/or HVAC energy reductions; and experimental data used to validate simulation results. Examples of each type of study and their results are presented in this section.

Computer Simulations

McHugh et al. (1998) used a ray-tracing technique coupled with BLAST to assist in the design of a Zero Energy Building in Ft. Collins, CO. The building was intended to take zero energy from the natural gas or electric grids. The various options tested included daylighting, clerestory windows, skylights, light shelves, evaporative cooling, and increased fenestration area. Six test cases were run and compared to determine the best building design. Only three cases were relevant to daylighting. Case A was used as a basic building design – conventional chiller, no clerestory or skylights, and a conventional lighting system. Case C included the effects of daylighting with clerestory windows and skylights but retained a conventional chiller. Case C showed a reduction of 70% in annual lighting energy usage and a reduction of 5% in annual chiller energy usage. The increase in fenestration area in Case C resulted in little difference in boiler energy usage. An attempt was made to determine daylighting's effect on boiler energy by using the same daylighting results (electric lighting energy reduction) in a building with the same fenestration area as Case A. In this situation, boiler energy increased by 14%.

Schrum and Parker (1996) conducted experiments to study the effect of window orientation and mini blinds on daylighting energy savings. The experiments were performed on the north and south windows from September through December of 1994 and on the east and west windows from January through April 1995. Four side-by-side offices were tested for each orientation, two with blinds and two without. Energy savings data was collected during daylight hours (6 AM to 6 PM) and compared to baseline data collected overnight to determine energy savings. The offices were occupied during the test period. Experimental results show an energy savings of 31-48% for rooms with no blinds and 24-37% for rooms with blinds. Energy savings was dependent on both blind condition and window orientation. Overall, the south window orientation with no blinds provided the greatest energy savings.

A DOE-2.1E computer simulation was developed in an attempt to predict the experimental results. A normal visible transmittance of 0.67 was used in conjunction with a blind schedule multiplier of 0.23 to model the mini blinds. Weather data measured during the experiments was used for the simulation. Results of the simulation show that the model was able to predict energy savings to within approximately 8% for rooms with no mini blinds and within approximately 17.4% for rooms with mini blinds. Overall, DOE-2 tended to overpredict lighting energy use.

Torcellini et al. (1999) developed a nine-step process for the design of a low energy building. The article outlines and describes the various steps of the process, then illustrates the method with a thermal test facility located outside Denver, CO. The test facility was built with three basic sections. The south section contains offices and conference rooms with windows to allow daylight and overhangs to reduce summer solar gain. The remaining two sections are located to the north of the first and contain clerestory windows to allow daylight into those spaces. Few fenestrations are located on the north, west, or east sides of the building.

Computer simulations were used throughout the design process to develop the final building plans. Once the building was actually built, the computer models for the base case and the final design were calibrated to match the actual building as closely as possible. A short-term data collection process was conducted to extrapolate actual annual building energy usage. Actual weather data was collected and used with the simulations to allow comparison between the computer-predicted base case, the computer-predicted final design, and the actual building performance.

The simulation predicted lighting energy savings of 75%. The improved lighting system included daylighting, electronic ballasts, and occupancy sensors. In addition, the base case included equal fenestration areas on all sides of the building. Cooling energy for the simulation was reduced by 43%. The energy reduction in the cooling system included an evaporative chiller system as well as the effects of the daylighting system.

Discrepancies were found between the calibrated building simulation and the final building performance. Most of the differences were the result of unforeseen occupancy changes. For instance, the initial daylighting system was inadequate and disabled by the occupants until a new system could be installed. In addition, equipment deliveries during the summer months caused large bay doors to remain open for long periods of time and resulted in much larger cooling loads than those predicted. Overall, however, the simulation provided a reasonable estimate of actual building energy usage.

Experimental Data

Yang and Tu (1992) studied light levels and energy savings with a daylighting system in Taiwan. Two west facing test rooms were used with mini blind window systems. The tests were conducted over a period of time in October and April. The base case was a room with no daylighting controls and venetian blinds that were closed when there was direct sunlight into the space to prevent increased internal loads. The daylighting controls used in the comparison room were step and not continuously dimmering. Tests were done on different days and not on a side-by-side basis, but an effort was made to determine the effect of sky condition on the overall results. The authors found that daylighting was able to save over 30% of the lighting energy when compared to the tests with no daylighting.

Lee et al. (1998) studied the effect of an automated mini blind system on daylighting savings. The experiments were conducted on two offices in a building in Oakland, CA as part of a larger study to develop a reliable automated venetian blind system. The test rooms were outfitted with the same lighting and window systems, including continuously dimmable ballasts and automated blind systems. The test rooms were located on an unfinished floor in the building and thus isolated from other conditioned space.

Two primary experiments were conducted. The first compared one room with automated blinds and dimmable controls with a room with static blinds and non-dimmable controls. The automated system was designed to adjust blind slat angle every 30 seconds to prevent direct solar gain but allow daylight access to the interior. The experiments were done for three differing static slat angles: 0 degrees (horizontal), 15 degrees, and 45 degrees (nearly closed). The data showed lighting energy savings on the order of 22 – 86%. In addition, cooling load measurements were taken for three representative test days in June and showed a reduction of 28% for the daylighting system. Energy savings varied according to the slat angle and outside conditions.

The second experiment compared one room with automated blinds and dimmable controls to a room with static blinds and dimmable controls. This test examined the ability of the automated system to improve daylighting over a conventional window system. The data showed lighting energy savings on the order of 19 – 52% for the dynamic system over the 45 degree static system. Savings were on the order of –14% – 11% for the dynamic system over the 0 degree static system. The horizontal static blind angle saved lighting energy in comparison to the automated system because it allowed direct sunlight into the space. However, the data showed a penalty in cooling load ranging from 17 – 32% for the same situation. Average daily cooling load reductions for the dynamic system over the 45 degree slat angle were just 7 – 15%.

Li and Lam (2001) conducted experiments on one floor of an office building in Hong Kong. The test area consisted of perimeter office space on the north and south side of the building and open space in the interior. Tests were conducted on illuminance patterns and electric lighting savings with an improved lighting system. The improved system included continuously dimmable ballasts, daylighting controls, and occupancy sensors. The illuminance tests suggested that the new ballasts had a greater luminous efficacy than the replaced ballasts, indicating that more light was delivered for the same amount of power.

To study the effect of only daylighting on energy savings, the authors excluded the lunch hour in their calculations to remove the effect of the occupancy sensors. According to information collected from the occupants of the space, the lights in all areas were on continuously all other times. Results from the experiment show an annual savings of 15.7 kWh/m^2. The authors estimate that this is approximately 50% of the total lighting energy usage.

Summary

Overall, the literature shows that lighting energy is saved with daylighting systems. The research done by Schrum and Parker most closely resembles the research outlined in this thesis. They showed that daylighting with blinds can reduce lighting energy use by 24 – 37%. In addition, they showed that DOE-2.1E was able to predict the experimental energy savings to within 20%. However, because the test space was occupied during the experiment, they were unable to address HVAC energy use. Therefore, although DOE-2.1E is capable of modeling and predicting the HVAC energy use, there was no experimental data to make an adequate validation of the results. The resulting outcome contains valid information but does not provide the complete energy picture.

McHugh et al. used only computer simulations to determine the effect of daylighting on energy usage. Care was taken to ensure that the simulation was complete and would provide good results. However, without experimental data to ensure that the program provides valid results, the study only shows relative savings to the degree that the program is able to predict them. Without validating the program itself, the results are suspect.

Torcellini et al. attempted to use experimental data to provide validation for their simulation results. In fact, the method used in the article most closely follows the actual design process. They used the predictions given by the simulation and basic assumptions about internal loads, building usage, and occupancy patterns to determine the final building design. Experimental data collected after the building was constructed was meant to validate the design process and determine how well the simulation was able to predict actual energy savings. However, the experimental data was once again taken in an occupied space and occupancy patterns did not exactly match the assumptions used to develop the simulation. The authors were testing their initial assumptions in addition to the computer's calculations in the validation process. In fact, discussion of the discrepancies between the experimental results and the simulation's predictions indicate that the errors were more due to incorrect assumptions than errors in the simulation.

Two main areas need to be addressed in daylighting energy research: what is the actual contribution of HVAC effects to energy savings, and how well do the conventional simulation programs predict these overall savings? The first question can be answered with increased research addressing both lighting energy savings and HVAC energy savings. The second question can be answered through validation studies similar to that conducted in this thesis. The author was unable to uncover full-scale empirical HVAC energy savings assessments or computer simulation validation studies within the scope of the review conducted for this paper.

RESEARCH OBJECTIVES

There are three objectives in this research project. The first objective is to use experimental data to compare lighting and HVAC energy consumption in rooms with daylighting to energy consumption in rooms with conventional lighting systems. The second objective is to use experimental data to compare lighting and HVAC energy consumption in rooms with daylighting and the MOLS window system to energy consumption in rooms with daylighting and mini blind window systems. The third objective is to develop a computer simulation for daylighting using the DOE-2.1E program and validate the computer results using the experimental data from the first objective.

The test facility and weather measurement system are described in Chapter 2. The experimental set up and data collection are described in Chapter 3. Results of the first two research objectives are also presented in Chapter 3. Development of the simulation and results of the validation study can be found in Chapter 4.

CHAPTER 2. TEST FACILITY

The experiments were conducted at the Energy Resource Station (ERS) on the campus of Des Moines Area Community College in Ankeny, Iowa. The ERS provides researchers with a unique opportunity to study commercial building HVAC and lighting components and controls. The facility was built in 1995 to act as a full-scale testing and demonstration station and allow side-by-side examination of multiple commercial building systems and their controls.

BUILDING DESCRIPTION

Ankeny, IA is located at 41.71 degrees North latitude and 93.61 degrees West longitude and has an elevation of 937 feet above sea level. The ERS is oriented for a true north/south solar alignment and is surrounded by grass with concrete walkways on the east and west sides. Figure 2.1 shows a photograph of the facility. The total floor area encompasses 9,208 square feet and the building height is 15 feet.

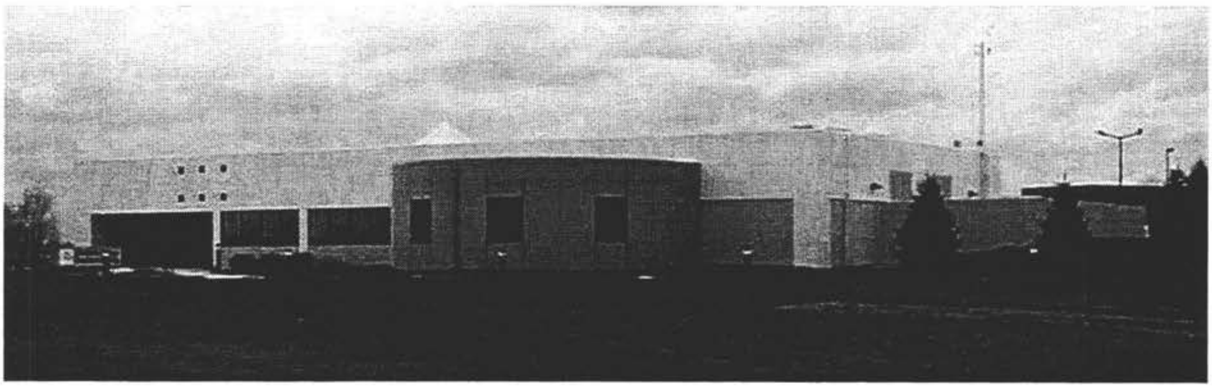


Figure 2.1 The Energy Resource Station in Ankeny, Iowa; from the northeast.

Figure 2.2 shows the building layout. The north side of the building contains the mechanical and storage spaces. The mechanical room houses three air handling units (AHU's) and five pumps in addition to the electronic data acquisition system and other mechanical systems not used in this experiment. Pairs of identical test rooms, dubbed "A" and "B", are located on each of the remaining exterior walls. Another pair of test rooms is located in the interior space. The interior rooms were excluded from this experiment because there is no daylight into the space. They were included in the building model described in Chapter 4 because the cooling coils in the air handling units serve all 4 A and all 4 B test rooms at once. In addition to the effects on the cooling coil, the interior rooms and the rest of the non-test space in the ERS were included in the building model to accurately account for all thermal interactions with the test space.

A summary of all the spaces in the ERS can be found in Table 2.1. Construction details of the test rooms are found in the following section. Construction details for the remainder of the building (non-test space) can be found in Lee (1999).

WALL CONSTRUCTION

The exterior walls of the test rooms are precast concrete panels with several layers of material and thermal mass on the outside of insulation. The construction layers (from inside to outside) are 3/8 inch of gypsum board, 4 3/8 inch of air space, 1 inch of insulation, and 4 inches of precast concrete. The exterior surface is light gray with an absorptivity of 0.675. The average U-value for the exterior test room walls is 0.181 Btu/(hr- ft^2-°F).

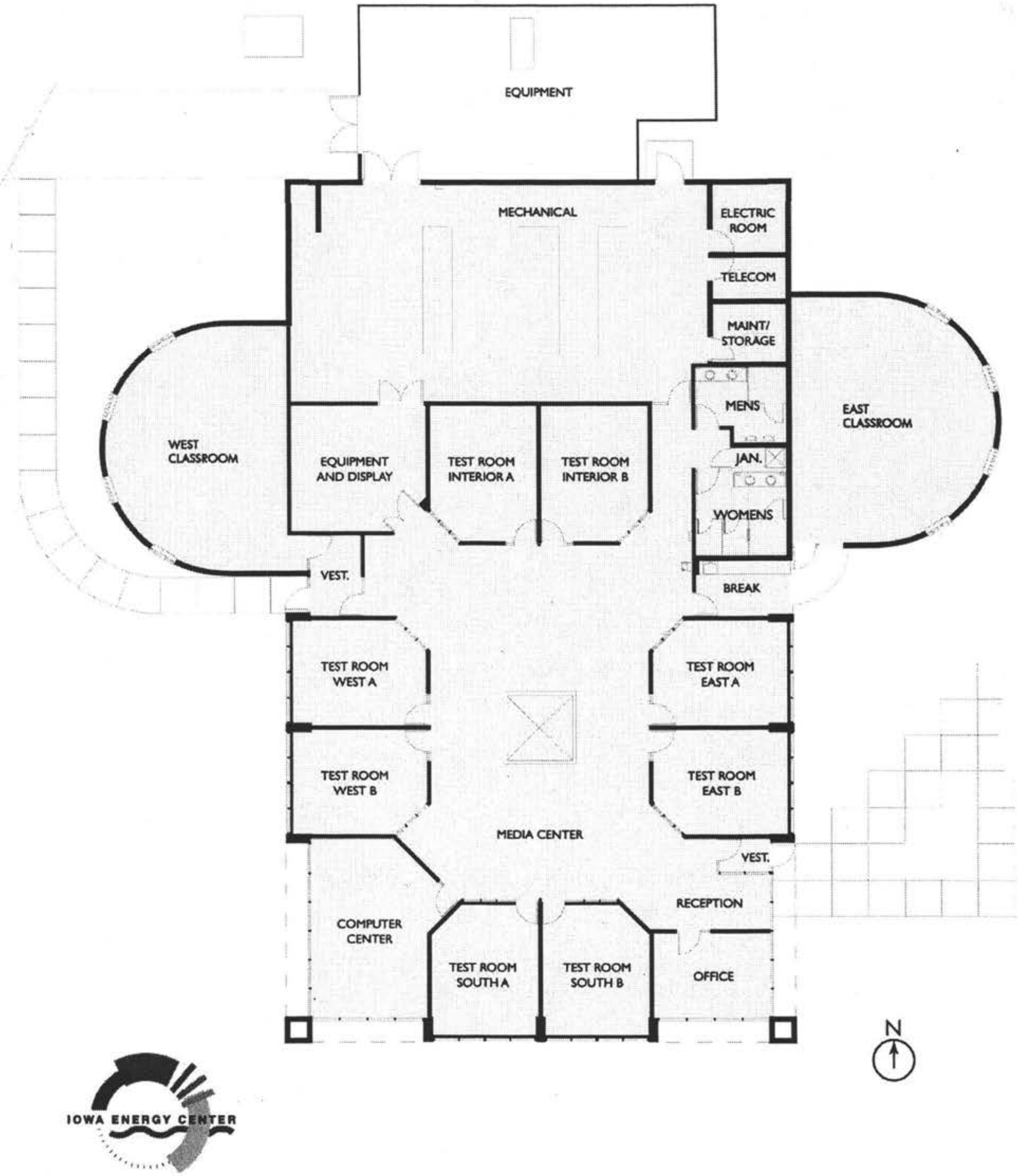


Figure 2.2 ERS floor plan.

Table 2.1 Room size summary.

Room	Net floor area (ft^2)	Ceiling height (ft)	Plenum height (ft)	Exterior wall area (ft^2)	Window area (ft^2)
Test room "A" and "B"					
East	267	8.5	5.5	137	74
South	267	8.5	5.5	137	74
West	267	8.5	5.5	137	74
Interior	267	8.5	5.5	0	0
Rest of building					
Mechanical	1764	14.0	0.0	180	0
Storage	90	14.0	0.0	294	0
Communications	66	14.0	0.0	88	0
Electrical	110	14.0	0.0	119	0
Service rooms	390	8.0	6.0	499	0
Display room	316	8.5	5.5	0	0
East Classroom	769	9.0	1.0	762	70
West Classroom	769	9.0	1.0	762	70
Vestibule (west)	85	8.5	5.5	125	30
Vestibule (east)	36	8.5	5.5	33	30
Media center	1888	10.0	4.0	0	0
Reception area	178	8.5	5.5	75	40
Office	197	8.5	5.5	238	136
Computer center	415	8.5	5.5	383	197

The windows in the test rooms are 5 feet high and 14.8 feet wide with aluminum frames and thermal breaks. The clear insulating glass is ¼ inch double-glazed with a ½ inch air space. There are no exterior shading devices. The shading coefficient for the glass is 0.85 and with light venetian blinds is 0.5.

The interior walls of the test rooms rise to the building's roof to prevent air exchange between the test area and the occupied area and between adjacent test rooms. The east wall of test room South A and the west wall of room South B are constructed of 5/8 inch gypsum board, 6 inch metal studs on 16 inch centers, and 5/8 inch gypsum board. The remaining test room interior walls are constructed of 5/8 inch gypsum board, 3 5/8 inch metal studs on 16 inch centers, and 5/8 inch gypsum board. The insulation inside the walls is a combination of blown fiberglass and expanding polystyrene.

The walls facing the media center have glass sections, which allow daylight to pass into the media center. The clear insulated glass section is 7 feet high by 7 feet wide single-glazed and ¼ inch thick. It has aluminum frames with thermal breaks. For these experiments, the glass was covered with sheetrock to prevent light from the interior space polluting the test area. Each room has a standard hollow-core metal door. Each A test room is a mirror image of its B counterpart.

FLOOR CONSTRUCTION

The floor is constructed of 4 inches of concrete on a 4 inch layer of sand. All test rooms are carpeted. The total thermal resistance of the floor is 4.31 (hr-ft^2-°F)/Btu.

ROOF CONSTRUCTION

The ERS has a flat built-up roof with thermal mass inside the insulation. The construction layers from inside to outside are 8 inches of precast prestressed cored-concrete slab, a vapor barrier, 4 inches of polyisocyanurate insulation, roof insulation tapering from 9 inches thick at the center of the building to 4 inches thick near the perimeter, a single-ply membrane, and rock ballast.

INTERNAL LOADS

For the daylighting experiments, the internal loads consist solely of loads from the recessed fluorescent lighting in the ceiling. Each test room is equipped with 2 stage lighting that can be scheduled to turn on and off at various times of the day. The test rooms are also equipped with 2 stages of electric baseboard heaters that were not utilized for these experiments.

LIGHTING SYSTEM

Each test room contains the same lighting system. Six fixtures contain three 32W T8 flourescent bulbs each. The fixtures are 2' by 2' with a clear prismatic acrylic lens and are manufactured by H.E. Williams, Inc. Each fixture is controlled by one dimmable electronic ballast Model Mark VII VZT-3S32, manufactured by Advance Transformers with a nominal minimum power of 30% of maximum lamp wattage. The control system was manufactured by General Electric and driven by a Watt Stopper LightSaver LS-30 light sensor. The sensor itself is a blue/green photo-diode with a Fresnel lens configuration capable of reading a 60 degree field of view. The range of the sensor is 10 – 150 fc. The lighting and sensor layout are found in Chapter 3. Figure 2.3 shows the ceiling, Watt Stopper, and window sensors.

HVAC SYSTEMS

The ERS has 3 independent air handling units (AHUs) that serve the building. AHU-A serves all the A test rooms, AHU-B serves all the B test rooms, and AHU-1 serves all of the remaining areas. AHU-1 is similar to but slightly larger than the two test units. Each unit

Figure 2.3 Ceiling and window light level sensors.

has a supply air (SA) fan, return air (RA) fan, preheat coil, cooling coil, heating coil, control valves, recirculate (RC) air damper, exhaust air (EA) damper, outdoor air (OA) damper, and ducts for air delivery. The fan motors are equipped with variable frequency drives. Each AHU is equipped with numerous sensors to provide the necessary experimental data during a test. Figure 2.4 shows a schematic of an AHU. Specifications for each AHU can be found in Table 2.2. More information on point names and locations can be found in Price and Smith (2000).

The rooms are equipped with variable air volume (VAV) boxes for supply air. The boxes contain both electronic and hydronic heating coils. Only electric reheat was used for these experiments. The non-test areas of the building have parallel fan powered VAV boxes

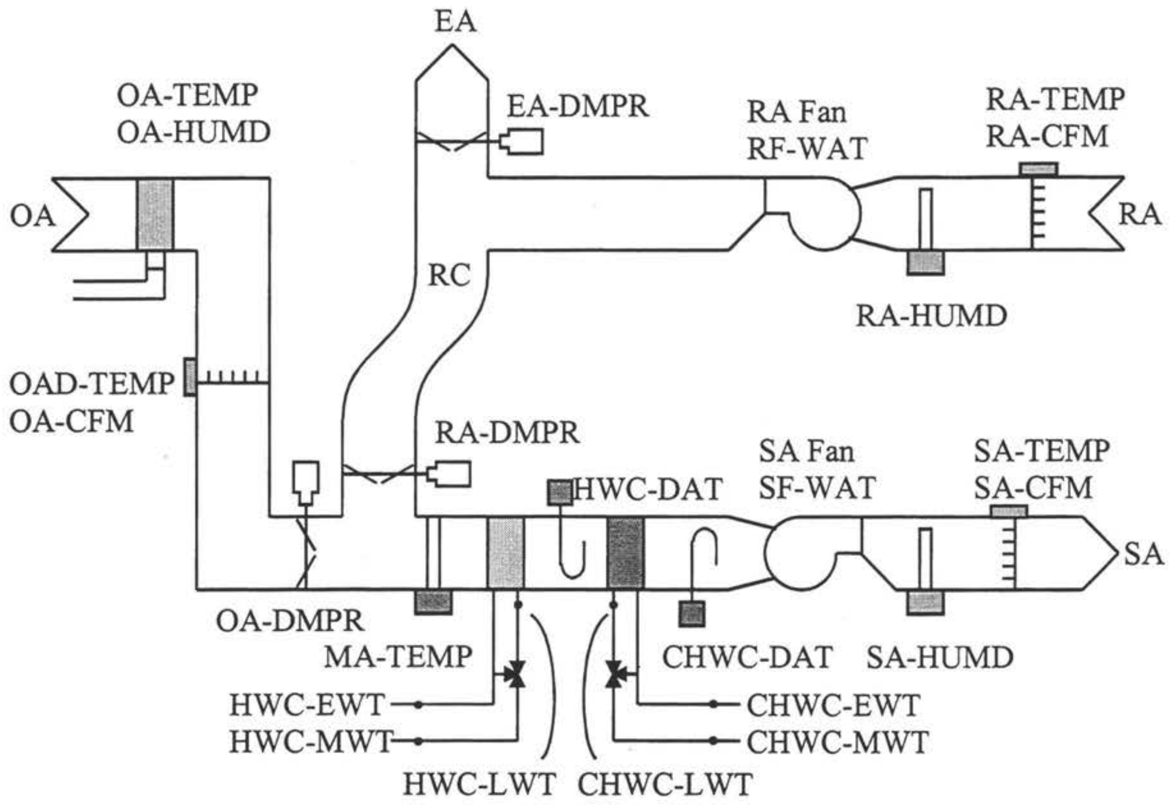


Figure 2.4 Air handling unit schematic.

with electric reheat coils only. The exterior test rooms have 3 stages of electric reheat available for a total maximum power of 5 kW. Figure 2.5 shows a schematic of a test room VAV box. Details on point names and locations can be found in Price and Smith (2000).

A central heating and cooling plant with multiple hydronic loops serves all AHUs. Each loop contains instrumentation to allow the energy flows for that loop to be calculated apart from the rest of the system. The boiler provides hot water to the three AHUs, the hydronic coils in the VAV boxes, and the preheat coil in the outside air duct. This experiment was designed to utilize 100% recirculated air, removing the need for any heating at the AHU level. Therefore no hot water was used in this experiment. Chilled water is

Table 2.2 Air handling unit specifications.

Specification	AHU value
cfm	3,200
Supply fan static pressure (in. H2O)	1.75
Return fan static pressure (in. H2O)	0.25
Supply fan hp	5
Return fan hp	2
Heating coil	
Entering air temperature (°F)	40.0
Leaving air temperature (°F)	100.0
Entering water temperature (°F)	180.0
Leaving water temperature (°F)	160.0
MBtu/hr	208
gpm	21
Cooling coil	
Entering air temperature (°F)	82.0
Leaving air temperature (°F)	54.4
Entering water temperature (°F)	44.0
Leaving water temperature (°F)	54.0
MBtu/hr	135
gpm	28

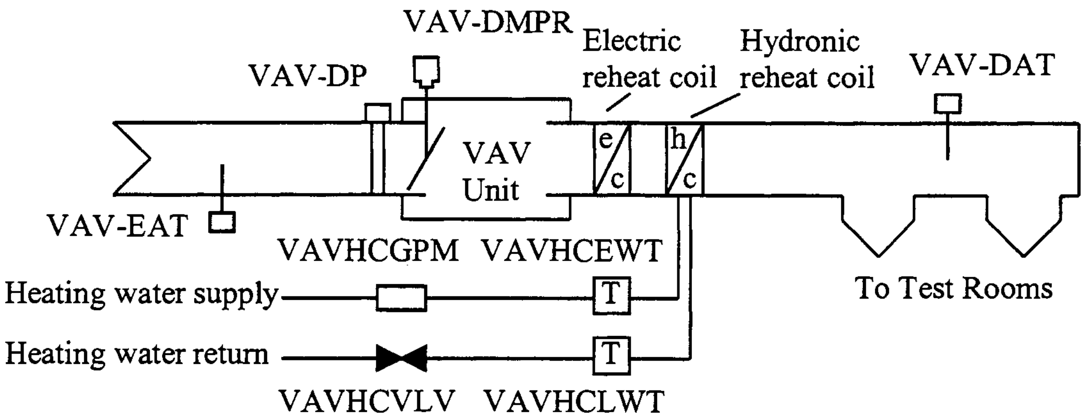


Figure 2.5 Variable air volume box schematic.

Table 2.3 Mechanical equipment specifications.

CHILLER	Value
Capacity	
Nominal tons	9.5
kW/Ton	1.15
EER	10.3
Steps of unloading	100 ~ 50
Evaporator Performance	
Inlet temperature (°F)	54
Outlet temperature (°F)	44
gpm	24
Maximum pressure drop	20 ft. H2O
Condenser Performance	
Refrigerant	R-22
Number of fans	2

PUMP	gpm	Head (ft. H2O)	rpm	hp	Pump efficiency (%)
For cooling					
Chiller (circulating)	24	50	1,750	1.0	40
AHU coil	28	26	1,750	0.5	48

provided by a 10-ton external air-cooled chiller, a 149 ton-hour thermal energy storage (TES) unit, or chilled water provided by the DMACC campus chilled water plant. A manual valve is used to switch between the various cooling systems. Chilled water is provided to the two test units using fixed speed pumps. Table 2.3 gives specifications for the on-site chiller, the TES unit, and the chilled water pumps. Figure 2.6 contains a schematic for the chilled water system.

W - electric power transducer

P - pressure transducer

F - flow meter

T - temperature probe

CHWP - chilled water pump

* - Point listed in Table A.7 for cooling plant

† - General Area System point

‡ - Point listed in Table A.9 for AHU-A and B

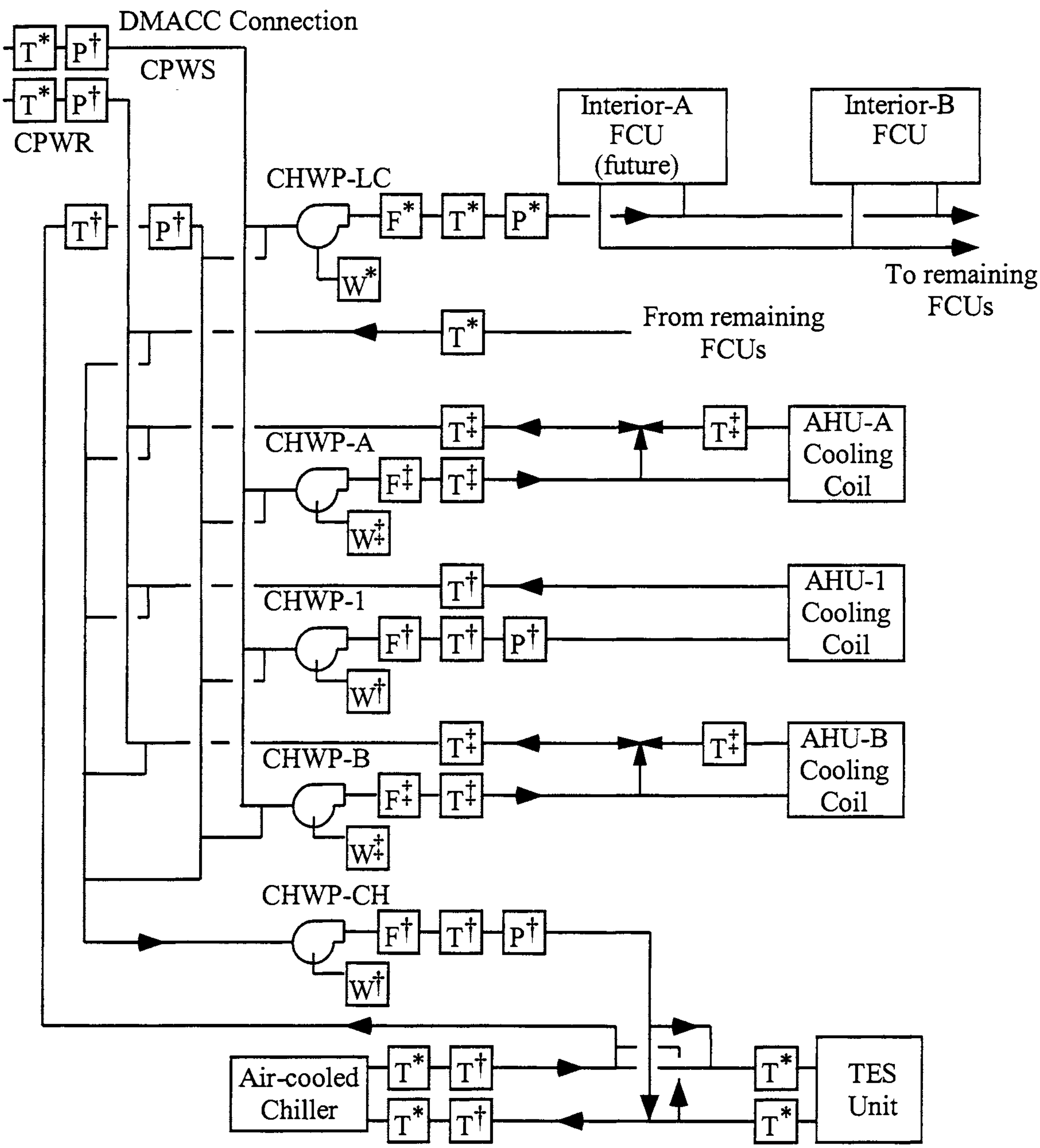


Figure 2.6 Chilled water flow diagram.

WEATHER STATION

The weather station is located on a mast extending several feet above the roof on the northwest corner of the building. The instrumentation located on the mast measures dry-bulb temperature, relative humidity, wind speed, wind direction, and barometric pressure.

A pyrheliometer and a pyranometer are located on the roof of the building. The pyrheliometer measures the beam radiation at the normal incidence using a collimated detector. The pyrheliometer is mounted on an electrically driven equatorial mount solar tracker and is geared to solar time to ensure continuous measurements. The pyranometer measures beam and diffuse solar radiation on a horizontal surface.

Light sensors are also installed on the vertical east, west, and south walls of the building between the two test rooms. One sensor measures the total light on the vertical surface while the other measures only the ground reflectance. Figure 2.7 shows a photograph of the vertical light sensors.

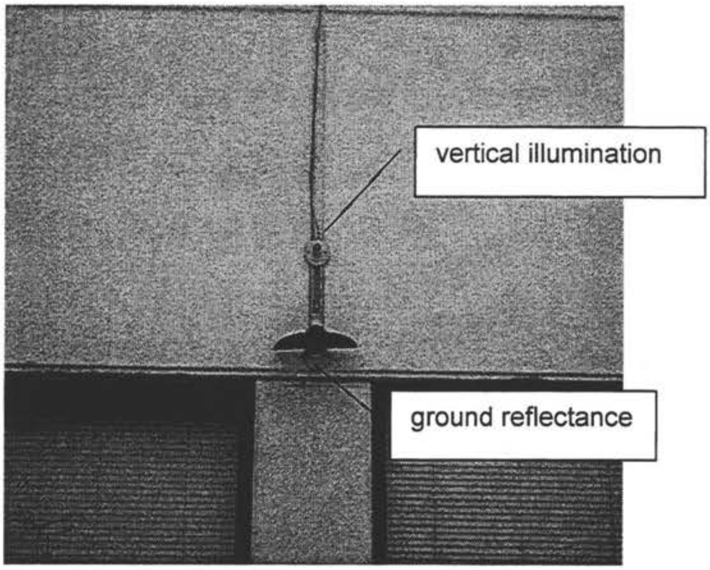


Figure 2.7 External vertical light sensors between A and B test rooms.

CHAPTER 3. EXPERIMENTAL ENERGY COMPARISONS

Eight daylighting tests were conducted at the ERS to study the effect of daylighting on energy consumption. The tests were spaced throughout the year in an attempt to achieve a variety of declination angles. The data collected during these tests were examined for reliability. Five tests were found to have reliable data, and the valid days from those tests were used in the experimental study. The remaining tests lacked good data readings for important measurements. A final list of the test days is found in Table 3.1.

The experiment was designed to emulate an unoccupied commercial building environment. Both test AHUs were set to the same specifications: 100% recirculated air (no outside air) and a supply air temperature of 58 °F. All six test rooms examined in these experiments used electric reheat at the VAV box and a minimum and maximum air flow rate of 450 and 1,000 cfm, respectively. The heating set-point temperature was 72 °F and the cooling set-point was 73 °F. The lights were set to come on at 6am and turn off at 8pm. Sheetrock was placed over the interior windows to prevent light interactions with the media center. The test room doors were closed and locked.

Table 3.1 Analyzed test days.

Test	Dates
Test 1	August 15, 2000 – August 22, 2000
Test 2	April 3, 2001 – April 8, 2001
Test 3	May 1, 2001 – May 7, 2001
Test 4	May 22, 2001 – May 23, 2001
Test 5	June 23, 2001 – July 1, 2001

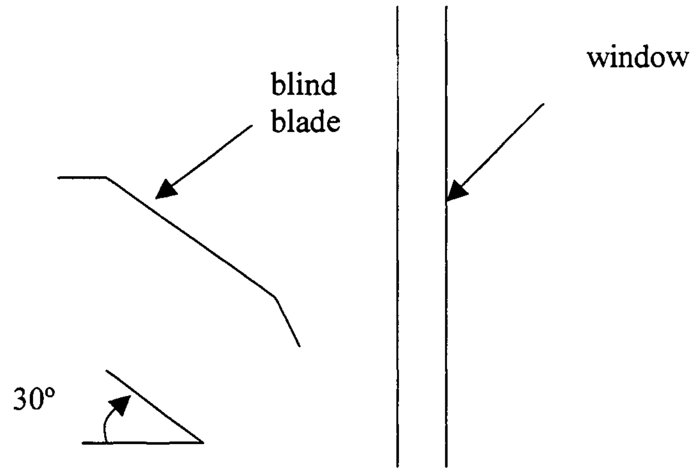


Figure 3.1 Schematic of the blind blade angle.

Blinds were installed on the windows and the blind angle was set at the beginning of the first test and held constant for the remainder of the tests. The blind angle was set such that there was maximum light and minimum glare at the time of the first test, at approximately 30°. A sketch of the final blade angle configuration is found in Figure 3.1.

Sensors were installed throughout the room during the daylighting tests. One sensor was placed on a table in each test room to simulate a desktop work plane. A sensor was located in the ceiling to measure the light level seen by the daylighting control system sensor. A final light sensor was mounted with a vertical orientation and placed on the centerline of the windows facing the exterior wall. The sensor was located approximately 5' from the floor and 1' from the wall. This sensor acted as a measure of the daylight entering the room and was placed to avoid light contamination from the electric fixtures. Figure 3.2 shows the layout of the lighting sensors.

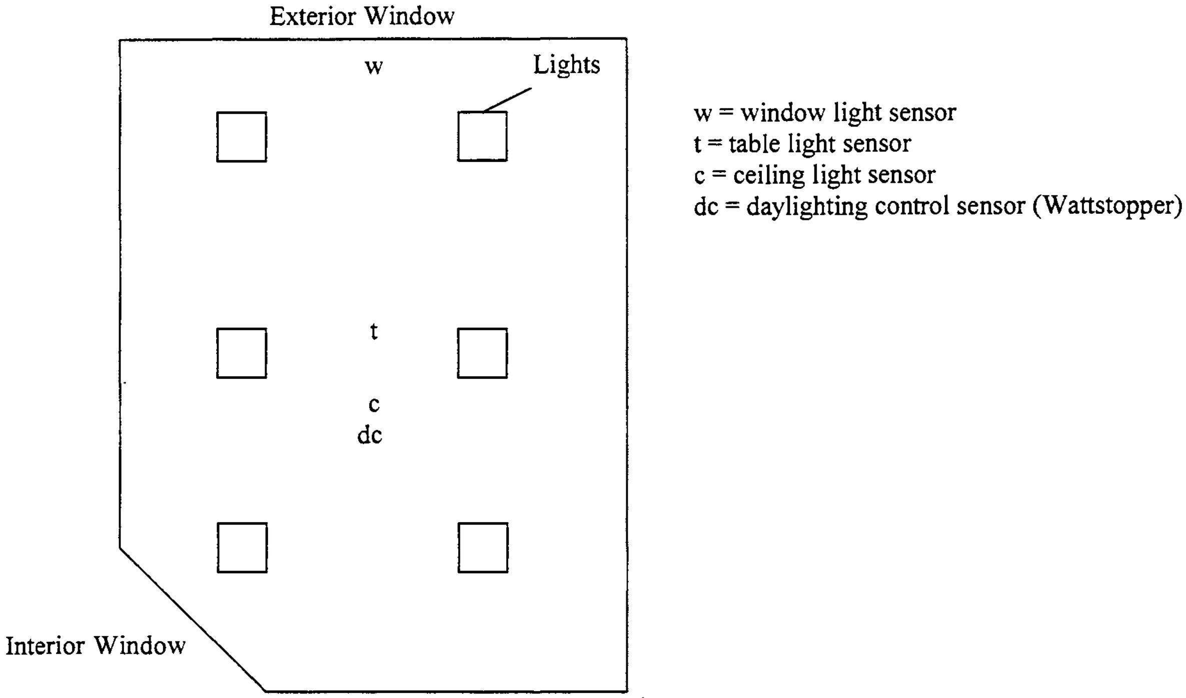


Figure 3.2 Light sensor layout for typical "A" test room (not to scale).

All the measurement light sensors were manufactured by LI-COR, photometric model LI-210SZ. The sensors were calibrated by the manufacturer against a standard lamp to within ± 5% of reading.

UNCERTAINTY ANALYSIS

As with all experimental data, the results are subject to error. The data acquisition system introduces error into every measurement made and the measurement instruments also carry a certain amount of uncertainty. Both types of error can be quantified and calculated. However, the portion of uncertainty that is perhaps the largest is a result of the building itself.

The ERS was designed as a test facility. The general purpose was to make the A and B test rooms as identical as possible. However, human error and construction allowances insure that there are differences between the test rooms, introducing a largely unquantifiable error into the experimental results. In addition, the mirror image nature of the two rooms introduces a level of error to this experiment that is not present in most other experiments conducted at the ERS. The path of the light in the room has an effect on the overall control system and therefore the experimental results. Because the rooms are mirror images and not completely identical the light cannot behave in the same manner in each room for all hours of the day. This error is also largely unquantifiable given the current level of instrumentation at the ERS.

The measurement error associated with the instrumentation at the ERS has been quantified by Price and Smith (2000). The energy calculations presented in this report are affected by the error associated by five different data points. These points and their corresponding error are found in Table 3.2. The error associated with the power measurements is applied directly to the final energy reading itself. However, the chilled water energy presented in the next sections was calculated from the chilled water flowrate and the temperature of the water entering and leaving the chilled water coil. The error

Table 3.2 Measurement error.

Data Point	Error
Chilled water flowrate	± 0.09 gpm
Entering chilled water temperature	± 0.25 °F
Leaving chilled water temperature	± 0.25 °F
Reheat power	± 0.2 % of reading
Light power	± 0.2 % of reading

associated with the three measurements is propagated through the calculation and is a function of the three data points. Details of the calculation and other error propagation equations can be found in Appendix A.

Examination of the data after the experiments were conducted showed some unusual discrepancies. The researchers expected the reheat and chiller energy measurements to be reasonably equal between the A and B test rooms during the hours of midnight and 5am. At this point in the day, the test rooms are under equal thermal conditions (wind speed, wind direction, outdoor air temperature, etc.) and there are no daylighting influences. The rooms have also had four hours to adjust to any thermal storage effects. However, some significant differences in energy measurements were observed.

There are a number of possible reasons for the discrepancies. Differences in infiltration rates, outside air flowrates, insulation properties, and control systems were all examined. The relationship between chiller energy and outdoor dry bulb temperature was looked at first. Figure 3.3 shows the difference in total chiller energy (System A minus System B) between the hours of midnight and 5am for each test day plotted against the outdoor air temperature. The figure shows a fairly strong correlation between energy and temperature. The x-intercept for the fit line is approximately equal to the supply air temperature, with energy differences above that temperature negative and below that temperature positive. In other words, when the outdoor temperature was above the supply air temperature, System B used more chiller energy than System A. System A used more energy when the outdoor temperature was below the supply air temperature. At maximum, differences are as much as 50% of chiller energy.

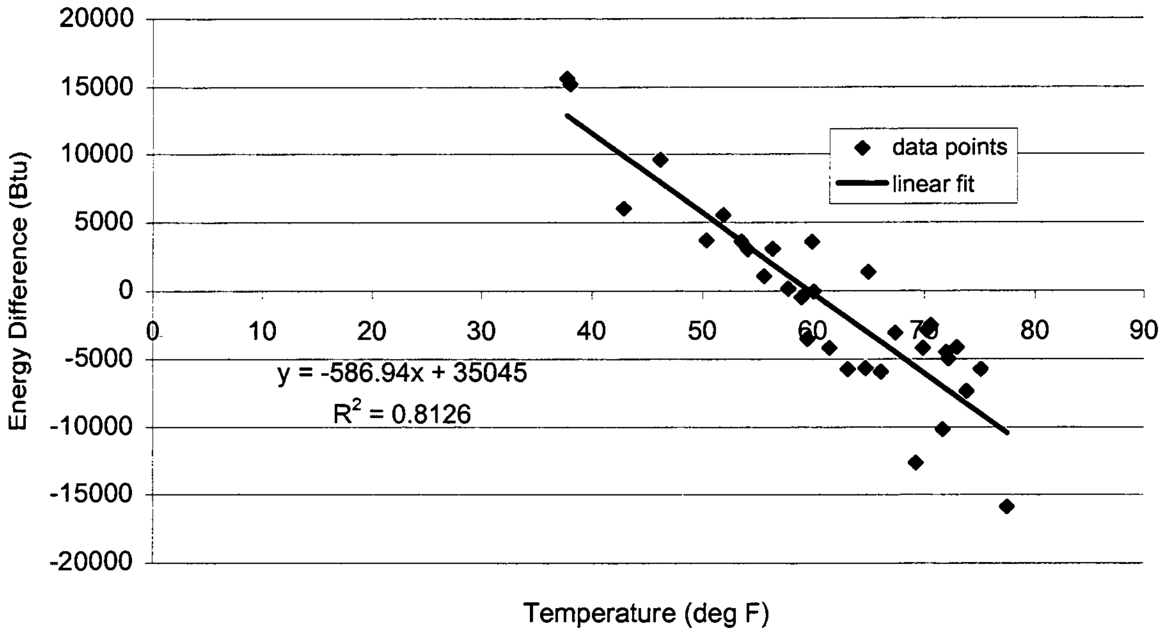


Figure 3.3 Chiller energy difference (A-B) as a function of outdoor temperature (midnight to 5am).

The most likely reason for this discrepancy is leakage in the outdoor air dampers. The experiment set-up specified no outdoor air to either HVAC system, but it is possible some leakage occurs through the damper system. When the outdoor air temperature was lower than the supply temperature, the air into the cooling coil for System B was cooler than System A resulting in lower chiller energy. Examination of the test data after the experiments were conducted shows a small outdoor air flowrate into both systems. Neither system showed significantly larger flowrate than the other. In general the average flowrate seemed to be approximately 2-3% of the total flowrate through the system. However, it is believed that even a small amount of outside air could affect the chiller energy in a noticeable manner. The ERS uses a pressure differential to measure the air flowrate in the duct, a method that introduces significant error at low velocities and could call the actual magnitude of the flowrate into question.

Further investigation into the facility is necessary before a conclusion can be made on the actual cause of the chiller system discrepancy. Regardless of the error, however, there is a definite correlation between outdoor air temperature and chiller energy difference. Therefore, the chiller energy was adjusted to account for the discrepancy by adding the energy difference to the System B results to correct the error. All System B chiller data reported in this chapter were adjusted according to this correlation.

The reheat energy was also examined for possible discrepancies. The difference in reheat energy for the hours of midnight to 5am was plotted versus outdoor dry-bulb temperature. The plot was repeated for each set of test rooms for all test days. The results of the plots are found in Figure 3.4. This plot would provide information on differences in heat transfer rates to the exterior between the test rooms. As seen in the figure, no clear correlation was found between reheat energy differences and outdoor air temperature. Based on the data collected during the experiment, there do not seem to be any significant differences in heat transfer rate to the exterior between the two test rooms.

Control system performance was investigated next. The product of supply air temperature and supply airflow rate was used as a measure of the energy entering the room through the supply air system. The sum of this energy for the A and B test rooms over the hours of midnight to 5am was placed on a bar graph. Results of these graphs for Test 1 can be found in Figure 3.5. Based on this data, the difference between the A and B rooms in energy entering the room through the supply air system is negligible. No clear evidence for reheat energy difference was found.

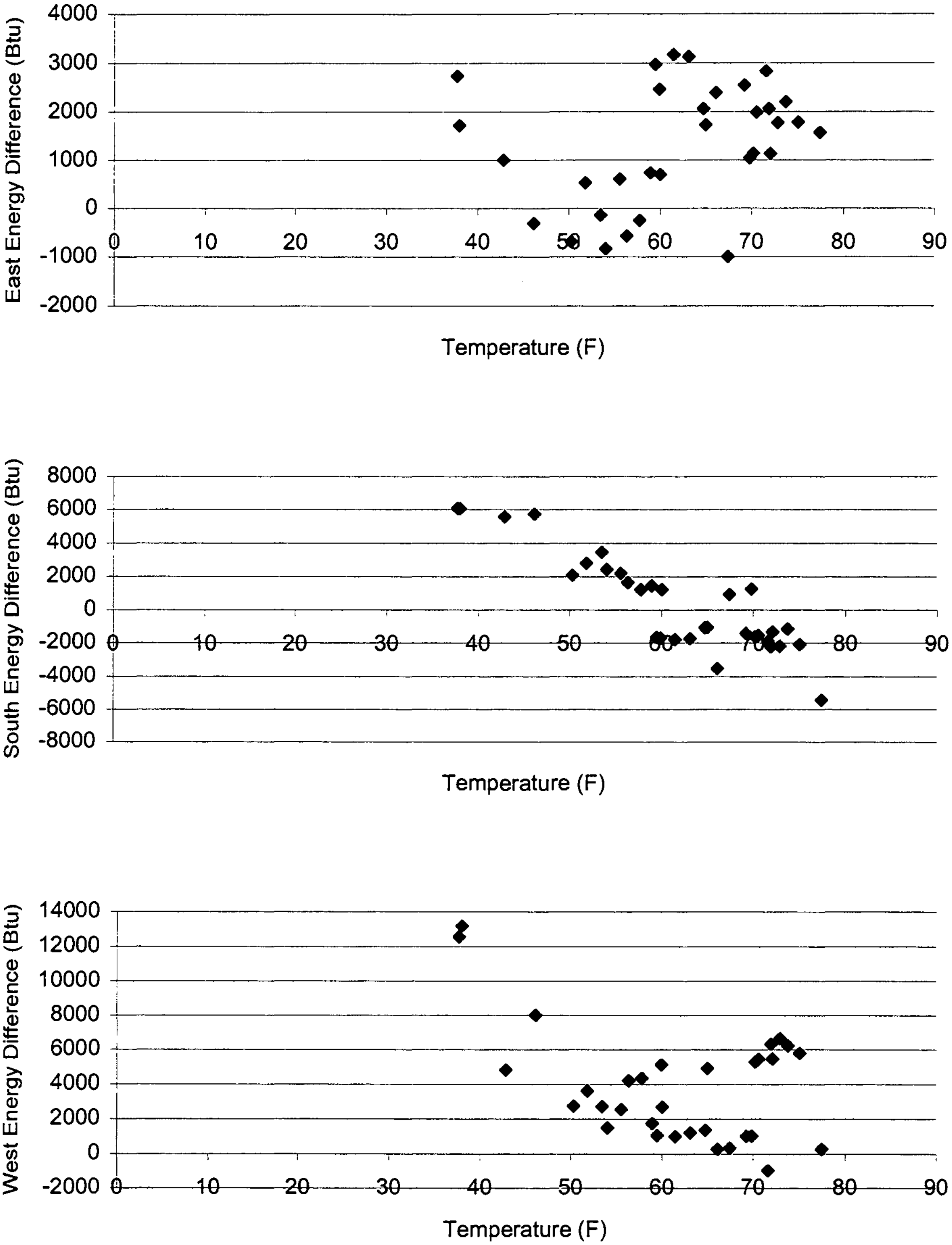


Figure 3.4 Correlation between reheat energy and outdoor dry-bulb temperature (midnight to 5am).

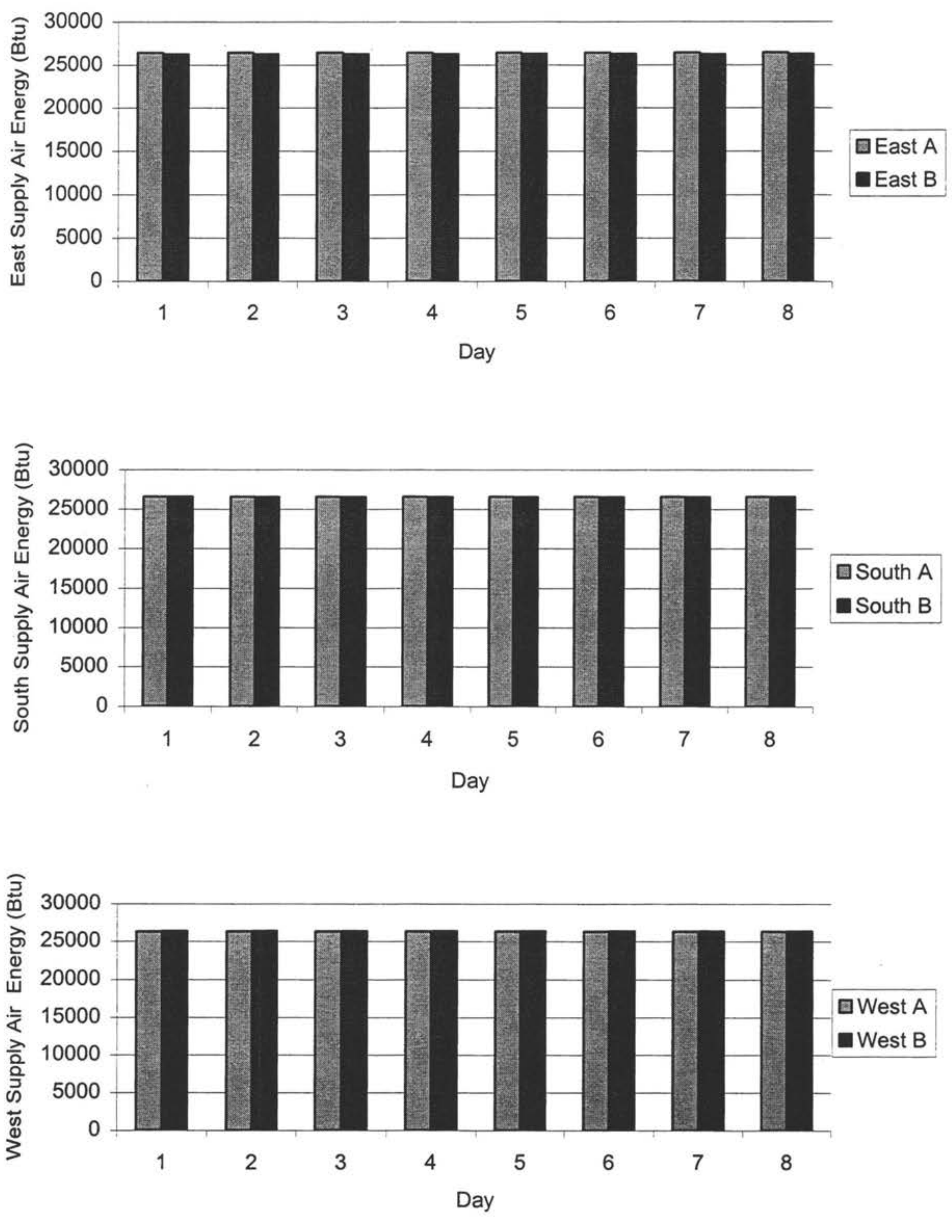


Figure 3.5 Supply air system uncertainty analysis for Test 1 (midnight to 5am).

Finally, the effects of infiltration rate were examined. The hourly average wind direction was examined for each test day to find a series of days for the analysis with similar wind directions. This method was chosen in an attempt to remove the effect of wind direction and as a first approximation to the infiltration analysis to determine whether a correlation existed. The researchers noted that the data did not show any test days with westerly winds, though the westerly wind is the prevailing wind direction for this area. Upon further investigation, the wind direction indicator at the ERS was examined and found to be faulty. Without accurate wind direction data, the infiltration rate could not be investigated.

Based on the data presented, there do not seem to be any obvious construction- or control system-based disagreements between the A and B test rooms. However, more examination and research should be conducted on the ERS to resolve the differences found in the test rooms. For the purposes of this thesis, the only error associated with the reheat energy will be the measurement error presented in Table 3.2. However, as noted earlier in this section, the data for the chiller energy was adjusted to account for the leak in the outdoor air damper for System B.

Investigation of the ERS after these experiments were performed showed evidence of temperature stratification in the test rooms. Temperature sensors were placed at one foot increments from the floor to the ceiling and the temperature was measured in one minute increments throughout the day for 11 test days. Figure 3.6 shows the results for January 3, 2002. The plot shows the stratification between the floor and the ceiling. Each line represents a different temperature sensor. The beginning of the day had a temperature difference of approximately 20 °F between the floor and the ceiling in the test room. The fluctuations in the temperature are a result of different stages of electric reheat. The figure shows that adding reheat energy to the supply air does not affect the lower temperature sensors at all. Researchers investigated various methods to improve the air mixing within the room. The final solution involved blocking one of the air supply diffusers to force all of the supply air through the other diffuser. In addition, vanes in the diffuser were changed to force the air down to the floor instead of spreading it across the ceiling. The figure shows that the room air temperature stratification decreased as a result of the diffuser modifications. However, it is likely that this stratification problem existed during the tests presented in this thesis.

The data collected during the tests are not extensive enough to prove what rooms experienced stratification, the actual effect of the stratification, or a possible correlation to

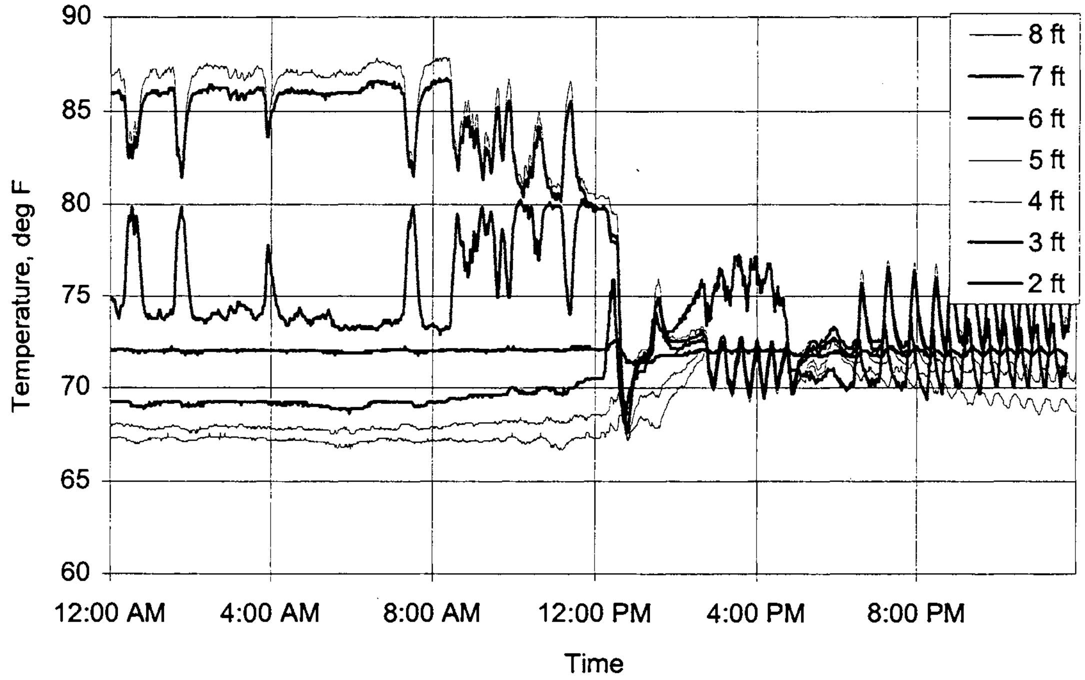


Figure 3.6 Stratification temperature measurements on January 3, 2002.

correct the error. Overall, stratification in the test rooms would produce higher than necessary reheat values.

DAYLIGHTING WITH VENETIAN BLINDS

The most direct energy savings with a daylighting control system are in the form of lighting energy resulting from the reduction of lighting power. The purpose of the daylighting system is to reduce the amount of power used by the electric lights. The quantity of power saved is a direct result of the amount of light that enters the room and therefore the amount of light that is incident on the building. Of course, the relationship between incident light and natural interior light is a function of both the declination angle of the sun and the blade angle of the blinds. In general, however, higher exterior insolation will result in lower lighting power.

Lighting Power

The effects of exterior insolation can be seen more fully by tracing the light as it makes its way to the control sensor. Figure 3.7 shows the hourly average* light levels incident on the exterior of the building for April 6, 2001 and April 8, 2001. The figure shows the light level on the vertical surfaces (east, south, and west) and also the light incident on the horizontal roof surface (global) for each day. It is clear when comparing the two days that April 8 was a much brighter, sunnier day than April 6. Further, Figure 3.7 shows the same light level for all three vertical sensors for every hour on April 6, indicating that the exterior

* All plots contained in this thesis show the hourly average of the value presented. The average was calculated from the data collected over the previous hour. Example: The value for hour 1 is the average of the data from midnight to 1 am.

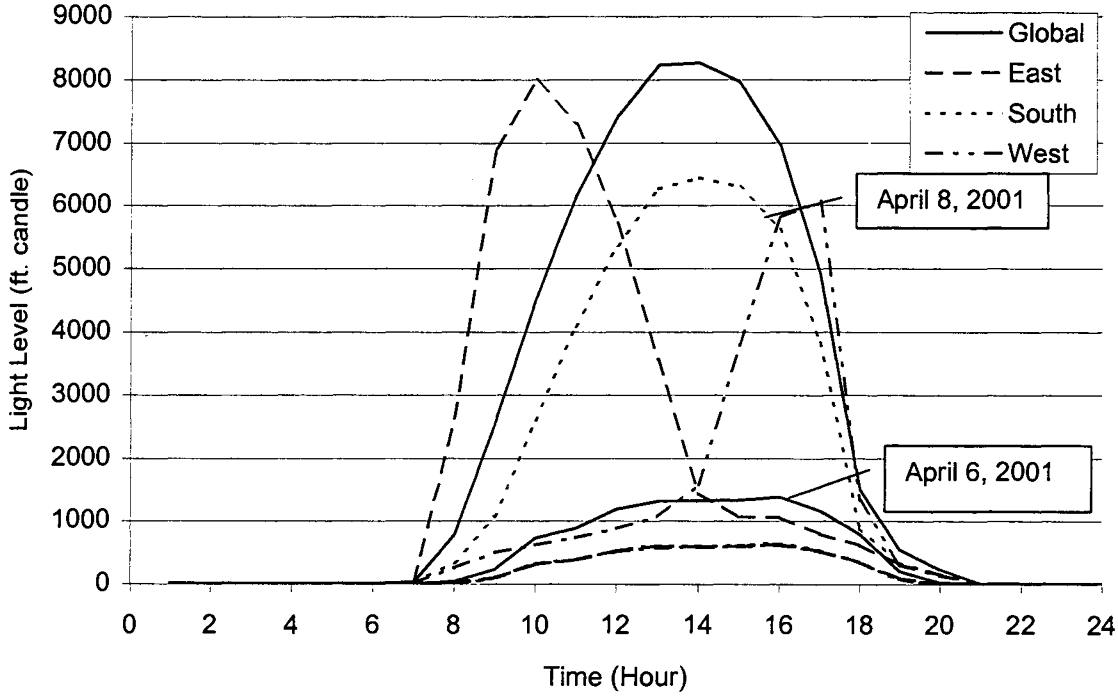


Figure 3.7 Exterior light levels for April 6, 2001 and April 8, 2001.

light levels were entirely diffuse – the day was completely cloudy for all daylight hours. On April 8, the east and south side vertical sensors show fairly symmetrical bell curves for light level readings, while the west side peaks early and drops off sharply. This indicates a largely clear day that became more cloudy as it progressed. By late afternoon, the day became mostly cloudy.

Of course, not all of the incident light on the exterior of the building enters the room. Figure 3.8 shows the average hourly light levels for the window light sensor in the B test rooms on April 6 and April 8. This is an indication of the amount of exterior light that traveled through the glass and blinds and into the room. Comparing this figure to Figure 3.7, it is clear than only approximately 20% of the light incident on the exterior of the building

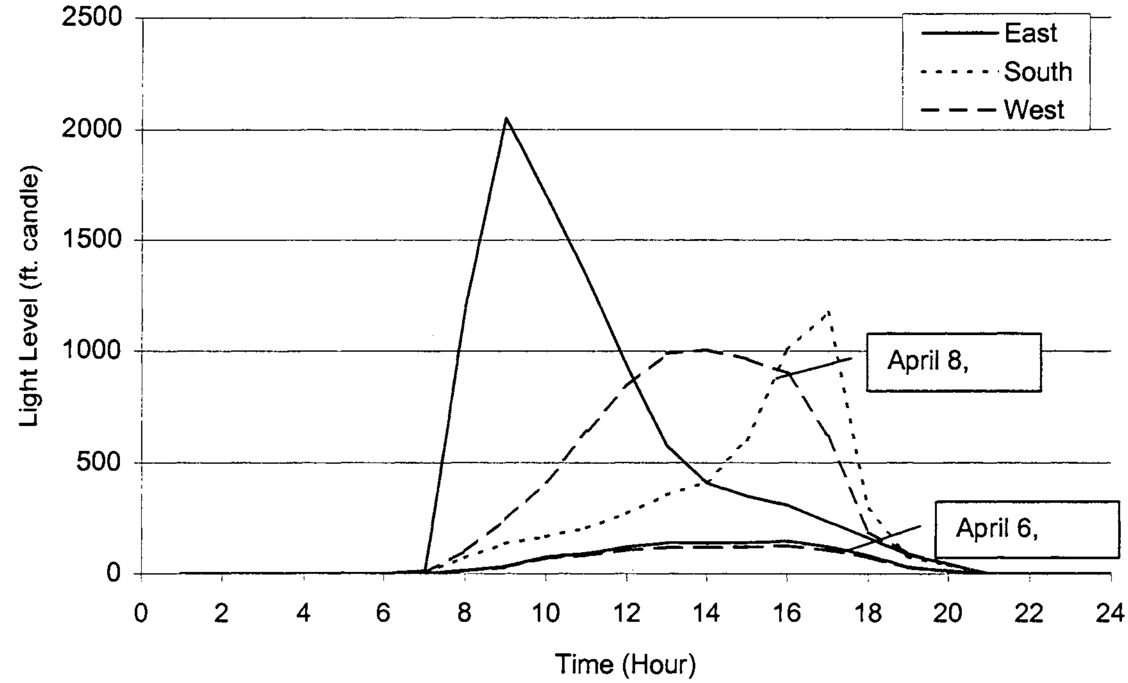


Figure 3.8 Room B window light levels for April 6, 2001 and April 8, 2001.

was sensed in the room on April 6. Approximately 15 – 25% of the light incident on the exterior of the building was measured in the room on April 8.

The control system senses the amount of light reflected off the work plane using the ceiling sensor and attempts to maintain a constant light level. Although the experiment included light sensors on the table and in the ceiling to measure incident light level at those locations, the light level measured there is no longer exclusively natural. Effects from the interior lights are included. Figure 3.9 shows the table light levels for South Rooms A and B on April 6 and April 8. The figure shows that the table light level in Room B stays relatively constant on April 6, while the level in Room A increases until solar noon then decreases before reaching the B room levels. The explanation for the pattern can be found by looking at a plot of the lighting power for the South Rooms on April 6, also found in Figure 3.9.

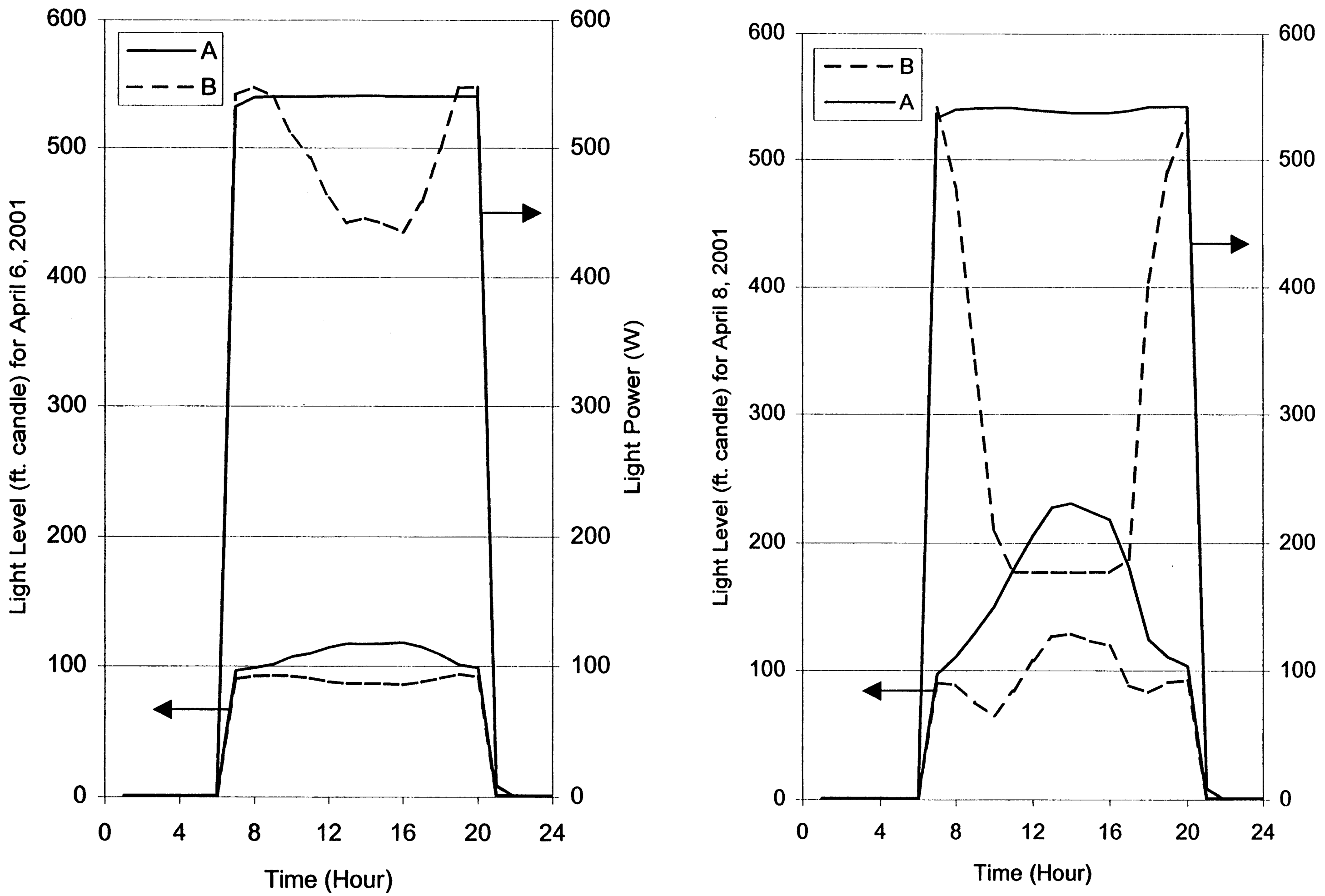


Figure 3.9 South Room A and B light power and table light levels for April 6, 2001 and April 2, 2001.

South Room A shows constant light power throughout the day resulting from the conventional lighting control strategy. Because of the constant electric power, the light levels in the room increase until solar noon because the natural light increases. However, in the B test room the electric light levels are changing in response to the outdoor light levels and therefore the interior light remains fairly constant throughout the day.

This trend becomes clearer when looking at data for a sunny day. Figure 3.9 shows the table light level and lighting power for South Rooms A and B for April 8. Figure 3.9 shows that although the light level is much lower in the B test room it is no longer constant. Once again the lighting power explains why. The dimmable ballasts reached minimum light levels (30%) early in the day and were forced to maintain that level for some hours. Because of the now constant electric light output, the interior light levels fluctuated in response to the natural light incident on the exterior.

Heating and Cooling Modes

The HVAC system maintains room temperature conditions by varying reheat power and airflow rates. Constant temperature supply air is sent to the test room from the AHU. In heating mode, the electric reheat coil in the VAV box is activated to heat the air before it enters the room, maintaining a constant room temperature. In cooling mode, the electric coil is turned off and the volumetric flow rate of the supply air is increased to maintain the thermostat set-point. The interior loads in the daylighting tests were low enough that the HVAC system was most often in heating mode. In heating mode the daylighting system should require more heat than the conventional lighting controls because a lower light wattage results in a lower light load to the space, thus increasing the energy required by the

HVAC system. In cooling mode, the opposite occurs and the energy usage of the HVAC system should be lower.*

Heating and cooling modes can be determined by studying a plot of the electric reheat energy or a plot of the airflow rate. In cooling mode, the plot of electric reheat energy shows no power into the system, indicating the coil has been turned off and the system is no longer in heating mode. The corresponding plot for airflow rate shows a spike in airflow for the same time period, indicating an increase in supply air to offset the increased loads in the space. This can be seen in Figure 3.10 which shows the reheat energy and airflow rate for each A test room for June 26, 2001. The reheat energy plot shows zero power for all three test rooms during some of the daylight hours, while the airflow rate plot shows spikes above the minimum set flowrate.

There is a third state for the HVAC system that is neither heating nor cooling mode. In this state the electric reheat coil is off, but the interior loads are accounted for by a near-minimum airflow rate and there is no significant increase in cooling energy. This is illustrated in Figure 3.11 which shows the reheat energy and airflow rate for each B test room for June 26, 2001. The reheat energy plot shows that the South B test room required no electric reheat power from the hours of 2:00 to 5:00pm. However, the airflow rate plot shows no significant increase in the airflow rate to the South B test room during those hours, indicating that the room is not in cooling mode. In general, the reheat energy plot indicates when the test room is in heating mode and the airflow rate plot indicates when the room is in

* Not all of the heat from the lights goes into the space to be seen by the thermostat. Some of the heat goes directly to the plenum. The plenum heat affects the chiller energy in the space, but because it is not seen by the thermostat, it does not affect the reheat energy.

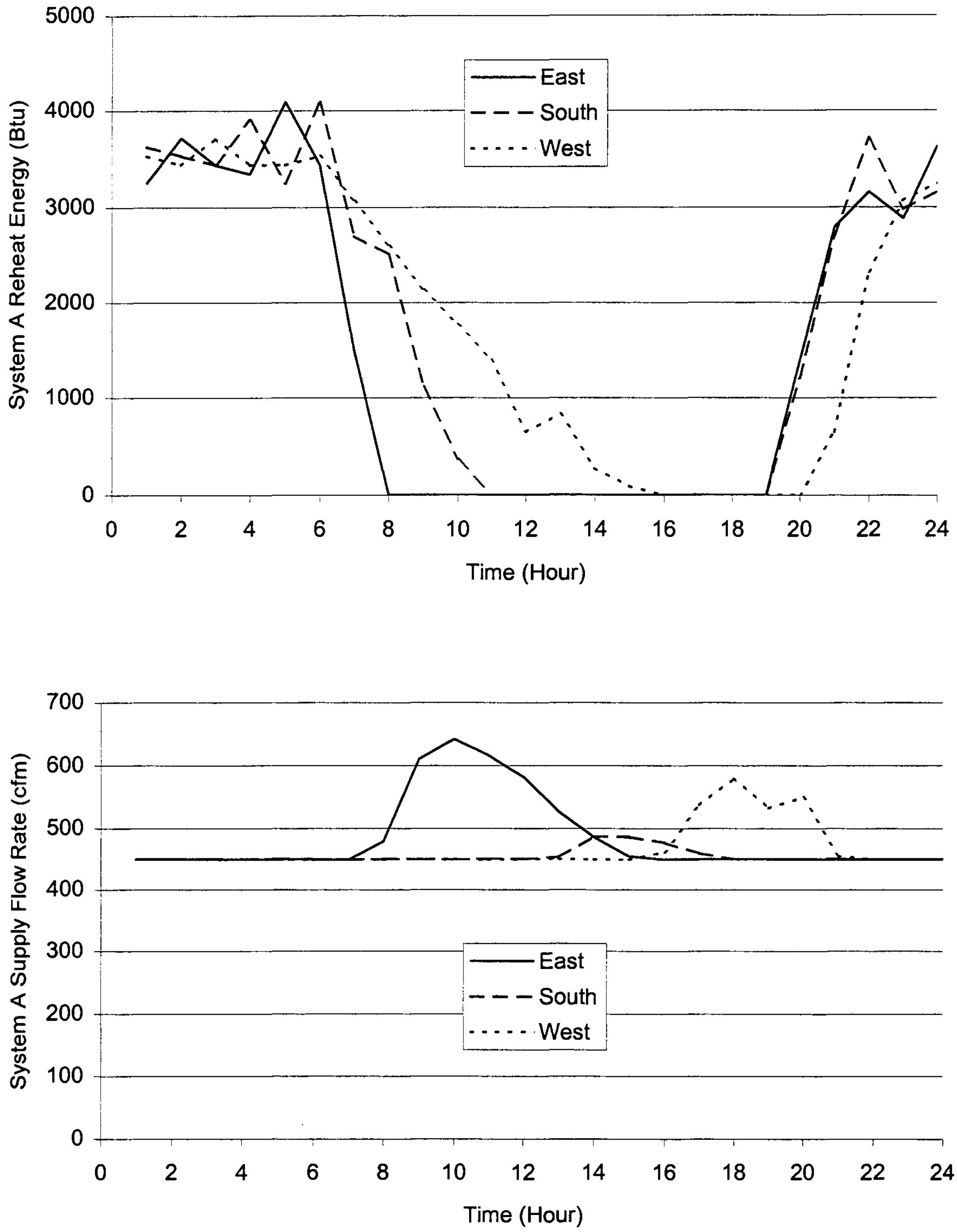


Figure 3.10 Hourly average System A reheat energy and supply air flow rate for June 26, 2001.

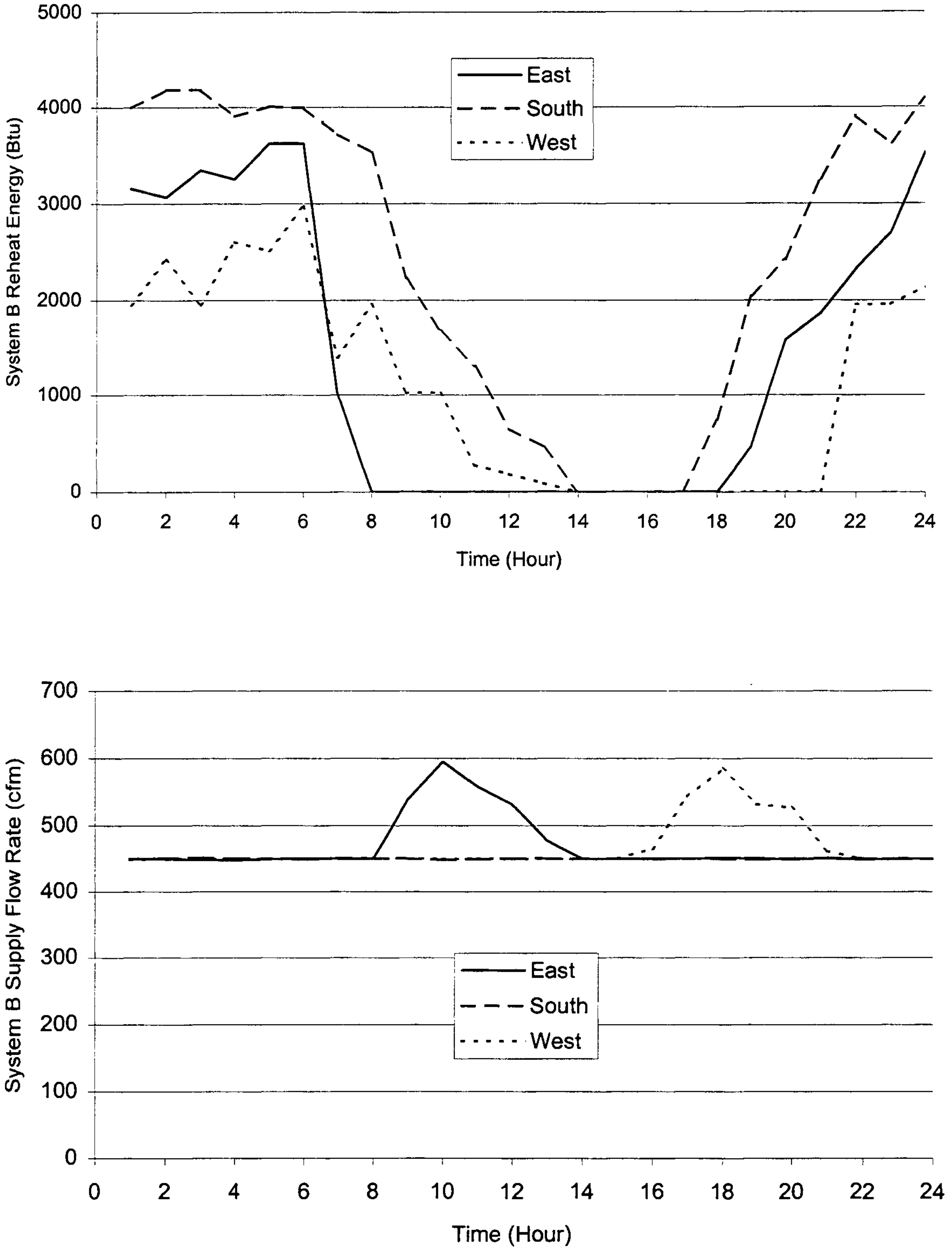


Figure 3.11 Hourly average System B reheat energy and supply air flow rate for June 26, 2001.

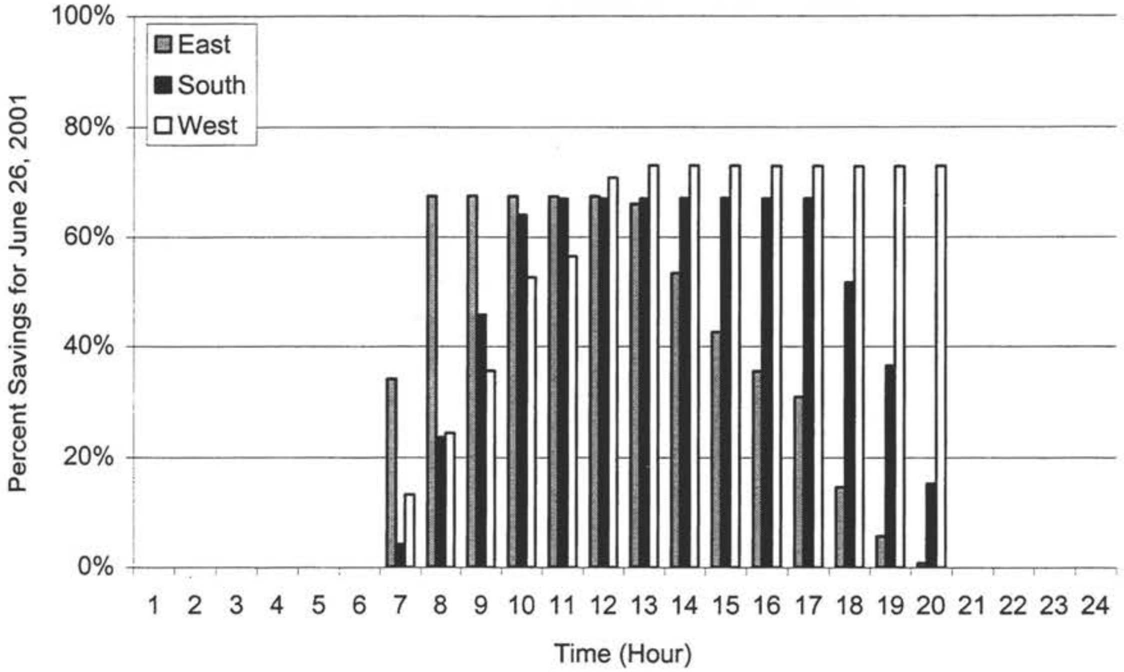
cooling mode. Only a comparison of the two plots will indicate when the room does not fall into either mode.

Energy Savings

Does daylighting control really increase overall energy usage while in heating mode? And how much energy is actually saved in cooling mode? To answer these questions, one must examine the percent energy savings between the A and B test rooms. Figure 3.12 shows a plot of the percent savings in light energy for the B rooms over the A rooms for June 26, 2001 and April 6, 2001. Maximum energy savings of approximately 70% were achieved for the morning hours in the east, the midday hours in the south, and the afternoon hours in the west. Differences in maximum percent savings are due to differences in ballast dimming capabilities and are a product of the manufacturer's quality control system. April 6 was cloudy and lighting power savings were relatively minimal. However, Figure 3.12 shows that lighting power savings of nearly 20% were still achieved in each of the test rooms.

Table 3.3 shows the percent lighting power saved for each test day. The daily power savings were calculated by summing the energy for each A and B room for the day and determining the percent savings based on those sums. Power savings ranged from as low as 1.8% to as high as nearly 60% for the day.

Figure 3.13 shows the percent reheat energy saved between the A and B test rooms for June 26, 2001 and April 6, 2001. The plot for April 6 shows relatively small energy differences between the two rooms, but with large fluctuations in percent savings from one hour to the next. This is in large part due to the volatility of the reheat energy measurements in comparison to the lighting energy measurements. Figures 3.10 and 3.11 in the previous



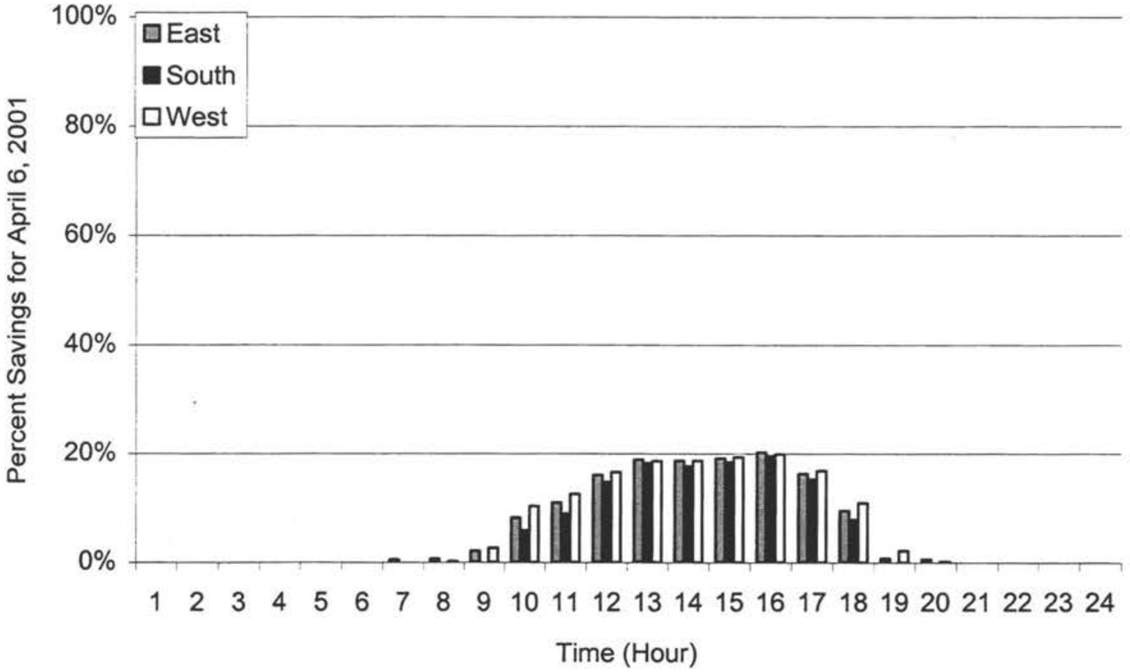
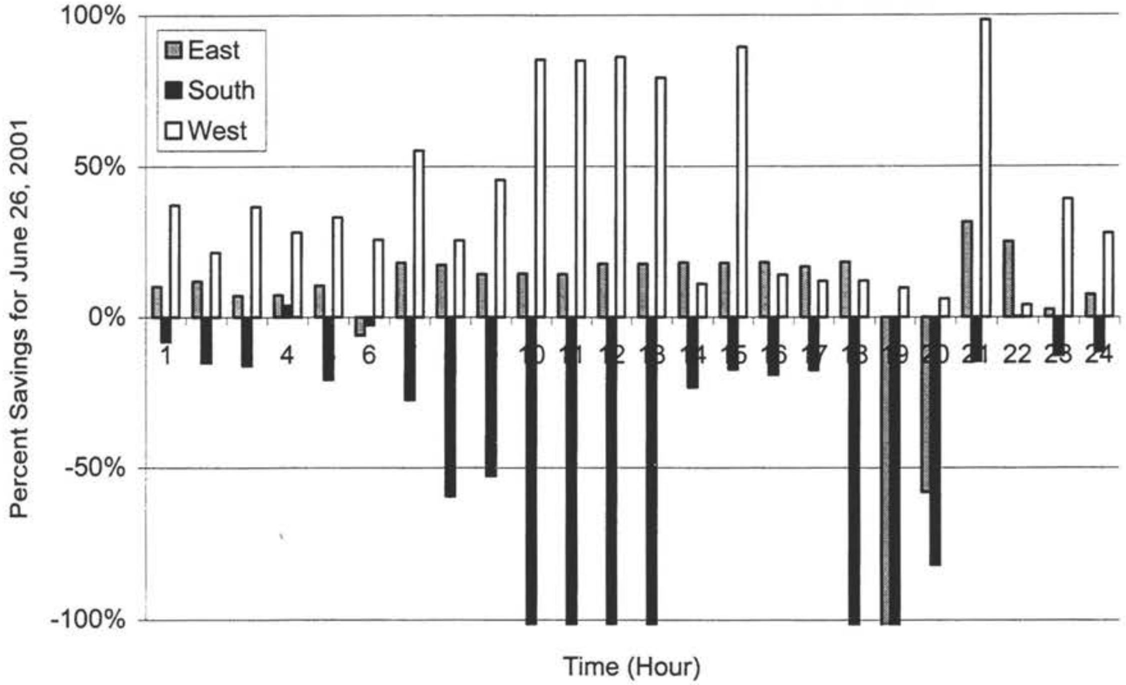


Figure 3.12 Percent savings lighting energy for June 26, 2001 and April 6, 2001.

Table 3.3 Percent lighting energy saved.

Date	East	West	South
Test 1			
August 15	27.54%	37.32%	34.56%
August 16	49.75%	34.30%	46.37%
August 17	31.75%	9.53%	25.55%
August 18	56.71%	41.36%	52.91%
August 19	42.77%	23.26%	35.66%
August 20	43.98%	22.61%	36.89%
August 21	33.78%	26.35%	32.03%
August 22	30.05%	25.34%	27.82%
Test 2			
April 3	38.00%	48.23%	38.59%
April 4	50.62%	45.22%	46.15%
April 5	17.53%	19.61%	17.47%
April 6	10.14%	10.61%	8.59%
April 7	50.81%	50.01%	46.43%
April 8	50.73%	38.84%	43.69%
Test 3			
May 1	39.23%	36.07%	42.74%
May 2	2.73%	4.33%	1.83%
May 3	12.31%	19.29%	19.30%
May 4	6.11%	15.12%	13.54%
May 5	4.49%	16.21%	14.54%
May 6	20.57%	36.29%	33.12%
May 7	41.78%	53.45%	45.93%
Test 4			
May 22	33.50%	52.03%	42.73%
May 23	24.24%	42.16%	33.11%
Test 5			
June 23	41.35%	54.59%	46.52%
June 24	42.83%	55.37%	48.99%
June 25	42.66%	55.84%	50.03%
June 26	44.27%	59.77%	50.76%
June 27	42.75%	57.00%	51.33%
June 28	42.88%	57.42%	51.67%
June 29	44.12%	58.41%	50.24%
June 30	41.41%	52.05%	44.70%
July 1	38.82%	56.55%	44.81%



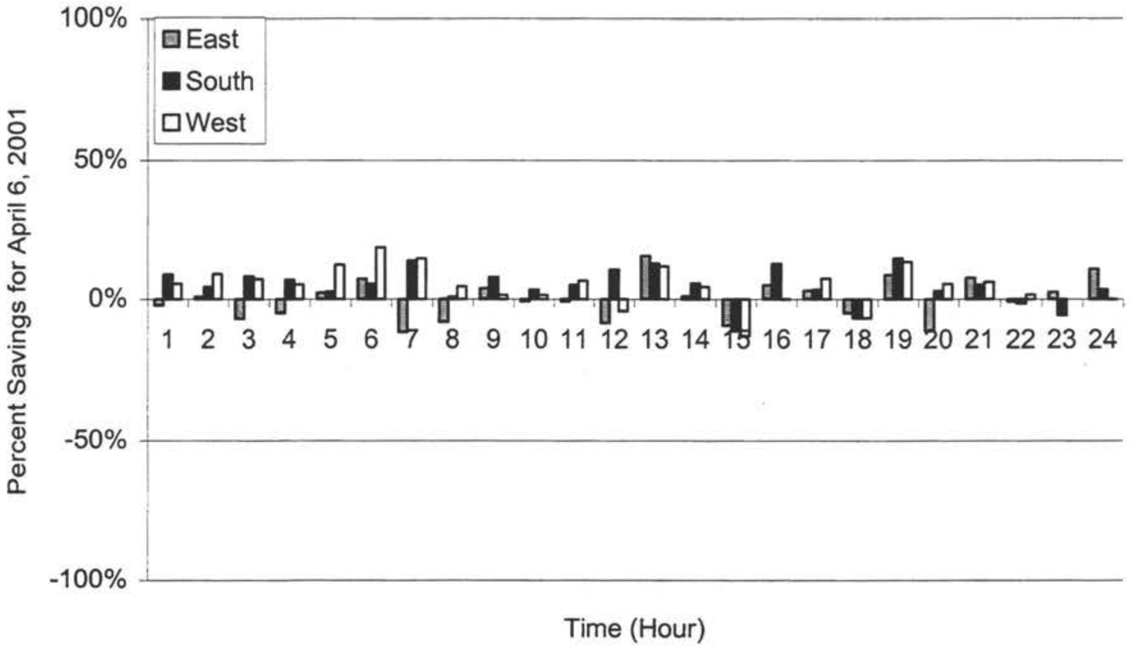


Figure 3.13 Percent savings reheat energy for June 26, 2001 and April 6, 2001.

section showed the reheat energy for the A and B test rooms for June 26. A brief comparison of the figures shows large variation in the energy measurements from one hour to the next. In addition, there are fairly large energy differences between the two systems, especially toward the middle of the day when the rooms approach zero reheat power. Even relatively minor quantitative differences during these hours can reflect large percent savings differences due to the nature of the percentage calculation. This is seen most strongly in the plot for percent reheat energy savings for June 26, 2001. The large numbers shown on the plot reflect relatively low energy measurements during those hours. When the calculations are done on a daily basis, the effects of the small measurements during the middle of the day are largely resolved.

Table 3.4 shows the daily reheat energy savings. As expected, the table shows that reheat energy is often increased with the use of daylighting. However, energy is often saved, also. As seen in the table, energy savings range from –40% in the south room during Test 5 to over 38% in the west room during Test 5.

Total electrical energy savings by room can be examined by looking at the sum of the reheat and lighting energy savings. Table 3.5 shows the daily percent savings in lighting and reheat energy for each test day. The table shows that energy is saved using the daylighting control system for every test day in the east rooms, all but one test day in the west rooms, and 19 of the 32 test days in the south rooms. Note the south test rooms for Test 5 – the percent increase in energy for the B room over the A room was drastically changed when the lighting energy was added to the reheat energy. This is more evidence of the fact that the reheat energy was relatively small over the course of that test. The impact of the lighting energy savings was large relative to the impact of the reheat energy savings because the magnitude

Table 3.4 Percent reheat energy saved.

Date	East	West	South
Test 1			
August 15	3.58%	-1.61%	-23.74%
August 16	1.80%	-2.73%	-11.33%
August 17	4.45%	-1.84%	-7.58%
August 18	3.60%	-1.50%	-11.34%
August 19	2.87%	-0.51%	-8.73%
August 20	3.06%	-0.45%	-9.01%
August 21	4.99%	-0.06%	-6.38%
August 22	4.89%	-0.93%	-3.71%
Test 2			
April 3	-0.25%	13.99%	7.87%
April 4	-4.43%	12.15%	2.85%
April 5	-0.28%	2.36%	3.53%
April 6	0.04%	5.42%	5.02%
April 7	-6.65%	2.54%	-5.23%
April 8	-4.50%	2.66%	1.70%
Test 3			
May 1	1.20%	2.86%	-13.86%
May 2	4.71%	3.25%	0.48%
May 3	1.56%	5.01%	-1.54%
May 4	1.89%	4.23%	-0.79%
May 5	1.23%	1.98%	1.07%
May 6	-0.34%	-0.22%	-5.14%
May 7	-1.64%	1.10%	-6.87%
Test 4			
May 22	-0.02%	5.41%	2.23%
May 23	0.87%	5.26%	2.59%
Test 5			
June 23	8.60%	32.56%	-39.39%
June 24	6.82%	30.74%	-40.80%
June 25	10.05%	36.70%	-37.26%
June 26	7.81%	38.71%	-30.49%
June 27	6.63%	35.14%	-33.09%
June 28	6.89%	34.82%	-30.12%
June 29	7.02%	32.91%	-32.37%
June 30	7.57%	34.96%	-37.66%
July 1	-1.00%	27.31%	-34.59%

Table 3.5 Percent energy saved, reheat and lighting combined.

Date	East	West	South	System
Test 1				
August 15	8.46%	6.42%	-9.39%	2.50%
August 16	10.56%	3.77%	0.37%	5.04%
August 17	8.93%	-0.05%	-1.77%	2.43%
August 18	13.73%	5.90%	1.59%	7.13%
August 19	9.14%	3.16%	-0.97%	3.95%
August 20	9.58%	3.17%	-1.09%	4.02%
August 21	9.39%	4.53%	0.35%	4.98%
August 22	8.79%	3.81%	1.81%	4.98%
Test 2				
April 3	5.04%	19.02%	12.32%	11.98%
April 4	5.18%	17.03%	10.28%	11.18%
April 5	2.83%	5.42%	5.94%	4.73%
April 6	1.64%	6.23%	5.58%	4.50%
April 7	5.56%	11.71%	5.14%	7.57%
April 8	6.85%	8.91%	10.03%	8.62%
Test 3				
May 1	9.39%	8.55%	-2.99%	5.00%
May 2	4.41%	3.41%	0.68%	2.83%
May 3	3.17%	7.02%	1.53%	3.96%
May 4	2.50%	5.75%	1.26%	3.20%
May 5	1.69%	4.00%	2.98%	2.89%
May 6	2.93%	5.60%	0.91%	3.15%
May 7	6.34%	9.74%	1.80%	5.95%
Test 4				
May 22	5.29%	12.00%	7.80%	8.47%
May 23	4.29%	10.36%	6.81%	7.20%
Test 5				
June 23	19.58%	39.45%	-13.54%	14.72%
June 24	20.47%	38.97%	-10.71%	16.14%
June 25	23.24%	43.57%	-6.05%	20.13%
June 26	22.61%	46.43%	-1.18%	22.52%
June 27	20.54%	42.76%	-3.68%	19.87%
June 28	20.39%	42.64%	-2.33%	20.12%
June 29	21.40%	41.90%	-3.91%	19.60%
June 30	20.29%	40.25%	-9.55%	17.74%
July 1	12.33%	35.40%	-9.76%	13.67%

of the lighting energy was larger.

The System column shows the overall reheat and lighting energy savings for all of the test rooms. This number is positive for each test day, indicating that daylighting always saved energy on a system level regardless of the amount of insolation and regardless of whether the room was primarily in heating mode. A graphical representation of Table 3.5 is found in Figure 3.14. Energy savings range from approximately 2% in August to approximately 20% in June. One possibility for the greater energy savings in June could be the lesser impact of the magnitude of reheat energy during that test. The reheat energy was small, therefore its contribution to the percent energy saved was also small, resulting in larger percentages.

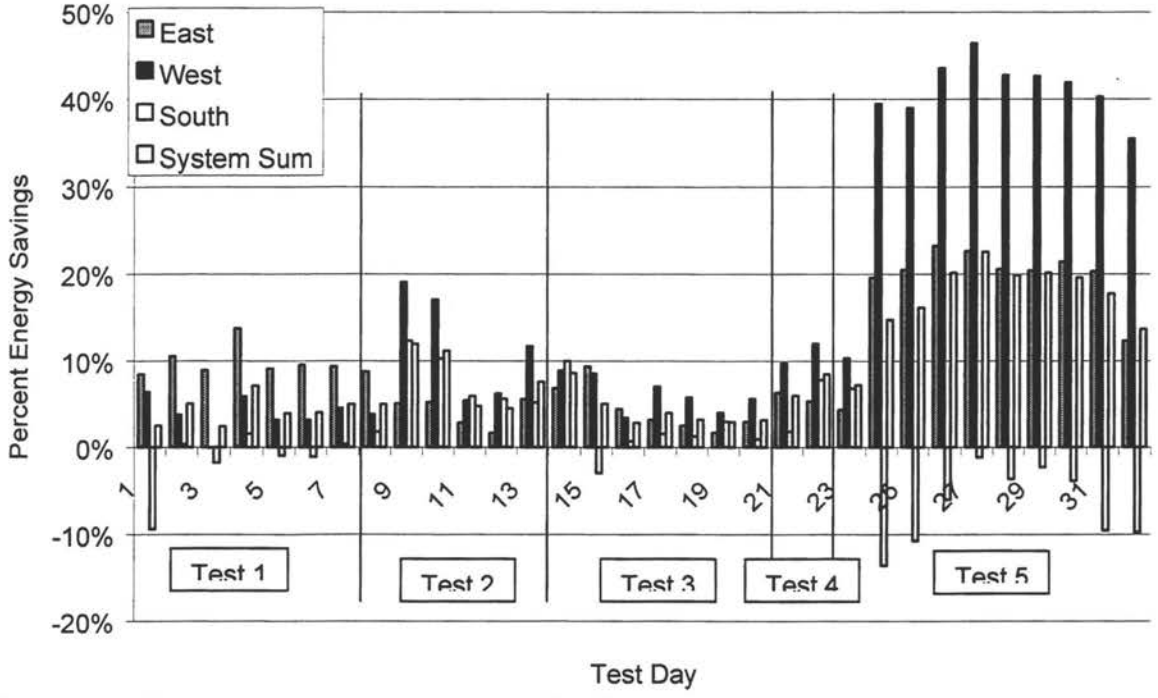


Figure 3.14 Percent energy saved, reheat and lighting.

The chiller data can be included with a system-level analysis. Figure 3.15 shows the System A and B lighting and reheat power for June 26, 2001 and April 6, 2001. On a system level it is easy to see that the B test rooms save energy over the A rooms, reinforcing the hypothesis that daylighting controls save energy. Figure 3.16 shows the chiller energy for Systems A and B for the same days. Figure 3.16 shows strong chiller energy savings for June 26 but an increase in chiller energy for room B for April 6.

Figure 3.17 shows the percent savings in total energy for System B over System A for June 26 and April 6. It's clear from the plot that significant energy is saved on June 26. However, the energy differences were smaller for April 6 and it seems there is actually an increase in energy with the daylighting system. This could be a result of the strong effect of

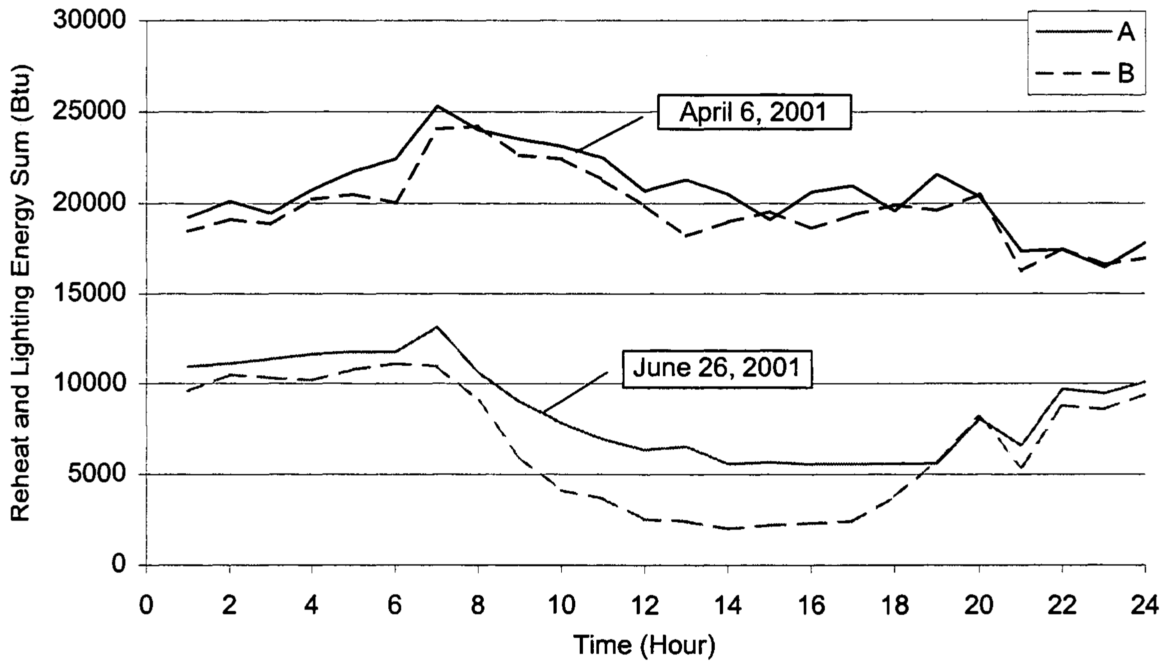


Figure 3.15 System A and B reheat and lighting energy sum for June 26, 2001 and April 6, 2001.

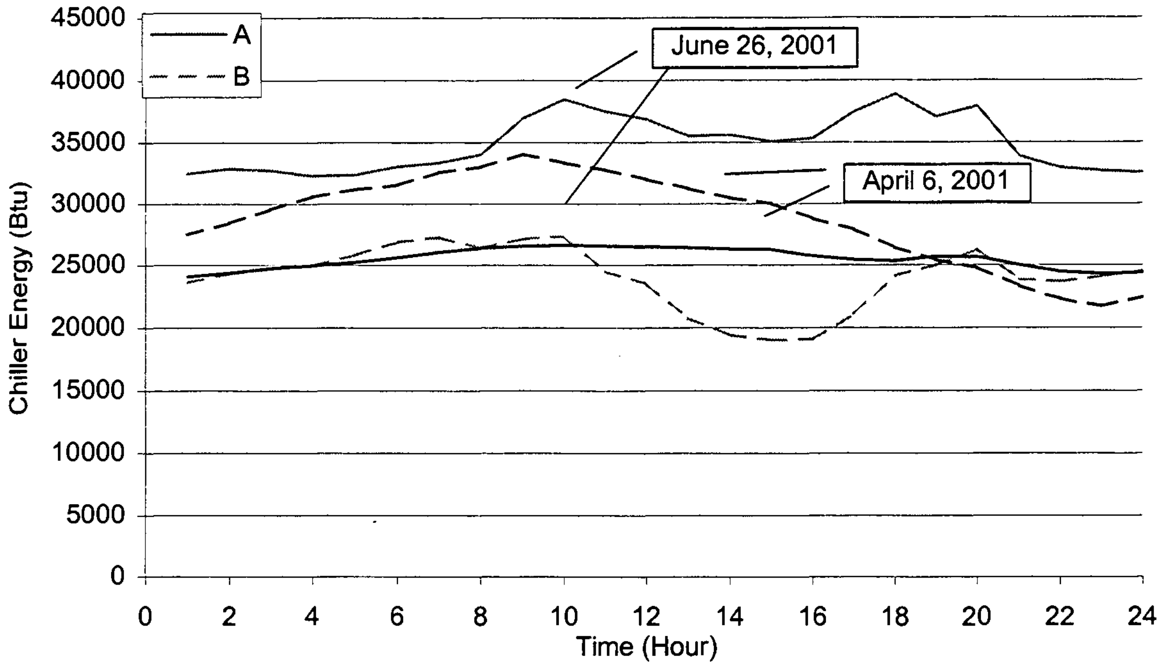


Figure 3.16 System A and B chiller energy for April 6, 2001 and June 26, 2001.

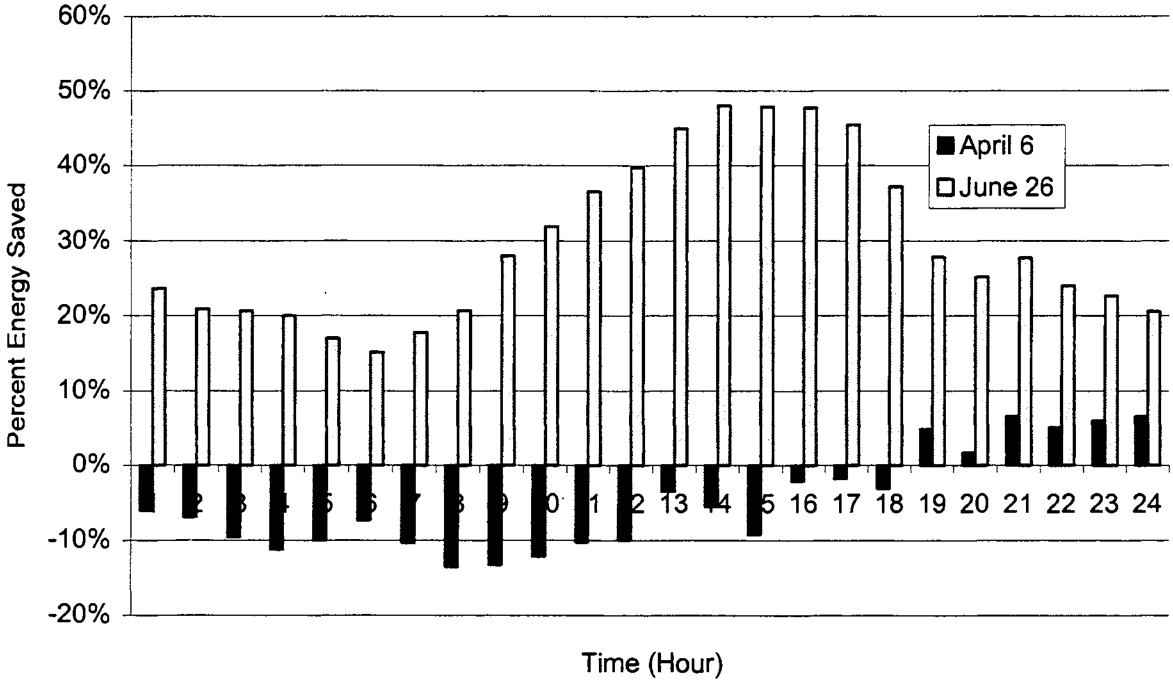


Figure 3.17 Total percent energy saved for June 26 and April 6, 2001.

chiller energy on whole-system results relative to the effect of reheat and lighting energy. In addition, the doubt placed on the accuracy of the chiller has a greater affect with little to no reheat and lighting energy changes to offset the uncertainty.

Table 3.6 shows the daily percent energy savings for each test day. The table shows that energy was saved in the lighting and reheat system on April 6. The energy increase was due to a large increase in energy for the chiller system on the same test day. The chiller energy can have a large effect on overall daily percent energy savings because the magnitude of energy usage is so large in comparison to the reheat and lighting magnitudes. However, it is not reasonable to expect the daylighting system to use significantly more chiller energy than the room with the conventional system. The results for April 6 could be reflecting the incomplete chiller energy correction data and may not be as accurate as expected.

Overall, Table 3.6 shows that energy was saved using daylighting controls for 24 of the 32 test days analyzed.

DAYLIGHTING WITH THE MINI OPTICAL LIGHT SYSTEM

One daylighting test was conducted at the ERS to study the effect of the Mini Optical Light System (MOLS) on the performance of daylighting control systems. MOLS are a window treatment developed by Architectural Energy Inc. in Boulder, CO specifically for daylighting applications. The MOLS are designed with an open upper section and a small light shelf to allow light into the room and deflect it toward the ceiling, reducing glare at the work plane. The lower section of the MOLS are fashioned similar to blinds with wide, adjustable blades that allow the occupant to adjust the amount of light entering the space. A picture of the MOLS can be found in Figure 3.18.

Table 3.6 Percent energy saved, lighting, reheat, and chiller combined.

Date	Lighting Only	Reheat Only	Reheat and Lighting	Chiller Only	Reheat, Lighting, and Chiller
Test 1					
August 15	33.13% ± 0.11%	-5.99% ± 0.17%	2.50% ± 0.13%	25.85% ± 0.25%	18.30% ± 0.28%
August 16	43.49% ± 0.09%	-3.76% ± 0.17%	5.04% ± 0.13%	18.95% ± 0.28%	13.81% ± 0.28%
August 17	22.30% ± 0.13%	-1.50% ± 0.17%	2.43% ± 0.14%	12.69% ± 0.31%	8.55% ± 0.28%
August 18	50.34% ± 0.08%	-2.84% ± 0.17%	7.13% ± 0.13%	13.28% ± 0.31%	10.97% ± 0.29%
August 19	33.92% ± 0.11%	-1.84% ± 0.17%	3.95% ± 0.14%	9.07% ± 0.33%	6.95% ± 0.28%
August 20	34.52% ± 0.11%	-1.90% ± 0.17%	4.02% ± 0.14%	10.52% ± 0.32%	7.86% ± 0.28%
August 21	30.73% ± 0.11%	-0.17% ± 0.16%	4.98% ± 0.13%	15.72% ± 0.30%	11.41% ± 0.28%
August 22	27.74% ± 0.12%	0.34% ± 0.16%	4.98% ± 0.13%	17.44% ± 0.29%	12.57% ± 0.27%
Test 2					
April 3	41.61% ± 0.10%	7.02% ± 0.15%	11.98% ± 0.13%	-31.84% ± 0.36%	-11.64% ± 0.26%
April 4	47.34% ± 0.09%	4.10% ± 0.16%	11.18% ± 0.13%	-17.64% ± 0.33%	-5.20% ± 0.26%
April 5	18.20% ± 0.13%	1.87% ± 0.16%	4.73% ± 0.13%	-3.17% ± 0.30%	0.18% ± 0.27%
April 6	9.78% ± 0.15%	3.51% ± 0.16%	4.50% ± 0.13%	-12.83% ± 0.32%	-5.08% ± 0.26%
April 7	49.09% ± 0.08%	-2.94% ± 0.17%	7.57% ± 0.13%	8.87% ± 0.25%	8.37% ± 0.27%
April 8	44.43% ± 0.09%	0.17% ± 0.16%	8.62% ± 0.13%	-7.26% ± 0.30%	-0.97% ± 0.27%

Table 3.6 cont. Percent energy saved, lighting, reheat, and chiller combined.

Date	Lighting Only	Reheat Only	Reheat and Lighting	Chiller Only	Reheat, Lighting, and Chiller
Test 3					
May 1	39.34% ± 0.10%	-3.12% ± 0.17%	5.00% ± 0.13%	18.66% ± 0.23%	13.70% ± 0.29%
May 2	2.97% ± 0.16%	2.81% ± 0.16%	2.83% ± 0.14%	5.23% ± 0.26%	4.21% ± 0.27%
May 3	16.95% ± 0.14%	1.75% ± 0.16%	3.96% ± 0.14%	-2.70% ± 0.29%	0.18% ± 0.27%
May 4	11.58% ± 0.14%	1.80% ± 0.16%	3.20% ± 0.14%	-4.28% ± 0.29%	-1.02% ± 0.27%
May 5	11.73% ± 0.14%	1.43% ± 0.16%	2.89% ± 0.14%	-3.11% ± 0.29%	-0.47% ± 0.27%
May 6	29.97% ± 0.11%	-1.89% ± 0.17%	3.15% ± 0.14%	4.64% ± 0.26%	4.02% ± 0.28%
May 7	47.05% ± 0.09%	-2.50% ± 0.17%	5.95% ± 0.13%	0.69% ± 0.28%	2.79% ± 0.30%
Test 4					
May 22	42.74% ± 0.09%	2.64% ± 0.16%	8.47% ± 0.13%	-11.78% ± 0.32%	-2.98% ± 0.27%
May 23	33.16% ± 0.11%	2.95% ± 0.16%	7.20% ± 0.13%	-18.22% ± 0.34%	-6.95% ± 0.27%
Test 5					
June 23	47.48% ± 0.09%	-0.39% ± 0.17%	14.72% ± 0.11%	17.56% ± 0.27%	16.87% ± 0.34%
June 24	49.05% ± 0.08%	-1.45% ± 0.17%	16.14% ± 0.10%	25.92% ± 0.23%	23.81% ± 0.32%
June 25	49.50% ± 0.08%	2.69% ± 0.16%	20.13% ± 0.10%	30.26% ± 0.21%	28.27% ± 0.30%
June 26	51.59% ± 0.08%	4.95% ± 0.16%	22.52% ± 0.09%	31.12% ± 0.22%	29.42% ± 0.30%
June 27	50.34% ± 0.08%	2.73% ± 0.16%	19.87% ± 0.10%	29.00% ± 0.22%	27.10% ± 0.31%
June 28	50.64% ± 0.08%	3.46% ± 0.16%	20.12% ± 0.10%	27.69% ± 0.23%	26.07% ± 0.32%
June 29	50.91% ± 0.08%	1.93% ± 0.16%	19.60% ± 0.10%	28.48% ± 0.22%	26.62% ± 0.32%
June 30	46.05% ± 0.09%	3.15% ± 0.16%	17.74% ± 0.10%	32.32% ± 0.21%	29.11% ± 0.31%
July 1	46.72% ± 0.09%	-0.92% ± 0.17%	13.67% ± 0.11%	17.93% ± 0.27%	16.88% ± 0.33%

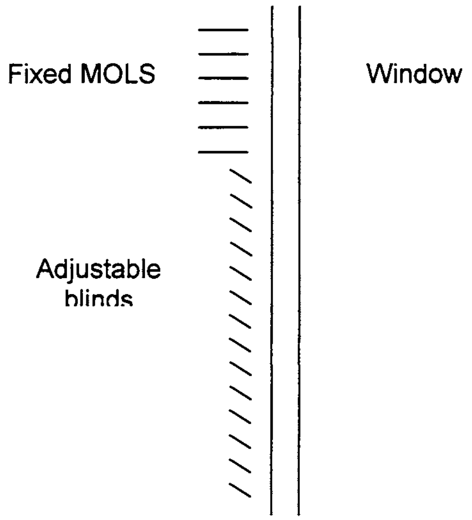


Figure 3.18 Schematic of the MOLS system (not to scale).

The test was conducted from September 16, 2000 to September 26, 2000. Data from September 18, 21, and 22 are not analyzed in this thesis because of unreliable data. The HVAC system was set to the same specifications as the tests described above. The B test rooms were equipped with daylighting controls and MOLS over the windows. The A test rooms were also equipped with daylighting controls but retained blinds as a window covering. Once again, sheetrock was placed over the interior windows of the test rooms to prevent light from the occupied space from interfering with the experiment. The blind angle in both test rooms was set at approximately 30° as in the other tests. Both rooms had continuously dimming ballasts with a minimum power of 30%. The light sensors were placed as described at the beginning of this chapter and shown in Figure 3.2.

Lighting Power

The MOLS system was designed to improve daylighting system performance but reduce glare on the work plane. However, the data collected in this experiment and the analysis in this paper will not address the visual quality of the system but only its effectiveness in saving lighting power and overall energy compared to blinds. The raw data were examined for viability and eight test days were retained for analysis.

Figure 3.19 shows the exterior insolation for September 23 and 26, 2000. September 23 was the cloudiest day of the test, while September 26 was sunny and clear. Overall, the first two and last two days of the test were very sunny. Of the remaining four days, three were completely overcast and one was partly cloudy.

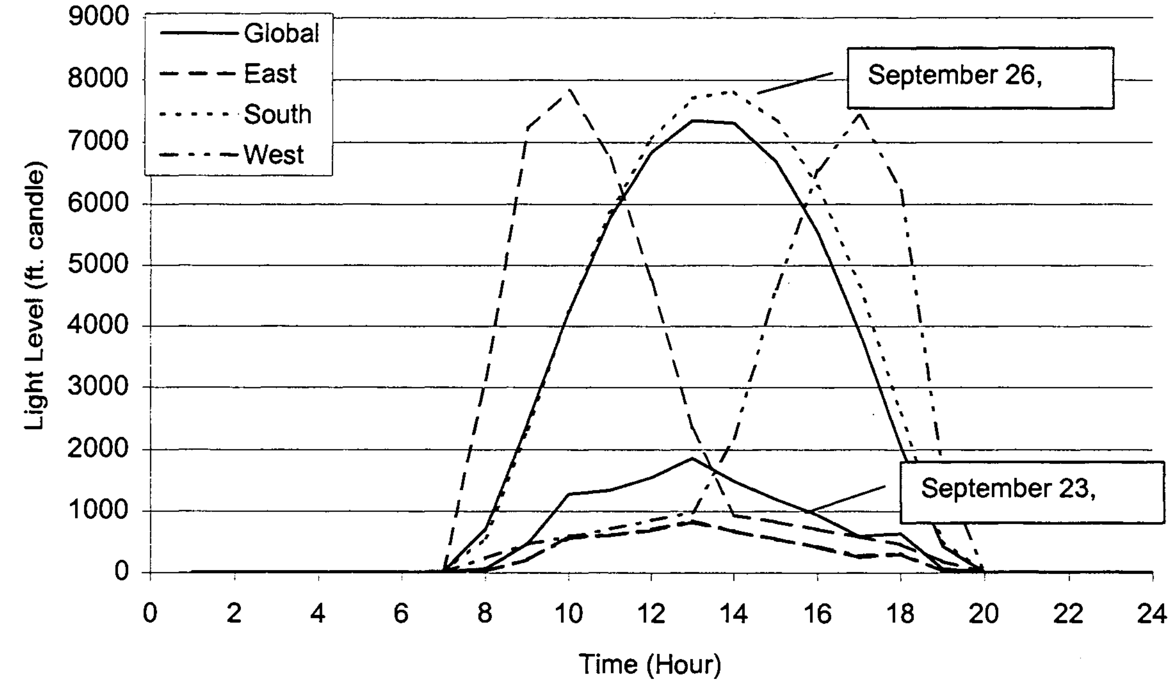


Figure 3.19 Exterior light levels for September 23 and September 26, 2000.

Figures 3.20 and 3.21 compare the A and B lighting power for September 23 and 26. The plots show very similar power measurements between the two rooms, especially during periods of direct sunlight. The B rooms show slightly higher power readings than the A rooms, suggesting that the MOLS system does not direct light to the work plane as well as the venetian blind system. The largest lighting differences seem to come during the indirect lighting hours (i.e. afternoon hours on the east side of the building).

Table 3.7 shows the percent lighting energy savings for each room and each test day. The table supports the findings of the figures. The room with the MOLS system used more lighting energy across the board. The south rooms showed the greatest lighting energy differences, with increases up to 26%. This could be a product of the declination angle of the sun and might improve with differing MOLS blade angles. More data is needed to fully explain the energy increase.

Table 3.7 Percent lighting energy saved with MOLS.

Date	East	West	South
Test 5			
September 16	-13.61%	-12.06%	-19.97%
September 17	-12.15%	-10.86%	-19.47%
September 19	-6.76%	-2.96%	-17.61%
September 20	-9.67%	-10.55%	-26.72%
September 23	-3.72%	-5.30%	-17.72%
September 24	-5.54%	-6.80%	-21.29%
September 25	-11.60%	-11.76%	-16.55%
September 26	-11.89%	-11.62%	-16.92%

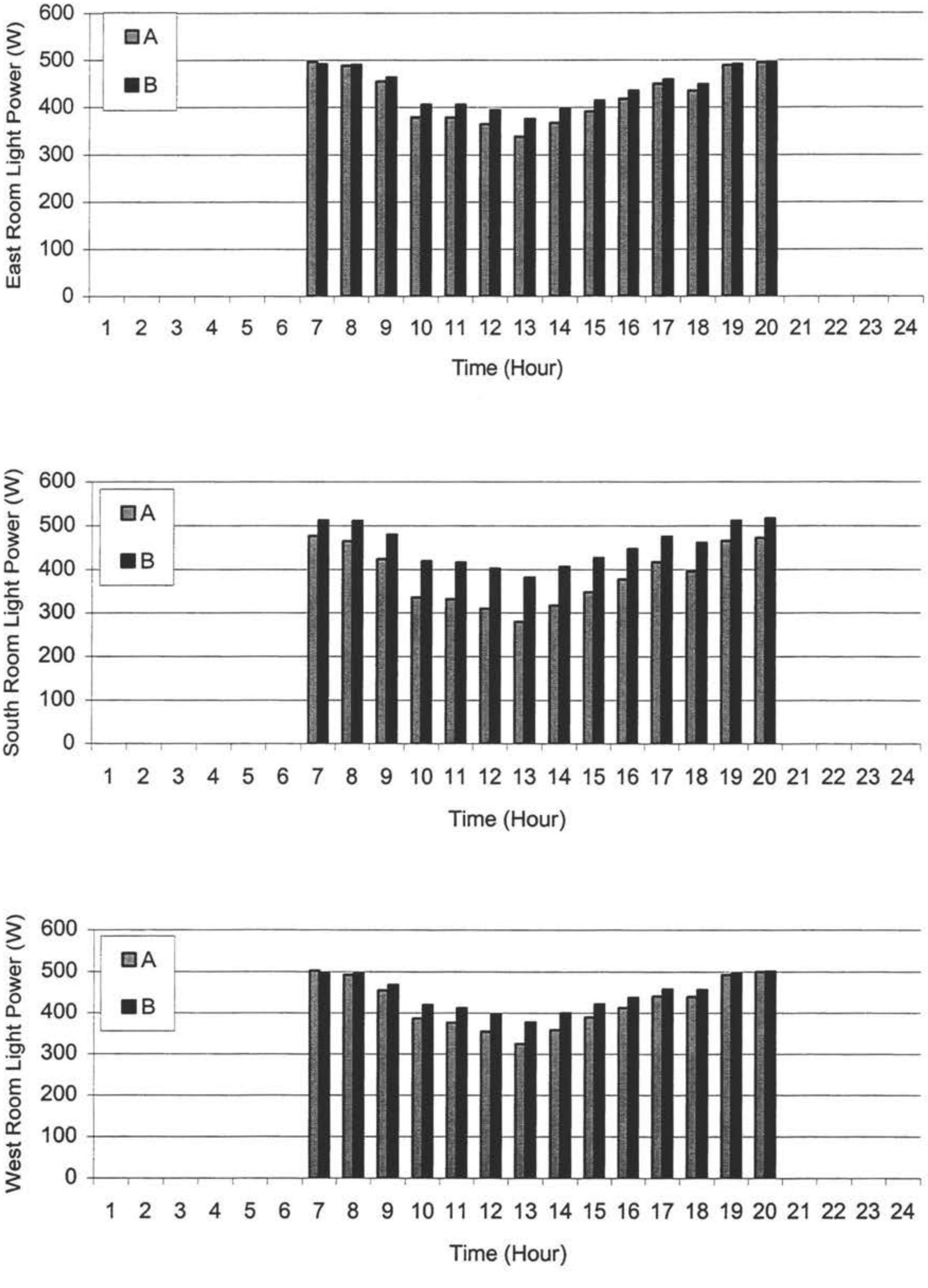


Figure 3.20 Room A and B light power for September 23, 2001.

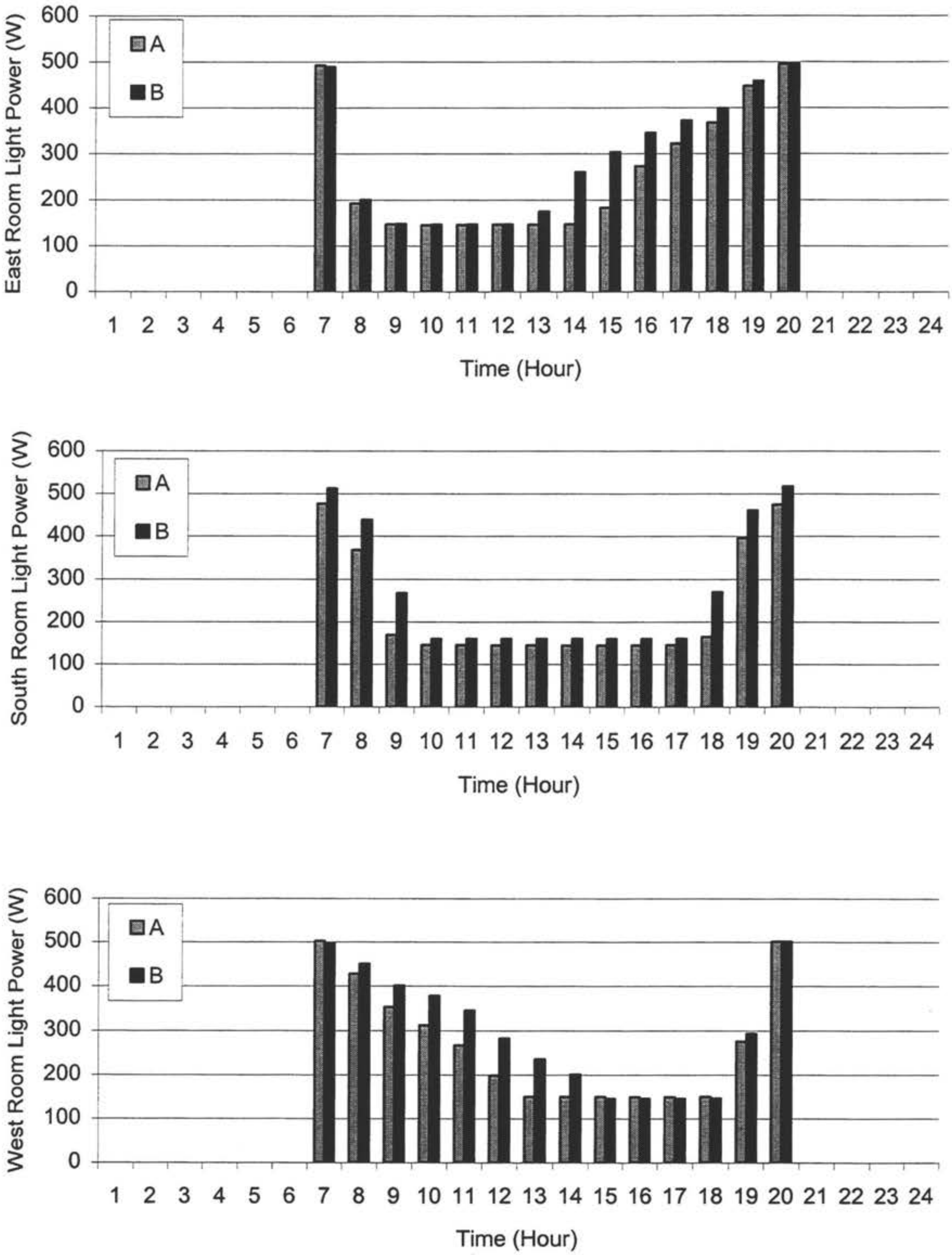


Figure 3.21 Room A and B light power for September 26, 2001.

Energy Savings

Table 3.8 shows the percent reheat energy savings by test room for each test day. The table shows energy savings for the B rooms over the A rooms. This is to be expected with the increase in lighting energy in the B rooms. However, it is interesting to note that the south side shows the lowest energy savings, and in some cases energy increases. One would expect the greatest lighting energy differences to also produce the greatest reheat energy differences.

Table 3.9 shows the effect of combining reheat and lighting energy on percent energy savings. When the two are combined, the reheat energy has a larger effect on the percent savings because the reheat energy magnitude is larger than the lighting energy magnitude. Therefore the combined percent savings still shows energy savings for the MOLS system over the blinds. The lighting difference magnitudes are even smaller with this experiment than the previous experiments because both test rooms have dimming systems.

Table 3.8 Percent reheat energy saved with MOLS.

Date	East	West	South
Test 5			
September 16	4.57%	4.44%	-0.98%
September 17	3.83%	1.97%	1.25%
September 19	7.96%	0.89%	-0.51%
September 20	6.70%	3.47%	-0.72%
September 23	5.19%	3.44%	0.04%
September 24	7.03%	6.63%	0.37%
September 25	6.96%	8.98%	1.09%
September 26	6.48%	6.40%	-0.43%

Table 3.9 Percent energy saved with MOLS, reheat and lighting combined.

Date	East	West	South	System
Test 5				
September 16	2.99%	3.08%	-2.69%	1.35%
September 17	2.23%	0.77%	-0.93%	0.78%
September 19	6.16%	0.39%	-2.70%	1.43%
September 20	5.15%	2.19%	-3.08%	1.60%
September 23	4.25%	2.53%	-1.83%	1.75%
September 24	5.85%	5.37%	-1.63%	3.35%
September 25	5.23%	7.01%	-0.80%	4.21%
September 26	4.94%	4.96%	-1.89%	2.99%

Table 3.10 summarizes the percent energy saved for all of the energy systems. The reported chiller energy savings do not seem to follow any particular pattern in relation to the lighting energy savings. The total energy savings also range from positive to negative with little regard to the lighting energy savings. It is possible that the chiller and total energy savings are strongly affected by the correction applied according to the outside air damper leakage in the B system. Results of the chiller energy might not be as accurate as the rest of the data.

The data for the MOLS system are largely inconclusive. The MOLS window treatments do not significantly reduce energy according to this experiment. In fact, the lighting energy increased with the MOLS for each room orientation and regardless of daylight availability. However, variations in MOLS blade angle and more complete data might provide more conclusive results for energy savings.

Table 3.10 Percent energy saved with MOLS, lighting, reheat and chiller combined.

Date	Lighting Only	Reheat Only	Reheat and Lighting	Chiller Only	Reheat, Lighting, and Chiller
Test 5					
September 16	-15.02% ± 0.19%	2.90% ± 0.16%	1.35% ± 0.15%	8.29% ± 0.44%	0.74% ± 1.04%
September 17	-13.94% ± 0.19%	2.40% ± 0.16%	0.78% ± 0.15%	28.43% ± 0.36%	-0.74% ± 1.09%
September 19	-8.87% ± 0.18%	2.92% ± 0.16%	1.43% ± 0.14%	18.05% ± 0.40%	-0.66% ± 0.97%
September 20	-15.17% ± 0.19%	3.31% ± 0.16%	1.60% ± 0.14%	-6.18% ± 0.51%	0.92% ± 0.95%
September 23	-8.64% ± 0.18%	2.97% ± 0.16%	1.75% ± 0.14%	-11.35% ± 0.53%	1.63% ± 0.91%
September 24	-10.84% ± 0.18%	4.81% ± 0.16%	3.35% ± 0.14%	-22.81% ± 0.58%	2.66% ± 0.88%
September 25	-13.14% ± 0.19%	6.09% ± 0.15%	4.21% ± 0.14%	-17.82% ± 0.70%	3.34% ± 1.23%
September 26	-13.32% ± 0.19%	4.48% ± 0.16%	2.99% ± 0.14%	-2.21% ± 0.49%	2.02% ± 1.02%

CHAPTER 4. DOE-2.1E SIMULATION

Most whole-building design and analysis involves building simulation software developed to determine building energy usage using typical weather conditions for a given area. One of the more accurate building simulation software packages is DOE-2, developed by the Lawrence Berkeley Laboratory for the U.S. Department of Energy. The program uses Building Description Language (BDL) as a means for the user to define the construction, mechanical systems, and usage of a building. The program calculates the thermal loads on the mechanical systems and determines the energy required to light and condition the building.

How accurately can energy savings with daylighting controls be predicted? A DOE-2 simulation was developed to model the experimental conditions and allow comparison between the actual experimental results and DOE-2 predictions. This chapter outlines the development of the model and compares the model results to the experimental data. Finally, the simulation was run for a full calendar year to determine the estimated total annual energy savings possible at the ERS using a daylighting control system.

SIMULATION DEVELOPMENT

As stated previously, the ERS was built as a test facility specifically to study HVAC systems and energy usage. Previous experiments have been conducted to validate the DOE-2 building simulation program, and one experiment was previously conducted at the ERS to study daylighting controls. The simulation described here was built on the base of the simulation developed by Sang-Soo Lee (Lee, 1999). A sample simulation used with this thesis can be found in Appendix B.

The building construction was modeled as described in Chapter 2. The test rooms were defined to have a cooling set-point temperature of 73 °F and a heating set-point temperature of 72 °F. No people or equipment were modeled in the space. The lights were set to turn on at 6am and turn off at 8pm. The rest of the facility was modeled for people and equipment during normal office hours, 8am to 6pm. The test AHUs were configured to produce a supply air temperature of 58 °F and no outside air to the test space.

The building models include the interior test rooms. The interior rooms are not affected by daylighting controls because there is no daylight in the space. The interior space has no effect on the lighting or reheat energy analysis because the measurement of these values are done on a room-level basis. However, the chiller energy is measured solely on a system-level basis and thus includes the energy necessary to cool the interior rooms. There should be no thermal load difference between the two interior rooms, thus they will contribute equally to each system's cooling load.

DOE-2 includes daylighting as a possible lighting control system. However, the program documentation cautions the user to apply the daylighting control system only to perfectly diffuse window treatments – bare windows, curtains, shades, etc. However, this experiment was done with venetian blinds because of their extensive use in office buildings. Therefore, the DOE-2 algorithm is not wholly suited to the current experimental setup due to the directional nature of light reflecting off the slats of the blinds.

The primary problem that arises when using venetian blinds is determining the appropriate visible transmittance for the daylit space. The visible transmittance can be defined as the percent of exterior light that reaches the interior space. Experiments have been done on diffuse window treatments to determine their value of visible transmittance. Because these window treatments spread light evenly throughout the room, the visible transmittance is not dependent on sun angle. However, depending on the sun angle, gaps between the blinds allow some direct light into the space. In addition, the blinds themselves reflect light into the space instead of evenly diffusing the light throughout the room.

An attempt was made to determine the visible transmittance experimentally. The test building is equipped with outdoor light sensors between each set of exterior test rooms as shown in Figure 2.7. As described in Chapter 2, a light sensor was mounted in the test room, facing the window and measuring the light coming in the window. The visible transmittance was calculated by taking the ratio of the interior light level to the exterior light level.

Most simulation software uses "typical" weather to perform energy calculations. For this research actual weather conditions were measured, converted into TMY format, and input into DOE-2. Some unreliable weather data prevented simulations from being done for every experimental test day.

SIMULATION RESULTS AND COMPARISON

The simulation was run for 8 test days. The test days were chosen in an effort to model both cloudy and sunny conditions and represent the widest variation of experimental conditions possible. The final simulation days are shown in Table 4.1.

The results of the simulations were plotted in a manner similar to the experimental results. The volumetric flow rate, lighting energy, and reheat energy were plotted for each test room. The illuminance due to daylight was plotted for the three B test rooms. On the

Table 4.1 Simulation dates.

Test	Dates
Test 1	August 18 and 21, 2001
Test 2	April 3 and 4, 2001
Test 3	May 5 and 7, 2001
Test 4	May 22 and 23, 2001

system level, the total reheat energy and the chiller energy were plotted. The experimental results were superimposed on the simulation plots for ease of comparison. The results for May 7, 2001 are found in Figures 4.1 – 4.10.

The exterior illuminance plot for May 7, 2001 can be found in Figure 4.1. The plot shows that May 7 was a fairly sunny day. The sunlight was most direct in the morning, with increasing clouds throughout the day. The plots of the experimental AHU supply air flow

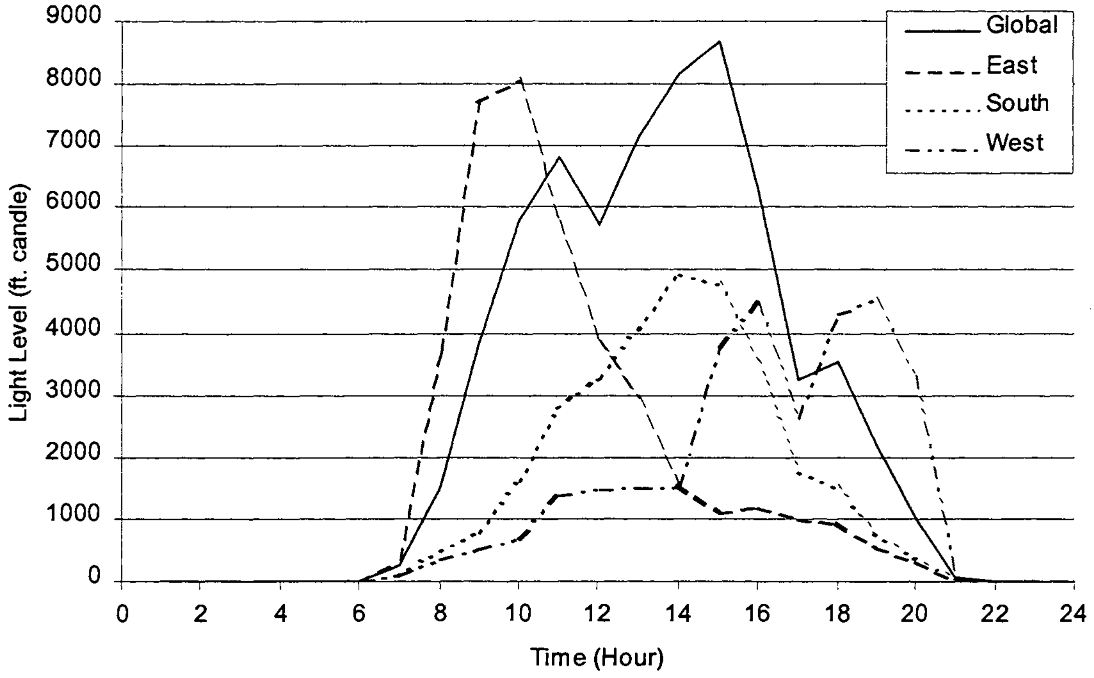
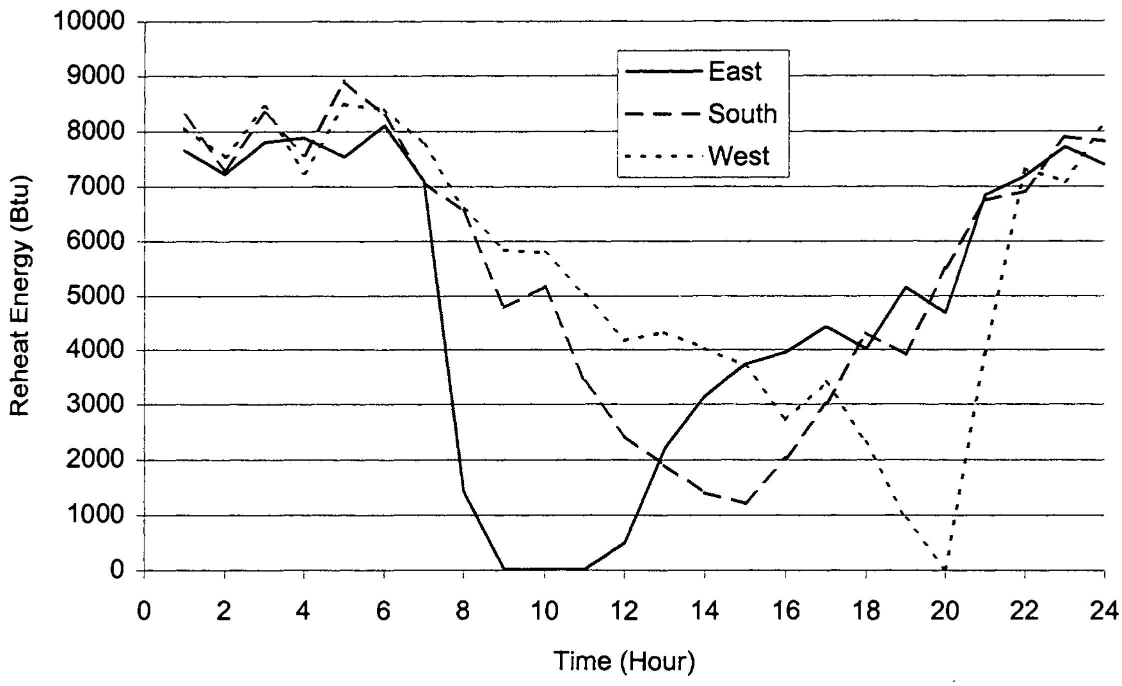


Figure 4.1 Exterior light levels for May 7, 2001.

rate, Figures 4.2 and 4.3 show that the East A, West A, and East B rooms all required space cooling for at least some time during the test. Finally, the reheat energy plots in Figures 4.2 and 4.3 show that there was no reheat power measured during a portion of the day for some of the rooms. All of this data supports the fact that May 7 was a bright, sunny day.

The ability of DOE-2 to predict the measured energy usage stems from its ability to match interior light levels and predict lighting power. DOE-2 calculates and reports the amount of daylight that reaches the light reference point location and adjusts the electric light power relative to that measurement. However, DOE-2 does not report the total amount of light (artificial and natural) that reaches the reference point. The experimental results reflect the total amount of light present at the reference location. Figure 4.4 shows the light due to daylight that reaches the work plane in the B test rooms. To determine the experimental light due to daylight only and allow comparison between the experimental and simulation results, a test was conducted to determine the light level at the work plane for various lighting powers. A description of the test and its results can be found in Appendix C. The results of the test were used to determine the artificial illuminance at the work plane. The artificial illuminance was subtracted from the overall illuminance to determine the light level due to daylight. The final value was compared to the DOE-2 predictions. The plots show that the DOE-2 prediction follows the same general trend as the experimental data. However, the DOE-2 prediction does not achieve the magnitude of the experimental results. In every case, the experimental results show much more light due to daylight on the work plane, reaching 2-3 times the light levels in the extremes.

Figure 4.4 also shows the experimental and predicted lighting power for the B test rooms. The effect of the light level differences can be seen in the lighting results. The DOE-



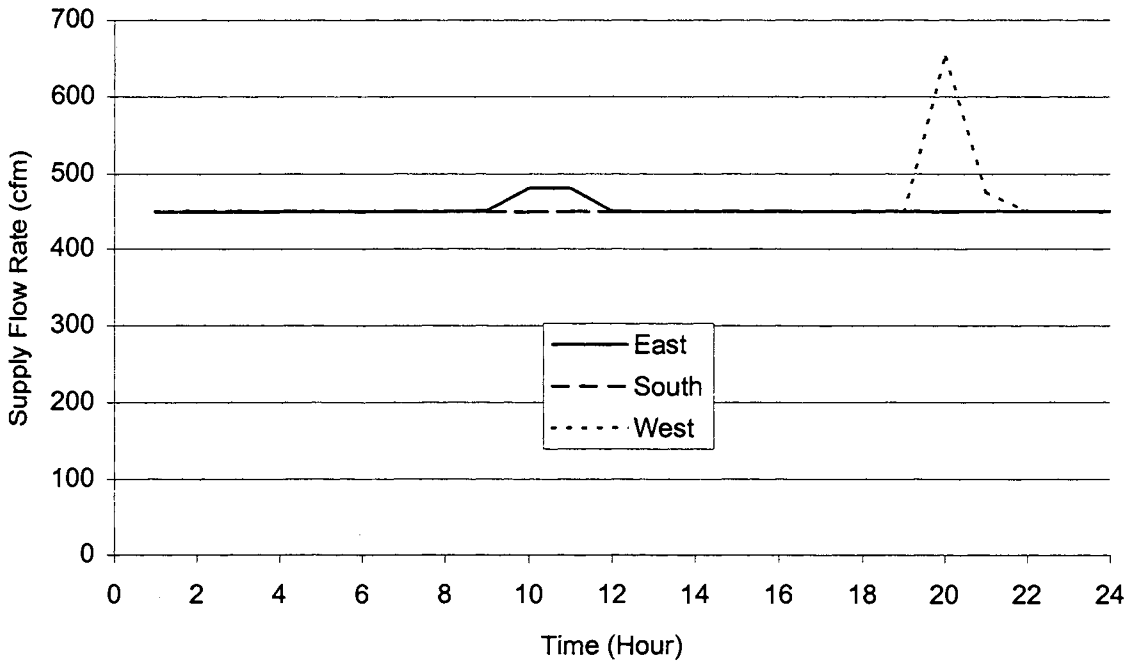


Figure 4.2 Room A experimental reheat power and supply air cfm for May 7, 2001.

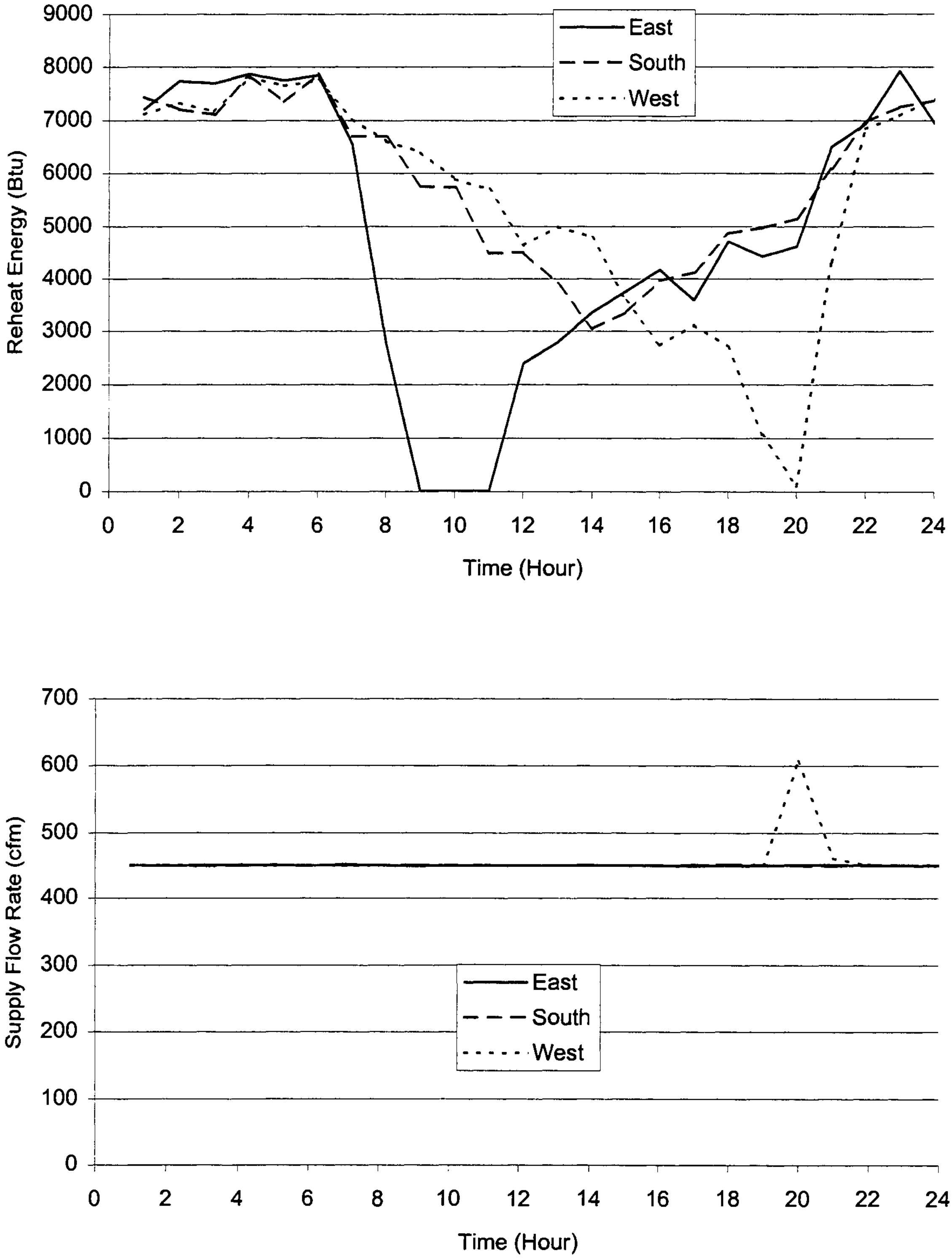


Figure 4.3 Room B experimental reheat power and supply air cfm for May 7, 2001.

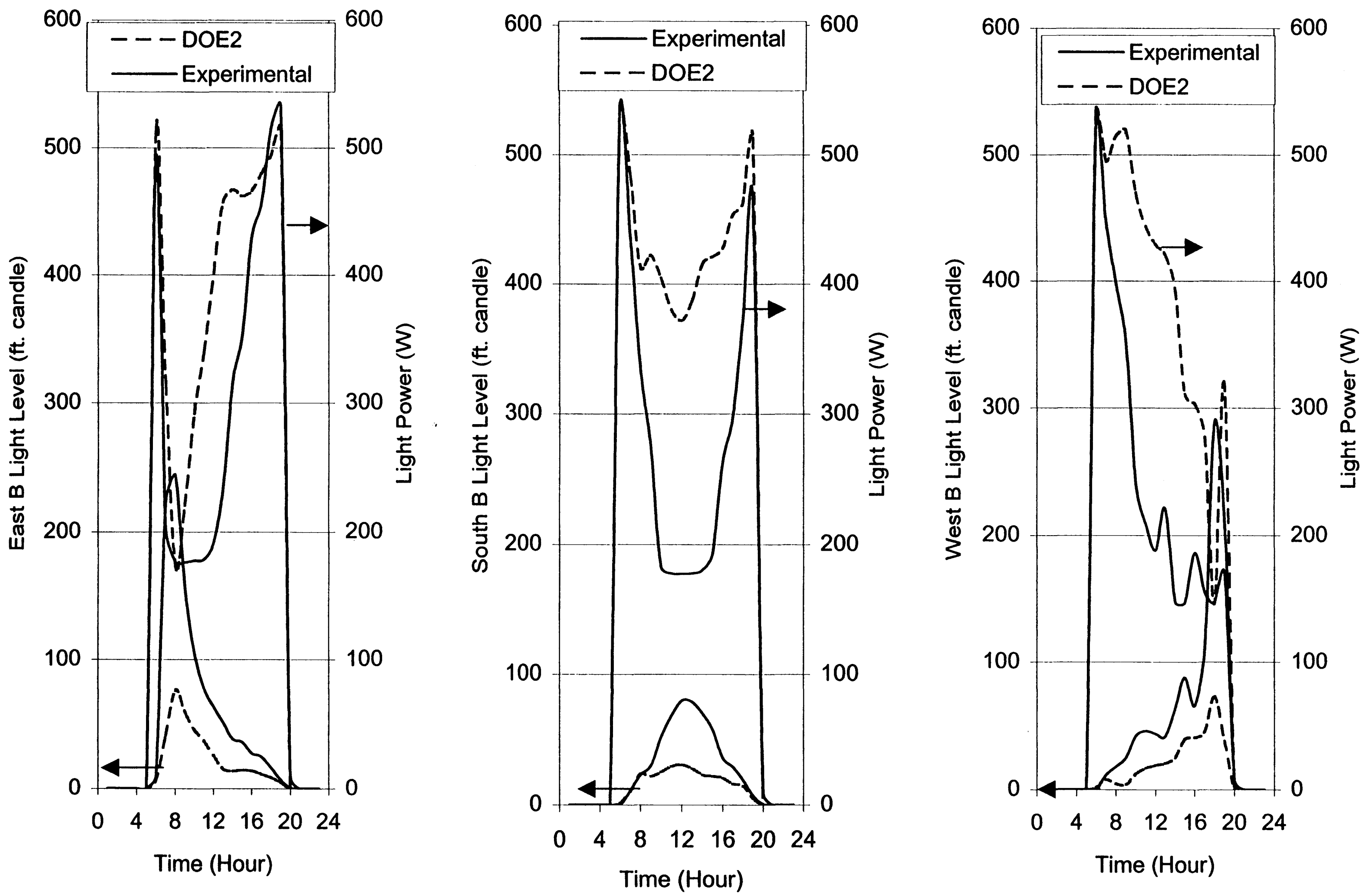
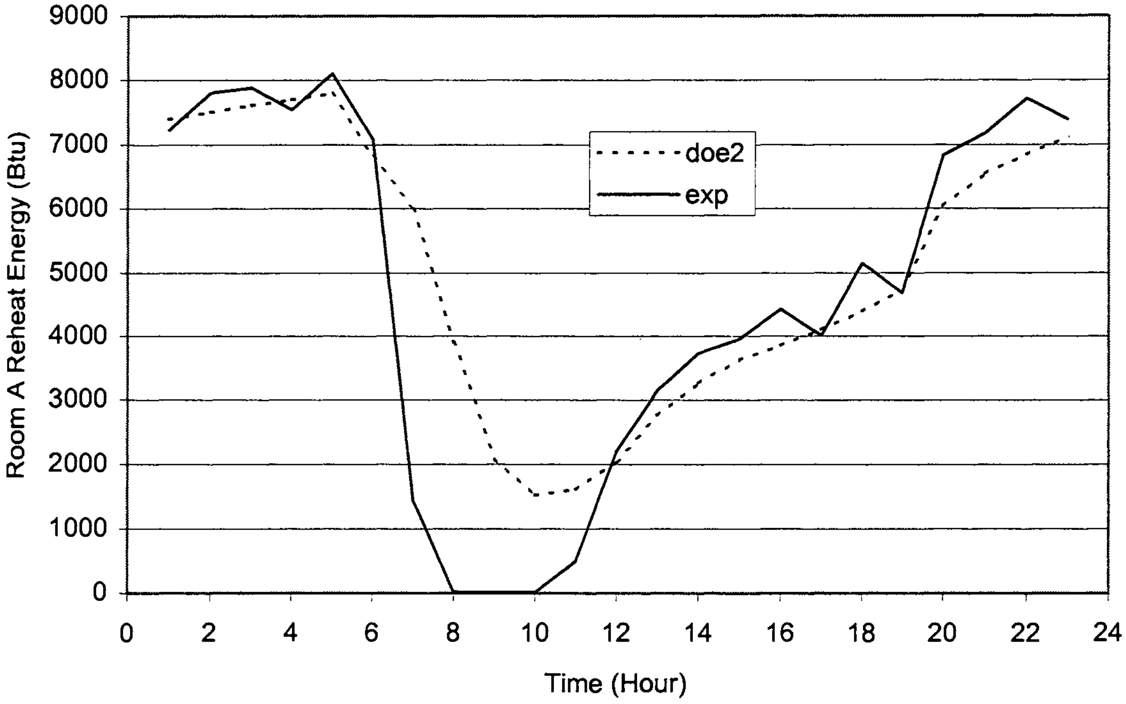


Figure 4.4 Room B experimental and simulation light power and illuminance for May 7, 2001.

2 predictions are always higher than the experimental results. The simulation needs more artificial light to achieve the same light level on the work plane because it predicts a lower contribution due to daylight. The effect is seen most clearly in the South B test room. The predicted light levels match the experimental results closely until 8am. At that point, the results diverge drastically until they come together again near 6pm. The lighting plot follows the same trend – the results diverge at 8am and come together again at 6pm.

Given higher predicted light wattage, one would expect the predicted reheat values to be consistently lower than the experimental values. However, that is not the case. Figures 4.5, 4.6, and 4.7 show the experimental and predicted reheat power for each test room. All 6 rooms show good agreement between the experimental and predicted results. In general the predicted results follow the same trend as the experimental results with no large differences between the two. However, the predicted results do not match the same extremes that the experimental results reach. This is especially true during the morning hours in the East rooms and the afternoon hours in the West room. The experimental results show that the reheat energy dips to nearly zero during those times, while the predicted results remain well above the experimental minimums. When the system is not near zero reheat energy, the results are within reasonable approximations. The experimental data tends to be more volatile, while the predicted results are smoother and more consistent.

The greatest differences in reheat energy seem to occur when the lighting power reaches minimum light levels. This corresponds to the time of day with the greatest direct sunlight in a given room. The illumination plots indicate that the experimental results show large levels of direct light in the space during those hours. This is especially true in the East and West test rooms, where the direct light corresponds to lower sun angles, thus allowing



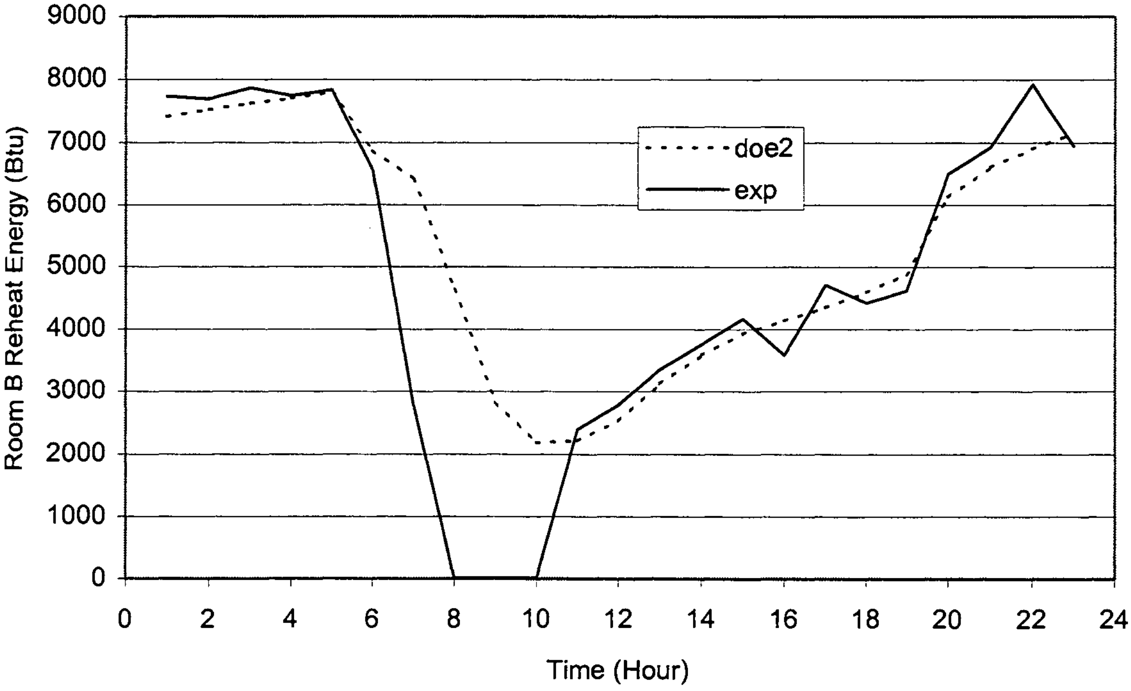
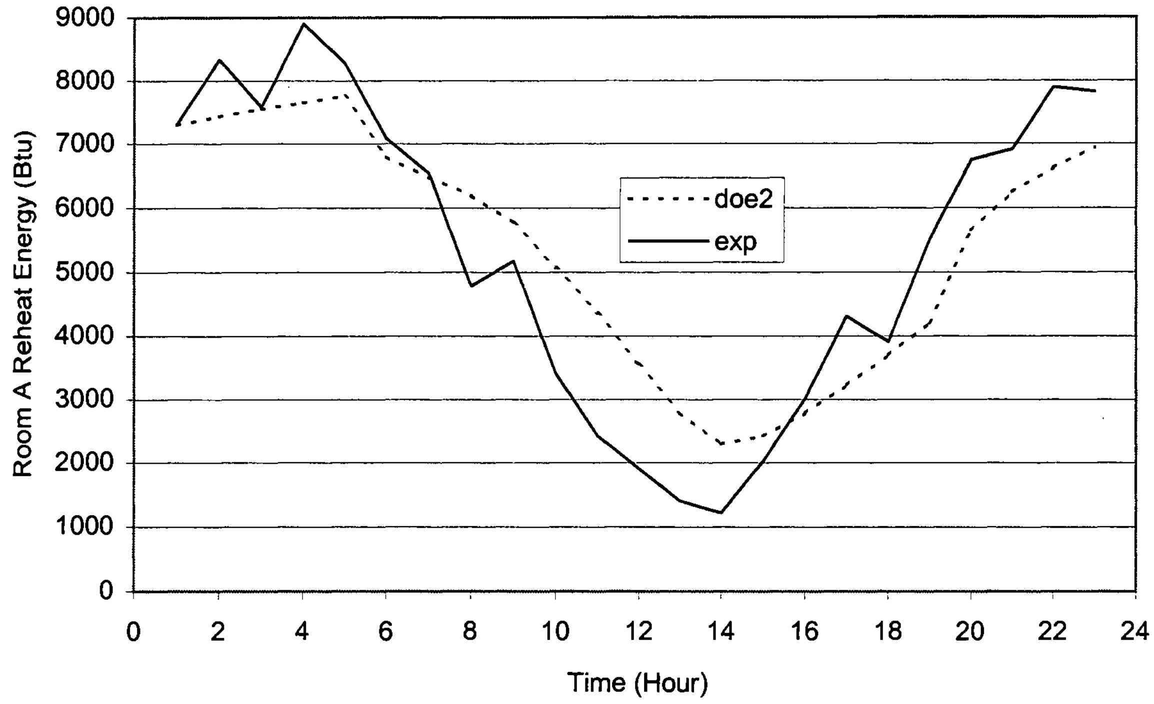


Figure 4.5 East Room A and B experimental and simulation reheat energy for May 7, 2001.



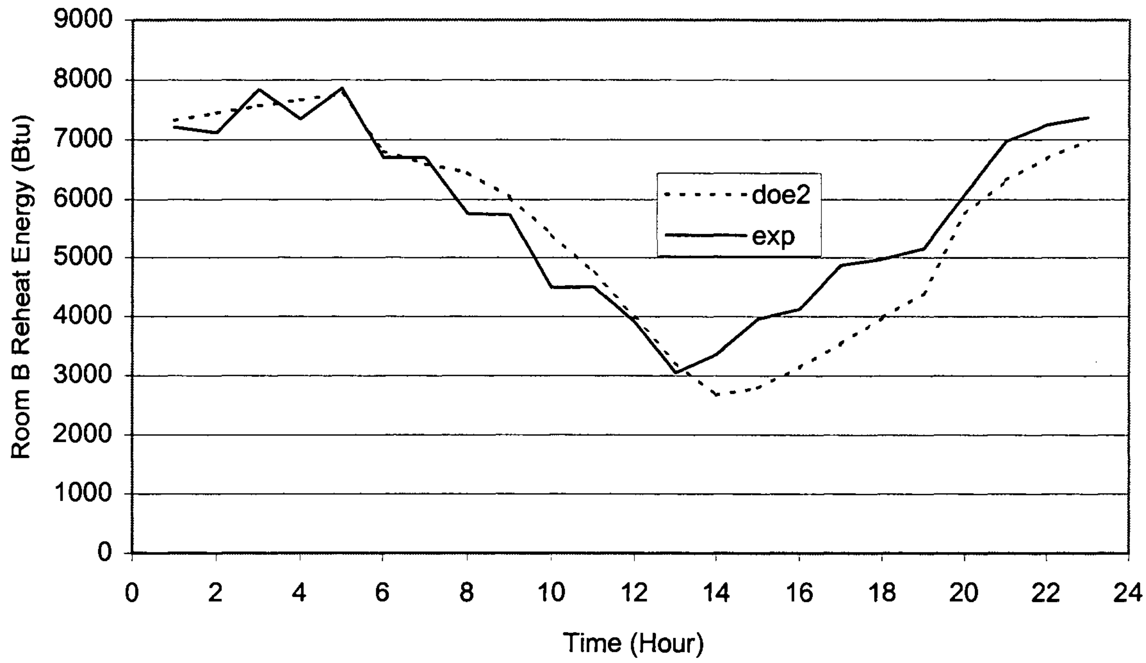
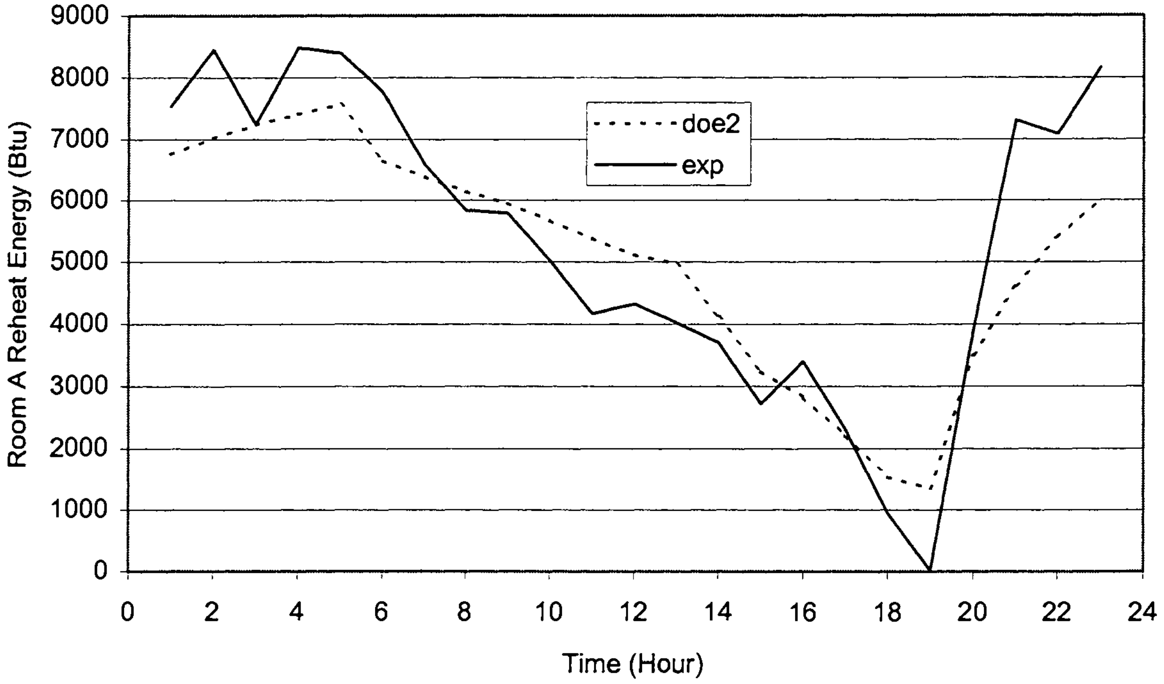


Figure 4.6 South Room A and B experimental and simulation reheat energy for May 7, 2001.



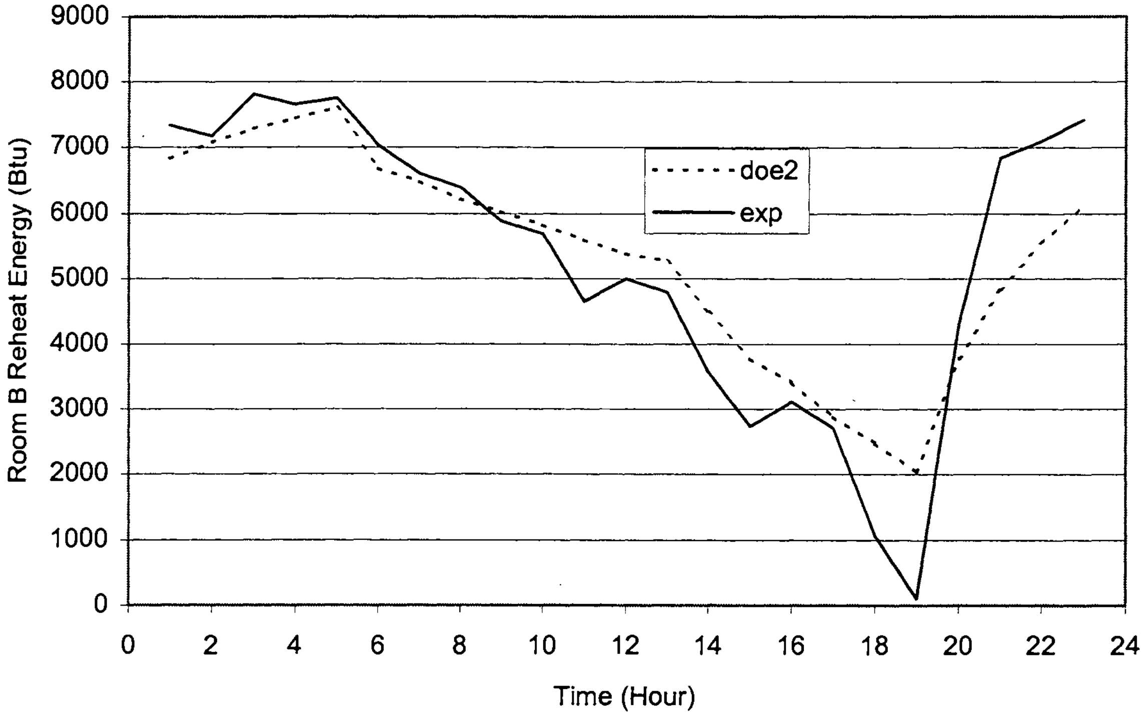


Figure 4.7 West Room A and B experimental and simulation reheat energy for May 7, 2001.

more direct daylight into the space through the blind blades. The effect is not as great in the South room, where the sun is high and less direct light is allowed through the blades. The effect is seen in both the A and B test rooms, indicating that differences may be associated more with DOE-2's ability to predict conditions with venetian blind window treatments than with DOE-2's ability to predict conditions with daylighting systems. Differences in calculation method with respect to thermal mass could also account for the disparities.

Figure 4.8 shows plots of the experimental and predicted supply air flow rate for each of the test rooms. The experimental results show spikes when the system enters cooling mode. However, the DOE-2 results show no change in flowrate and therefore does not predict cooling mode at any point during the test day. The inability of the predicted system to reach cooling mode is consistent throughout the simulations – at no point did DOE-2 predict an increase in supply air flow rate for any of the test rooms. The simulation predicted minimum flow rate at all times and for all rooms.

At the system level the DOE-2 predictions are again close to the experimental results. Figure 4.9 shows the System A and B reheat energy. On the system level the peak differences in reheat energy are somewhat repressed by the agreement in the other two test rooms. For example, although large differences in reheat energy are seen during the morning hours in the East test room, the South and West rooms show good agreement during the same time period. Therefore, although the effects of the East difference are still seen in the system plot, they are dampened by the good agreement in the South and West rooms. In this way, the System plot can be seen as something of an average approximation of the overall results.

Figure 4.10 shows the System A and B chiller energy plots. As mentioned before, these plots include the results of the interior test rooms also. The original chiller results

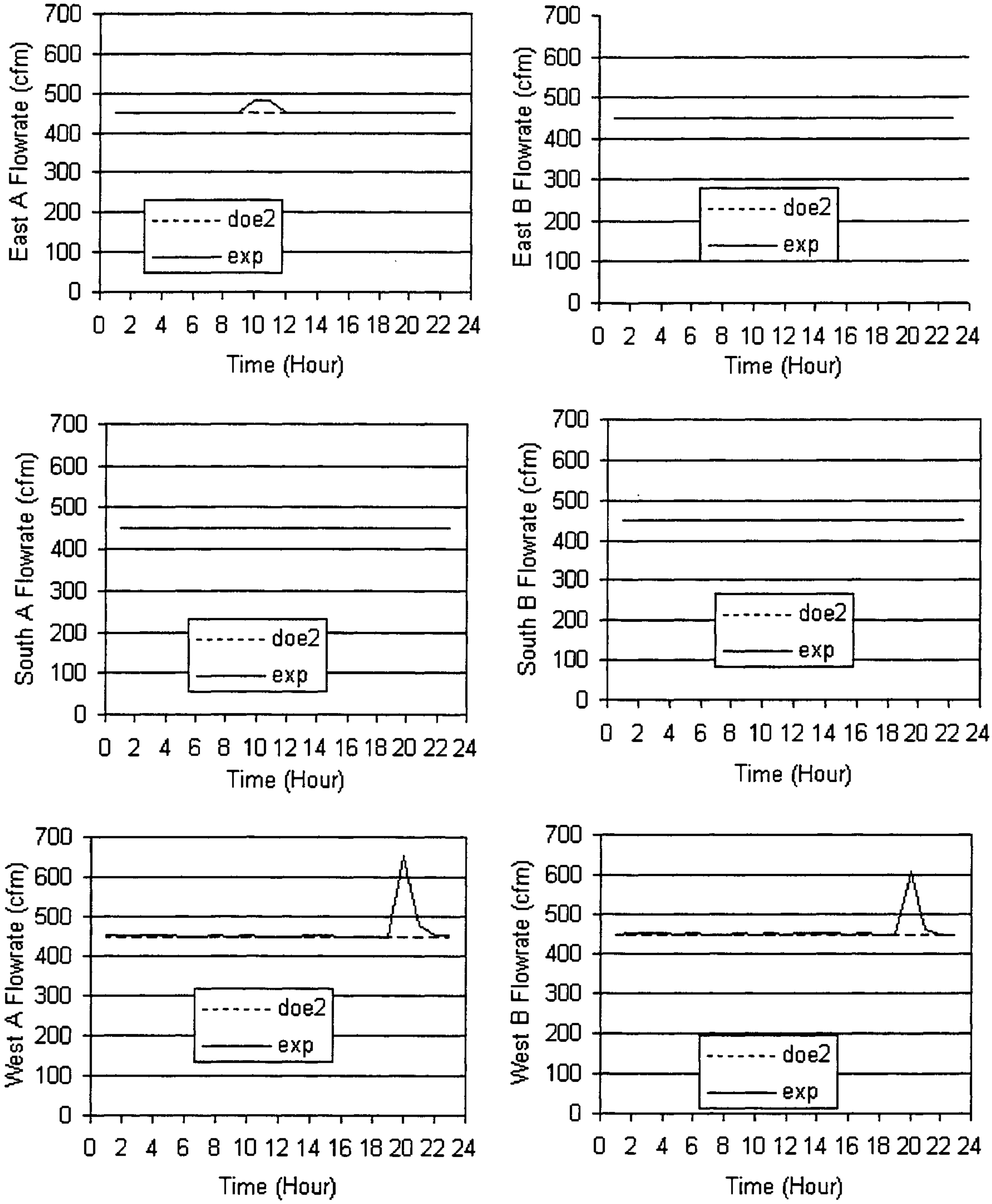
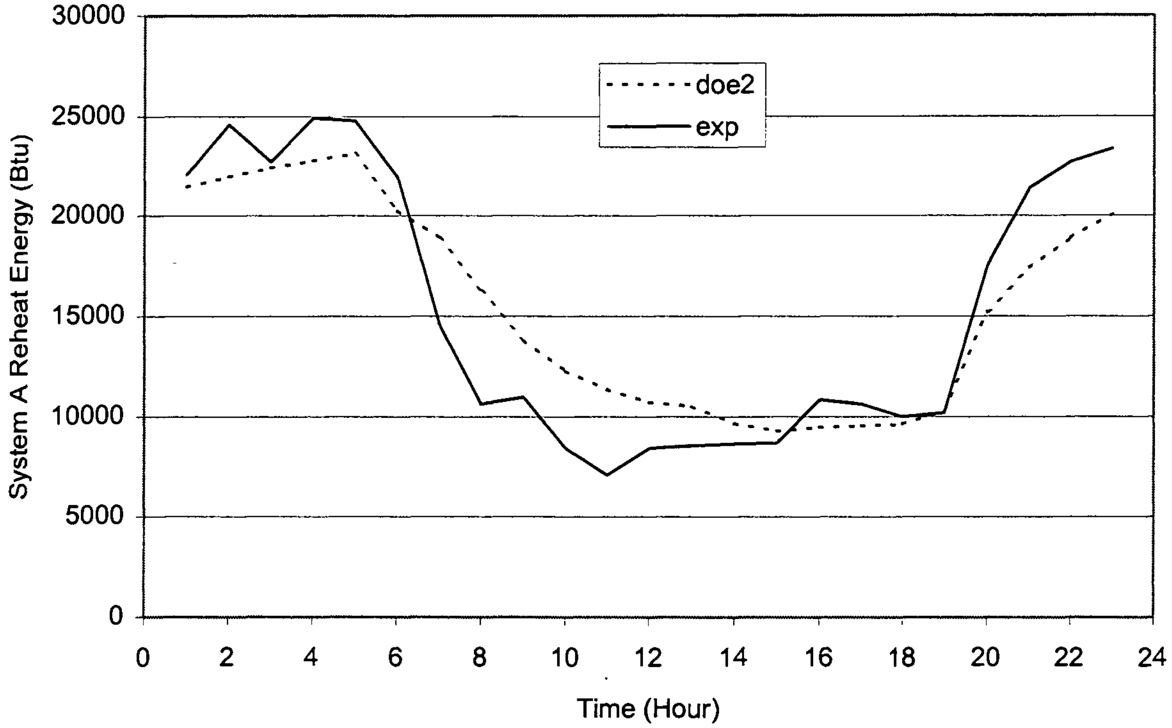


Figure 4.8 Experimental and simulation supply air flowrate for May 7, 2001.



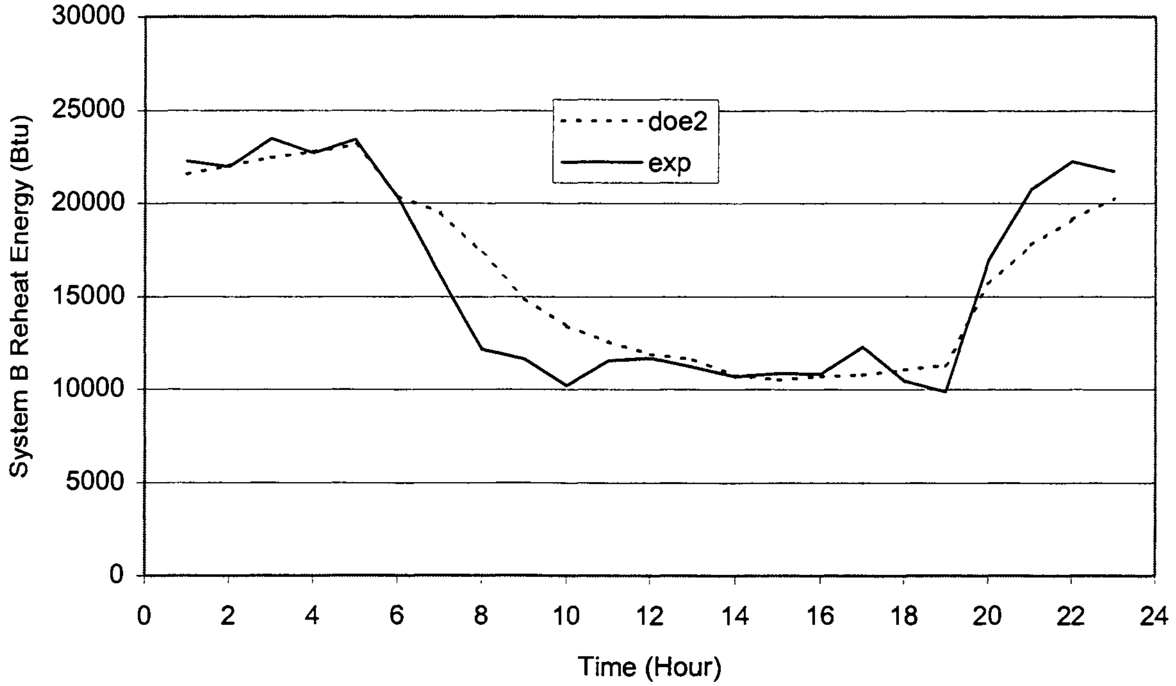
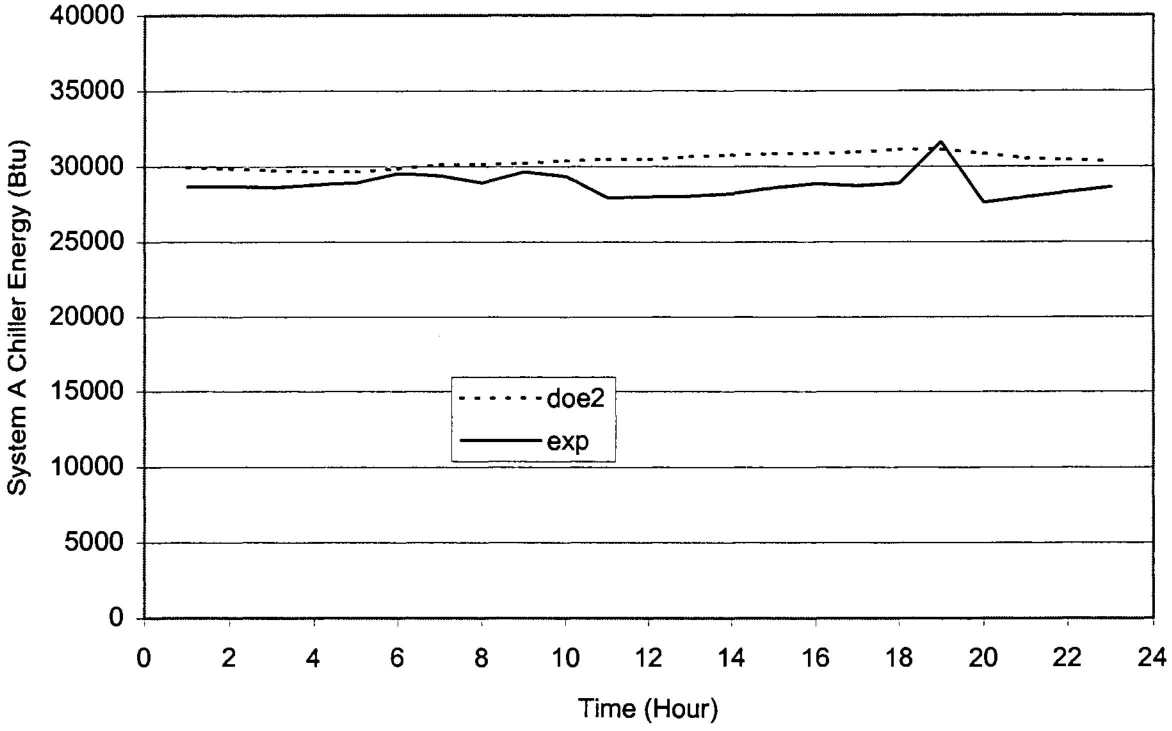


Figure 4.9 System A and B experimental and simulation reheat energy for May 7, 2001.



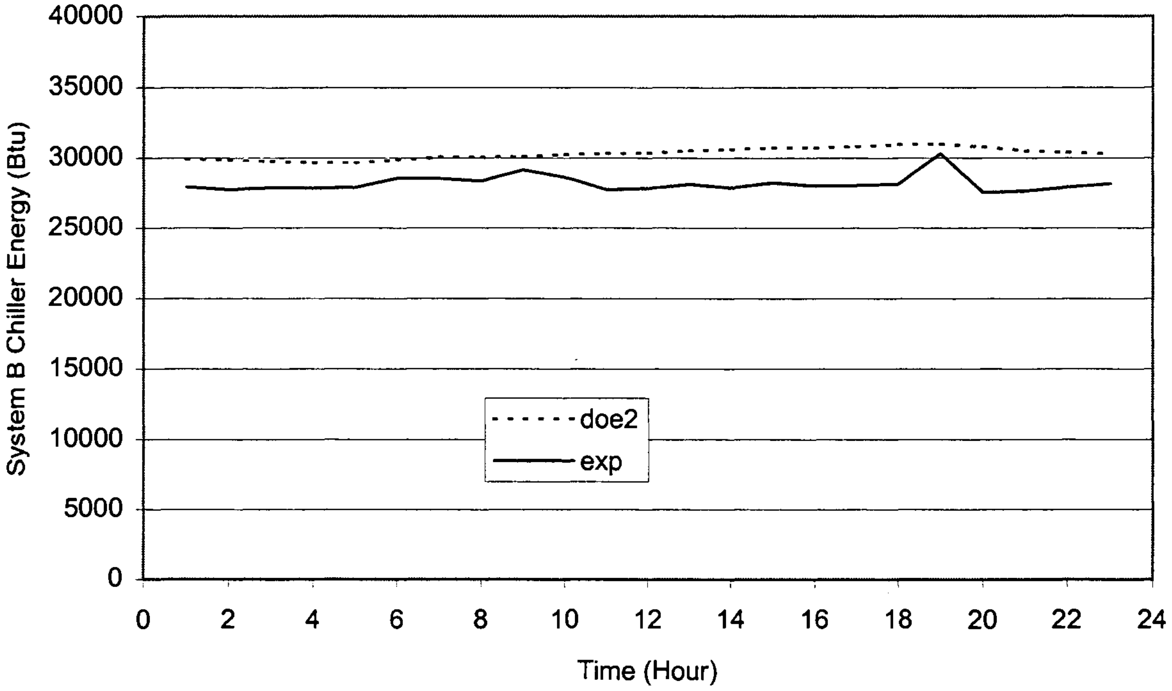


Figure 4.10 System A and B experimental and simulation chiller energy for May 7, 2001.

(prior to the correction explained in Chapter 3) were used for comparison to DOE-2 results. The original results were used because there is no clear indication on absolute corrections for System A or System B, only a correction for the difference in energy between the two systems. The experimental results indicate a spike in chiller energy in the afternoon as a result of the increased air flow into the West test rooms. The simulation did not predict an increase of air flow, therefore there is no corresponding increase in chiller energy. Overall, the results are similar, with DOE-2 predicting higher chiller energy output for the entire day.

Figure 4.11 shows the exterior illuminance for May 5, 2001. The figure shows that the day was fairly cloudy, with no real direct sunlight. It was mentioned previously that the differences in reheat energy between the DOE-2 predictions and the experimental data could

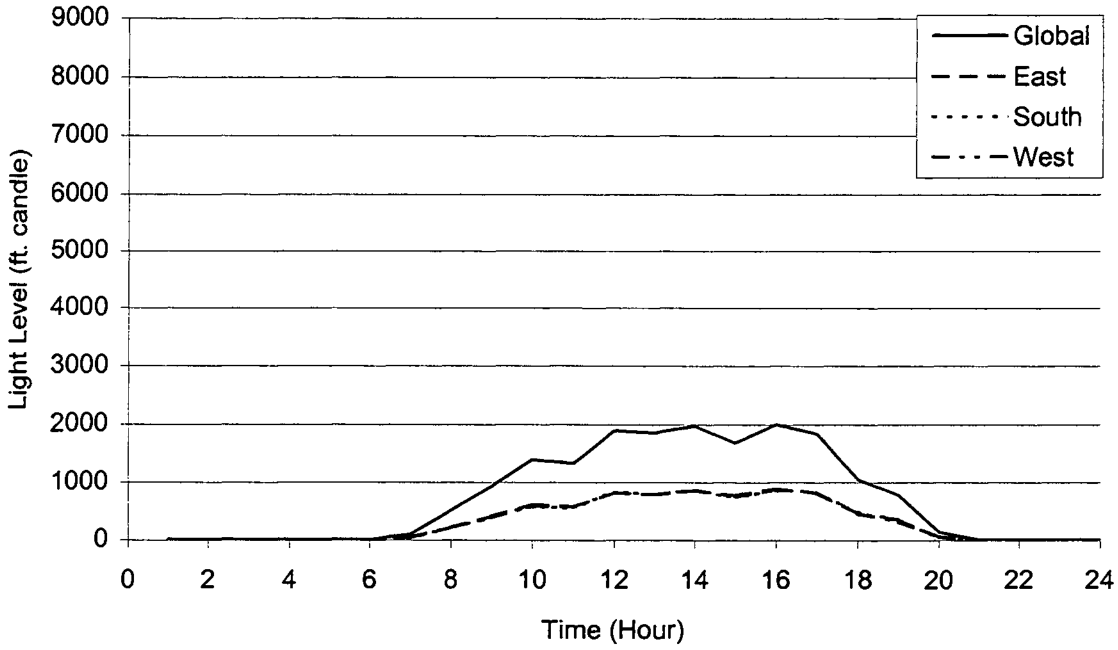


Figure 4.11 Experimental exterior light levels for May 5, 2001.

be due to DOE-2's inability to model venetian blinds. Blinds present a problem because they allow bands of direct sunlight into the space. The amount of direct light changes with changing sun and blind angle. In addition, the light that is not allowed directly into the space is reflected off the blade angle and not diffused into the room. The effects of the blinds are decreased in diffuse light (i.e. cloudy day instead of sunny day), therefore the results for a cloudy day should be better than the results for a sunny day.

Figure 4.12 shows the experimental and predicted illuminance due to daylight on the work plane. The plots show that the experimental values are usually higher than the predicted but the magnitude of difference is much smaller. The morning hours in the East and South rooms and the evening hours in the West room show higher predicted illuminance than measured illuminance. The lighting plots in Figure 4.12 show the result of the higher level. The East room shows lower predicted light energy during the morning hours, corresponding to the times with higher predicted illumination. The other two rooms follow the same pattern as seen on the sunny day – lower predicted illumination and higher predicted light energy.

Figures 4.13 – 4.15 show the experimental and predicted reheat energy for each test room. The predicted and experimental results match almost perfectly. In fact, the only real difference between the two situations results from the data scatter found with all experimental results. The close agreement extends to the system level. Figures 4.16 and 4.17 show the experimental and predicted system reheat and chiller energy. On the system level, the experimental reheat energy matches the predicted even more closely than on the room level. The closer agreement can be attributed to the damping effect described in the

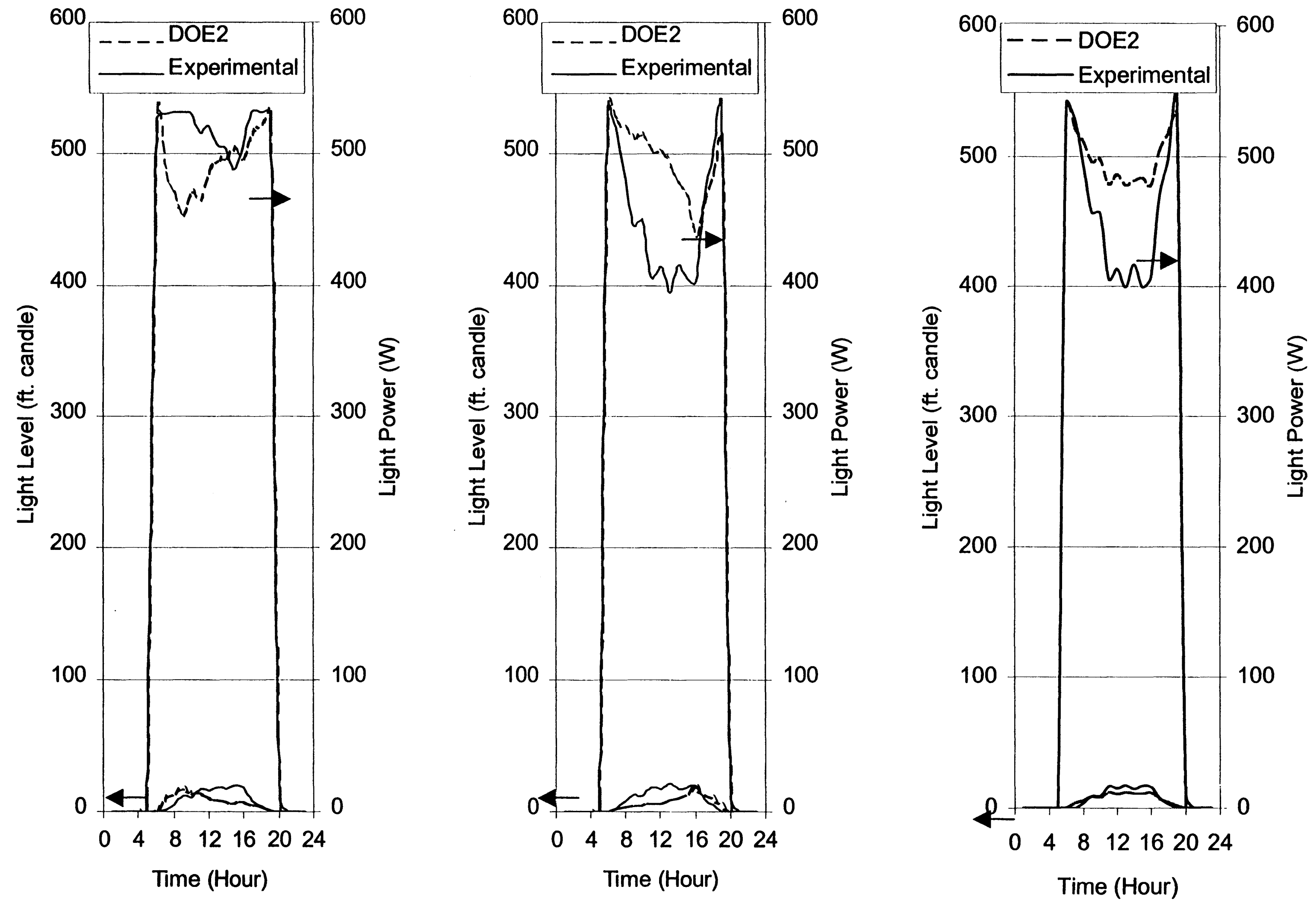
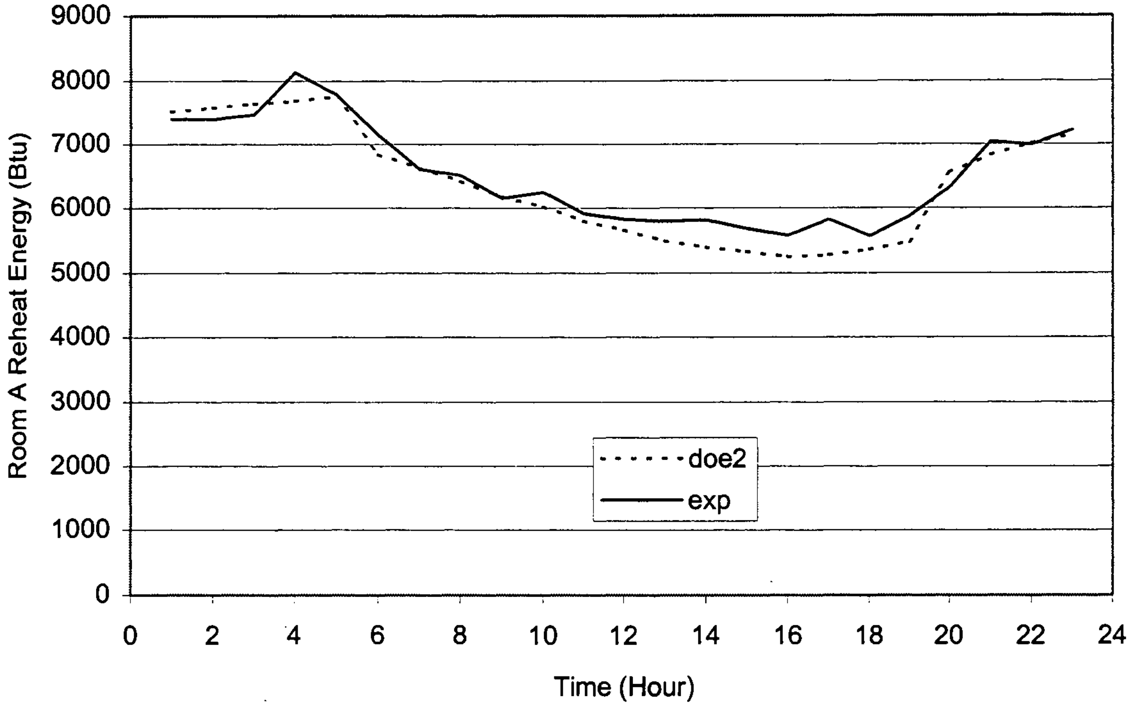


Figure 4.12 Room B experimental and simulation light power and illumination for May 5, 2001.



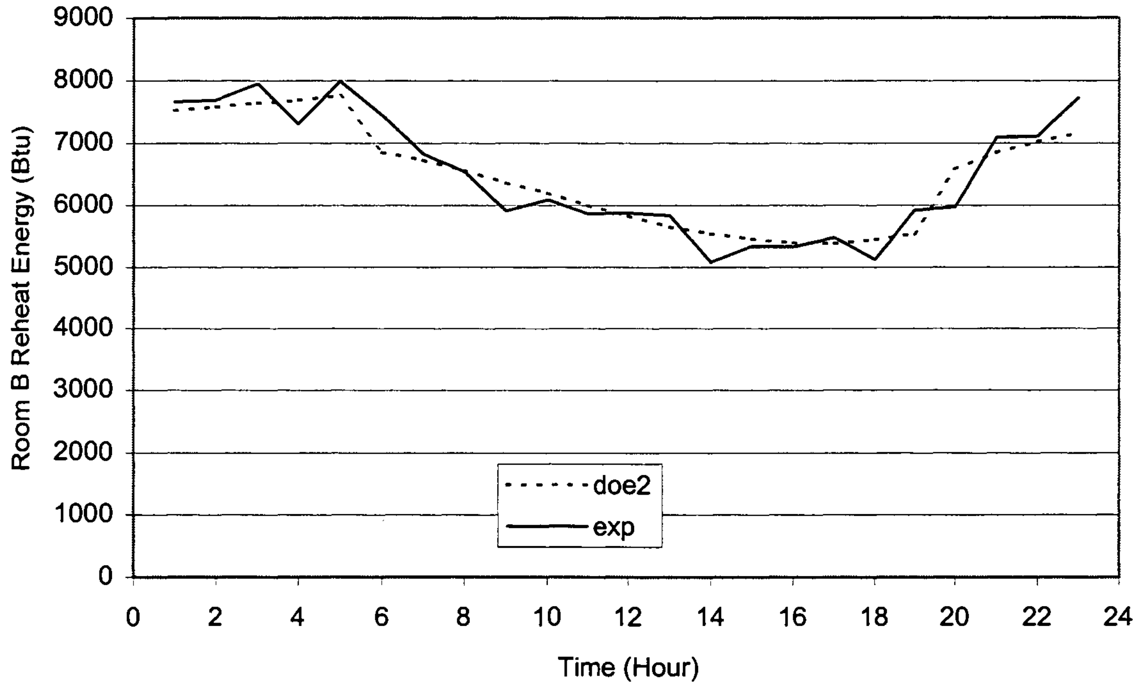
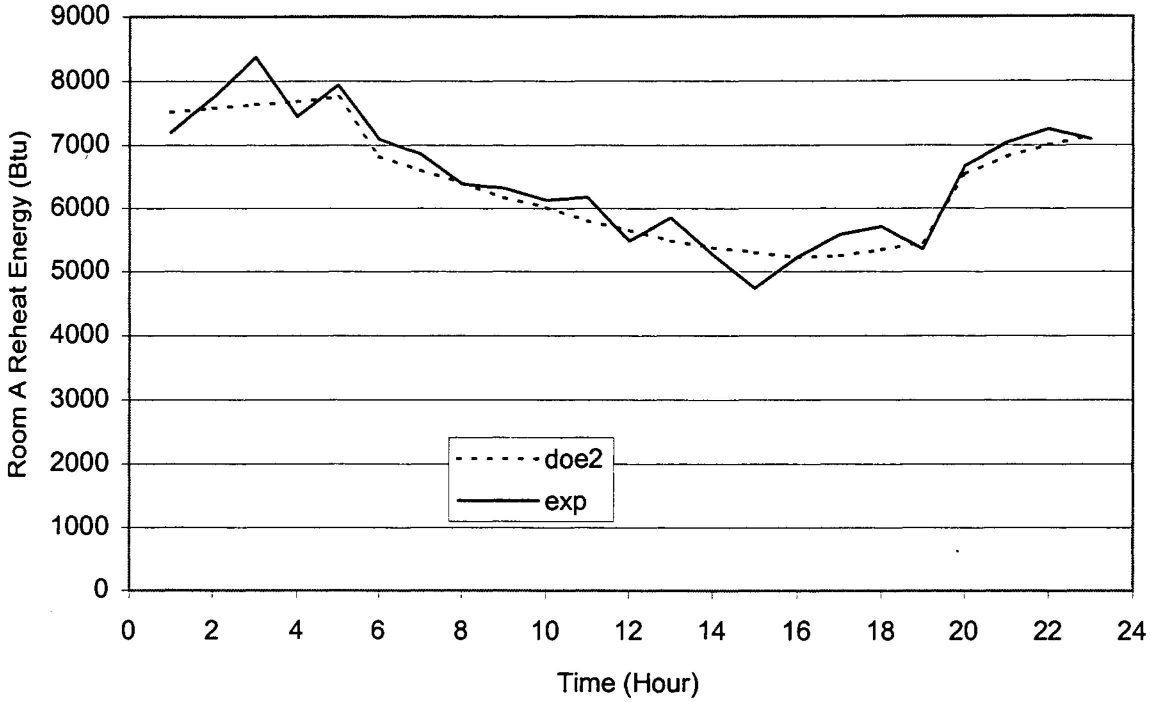


Figure 4.13 East Room A and B experimental and simulation reheat energy for May 5, 2001.



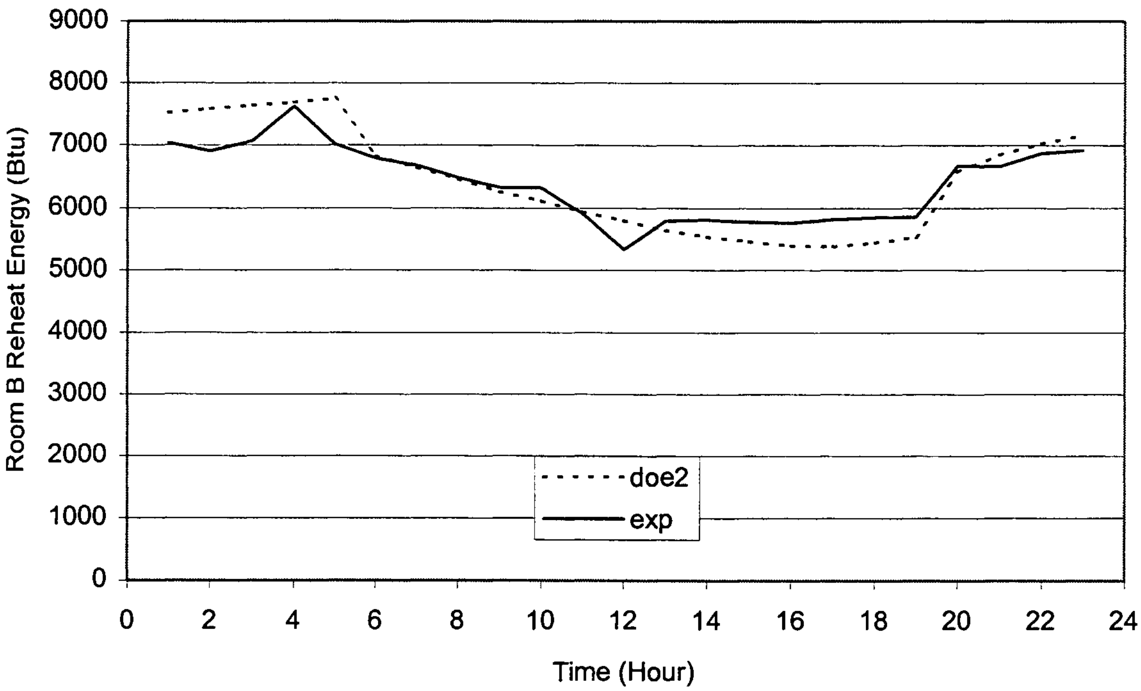
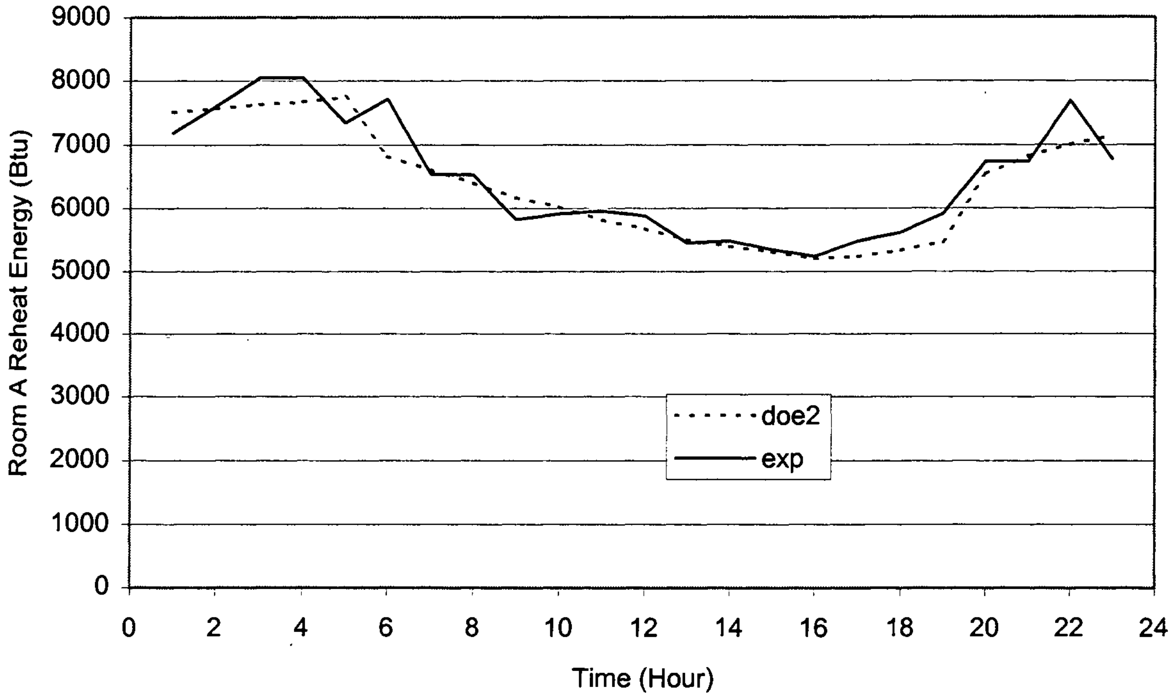


Figure 4.14 South Room A and B experimental and simulation reheat energy for May 5, 2001.



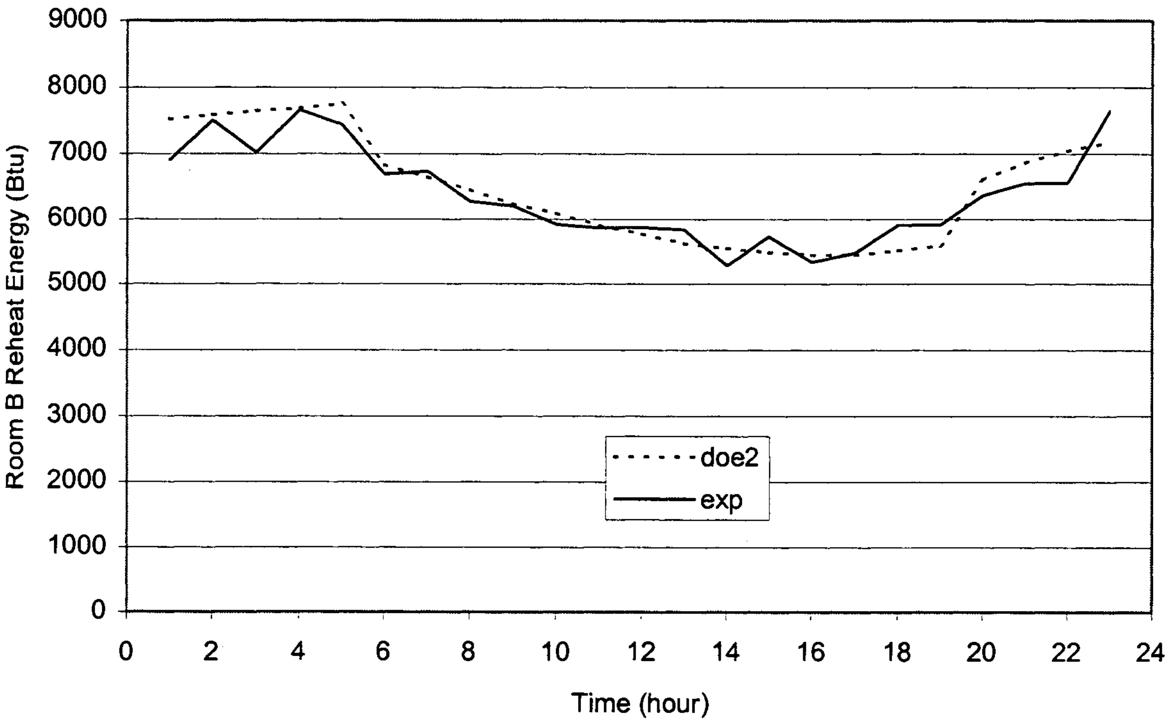
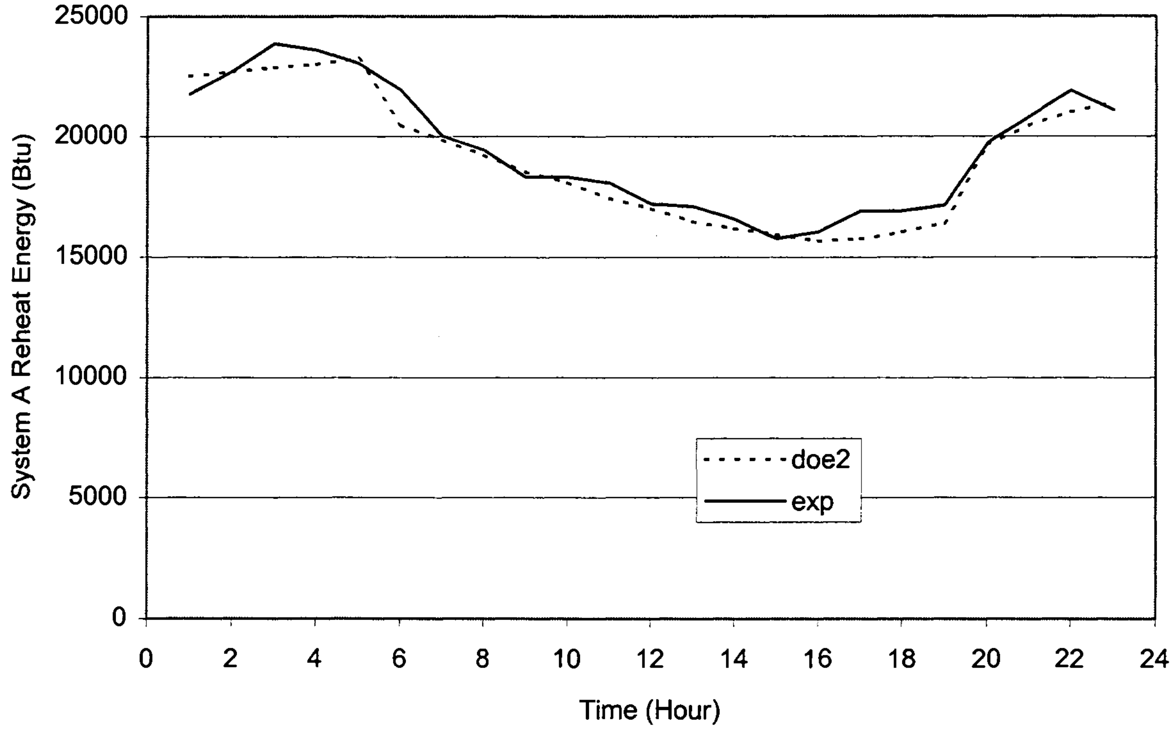


Figure 4.15 West Room A and B experimental and simulation reheat energy for May 5, 2001.



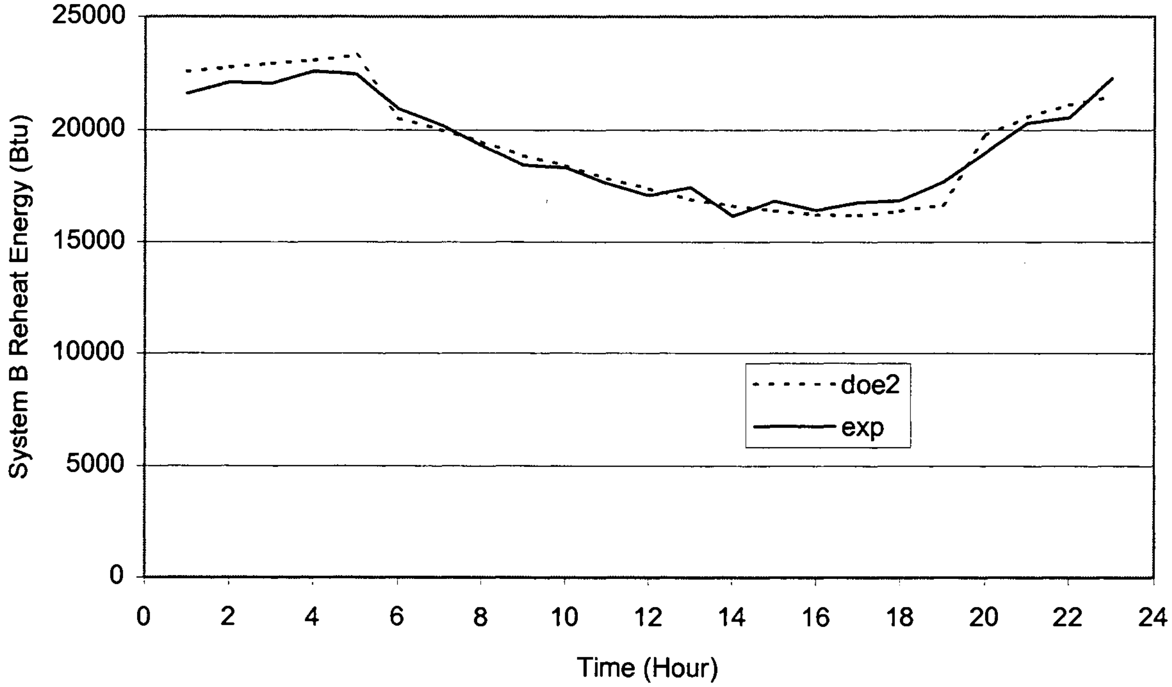
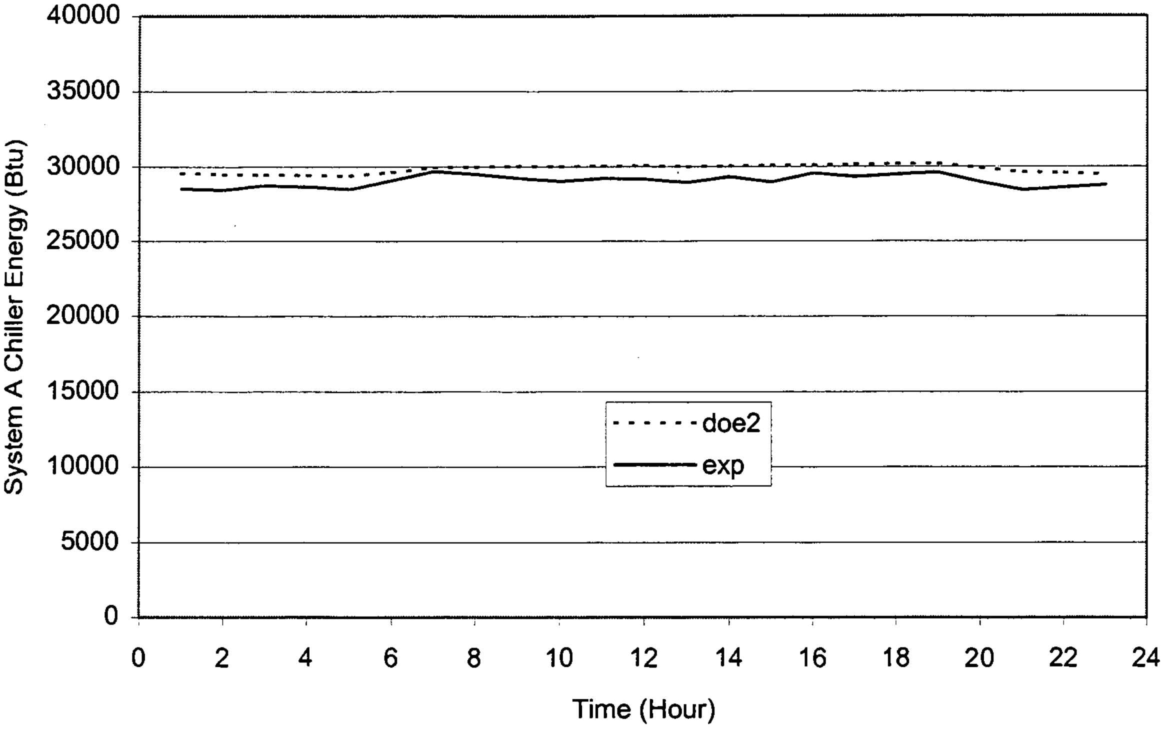


Figure 4.16 System A and B experimental and simulation reheat energy for May 5, 2001.



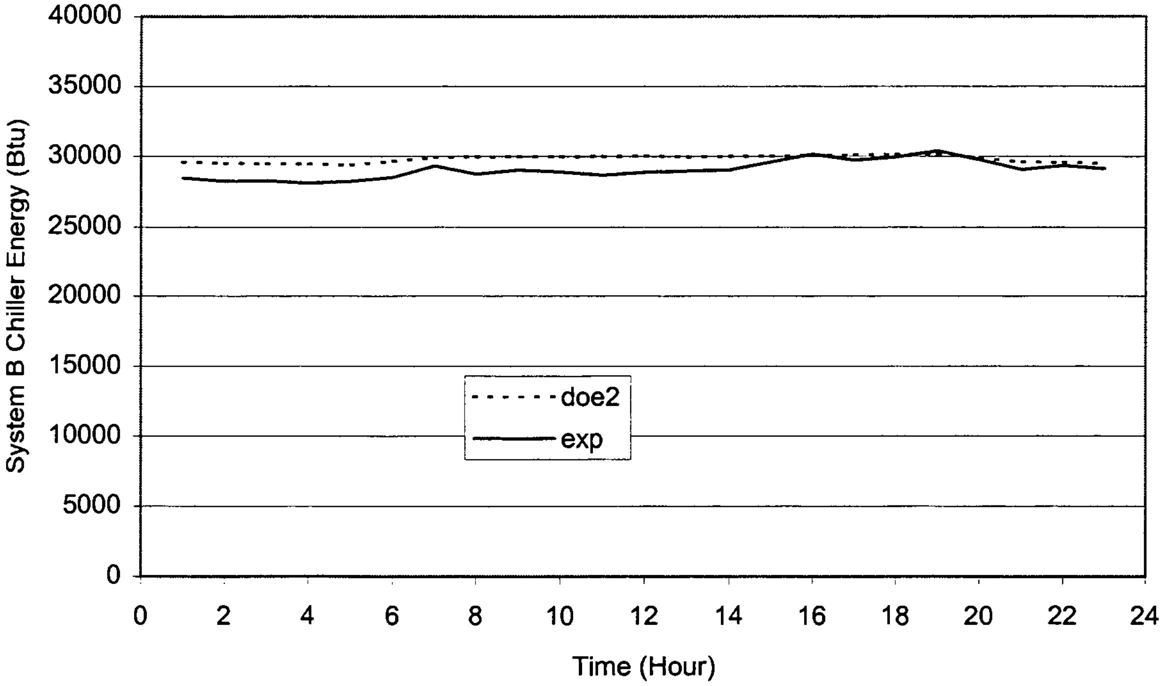


Figure 4.17 System A and B experimental and simulation chiller energy for May 5, 2001.

analysis of May 7. The chiller energy shows excellent agreement also, with the DOE-2 predictions just slightly larger than the experimental results.

Results Summary

Overall, the same general trends explained above are followed for each simulation day. Of course, given the number of simulation days, the results are not always so clearly defined as they are described above. Overall, however, the experimental results show a larger light contribution than that predicted by DOE-2. This translates into higher predicted light wattage. Differences in reheat energy are relatively minimal, with the greatest differences seen when the experimental system goes into cooling mode and zero reheat energy. The model also fails to predict large daily fluctuations in reheat energy. For instance, when the experimental data shows high morning reheat energy but low afternoon energy, the model tends to split the difference and does not approach either extreme. An example of this can be seen in Figure 4.18, which shows the reheat energy for the East A room on April 4, 2001.

It is possible that the perceived differences between the experimental and predicted values lie not with the daylighting controls but with DOE-2's ability to conduct load calculations using venetian blind window treatments. This is supported by the fact that the error between experimental and predicted results is greater for sunny days and greater in periods of direct sunlight, when the effect of the venetian blinds is the greatest. In addition, reheat and chiller system results are similar between the A and B test rooms, as seen in Tables 4.2 and 4.3 which show the percent error in system reheat and chiller energy for Systems A and B. Table 4.2 shows errors on the order of ± 15% for the system reheat values

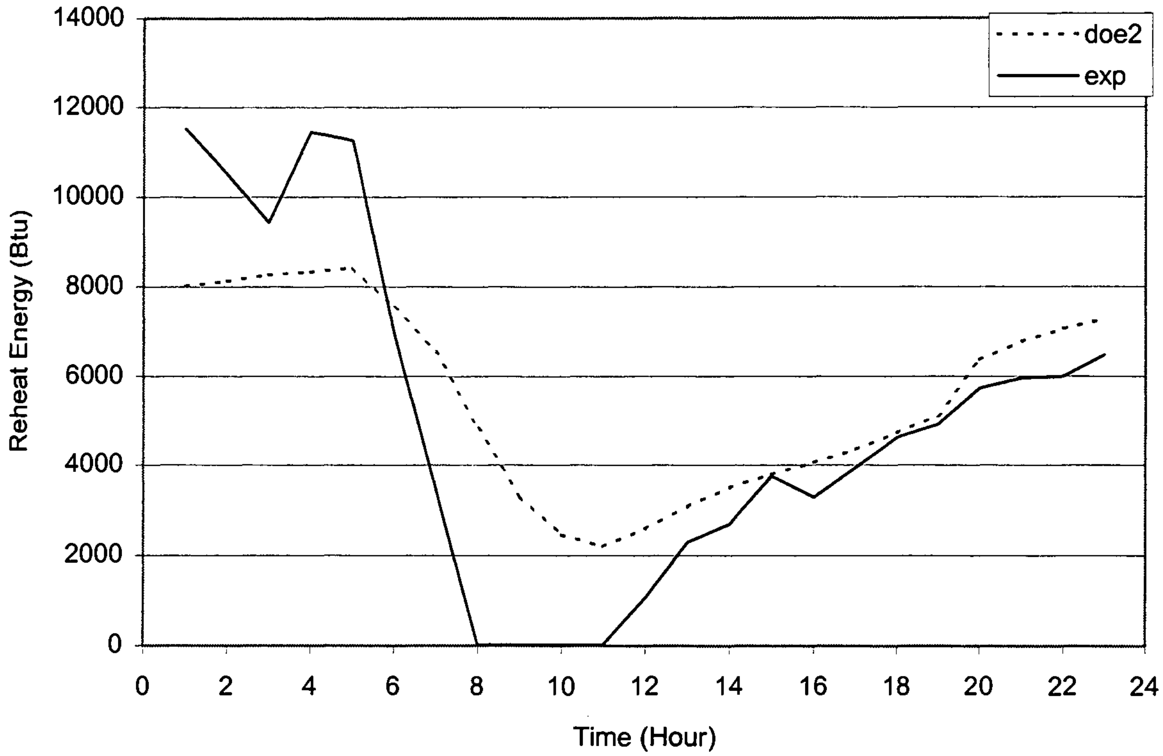


Figure 4.18 East Room A reheat energy for April 4, 2001.

Table 4.2 Reheat energy error.

Date	Predicted Energy Usage System A Btu	Experimental Energy Usage System A Btu	Percent Error	Predicted Energy Usage System B Btu	Experimental Energy Usage System B Btu	Percent Error
18-Aug	351,514	331,411	6%	366,653	340,807	7%
21-Aug	402,837	375,322	7%	412,656	374,029	9%
3-Apr	439,295	465,352	-6%	453,780	432,663	5%
4-Apr	391,319	397,507	-2%	408,558	381,220	7%
5-May	440,015	470,954	-7%	445,577	464,238	-4%
7-May	355,208	377,865	-6%	371,620	387,305	-4%
22-May	411,593	458,581	-11%	426,001	446,452	-5%
23-May	411,502	475,562	-16%	425,896	461,521	-8%

Table 4.3 Chiller energy error.

Date	Predicted Energy Usage System A Btu	Experimental Energy Usage System A Btu	Percent Error	Predicted Energy Usage System B Btu	Experimental Energy Usage System B Btu	Percent Error
18-Aug	738,543	677,114	8%	736,851	690,266	6%
21-Aug	732,493	704,805	4%	731,372	763,102	-4%
3-Apr	649,820	634,855	2%	648,145	588,251	9%
4-Apr	661,638	625,674	5%	659,720	584,842	11%
5-May	686,597	696,432	-1%	685,930	697,489	-2%
7-May	699,183	690,643	1%	697,384	676,810	3%
22-May	678,527	697,331	-3%	676,892	664,113	2%
23-May	678,222	695,457	-3%	676,587	665,183	2%

and ± 10% for the chiller values. In fact, System A shows the greatest error in reheat values, supporting the theory that daylighting is not the greatest cause for the error. The greatest chiller error is found in System B.

Overall the energy output predicted by the simulation is within 11% of the energy output that was found experimentally. The greatest error was positive, indicating that DOE-2 over-predicted energy usage. When the error was negative, the results were within 2%. Using these results, it would appear that DOE-2 produces a reasonable estimation of the energy that can be saved using daylighting controls with venetian blinds. Table 4.4 shows the total experimental and predicted energy usage for each simulation day.

DOE-2's ability to accurately predict energy and power magnitude is important in sizing equipment and determining initial capital cost. However, most daylighting simulations are conducted to compare to an appropriate base case to determine percent savings, similar to the process used for the experimental results in Chapter 3. How well does DOE-2 predict the percent energy savings found from the experimental results?

Table 4.4 Total System B usage error.

Date	Predicted Energy Usage Btu/hr	Experimental Energy Usage Btu/hr	Percent Error
18-Aug	1,162,681	1,069,047	8%
21-Aug	1,209,239	1,192,385	1%
3-Apr	1,163,030	1,066,349	8%
4-Apr	1,126,263	1,007,042	11%
5-May	1,202,775	1,230,389	-2%
7-May	1,127,894	1,105,266	2%
22-May	1,163,913	1,155,173	1%
23-May	1,163,503	1,178,774	-1%

Table 4.5 shows the predicted and actual percent energy savings for System B over System A. The table shows that DOE-2 does not predict a large energy difference between the two systems. In fact, DOE-2 shows a total energy savings of less than 1% for the daylighting control system over a conventional system. This is in strong contrast to the experimental energy savings for the same test days which range from –11% to +11%.

Table 4.5 Predicted energy savings with the DOE-2 simulation.

Date	Predicted Energy Usage System A Btu	Predicted Energy Usage System B Btu	Predicted Percent Savings	Experimental Percent Savings
18-Aug	1,166,602	1,162,681	0.34%	10.97%
21-Aug	1,211,875	1,209,239	0.22%	11.41%
3-Apr	1,165,660	1,163,030	0.23%	-11.64%
4-Apr	1,129,502	1,126,263	0.29%	-5.20%
5-May	1,203,157	1,202,775	0.03%	-0.47%
7-May	1,130,936	1,127,894	0.27%	2.79%
22-May	1,166,665	1,163,913	0.24%	-2.98%
23-May	1,166,269	1,163,503	0.24%	-6.95%

The smaller predicted energy savings is probably a reflection of the simulation's tendency to "smooth out" the extremes seen in the experimental data. Overall, however, it is important to note that the simulation always predicts energy savings with the daylighting system, even when the chiller and reheat energy are included in the analysis. Therefore, the daylighting system always saves energy, regardless of any reheat energy increase that may be associated with reducing the heat from the lights with the daylighting system.

Constant Visible Transmittance

The simulations described above were run with a variable visible transmittance, τ_v, in an effort to more closely match the experimental conditions. In general, however, a simulation would be conducted with a constant visible transmittance. Based on observation of the experimental data, an appropriate visible transmittance should fall within a range from approximately is 0.25 – 0.3 for light colored venetian blinds set at an angle of approximately 30°.

The simulations were run again with a constant visible transmittance of 0.27. The effect of the constant visible transmittance can be seen in Table 4.6. The table clearly shows that using a constant visible transmittance has little effect on the total simulation error. In fact, the error was the same for both constant and variable visible transmittance for all test days but two. Therefore, the use of an appropriate constant visible transmittance does not seem to affect the energy predictions.

Table 4.6 Total energy error with constant visible transmittance, τ_v.

Date	Predicted Energy Usage Btu/hr	Experimental Energy Usage Btu/hr	Percent Error (τ_v = constant)	Percent Error (τ_v = variable)
18-Aug	1,161,086	1,069,047	8%	8%
22-Aug	1,208,237	1,192,385	1%	1%
3-Apr	1,161,967	1,066,349	8%	8%
4-Apr	1,124,921	1,007,042	10%	11%
5-May	1,202,261	1,230,389	-2%	-2%
7-May	1,126,450	1,105,266	2%	2%
22-May	1,163,354	1,155,173	1%	1%
23-May	1,181,667	1,178,774	0%	-1%

CHAPTER 5. SUMMARY AND RECOMMENDATIONS

Daylighting is the name given to a lighting control system that adjusts the amount of electric light produced in relation to the amount of daylight that is incident on a work plane. Numerous studies have shown that daylighting is an effective lighting energy saver. However, the heat given off by light systems means that this lighting control strategy affects not only the lighting energy but the HVAC energy as well. Given that lights give off heat, it was hypothesized that daylighting would save HVAC energy in cooling mode but increase energy in heating mode.

Experiments were designed to study daylighting and its effect on total building energy usage. The experiments were conducted at the ERS in Ankeny, Iowa. Initial results of the experiments indicate that daylighting saves energy in nearly any situation. In fact, out of 32 total test days studied in this report, 24 had energy savings when using daylighting. HVAC energy savings were not limited to cooling mode, either. Over the course of the experiment days, cooling mode (i.e. no reheat energy necessary) in the test rooms was rarely achieved because of low internal loads, especially in rooms with daylighting which reduced the overall lighting load. That did not seem to affect energy savings, however. The total lighting energy savings was usually found to offset the increased reheat energy during heating mode periods. Therefore, total energy was saved even during heating mode.

The decision to use daylighting controls in a building is usually made before construction begins. It is important to determine the effect of daylighting on HVAC energy usage to determine whether the added cost of a daylighting system is worth the energy savings. Therefore, DOE2, a building simulation package, was used to model the experimental situation to determine how effectively the program could predict overall energy savings.

Overall, DOE2 was able to model System A, the system without daylighting controls, as well as System B, the system with daylighting controls. The program underestimated the amount of daylight entering the room for nearly every simulation day. It is suspected that the difference between experimental and predicted results is due more to the presence of venetian blinds as a window treatment than the inclusion of a daylighting control system in half of the test rooms.

The simulations were run with the same weather conditions as those encountered during the actual experiment. Final results were close to the experimental results, falling within –2% to +11%. Differences between the experimental and simulation results could be the result of measurement error, calculation method, or differences between the model and the actual building.

The simulations were run with a measured variable visible transmittance. In a typical design simulation this number would potentially be estimated as some constant for all daylit hours. The simulations were run again with a constant visible transmittance of 0.27. There was little to no difference in DOE-2's ability to predict the experimental results with a constant visible transmittance instead of a variable visible transmittance.

One other window treatment was tested experimentally. The MOLS window system was used against venetian blinds to test its efficiency in a daylighting control situation. The test was inconclusive. No significant energy increase or decrease was found using either window treatment.

RECOMMENDATIONS

This area of research is wide open in terms of scope and possibilities. The use of the ERS as a test facility, which allows the side-by-side study of lighting control systems and HVAC energy effects, offers a unique opportunity for the researcher. More study of daylighting systems is recommended.

Savings resulting from daylighting controls may be affected by the declination angle of the sun. To determine the effects of sun angle it is important to run more experiments at other times of the year, especially over or near Winter Solstice. In addition, tests that contain more reflective ground cover (such as snow) may yield interesting results.

Controlled baseboard heating should be used to simulate people and equipment in the office space. The increased heat serves not only to more closely match a "typical office environment" but will also increase the number of hours in cooling mode and allow better study of the effect of daylighting on that situation.

The blinds used in this report were kept at a constant angle throughout the conducted experiments. The angle was chosen to reduce glare for the first test conducted in August 2000. Studies on variable blade angle and their effect on daylighting energy savings could be conducted for a relatively constant declination angle. In addition, the relationship between sun angle, blade angle, and interior glare could be studied in conjunction with energy savings. Is the "best" blade angle visually also the "best" blade angle for energy savings?

The researcher would be well served to maintain a closer real-time examination of the data received from the ERS to determine where incorrect data is being measured. More experimental results would have been available for this report if inconsistencies had been found sooner. More work is needed at the ERS to verify that the test rooms are actually identical in construction. Tests on conduction rate, infiltration rate, and other construction related differences need to be conducted to remove their effect on the experimental data.

Finally, the MOLS test system may be a more effective window treatment than venetian blinds when coupled with daylighting controls. More data is needed to determine its overall effectiveness. In addition, a method for determining the quality of light on the work plane should be examined. The MOLS system, while it may not save energy, may produce less glare and more efficient light on the work plane than venetian blinds.

APPENDIX A. ERROR PROPAGATION

Propagation of measurement error through a calculation is a function of the individual measurement errors. For a function $z = f(x, y, t)$, the expression for the uncertainty of z is

$$(\varepsilon_z)^2 = (\partial z/\partial x)^2 (\varepsilon_x)^2 + (\partial z/\partial y)^2 (\varepsilon_y)^2 + (\partial z/\partial t)^2 (\varepsilon_t)^2$$

where the epsilons (ε) are measurement uncertainties and $\partial z/\partial x$, $\partial z/\partial y$, and $\partial z/\partial t$ are partial derivatives.

The equation for chiller energy is

$$E = C\, q\, (T_L - T_E)$$

where

E = chiller energy,

q = water flowrate,

T_L = temperature of the water leaving the cooling coil,

T_E = temperature of the water entering the water, and

C = constant encompassing water density, specific heat, and a conversion constant.

The partial derivatives necessary for the error propagation calculation are

$\partial E/\partial q = C\,(T_L - T_E)$

$\partial E/\partial T_L = C\,q$

$\partial E/\partial T_E = C\,q$

The final equation to calculate chiller error is

$$\varepsilon_E^{\,2} = [C\,(T_L - T_E)]^2\,(\varepsilon_q)^2 + (C\,q)^2\,(\varepsilon_{TL})^2 + (C\,q)^2\,(\varepsilon_{TE})^2$$

All of the percent energy savings calculations required error propagation analysis. The equation for error for the lighting and reheat percent savings calculations are

$$\varepsilon_{PSL} = 0.0028\ L_B\ /\ L_A \qquad\qquad \varepsilon_{PSR} = 0.0028\ R_B\ /\ R_A$$

where

ε_{PSL} = error for percent savings lighting energy

ε_{PSR} = error for percent savings reheat energy

L_B, L_A = lighting measurement for the B and A rooms

R_B, R_A = reheat measurement for the B and A rooms

The remaining percent savings calculations all involve pre-calculations. For example, before the error can be calculated for the percent energy savings for the reheat and lighting sum, first the error must be calculated for the reheating and lighting sum itself. Other calculations that follow this pattern are the reheat system sum, the lighting system sum, the reheat and lighting system sum, and the total energy sum. The error equations for those calculations are

$$\varepsilon_{RL}^2 = 0.002^2 (R^2 + L^2)$$

$$\varepsilon_{SR}^2 = 0.002^2 (R_E^2 + R_W^2 + R_S^2)$$

$$\varepsilon_{SL}^2 = 0.002^2 (L_E^2 + L_W^2 + L_S^2)$$

$$\varepsilon_{SRL}^2 = \varepsilon_{SR}^2 + \varepsilon_{SL}^2$$

$$\varepsilon_{SRLC}^2 = \varepsilon_{SR}^2 + \varepsilon_{SL}^2 + \varepsilon_E^2$$

where

ε_{RL} = error for lighting and reheat energy sum

ε_{SR} = error for system reheat energy sum

ε_{SL} = error for system lighting energy sum

ε_{SRL} = error for system reheat and lighting energy sum

ε_{SRLC} = error for system reheat, lighting, and chiller energy sum

R = magnitude of reheat measurement (subscript designates room)

L = magnitude of lighting measurement (subscript designates room)

The corresponding percent savings error equations are

$$\varepsilon_{PSRL}^2 = (RL_B^2 / RL_A^4)\, \varepsilon_{RLA}^2 + (-1 / RL_A^2)\, \varepsilon_{RLB}^2$$

$$\varepsilon_{PSSR}^2 = (SR_B^2 / SR_A^4)\, \varepsilon_{SRA}^2 + (-1 / SR_A^2)\, \varepsilon_{SRB}^2$$

$$\varepsilon_{PSSL}^2 = (SL_B^2 / SL_A^4)\, \varepsilon_{SLA}^2 + (-1 / SL_A^2)\, \varepsilon_{SLB}^2$$

$$\varepsilon_{PSSRL}^2 = (SRL_B^2 / SRL_A^4)\ \varepsilon_{SRLA}^2 + (-1 / SRL_A^2)\ \varepsilon_{SRLB}^2$$

$$\varepsilon_{PSSRLC}^2 = (SRLC_B^2 / SRLC_A^4)\ \varepsilon_{SRLCA}^2 + (-1 / SRCL_A^2)\ \varepsilon_{SRLCB}^2$$

where

ε_{PSRL} = error for percent savings lighting and reheat energy sum

ε_{PSSR} = error for percent savings system reheat energy sum

ε_{PSSL} = error for percent savings system lighting energy sum

ε_{PSSRL} = error for percent savings system reheat and lighting energy sum

ε_{PSSRLC} = error for percent savings system reheat, lighting, and chiller energy sum

RL = magnitude of reheat and lighting energy sum (subscript denotes system)

SR = magnitude of system reheat energy sum (subscript denotes system)

SL = magnitude of system lighting energy sum (subscript denotes system)

SRL = magnitude of system reheat and lighting energy sum (subscript denotes system)

SRLC = magnitude of system reheat, lighting, and chiller energy sum (subscript denotes system)

APPENDIX B. DOE-2.1E SIMULATION FOR APRIL 3, 2001

```
$**********************************************************************
*
$                              INPUT FOR ERS LOAD
*
$**********************************************************************
*
INPUT LOADS              INPUT-UNITS = ENGLISH   OUTPUT-UNITS = ENGLISH ..

TITLE                    LINE-1 *Daylighting 1* ..

ABORT                    IF ERRORS ..

DIAGNOSTIC               WARNINGS        CAUTIONS ..

RUN-PERIOD               APR 3 1999 THRU APR 3 1999 ..

$***************************** BUILDING DESCRIPTION *******************
BUILDING-LOCATION       LATITUDE = 41.71        LONGITUDE = 93.61
                  ALTITUDE = 0.0          AZIMUTH = 0.0
                  TIME-ZONE = 6           DAYLIGHT-SAVINGS = NO
                  HOLIDAY = NO ..


$********************** SCHEDULES FOR TEST ROOMS ***********************
$*** LIGHTING *********
LIGHT-SCH = SCHEDULE THRU DEC 31 (ALL) (1,5)(0) (6,19)(1) (20,24)(0) ..

$*** EAST TRANSMITTANCE ********
EASTVIS-SCH = SCHEDULE THRU DEC 31 (ALL) (1,6)(0) (7)(0.02) (8)(0.33)
                                    (9)(0.26) (10)(0.25) (11)(0.24)
                                    (12,14)(0.22) (15)(0.23) (16)(0.24)
                                    (17,18)(0.3) (19)(0.31) (20)(0.34)
                                    (21,24) (0) ..

$*** WEST TRANSMITTANCE ********
WESTVIS-SCH = SCHEDULE THRU DEC 31 (ALL) (1,6)(0) (7)(0.02) (8)(0.31)
                                    (9)(0.22)(10,11)(0.21) (12)(0.2)
                                    (13,14)(0.21) (15,16)(0.2)
                                    (17)(0.19) (18)(0.24) (19)(0.34)
                                    (20)(0.36) (21,24) (0) ..

$*** SOUTH TRANSMITTANCE ********
SOUTHVIS-SCH = SCHEDULE THRU DEC 31 (ALL) (1,6)(0) (7)(0.03) (8)(0.33)
                                    (9,11)(0.24) (12,13)(0.22)
                                    (14)(0.23) (15)(0.21) (16)(0.2)
                                    (17)(0.16) (18)(0.15) (19)(0.2)
                                    (20)(0.33) (21,24)(0) ..

$*** SHADING SCHEDULE FOR ALL ROOMS ********
```

```
SC-SCH = SCHEDULE THRU DEC 31 (ALL) (1,24)(0.8) ..

$********************* SCHEDULES FOR OTHER ROOMS ***********************
ZERO-SCH        = SCHEDULE THRU DEC 31 (ALL) (1,24)(0) ..
PEOPLE-STANDARD = SCHEDULE THRU DEC 31 (ALL) (1,7)(0) (8,18)(1)
                                                (19,24)(0) ..
LIGHT-STANDARD  = SCHEDULE THRU DEC 31 (ALL) (1,7)(0.05) (8,18)(1)
                                               (19,24)(0.05) ..
EQP-STANDARD = SCHEDULE THRU DEC 31 (ALL) (1,7)(0) (8,18)(1) (19,24)(0) ..


$***************************** MATERIAL DEFINITION **********************
$** THIS MATERIAL DEFINITION FOR MATERIAL THAT IS NOT AVAILABLE IN DOE2
DATABASE **
GL1                     = MATERIAL
                        THICKNESS = 0.0208       CONDUCTIVITY = 0.797
                        DENSITY = 138.5          SPECIFIC-HEAT = 0.178 ..


$***************************** GLASS TYPES ******************************
WINDOW-TEST     = GLASS-TYPE
                        SHADING-COEF = 0.85     GLASS-CONDUCTANCE = 0.55
                        PANES = 2 ..

WINDOW-TYPICAL  = GLASS-TYPE
                        SHADING-COEF = 0.31     GLASS-CONDUCTANCE = 0.30
                        PANES = 2 ..

WINDOW-SKYLITE  = GLASS-TYPE
                        SHADING-COEF = 0.35     GLASS-CONDUCTANCE = 0.24
                        PANES = 1 ..

$***************************** LAYERS DEFININTION **********************
SET-DEFAULT FOR LAYERS          INSIDE-FILM-RES = 0.68 .. $ FOR EXTERIOR
WALLS & ROOFS

$** ROOF FOR BUILDING EXCEPT THE CLASS ROOMS **
LAY-ROOF       = LAYERS MATERIAL = (RG02,AR02,IN47,BP01,CC02,AL23,CC02) ..

$** ROOF FOR CLASS ROOM **
LAY-CLASS-ROOF  = LAYERS        MATERIAL = (RG02,AR02,IN47,AS01) ..

$** BOTTOM WALL FOR TEST ROOMS **
LAY-TESTWALL-B  = LAYERS     MATERIAL = (CC03,IN42,IN43,AL11,BP01,GP02) ..

$** TOP WALL FOR TEST ROOMS **
LAY-TESTWALL-T  = LAYERS        MATERIAL = (CC04,IN43,AL11,GP02) ..

$** SPANDREL WALL **
LAY-SPAND-WALL= LAYERS MATERIAL=(GL1,AL11,GL1,AL31,IN43,IN13,BP01,GP02) ..

$** OVERHEAD WALL **
LAY-OVH-WALL    = LAYERS        MATERIAL = (CC04,IN43,AL11,IN13) ..

$** CLASS ROOMS WALL **
```

```
LAY-CLASS-WALL  = LAYERS     MATERIAL = (CC04,IN43,AL21,IN13,BP01,GP03) ..

$** BOTTOM WALL FOR BUILDING **
LAY-WALL-B      = LAYERS     MATERIAL = (CC03,IN43,AL11,IN13,BP01,GP02) ..

$** TOP WALL FOR BUILDING **
LAY-WALL-T      = LAYERS        MATERIAL = (CC03,IN43,AL11,IN13,GP02) ..

$** INTERIOR WALL
LAY-INT-WALL    = LAYERS        MATERIAL = (GP02,IN13,GP02) ..

$** CEILING **
LAY-CEILING     = LAYERS        MATERIAL = (AC03)       I-F-R = 0.61 ..

$** GROUND FLOOR **
LAY-FLOOR       = LAYERS        MATERIAL = (CC03,CP02)  I-F-R = 0.61 ..


$*** CONSTRUCTIONS DEFINITION FOR ROOF, WALL, CEILING, PARTITION, FLOOR,
WINDOW AND DOOR *****

$** ROOF FOR BUILDING EXCEPT CLASS ROOM **
ROOF-STD                = CONSTRUCTION
                        LAYERS = LAY-ROOF
                        ABSORPTANCE = 0.29      ROUGHNESS = 1 ..

$** ROOF FOR CLASS ROOM **
ROOF-CLASS              = CONSTRUCTION LIKE ROOF-STD
                        LAYERS = LAY-CLASS-ROOF ..

$** TEST ROOM BOTTOM WALL **
WALL-TESTROOM-B = CONSTRUCTION
                        LAYERS = LAY-TESTWALL-B
                        ABSORPTANCE = 0.69      ROUGHNESS = 3 ..

$** TEST ROOM TOP WALL **
WALL-TESTROOM-T = CONSTRUCTION LIKE WALL-TESTROOM-B
                        LAYERS = LAY-TESTWALL-T ..

$** SPANDRELL WALL **
WALL-SPANDRELL  = CONSTRUCTION
                        LAYERS = LAY-SPAND-WALL
                        ABSORPTANCE = 0.90      ROUGHNESS = 6 ..

$** OVERHEAD WALL **
WALL-OVERHEAD   = CONSTRUCTION LIKE WALL-TESTROOM-B
                        LAYERS = LAY-OVH-WALL ..

$** CLASSROOM WALL **
WALL-CLASSROOM  = CONSTRUCTION LIKE WALL-TESTROOM-B
                        LAYERS = LAY-CLASS-WALL ..

$** TYPICAL BUILDING BOTTOM-WALL **
WALL-BOTTOM     = CONSTRUCTION LIKE WALL-TESTROOM-B
                        LAYERS = LAY-WALL-B ..
```

```
$** TYPICAL BUILDING TOP-WALL **
WALL-TOP        = CONSTRUCTION LIKE WALL-TESTROOM-B
                        LAYERS = LAY-WALL-T ..

$** INTERIOR WALL FOR SPACE "INTERIOR-WALL" **
INT-WALL        = CONSTRUCTION          LAYERS = LAY-INT-WALL ..

$** INTERIOR WALL FOR INTERIOR ROOMS
WALL-INT        = CONSTRUCTION          U = 0.6 ..

$** CEILING **
CEILING         = CONSTRUCTION          LAYERS = LAY-CEILING ..

$** GROUND FLOOR **
GND-FLOOR       = CONSTRUCTION          LAYERS = LAY-FLOOR ..


$***************** SET DEFAULT VALUES *****************************
SET-DEFAULT FOR WINDOW          X = 0   Y = 3   WIDTH = 14
                                                HEIGHT = 5 ..

SET-DEFAULT FOR ROOF            CONSTRUCTION = ROOF-STD Z = 14
                              AZIMUTH = 180   TILT = 0        G-R = 0 ..

SET-DEFAULT FOR UNDERGROUND-FLOOR
                              CONSTRUCTION = GND-FLOOR
                              U-EFF = 0.05    TILT = 180 ..

SET-DEFAULT FOR INTERIOR-WALL
                              CONSTRUCTION = INT-WALL         TILT = 90 ..

SET-DEFAULT FOR SPACE           AREA = 275 ..


$****************** SPACE CONDITIONS *********************************
$** SPACE CONDITION FOR TEST ROOM **
TEST-ROOM-A             = SPACE-CONDITIONS
                        ZONE-TYPE       = CONDITIONED
                        TEMPERATURE     = (72.5)
                        LIGHTING-SCHEDULE= LIGHT-SCH
                        LIGHTING-TYPE   = REC-FLUOR-NV
                        LIGHT-TO-SPACE  = 0.8  $ 1
                        LIGHTING-KW     = 0.542
                        LIGHT-RAD-FRAC  = (0)
                        FLOOR-WEIGHT    = 20 ..

$ SPACE CONDITION FOR B ROOMS WITH DAYLIGHTING
TEST-ROOM-B             = SPACE-CONDITIONS
                        ZONE-TYPE       = CONDITIONED
                        TEMPERATURE     = (72.5)
                        LIGHTING-SCHEDULE= LIGHT-SCH
                        LIGHTING-TYPE   = REC-FLUOR-NV
                        LIGHT-TO-SPACE  = 0.8  $ 1
                        LIGHTING-KW     = 0.542
```

```
                         LIGHT-RAD-FRAC   = (0)
                         DAYLIGHTING      = YES
                         LIGHT-REF-POINT1= (7.3,10.4,2.5)
                         LIGHT-SET-POINT1= 85
                         ZONE-FRACTION1   = 1.0
                         LIGHT-CTRL-TYPE1= CONTINUOUS
                         FLOOR-WEIGHT     = 20 ..


$** SPACE CONDITION FOR INTERIOR ROOM **
INT-SC          = S-C          LIKE TEST-ROOM-A
                              EQUIPMENT-KW = 1 ..

$** SPACE CONDITION FOR OTHER ROOMS **
PLENUMS         = S-C          ZONE-TYPE = PLENUM      FLOOR-WEIGHT = 5 ..

$* BREAK ROOM AND STORAGE ROOM *
BREAKROOM-COND  = S-C          LIKE TEST-ROOM-A
                              P-SCH = ZERO-SCH
                              L-SCH = LIGHT-STANDARD  L-T = REC-FLUOR-RV
                              E-SCH = EQP-STANDARD    E-KW = 0.5 ..

$* RECEPTION ROOM, MEDIA CENTER *
MEDIAROOM-COND  = S-C          LIKE TEST-ROOM-A
                              P-SCH = PEOPLE-STANDARD N-O-P = 5
                              L-SCH = LIGHT-STANDARD  L-T = REC-FLUOR-RV
                              E-SCH = EQP-STANDARD    E-KW = 0.8 ..

$* OFFICE *
OFFICE-COND             = S-C          LIKE TEST-ROOM-A
                              P-SCH = PEOPLE-STANDARD N-O-P = 1
                              L-SCH = LIGHT-STANDARD  L-T = REC-FLUOR-RV
                              E-SCH = EQP-STANDARD    E-KW = 0.5 ..

$* COMPUTER ROOM AND DISPLAY ROOM *
COMPUTER-COND   = S-C          LIKE TEST-ROOM-A
                              P-SCH = PEOPLE-STANDARD N-O-P = 1
                              L-SCH = LIGHT-STANDARD  L-T = REC-FLUOR-RV
                              E-SCH = EQP-STANDARD    E-KW = 1 ..

$* CLASS ROOM *
CLASS-COND              = S-C          LIKE TEST-ROOM-A
                              P-SCH = PEOPLE-STANDARD AREA/PERSON = 100
                              L-SCH = LIGHT-STANDARD  L-T = REC-FLUOR-RV
                              E-SCH = EQP-STANDARD    E-KW = 1 ..

$* MECHANICAL ROOM *
MECHANICAL-COND = S-C          LIKE TEST-ROOM-A
                              PEOPLE-HG-LAT = 205     PEOPLE-HG-SENS = 245
                              P-SCH = PEOPLE-STANDARD N-O-P = 1
                              TEMPERATURE = (72.5)
                              L-SCH = LIGHT-STANDARD  L-T = SUS-FLUOR
                              LIGHTING-W/SQFT = 2.5
                              E-SCH = EQP-STANDARD    E-KW = 2 ..
```

```
$*********** SPACE DESCRIPTION OF TEST ROOMS IN ERS *******************

$** DESCRIPTION OF PLENUM IN EAST-A ROOM **
P-EAST-A                = SPACE
                        VOLUME = 1512.5 SPACE-CONDITIONS = PLENUMS ..
      PEWL-EAST-A             = EXTERIOR-WALL
                              X = 69.6       Y = 43.5       Z = 8.5
                              AZ = 90 TILT = 90
                              HEIGHT = 5.5   WIDTH = 15.5
                              CONSTRUCTION = WALL-TESTROOM-T ..
      ROOF-EAST-A             = ROOF
                              X = 50.3       Y = 43.5
                              HEIGHT = 15.5  WIDTH = 17.741 ..
      PIW1-EAST-A             = I-W     A = 85.25      N-T = P-MED-1   ..
      PIW2-EAST-A             = I-W     A = 94.58      N-T = P-EAST-B  ..
      PIW3-EAST-A             = I-W     A = 94.58      N-T = P-BREAK   ..
      CEIL-EAST-A             = I-W          A = 275 N-T = EASTROOM-A
                              TILT = 180     CONSTRUCTION = CEILING ..

$** DESCRIPTION OF PLENUM IN SOUTH-A ROOM **
P-SOUTH-A               = SPACE LIKE P-EAST-A ..
      PEWL-SOUTH-A      = EXTERIOR-WALL
                              X = 19.3       Y = 0          Z = 8.5
                              AZ = 180       TILT = 90
                              HEIGHT = 5.5   WIDTH = 15.5
                              CONSTRUCTION = WALL-TESTROOM-T ..
      ROOF-SOUTH-A      = ROOF
                              X = 19.3       Y = 0
                              HEIGHT = 17.741 WIDTH = 15.5 ..
      PIW1-SOUTH-A      = I-W          A = 85.25      N-T = P-MED-1 ..
      PIW2-SOUTH-A      = I-W          A = 94.58      N-T = P-SOUTH-B ..
      PIW3-SOUTH-A      = I-W          A = 94.58      N-T = P-COMPUTER ..
      CEIL-SOUTH-A      = I-W          A = 275 N-T = SOUTHROOM-A
                              TILT = 180     CONSTRUCTION = CEILING ..

$** DESCRIPTION OF PLENUM IN WEST-A ROOM **
P-WEST-A                = SPACE LIKE P-EAST-A ..
      PEWL-WEST-A             = EXTERIOR-WALL
                              X = 0          Y = 59  Z = 8.5
                              AZ = 270       TILT = 90
                              HEIGHT = 5.5   WIDTH = 15.5
                              CONSTRUCTION = WALL-TESTROOM-T ..
      ROOF-WEST-A             = ROOF
                              X = 0          Y = 43.5
                              HEIGHT = 15.5  WIDTH = 17.741  ..
      PIW1-WEST-A             = I-W     A = 179.83     N-T = P-MED-1   ..
      PIW2-WEST-A             = I-W     A = 94.58      N-T = P-WEST-B  ..
      CEIL-WEST-A             = I-W      A = 275 N-T = WESTROOM-A
                              TILT = 180     CONSTRUCTION = CEILING ..

$** DESCRIPTION OF PLENUM IN INTERIOR-A ROOM **
P-INT-A         = SPACE LIKE P-EAST-A ..
      ROOF-INT-A              = ROOF
                              X = 18.6       Y = 70
```

```
                              HEIGHT = 17.741 WIDTH = 15.5 ..
      PIW1-INT-A              = I-W     A = 85.25      N-T = P-MED-1   ..
      PIW2-INT-A              = I-W     A = 94.58      N-T = P-INT-B   ..
      PIW3-INT-A              = I-W     A = 94.58      N-T = P-DISPLAY ..
      PIW4-INT-A              = I-W     A = 85.25      N-T = MECH-ROOM ..
      CEIL-INT-A              = I-W     A = 275        N-T = INTROOM-A
                              TILT = 180     CONSTRUCTION = CEILING ..

$** DESCRIPTION OF EAST-A ROOM **
EASTROOM-A              = SPACE
                        VOLUME = 2337.5 SPACE-CONDITIONS = TEST-ROOM-A ..
      REWL-EAST-A             = EXTERIOR-WALL
                              X = 69.6        Y = 43.5        Z = 0
                              AZ = 90 TILT = 90
                              HEIGHT = 8.5    WIDTH = 15.5
                              CONSTRUCTION = WALL-TESTROOM-B ..
      WIND-EAST-A             = WINDOW        GLASS-TYPE = WINDOW-TEST
                                    SHADING-SCHEDULE = SC-SCH
                                    VIS-TRANS-SCH = EASTVIS-SCH ..
      RIW1-EAST-A             = I-W           AREA = 131.75   NEXT-TO =
MEDIA-CENTER
                                    CONS = WALL-INT ..
      RIW2-EAST-A             = I-W AREA = 150.8   NEXT-TO = EASTROOM-B ..
      RIW3-EAST-A             = I-W AREA = 150.8    NEXT-TO = BREAKROOM ..
      FLOOR-EAST-A            = UNDERGROUND-FLOOR  H = 15.5  W = 17.741 ..

$** DESCRIPTION OF SOUTH-A ROOM **
SOUTHROOM-A             = SPACE
                        VOLUME = 2337.5 SPACE-CONDITIONS = TEST-ROOM-A ..
      REWL-SOUTH-A    = EXTERIOR-WALL
                              X = 19.3        Y = 0           Z = 0
                              AZ = 180        TILT = 90
                              HEIGHT = 8.5    WIDTH = 15.5
                              CONSTRUCTION = WALL-TESTROOM-B ..
      WIND-SOUTH-A    = WINDOW        GLASS-TYPE = WINDOW-TEST
                              SHADING-SCHEDULE = SC-SCH
                              VIS-TRANS-SCH = SOUTHVIS-SCH ..
      RIW1-SOUTH-A    = I-W   AREA = 131.75   NEXT-TO = MEDIA-CENTER
                              CONS = WALL-INT ..
      RIW2-SOUTH-A    = I-W   AREA = 150.8    NEXT-TO = SOUTHROOM-B   ..
      RIW3-SOUTH-A    = I-W   AREA = 150.8    NEXT-TO = COMPUTER-RM ..
      FLOOR-SOUTH-A   = UNDERGROUND-FLOOR H = 17.741      W = 15.5 ..

$** DESCRIPTION OF WEST-A ROOM **
WESTROOM-A              = SPACE
                        VOLUME = 2337.5 SPACE-CONDITIONS = TEST-ROOM-A ..
      REWL-WEST-A             = EXTERIOR-WALL
                              X = 0           Y = 59  Z = 0
                              AZ = 270        TILT = 90
                              HEIGHT = 8.5    WIDTH = 15.5
                              CONSTRUCTION = WALL-TESTROOM-B ..
      WIND-WEST-A             = WINDOW        GLASS-TYPE = WINDOW-TEST
                              SHADING-SCHEDULE = SC-SCH
                              VIS-TRANS-SCH = WESTVIS-SCH ..
      RIW1-WEST-A             = I-W   AREA = 131.75 NEXT-TO = MEDIA-CENTER
```

```
                                CONS = WALL-INT ..
      RIW2-WEST-A       = I-W   AREA = 150.8     NEXT-TO = WESTROOM-B ..
      RIW3-WEST-A       = I-W         AREA = 150.8  NEXT-TO = COMPUTER-RM ..
      FLOOR-WEST-A      = UNDERGROUND-FLOOR H = 15.5.        W = 17.741 ..

$** DESCRIPTION OF INTERIOR-A ROOM **
INTROOM-A                 = SPACE
                          VOLUME = 2337.5 SPACE-CONDITIONS = INT-SC ..
      RIW1-INT-A                = I-W AREA = 131.75   NEXT-TO = MEDIA-CENTER
                                      CONS = WALL-INT ..
      RIW2-INT-A                = I-W AREA = 150.8    NEXT-TO = INTROOM-B ..
      RIW3-INT-A                = I-W AREA = 150.8   NEXT-TO = DISPLAY-RM ..
      RIW4-INT-A                = I-W AREA = 131.75   NEXT-TO = MECH-ROOM ..
      FLOOR-INT-A               = UNDERGROUND-FLOOR H = 17.741      W = 15.5
                                          U-EFF = 0.005 ..

$** DESCRIPTION OF PLENUM IN EAST-B ROOM **
P-EAST-B                  = SPACE
                          VOLUME = 1512.5 SPACE-CONDITIONS = PLENUMS ..
      PEWL-EAST-B               = EXTERIOR-WALL
                                X = 69.6        Y = 28  Z = 8.5
                                AZ = 90 TILT = 90
                                HEIGHT = 5.5    WIDTH = 15.5
                                CONSTRUCTION = WALL-TESTROOM-T ..
      ROOF-EAST-B               = ROOF
                                X = 50.3        Y = 28
                                HEIGHT = 15.5   WIDTH = 17.741  ..
      PIW1-EAST-B               = I-W   AREA = 85.25    NEXT-TO = P-MED-1 ..
      PIW2-EAST-B               = I-W  AREA = 95.28 NEXT-TO = P-RECEPTION ..
      CEIL-EAST-B               = I-W   AREA = 275   NEXT-TO = EASTROOM-B
                                TILT = 180  CONSTRUCTION = CEILING ..

$** DESCRIPTION OF PLENUM IN SOUTH-B ROOM **
P-SOUTH-B                 = SPACE LIKE P-EAST-B ..
      PEWL-SOUTH-B      = EXTERIOR-WALL
                                X = 34.8        Y = 0             Z = 8.5
                                AZ = 180        TILT = 90
                                HEIGHT = 5.5    WIDTH = 15.5
                                CONSTRUCTION = WALL-TESTROOM-T ..
      ROOF-SOUTH-B      = ROOF
                                X = 34.8        Y = 0
                                HEIGHT = 17.741 WIDTH = 15.5 ..
      PIW1-SOUTH-B      = I-W           AREA = 85.25    NEXT-TO = P-MED-1 ..
      PIW2-SOUTH-B      = I-W          AREA = 95.28   NEXT-TO = P-OFFICE  ..
      CEIL-SOUTH-B      = I-W           AREA = 275     NEXT-TO = SOUTHROOM-B
                                      TILT = 180 CONSTRUCTION = CEILING ..

$** DESCRIPTION OF PLENUM IN WEST-B ROOM **
P-WEST-B                  = SPACE LIKE P-EAST-B ..
      PEWL-WEST-B               = EXTERIOR-WALL
                                X = 0           Y = 43.5          Z = 8.5
                                AZ = 270        TILT = 90
                                HEIGHT = 5.5    WIDTH = 15.5
                                CONSTRUCTION = WALL-TESTROOM-T ..
      ROOF-WEST-B               = ROOF
```

```
                              X = 0            Y = 28
                              HEIGHT = 15.5    WIDTH = 17.741  ..
     PIW1-WEST-B              = I-W   AREA = 85.25   NEXT-TO = P-MED-1  ..
     PIW2-WEST-B              = I-W   AREA = 95.28 NEXT-TO = P-COMPUTER ..
     CEIL-WEST-B              = I-W   AREA = 275      NEXT-TO = WESTROOM-B
                              TILT = 180      CONSTRUCTION = CEILING ..

$** DESCRIPTION OF PLENUM IN INTERIOR-B ROOM **
P-INT-B         = SPACE LIKE P-EAST-B ..
     ROOF-INT-B               = ROOF
                              X = 34.1         Y = 70
                              HEIGHT = 17.741 WIDTH = 15.5 ..
     PIW1-INT-B              = I-W AREA = 179.8 NEXT-TO = P-MED-1        ..
     PIW2-INT-B               = I-W   AREA = 85.25 NEXT-TO = MECH-ROOM  ..
     CEIL-INT-B               = I-W   AREA = 275      NEXT-TO = INTROOM-B
                              TILT = 180      CONSTRUCTION = CEILING ..

$** DESCRIPTION OF EAST-B ROOM **
EASTROOM-B               = SPACE
                         VOLUME = 2337.5 SPACE-CONDITIONS = TEST-ROOM-B
                         MIN-POWER-FRAC = 0.27 ..
     REWL-EAST-B              = EXTERIOR-WALL
                              X = 69.6         Y = 28  Z = 0
                              AZ = 90 TILT = 90
                              HEIGHT = 8.5    WIDTH = 15.5
                              CONSTRUCTION = WALL-TESTROOM-B ..
     WIND-EAST-B              = WINDOW         GLASS-TYPE = WINDOW-TEST
                                   SHADING-SCHEDULE = SC-SCH
                                   VIS-TRANS-SCH = EASTVIS-SCH ..
     RIW1-EAST-B              = I-W   AREA = 131.75   NEXT-TO = MEDIA-
CENTER
                              CONSTRUCTION = WALL-INT ..
     RIW2-EAST-B             = I-W  AREA = 150.8 NEXT-TO = RECEPTION-RM ..
     FLOOR-EAST-B    = UNDERGROUND-FLOOR H = 15.5      W = 17.741      ..

$** DESCRIPTION OF SOUTH-B ROOM **
SOUTHROOM-B              = SPACE
                         VOLUME = 2337.5 SPACE-CONDITIONS = TEST-ROOM-B
                         MIN-POWER-FRAC = 0.32 ..
     REWL-SOUTH-B    = EXTERIOR-WALL
                              X = 34.8         Y = 0            Z = 0
                              AZ = 180         TILT = 90
                              HEIGHT = 8.5    WIDTH = 15.5
                              CONSTRUCTION = WALL-TESTROOM-B ..
     WIND-SOUTH-B    = WINDOW        GLASS-TYPE = WINDOW-TEST
                              SHADING-SCHEDULE = SC-SCH
                              VIS-TRANS-SCH = SOUTHVIS-SCH ..
     RIW1-SOUTH-B    = I-W   AREA = 131.75   NEXT-TO = MEDIA-CENTER
                                   CONSTRUCTION = WALL-INT ..
     RIW2-SOUTH-B    = I-W           AREA = 150.8    NEXT-TO = OFFICE  ..
     FLOOR-SOUTH-B   = UNDERGROUND-FLOOR
                              H = 17.741      W = 15.5  ..

$** DESCRIPTION OF WEST-B ROOM **
WESTROOM-B               = SPACE
```

```
                    VOLUME = 2337.5 SPACE-CONDITIONS = TEST-ROOM-B
                    MIN-POWER-FRAC = 0.22 ..
      REWL-WEST-B          = EXTERIOR-WALL
                           X = 0           Y = 43.5        Z = 0
                           AZ = 270        TILT = 90
                           HEIGHT = 8.5    WIDTH = 15.5
                           CONSTRUCTION = WALL-TESTROOM-B ..
      WIND-WEST-B          = WINDOW        GLASS-TYPE = WINDOW-TEST
                                 SHADING-SCHEDULE= SC-SCH
                                 VIS-TRANS-SCH = WESTVIS-SCH ..
      RIW1-WEST-B          = I-W AREA = 131.75   NEXT-TO = MEDIA-CENTER
                                 CONSTRUCTION = WALL-INT ..
      RIW2-WEST-B     = I-W      AREA = 150.8    NEXT-TO = COMPUTER-RM ..
      FLOOR-WEST-B    = UNDERGROUND-FLOOR
                           H = 15.5        W = 17.741           ..

$** DESCRIPTION OF INTERIOR-B ROOM **
INTROOM-B                = SPACE
                    VOLUME = 2337.5 SPACE-CONDITIONS = INT-SC ..
      RIW1-INT-B          = I-W  AREA = 282.55   NEXT-TO = MEDIA-CENTER
                                 CONSTRUCTION = WALL-INT  ..
      RIW2-INT-B          = I-W  AREA = 131.75  NEXT-TO = MECH-ROOM  ..
      FLOOR-INT-B         = UNDERGROUND-FLOOR
                    H = 17.741      W = 15.5        U-EFF = 0.005 ..

$*********** SPACE DESCRIPTION OF OTHER ROOMS IN ERS *******************

$** DESCRIPTION OF PLENUM IN BREAK ROOM **
P-BREAK          = SPACE
                    V = 2341.8      A = 390.3       SPACE-CONDITIONS =
PLENUMS ..
      PEWL-BREAK           = EXTERIOR-WALL
                           X = 69.6        Y = 59  Z = 8
                           AZ = 90 TILT = 90
                           HEIGHT = 6      WIDTH = 36.6
                           CONSTRUCTION = WALL-TOP ..
      ROOF-BREAK           = ROOF
                           X = 58.94       Y = 59
                           HEIGHT = 36.6   WIDTH = 10.66  ..
      PIW1-BREAK           = I-W   AREA = 63.96  NEXT-TO = MECH-ROOM ..
      PIW2-BREAK           = I-W   AREA = 219.6    NEXT-TO = P-MED-1 ..
      CEIL-BREAK           = I-W   AREA = 390.3    NEXT-TO = BREAKROOM
                           TILT = 180      CONSTRUCTION = CEILING ..

$** DESCRIPTION OF PLENUM IN RECEPTION AREA **
P-RECEPTION      = SPACE
                  V = 1268.48 A = 230.63 SPACE-CONDITIONS = PLENUMS ..
      PEWL-RECEPTION  = EXTERIOR-WALL
                           X = 66.6        Y = 15  Z = 8.5
                           AZ = 90 TILT = 90
                           HEIGHT = 5.5    WIDTH = 13
                           CONSTRUCTION = WALL-OVERHEAD ..
      ROOF-RECEPTION  = ROOF
                           X = 50.3        Y = 15
                           HEIGHT = 13             WIDTH = 17.741 ..
```

```
     CEIL-RECEPTION  = I-W          AREA = 230.63  NEXT-TO = RECEPTION-RM
                                   TILT = 180   CONSTRUCTION = CEILING ..

$** DESCRIPTION OF PLENUM IN OFFICE **
P-OFFICE                 = SPACE
                         V = 1087.8 A = 197.8 SPACE-CONDITIONS = PLENUMS ..
     PEW1-OFFICE              = EXTERIOR-WALL
                              X = 66.6        Y = 3           Z = 8.5
                              AZ = 90 TILT = 90
                              HEIGHT = 5.5    WIDTH = 12.1
                              CONSTRUCTION = WALL-OVERHEAD ..
     PEW2-OFFICE              = EXTERIOR-WALL
                              X = 34.2        Y = 0           Z = 8.5
                              AZ = 180        TILT = 90
                              HEIGHT = 5.5    WIDTH = 16.4
                              CONSTRUCTION = WALL-OVERHEAD ..
     ROOF-OFFICE     = ROOF
                              X = 50.3        Y = 3
                              HEIGHT = 12.1   WIDTH = 16.4 ..
     CEIL-OFFICE     = I-W          AREA = 197.8    NEXT-TO = OFFICE
                                   TILT = 180  CONSTRUCTION = CEILING ..

$** DESCRIPTION OF PLENUM IN COMPUTER ROOM **
P-COMPUTER               = SPACE
                         V = 2284.3 A = 415.3 SPACE-CONDITIONS = PLENUMS ..
     PEW1-CMPTR               = EXTERIOR-WALL
                              X = 3           Y = 3           Z = 8.5
                              AZ = 180        TILT = 90
                              HEIGHT = 5.5    WIDTH = 16.3
                              CONSTRUCTION = WALL-OVERHEAD ..
     PEW2-CMPTR               = EXTERIOR-WALL
                              X = 3           Y = 28  Z = 8.5
                              AZ = 270        TILT = 90
                              HEIGHT = 5.5    WIDTH = 25.1
                              CONSTRUCTION = WALL-OVERHEAD ..
     ROOF-CMPTR               = ROOF
                              X = 3           Y = 3
                              HEIGHT = 25.1   WIDTH = 16.3  ..
     CEIL-CMPTR               = I-W AREA = 415.3    NEXT-TO = COMPUTER-RM
                                   TILT = 180 CONSTRUCTION = CEILING ..

$** DESCRIPTION OF PLENUM IN WEST CLASS ROOM **
P-CLASS-W                = SPACE
                         V = 769.7 A = 769.7 SPACE-CONDITIONS = PLENUMS ..
     PEW1-CLASS-W    = EXTERIOR-WALL
                              X = -22.2       Y = 65  Z = 9
                              AZ = 180        TILT = 90
                              HEIGHT = 1      WIDTH = 22.2
                              CONSTRUCTION = WALL-CLASSROOM ..
     PEW2-CLASS-W    = EXTERIOR-WALL
                              X = -22.2       Y = 99.3        Z = 9
                              AZ = 270        TILT = 90
                              HEIGHT = 1      WIDTH = 34.67
                              CONSTRUCTION = WALL-CLASSROOM ..
     PEW3-CLASS-W    = EXTERIOR-WALL
```

```
                        X = 0           Y = 99.3        Z = 9
                        AZ = 0  TILT = 90
                        HEIGHT = 1      WIDTH = 22.2
                        CONSTRUCTION = WALL-CLASSROOM ..
      ROOF-CLASS-W    = ROOF
                        X = -22.5               Y = 65
                        HEIGHT = 34.67  WIDTH = 22.2
                        CONSTRUCTION = ROOF-CLASS ..
      CEIL-CLASS-W    = I-W           AREA = 796.7   NEXT-TO = CLASSROOM-W
                                    TILT = 180 CONSTRUCTION = CEILING ..

$** DESCRIPTION OF PLENUM IN EAST CLASS ROOM **
P-CLASS-E               = SPACE
                        V = 769.7 A = 769.7 SPACE-CONDITIONS = PLENUMS ..
      PEW1-CLASS-E    = EXTERIOR-WALL
                        X = 91.8        Y = 65  Z = 9
                        AZ = 180        TILT = 90
                        HEIGHT = 1      WIDTH = 22.2
                        CONSTRUCTION = WALL-CLASSROOM ..
      PEW2-CLASS-E    = EXTERIOR-WALL
                        X = 91.8        Y = 99.3        Z = 9
                        AZ = 90 TILT = 90
                        HEIGHT = 1      WIDTH = 34.67
                        CONSTRUCTION = WALL-CLASSROOM ..
      PEW3-CLASS-E    = EXTERIOR-WALL
                        X = 69.6        Y = 99.3        Z = 9
                        AZ = 0  TILT = 90
                        HEIGHT = 1      WIDTH = 22.2
                        CONSTRUCTION = WALL-CLASSROOM ..
      ROOF-CLASS-E    = ROOF
                        X = 91.8                Y = 65
                        HEIGHT = 34.67  WIDTH = 22.2
                        CONSTRUCTION = ROOF-CLASS ..
      CEIL-CLASS-E    = I-W           AREA = 796.7   NEXT-TO = CLASSROOM-E
                                    TILT = 180 CONSTRUCTION = CEILING ..

$** DESCRIPTION OF PLENUM IN DISPLAY ROOM **
P-DISPLAY               = SPACE
                        V = 1740.4 A = 316.4 SPACE-CONDITIONS = PLENUMS ..
      PEW1-DISPLAY    = EXTERIOR-WALL
                        X = 0           Y = 88  Z = 10
                        AZ = 270        TILT = 90
                        HEIGHT = 4      WIDTH = 17.741
                        CONSTRUCTION = WALL-TOP ..
      ROOF-DISPLAY    = ROOF
                        X = 0           Y = 70
                        HEIGHT = 17.741 WIDTH = 17.783 ..
      PIWL-DISPLAY    = I-W          AREA = 98.07  NEXT-TO = MECH-ROOM  ..
      CEIL-DISPLAY    = I-W           AREA = 316.4    NEXT-TO = DISPLAY-RM
                                    TILT = 180 CONSTRUCTION = CEILING ..

$** DESCRIPTION OF PLENUM IN MEDIA CENTER **
P-MED-1         = SPACE
                V = 7751.6 A = 1824.1 SPACE-CONDITIONS = PLENUMS ..
      PEW1-MED-1              = EXTERIOR-WALL
```

```
                              X = 0                    Y = 65  Z = 8.5
                              AZ = 270                 TILT = 90
                              HEIGHT = 5.5    WIDTH = 6
                              CONSTRUCTION = WALL-TOP ..
      ROOF-MED-1              = ROOF
                              X = 17.75                Y = 17.75
                              HEIGHT = 60.8   WIDTH = 30 ..
      PIW1-MED-1              = I-W   AREA = 33     NEXT-TO = MECH-ROOM ..
      CEIL-MED-1             = I-W   AREA = 1824.1   NEXT-TO = MEDIA-
CENTER
                              TILT = 180      CONSTRUCTION = CEILING ..

$** DESCRIPTION OF BREAK ROOM **
BREAKROOM                = SPACE
            V = 3122.4 A = 390.3 SPACE-CONDITIONS = BREAKROOM-COND ..
      REWL-BREAK              = EXTERIOR-WALL
                              X = 69.6        Y = 59
                              AZ = 90 TILT = 90
                              HEIGHT = 8      WIDTH = 36.6
                              CONSTRUCTION = WALL-BOTTOM ..
      RIW1-BREAK           = I-W   AREA = 85.28 NEXT-TO = STORAGE-RM    ..
      RIW2-BREAK        = I-W   AREA = 292.8    NEXT-TO = MEDIA-CENTER  ..
      FLOOR-BREAK             = U-F   HEIGHT = 36.6   WIDTH = 10.66    ..

$** DESCRIPTION OF RECEPTION ROOM **
RECEPTION-RM    = SPACE
            V = 1960.36 A = 230.63 SPACE-CONDITIONS = MEDIAROOM-COND ..
      REWL-RECEPT             = EXTERIOR-WALL
                              X = 66.6        Y = 15
                              AZ = 90         TILT = 90
                              HEIGHT = 8.5    WIDTH = 13
                              CONSTRUCTION = WALL-SPANDRELL ..
      WIND-RECEPT     = WINDOW        G-T = WINDOW-TYPICAL
                              H = 5   W = 7.9 ..
      RIW1-RECEPT     = I-W           AREA = 150.8    NEXT-TO = OFFICE ..
      FLOOR-RECEPT    = U-F           HEIGHT = 13     WIDTH = 17.741 ..

$** DESCRIPTION OF OFFICE **
OFFICE          = SPACE
                  V = 1681.2 A = 197.8  SPACE-CONDITIONS = OFFICE-COND ..
      REW1-OFFICE             = EXTERIOR-WALL
                              X = 66.6                Y = 3
                              AZ = 90         TILT = 90
                              HEIGHT = 8.5    WIDTH = 12.1
                              CONSTRUCTION = WALL-SPANDRELL ..
      WIN1-OFFICE             = WINDOW        G-T = WINDOW-TYPICAL
                                    H = 5   W = 11.8 ..
      REW2-OFFICE             = EXTERIOR-WALL
                              X = 50.3        Y = 3
                              AZ = 180        TILT = 90
                              HEIGHT = 8.5    WIDTH = 16.4
                              CONSTRUCTION = WALL-SPANDRELL ..
      WIN2-OFFICE             = WINDOW        G-T = WINDOW-TYPICAL
                                    H = 5   W = 15.3 ..
      FLOOR-OFFICE            = U-F   HEIGHT = 12.1   WIDTH = 16.4
```

```
                              CONS = GND-FLOOR ..

$** DESCRIPTION OF COMPUTER ROOM **
COMPUTER-RM       = SPACE
                  V = 3530.3 A= 415.3  SPACE-CONDITIONS = COMPUTER-COND ..
      REW1-COMP               = EXTERIOR-WALL
                              X = 3                   Y = 3
                              AZ = 180                TILT = 90
                              HEIGHT = 8.5    WIDTH = 16.3
                              CONSTRUCTION = WALL-SPANDRELL ..
      WIN1-COMP               = WINDOW        G-T = WINDOW-TYPICAL
                                    H = 5   W = 15.3 ..
      REW2-COMP               = EXTERIOR-WALL
                              X = 3                   Y = 28
                              AZ = 270                TILT = 90
                              HEIGHT = 8.5    WIDTH = 25.1
                              CONSTRUCTION = WALL-SPANDRELL ..
      WIN2-COMP               = WINDOW        G-T = WINDOW-TYPICAL
                                    H = 5   W = 24 ..
      RIW1-COMP               = I-W   A = 85  NEXT-TO = DISPLAY-RM ..
      FLOOR-COMP              = U-F   HEIGHT = 25.1   WIDTH = 16.3 ..

$** DESCRIPTION OF WEST CLASSROOM **
CLASSROOM-W             = SPACE
                        V = 3530.3     A = 415.3      SPACE-CONDITIONS =
CLASS-COND ..
      REW1-CLASS-W    = EXTERIOR-WALL
                              X = -22.2               Y = 65
                              AZ = 180                TILT = 90
                              HEIGHT = 9              WIDTH = 22.2
                              CONSTRUCTION = WALL-CLASSROOM ..
      WIN1-CLASS-W    = WINDOW  G-T = WINDOW-TYPICAL    H = 5   W = 3.5 ..
      REW2-CLASS-W    = EXTERIOR-WALL
                              X = -22.2               Y = 99.3
                              AZ = 270                TILT = 90
                              HEIGHT = 9              WIDTH = 34.67
                              CONSTRUCTION = WALL-CLASSROOM ..
      WIN2-CLASS-W    = WINDOW    G-T = WINDOW-TYPICAL    H = 5   W = 7 ..
      REW3-CLASS-W    = EXTERIOR-WALL
                              X = 0                   Y = 99.3
                              AZ = 0          TILT = 90
                              HEIGHT = 9              WIDTH = 22.2
                              CONSTRUCTION = WALL-CLASSROOM ..
      WIN3-CLASS-W    = WINDOW  G-T = WINDOW-TYPICAL    H = 5   W = 3.5 ..
      RIW1-CLASS-W    = I-W           A = 85  NEXT-TO = DISPLAY-RM     ..
      FLOOR-CLASS-W   = U-F           HEIGHT = 34.67  WIDTH = 22.2     ..

$** DESCRIPTION OF EAST CLASSROOM **
CLASSROOM-E             = SPACE
                  V = 3530.3 A = 415.3    SPACE-CONDITIONS = CLASS-COND ..
      REW1-CLASS-E    = EXTERIOR-WALL
                              X = 91.8                Y = 65
                              AZ = 180                TILT = 90
                              HEIGHT = 9              WIDTH = 22.2
                              CONSTRUCTION = WALL-CLASSROOM ..
```

```
      WIN1-CLASS-E      = WINDOW  G-T = WINDOW-TYPICAL    H = 5   W = 3.5 ..
      REW2-CLASS-E      = EXTERIOR-WALL
                                X = 91.8                Y = 99.3
                                AZ = 90         TILT = 90
                                HEIGHT = 9              WIDTH = 34.67
                                CONSTRUCTION = WALL-CLASSROOM ..
      WIN2-CLASS-E      = WINDOW    G-T = WINDOW-TYPICAL    H = 5   W = 7 ..
      REW3-CLASS-E      = EXTERIOR-WALL
                                X = 69.6                Y = 99.3
                                AZ = 0          TILT = 90
                                HEIGHT = 9              WIDTH = 22.2
                                CONSTRUCTION = WALL-CLASSROOM ..
      WIN3-CLASS-E      = WINDOW  G-T = WINDOW-TYPICAL    H = 5   W = 3.5 ..
      RIW1-CLASS-E      = I-W           A = 85  NEXT-TO = BREAKROOM     ..
      FLOOR-CLASS-E     = U-F           HEIGHT = 34.67  WIDTH = 22.2    ..

$** DESCRIPTION OF DISPLAY ROOM **
DISPLAY-RM                = SPACE
            V = 2689.7 A = 316.4  SPACE-CONDITIONS = COMPUTER-COND ..
      RIW1-DISP                 = I-W A = 151.56      NEXT-TO = MECH-ROOM ..
      RIW2-DISP                 = I-W A = 150.80      NEXT-TO = P-MED-1 ..
      FLOOR-DISP                = U-F           H = 17.741      W = 17.83 ..

$** DESCRIPTION OF STORAGE ROOM **
STORAGE-RM                = SPACE
            V = 2689.7 A = 316.4 SPACE-CONDITIONS = BREAKROOM-COND ..
      REW1-STORE                = EXTERIOR-WALL
                                X = 69.6        Y = 95.6
                                AZ = 90         TILT = 90
                                HEIGHT = 8.5    WIDTH = 25.3
                                CONSTRUCTION = WALL-BOTTOM ..
      REW2-STORE                = EXTERIOR-WALL
                                X = 69.6        Y = 118.6
                                AZ = 0          TILT = 90
                                HEIGHT = 8.5    WIDTH = 10.52
                                CONSTRUCTION = WALL-BOTTOM ..
      RIW1-STORE                = I-W A = 215.05      NEXT-TO = MECH-ROOM ..
      RIW2-STORE                = I-W   A = 266.1       NEXT-TO = MECH-ROOM
                                TILT = 0 ..
      FLOOR-STORE               = U-F   HEIGHT = 25.3   WIDTH = 10.55  ..

$** DESCRIPTION OF MEDIA CENTER **
MEDIA-CENTER      = SPACE
            V = 19187.4A = 1924.1 SPACE-CONDITIONS = MEDIAROOM-COND ..
      REWL-MEDIA                = EXTERIOR-WALL
                                X = 0           Y = 65
                                AZ = 270        TILT = 90
                                HEIGHT = 8.5    WIDTH = 6
                                CONSTRUCTION = WALL-BOTTOM ..
      ROOF-MEDIA              = ROOF  X = 29.8 Y = 38.5 H = 10.5 W = 10.5 ..
      WIND-MEDIA                = WINDOW
                                X = 0   Y = 0
                                H = 10  W = 10.5
                                G-T = WINDOW-SKYLITE ..
      RIW1-MEDIA                = I-W   A = 51  NEXT-TO = MECH-ROOM ..
```

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      FLOOR-MEDIA              = U-F   HEIGHT = 64.14  WIDTH = 30 ..

$** DESCRIPTION OF MECHANICAL ROOM **
MECH-ROOM                = SPACE
            V = 26159 A = 1764  SPACE-CONDITIONS = MECHANICAL-COND ..
      REW1-MECH                = EXTERIOR-WALL
                               X = 0          Y = 118.6
                               AZ = 270       TILT = 90
                               HEIGHT = 14    WIDTH = 19.1
                               CONSTRUCTION = WALL-TOP ..
      REW2-MECH                = EXTERIOR-WALL
                               X = 59.1       Y = 118.6
                               AZ = 0         TILT = 90
                               HEIGHT = 14    WIDTH = 57.8
                               CONSTRUCTION = WALL-TOP ..
      REW3-MECH                = EXTERIOR-WALL
                               X = 69.6       Y = 95.6   Z = 8.5
                               AZ = 90        TILT = 90
                               HEIGHT = 5.5   WIDTH = 25.3
                               CONSTRUCTION = WALL-TOP ..
      REW4-MECH                = EXTERIOR-WALL
                               X = 0          Y = 99.3   Z = 10
                               AZ = 270       TILT = 90
                               HEIGHT = 4     WIDTH = 11.3
                               CONSTRUCTION = WALL-TOP ..
      ROOF-MECH              = ROOF  X = 0   Y = 88  H = 30.6   W = 66.3 ..
      FLOOR-MECH               = U-F   HEIGHT = 30.6   WIDTH = 57.5 ..


$****************** REPORTS ******************************
$** LOAD HOURLY REPORT **
L-REPORT-SCH    = SCHEDULE THRU DEC 31 (ALL) (1,24) (1) ..

RS      = R-B V-T = GLOBAL      V-L = (38,39,40,46,4,5,14,15) ..

$* REPORT BLOCK FOR SPACE ELECTRIC FROM LIGHT WITH VARIABLE LIST 45
RL-EA   = R-B   V-T = EASTROOM-A        V-L = (45) ..
RL-SA   = R-B   V-T = SOUTHROOM-A       V-L = (45) ..
RL-WA   = R-B   V-T = WESTROOM-A        V-L = (45) ..

RL-EB   = R-B   V-T = EASTROOM-B        V-L = (45,49) ..
RL-SB   = R-B   V-T = SOUTHROOM-B       V-L = (45,49) ..
RL-WB   = R-B   V-T = WESTROOM-B        V-L = (45,49) ..


HOURLY-LOAD    = HOURLY-REPORT
                   REPORT-SCHEDULE = L-REPORT-SCH
                   REPORT-BLOCK    = (RL-EA,RL-SA,RL-WA,
                              RL-EB,RL-SB,RL-WB,RS)
                   OPTION          = PRINT ..


END ..
COMPUTE LOADS ..
```

```
$**********************************************************************
*
$                       INPUT FOR ERS HVAC SYSTEM
*
$**********************************************************************
*
INPUT SYSTEMS   INPUT-UNITS = ENGLISH   OUTPUT-UNITS = ENGLISH ..


$****************** SCHEDULE FOR ZONE TEMPERATURES **********************
$** HEATING SET POINT **
HEAT-SPT = SCHEDULE THRU DEC 31 (ALL) (1,24)(72) ..

$** COOLING SET POINT **
COOL-SPT = SCHEDULE THRU DEC 31 (ALL) (1,24)(73) ..

$***************** SCHEDULE FOR SUPPLY FAN ******************************
FAN-SCH = SCHEDULE THRU DEC 31 (ALL) (1,24)(1) ..

$**************** SCHEDULE FOR OUTSIDE AIR ******************************
OA-SCH = SCHEDULE THRU DEC 31 (ALL) (1,24)(0) ..

$**************** SCHEDULE FOR SYSTEM CONTROL ***************************
$** HEATING SCHEDULE **
HEAT-SCH = SCHEDULE THRU DEC 31 (ALL) (1,24)(1) ..

$** COOLING SCHEDULE **
COOL-SCH = SCHEDULE THRU DEC 31 (ALL) (1,24)(1) ..

$********************* ZONE CONTROL *************************************
ZONE-CTRL       = ZONE-CONTROL
                  DESIGN-HEAT-T   = 72
                  HEAT-TEMP-SCH   = HEAT-SPT
                  DESIGN-COOL-T   = 73
                  COOL-TEMP-SCH   = COOL-SPT
                  THERMOSTAT-TYPE = REVERSE-ACTION
                  THROTTLING-RANGE        = 1.5 ..

$********************* ZONE AIR *****************************************
ZA-TEST = ZONE-AIR              ASSIGNED-CFM    = 1000 ..
ZA-INT  = ZONE-AIR              ASSIGNED-CFM    = 550 ..
ZA-BREAK= ZONE-AIR              ASSIGNED-CFM    = 340 ..
ZA-RECEPT= ZONE-AIR             ASSIGNED-CFM    = 530 ..
ZA-OFFICE= ZONE-AIR             ASSIGNED-CFM    = 480 ..
ZA-CMPTR= ZONE-AIR              ASSIGNED-CFM    = 1500 ..
ZA-CLASS= ZONE-AIR              ASSIGNED-CFM    = 1200 ..
ZA-DISPLAY= ZONE-AIR            ASSIGNED-CFM    = 1200 ..
ZA-STOR = ZONE-AIR              ASSIGNED-CFM    = 170 ..
ZA-MEDIA= ZONE-AIR              ASSIGNED-CFM    = 1835 ..
ZA-MECH = ZONE-AIR              ASSIGNED-CFM    = 1300 ..


$*********************** ZONES OPERATION ********************************
```

```
$** TEST ROOMS A **
P-EAST-A          = ZONE  ZONE-TYPE       = PLENUM ..
P-SOUTH-A         = ZONE  ZONE-TYPE       = PLENUM ..
P-WEST-A          = ZONE  ZONE-TYPE       = PLENUM ..
P-INT-A           = ZONE  ZONE-TYPE       = PLENUM ..

EASTROOM-A        = ZONE
                    ZONE-TYPE       = CONDITIONED
                    ZONE-CONTROL    = ZONE-CTRL
                    ZONE-AIR        = ZA-TEST
                    MIN-CFM-RATIO   = 0.45 ..

SOUTHROOM-A       = ZONE  LIKE EASTROOM-A ..
WESTROOM-A        = ZONE  LIKE EASTROOM-A ..
INTROOM-A         = ZONE  LIKE EASTROOM-A Z-A = ZA-INT    M-C-R = 0.50 ..

$** TEST ROOMS B **
P-EAST-B          = ZONE  ZONE-TYPE       = PLENUM ..
P-SOUTH-B         = ZONE  ZONE-TYPE       = PLENUM ..
P-WEST-B          = ZONE  ZONE-TYPE       = PLENUM ..
P-INT-B = ZONE  ZONE-TYPE       = PLENUM ..

EASTROOM-B        = ZONE  LIKE EASTROOM-A ..
SOUTHROOM-B       = ZONE  LIKE EASTROOM-A ..
WESTROOM-B        = ZONE  LIKE EASTROOM-A ..
INTROOM-B         = ZONE  LIKE EASTROOM-A Z-A = ZA-INT    M-C-R = 0.50 ..

$** OTHER ROOMS IN ERS **
P-BREAK           = ZONE  ZONE-TYPE       = PLENUM ..
P-RECEPTION       = ZONE  ZONE-TYPE       = PLENUM ..
P-OFFICE          = ZONE  ZONE-TYPE       = PLENUM ..
P-COMPUTER        = ZONE  ZONE-TYPE       = PLENUM ..
P-CLASS-W         = ZONE  ZONE-TYPE       = PLENUM ..
P-CLASS-E         = ZONE  ZONE-TYPE       = PLENUM ..
P-DISPLAY         = ZONE  ZONE-TYPE       = PLENUM ..
P-MED-1 = ZONE  ZONE-TYPE       = PLENUM ..

BREAKROOM         = ZONE  LIKE EASTROOM-A Z-A = ZA-BREAK  M-C-R = 0.308 ..
RECEPTION-RM      = ZONE  LIKE EASTROOM-A Z-A = ZA-RECEPT M-C-R = 0.113 ..
OFFICE            = ZONE  LIKE EASTROOM-A Z-A = ZA-OFFICE M-C-R = 0.063 ..
COMPUTER-RM       = ZONE  LIKE EASTROOM-A Z-A = ZA-CMPTR  M-C-R = 0.08 ..
CLASSROOM-W       = ZONE  LIKE EASTROOM-A Z-A = ZA-CLASS  M-C-R = 0.313 ..
CLASSROOM-E       = ZONE  LIKE EASTROOM-A Z-A = ZA-CLASS  M-C-R = 0.313 ..
DISPLAY-RM        = ZONE  LIKE EASTROOM-A Z-A = ZA-DISPLAY   M-C-R = 0.25 ..
STORAGE-RM        = ZONE  LIKE EASTROOM-A Z-A = ZA-STOR   M-C-R = 0.0 ..
MEDIA-CENTER      = ZONE  LIKE EASTROOM-A Z-A = ZA-MEDIA  M-C-R = 0.14 ..
MECH-ROOM         = ZONE  LIKE EASTROOM-A Z-A = ZA-MECH   M-C-R = 0.29 ..


$********************** SYSTEM CONTROL ************************************
$** TEST ROOMS SYSTEMS **
SC-TEST = SYSTEM-CONTROL
                  MAX-SUPPLY-T          = 92
                  MIN-SUPPLY-T          = 55
                  HEATING-SCHEDULE      = HEAT-SCH
```

```
                 COOLING-SCHEDULE        = COOL-SCH
                 COOL-CONTROL            = CONSTANT
                 COOL-SET-T              = 58 ..

SC-MAIN = SYSTEM-CONTROL
                 MAX-SUPPLY-T            = 130
                 MIN-SUPPLY-T            = 55
                 HEATING-SCHEDULE        = HEAT-SCH
                 COOLING-SCHEDULE        = COOL-SCH
                 COOL-CONTROL            = CONSTANT
                 COOL-SET-T              = 55 ..

$******************** SYSTEM AIR ****************************************
SA-TEST = SYSTEM-AIR
                 OA-CONTROL       = TEMP
                 DUCT-AIR-LOSS    = 0
                 DUCT-DELTA-T     = 0 ..

SA-MAIN = SYSTEM-AIR
                 OA-CONTROL       = TEMP
                 SUPPLY-CFM       = 6000
                 MIN-OUTSIDE-AIR = 0.07
                 DUCT-AIR-LOSS    = 0
                 DUCT-DELTA-T     = 0 ..

$******************* SYSTEM FAN *****************************************
SYSTEM-FAN       = SYSTEM-FANS
                 FAN-SCHEDULE     = FAN-SCH
                 FAN-CONTROL      = INLET
                 SUPPLY-DELTA-T  = 2.4
                 SUPPLY-KW               = 0.00109
                 RETURN-DELTA-T  = 0.2
                 RETURN-KW               = 0.000528
                 NIGHT-CYCLE-CTRL        = CYCLE-ON-ANY ..


$***************** SYSTEM TERMINAL *************************************
ST-TEST = SYSTEM-TERMINAL  REHEAT-DELTA-T = 25 ..
ST-MAIN = SYSTEM-TERMINAL  REHEAT-DELTA-T = 75     MIN-CFM-RATIO = 0.07 ..


$******************* SYSTEMS OPERATION *********************************
AHU-A = SYSTEM
                 SYSTEM-CONTROL  = SC-TEST
                 SYSTEM-AIR      = SA-TEST
                 SYSTEM-FANS     = SYSTEM-FAN
                 SYSTEM-TERMINAL = ST-TEST
                 SYSTEM-TYPE     = VAVS
                 PLENUM-NAMES    = (P-EAST-A,P-SOUTH-A,P-WEST-A)
                 ZONE-NAMES      = (P-EAST-A,P-SOUTH-A,P-WEST-A,
                                   P-INT-A,EASTROOM-A,SOUTHROOM-A,
                                   WESTROOM-A,INTROOM-A)
                 ZONE-HEAT-SOURCE = ELECTRIC
                 RETURN-AIR-PATH = PLENUM-ZONES ..
```

```
AHU-B = SYSTEM
                  SYSTEM-CONTROL   = SC-TEST
                  SYSTEM-AIR       = SA-TEST
                  SYSTEM-FANS      = SYSTEM-FAN
                  SYSTEM-TERMINAL = ST-TEST
                  SYSTEM-TYPE      = VAVS
                  PLENUM-NAMES     = (P-EAST-B,P-SOUTH-B,P-WEST-B)
                  ZONE-NAMES       = (P-EAST-B,P-SOUTH-B,P-WEST-B,P-INT-B,
                                 EASTROOM-B,SOUTHROOM-B,WESTROOM-B,
                                 INTROOM-B)
                  ZONE-HEAT-SOURCE = ELECTRIC
                  RETURN-AIR-PATH = PLENUM-ZONES ..

AHU-MAIN = SYSTEM
                  SYSTEM-CONTROL   = SC-MAIN
                  SYSTEM-AIR       = SA-MAIN
                  SYSTEM-FANS      = SYSTEM-FAN
                  SYSTEM-TERMINAL = ST-MAIN
                  SYSTEM-TYPE      = VAVS
                  PLENUM-NAMES     = (P-MED-1,P-COMPUTER,P-OFFICE)
                  ZONE-NAMES       = (P-MED-1,P-COMPUTER,P-OFFICE,P-BREAK,
                                 P-RECEPTION,P-CLASS-W,P-CLASS-E,
                                 P-DISPLAY,MEDIA-CENTER,COMPUTER-RM,
                                 OFFICE,BREAKROOM,RECEPTION-RM,
                                 CLASSROOM-W,CLASSROOM-E,DISPLAY-RM,
                                 MECH-ROOM,STORAGE-RM)
                  ZONE-HEAT-SOURCE = HOT-WATER
                  RETURN-AIR-PATH = PLENUM-ZONES ..

$*************************** PLANT ASSIGNMENT *****************************

PLANT-1 = PLANT-ASSIGNMENT
                  SYSTEM-NAMES     = (AHU-MAIN,AHU-A,AHU-B) ..


$***************** REPORTS ******************************
$** LOAD HOURLY REPORT **
S-REPORT-SCH     = SCHEDULE THRU DEC 31 (ALL) (1,24) (1) ..

$* REPORT BLOCK FOR ZONE TEMPERATURE, CFM, AND ZONE COIL HEATING WITH
VARIABLE LIST 6,14,32
RS-EA    = R-B   V-T = EASTROOM-A         V-L = (6,14,32) ..
RS-SA    = R-B   V-T = SOUTHROOM-A        V-L = (6,14,32) ..
RS-WA    = R-B   V-T = WESTROOM-A         V-L = (6,14,32) ..
$RS-IA    = R-B   V-T = INTROOM-A V-L = (6,14,32) ..

RS-EB    = R-B   V-T = EASTROOM-B         V-L = (6,14,32) ..
RS-SB    = R-B   V-T = SOUTHROOM-B        V-L = (6,14,32) ..
RS-WB    = R-B   V-T = WESTROOM-B         V-L = (6,14,32) ..

HOURLY-SYSTEM1 = HOURLY-REPORT
                         REPORT-SCHEDULE = S-REPORT-SCH
                         REPORT-BLOCK     = (RS-EA,RS-SA,RS-WA,
                                             RS-EB,RS-SB,RS-WB)
```

```
                           OPTION           = PRINT ..

$* REPORT BLOCK FOR COOLING COIL ENERGY INPUT AND TOTAL ZONE HEATING
ENERGY INPUT (6 & 7)
RS-SYA         = R-B   V-T = AHU-A               V-L = (6,7) ..
RS-SYB         = R-B   V-T = AHU-B               V-L = (6,7) ..

HOURLY-SYSTEM3 = HOURLY-REPORT
                           REPORT-SCHEDULE = S-REPORT-SCH
                           REPORT-BLOCK    = (RS-SYA,RS-SYB)
                           OPTION          = PRINT ..

END ..
COMPUTE SYSTEMS ..
STOP ..
```

APPENDIX C. ARTIFICIAL ILLUMINATION

DOE2 is able to predict the amount of light due to daylight that is incident on a defined work plane. Comparison between this result and the actual daylight that is incident on the plane reveals the program's ability to predict the actual behavior of light in the room. However, during the experiment the light sensor on the work plane measured not only the light due to daylight but also the light due to electronic light. To make an adequate comparison between predicted and experimental results a method of removing the effects of electronic lights was necessary. Once the artificial illumination level was determined it was subtracted from the total experimental illumination leaving only the light due to daylight.

A separate experiment was conducted to determine the relationship between the power to the lights and the light level produced on the work plane. The power to the lights was varied and the light level on the surface measured to determine a relationship between power and illumination. Measurements of light power and work plane light level were made during the night to remove contamination by exterior light. The results of the experiment can be found in Table C.1.

Table C.1 Artificial light contribution data.

Light Power (Watts)	Light Level (Foot candles)
129.5	5.602
189.3	16.703
311.8	45.219
431.3	73.688
534.0	95.688
535.5	96.188

The data points were plotted and a curve was fit to determine the relationship between power and light level. The resulting plot can be found in Figure C.1. The plot shows a strong linear relationship between the two variables. The resulting curve-fit equation is found in Eq (C1). The correlation for this equation is $R^2 = 0.9995$.

$$\text{Illuminance} = 0.2261\ (\text{Power}) - 24.795 \qquad \text{(C1)}$$

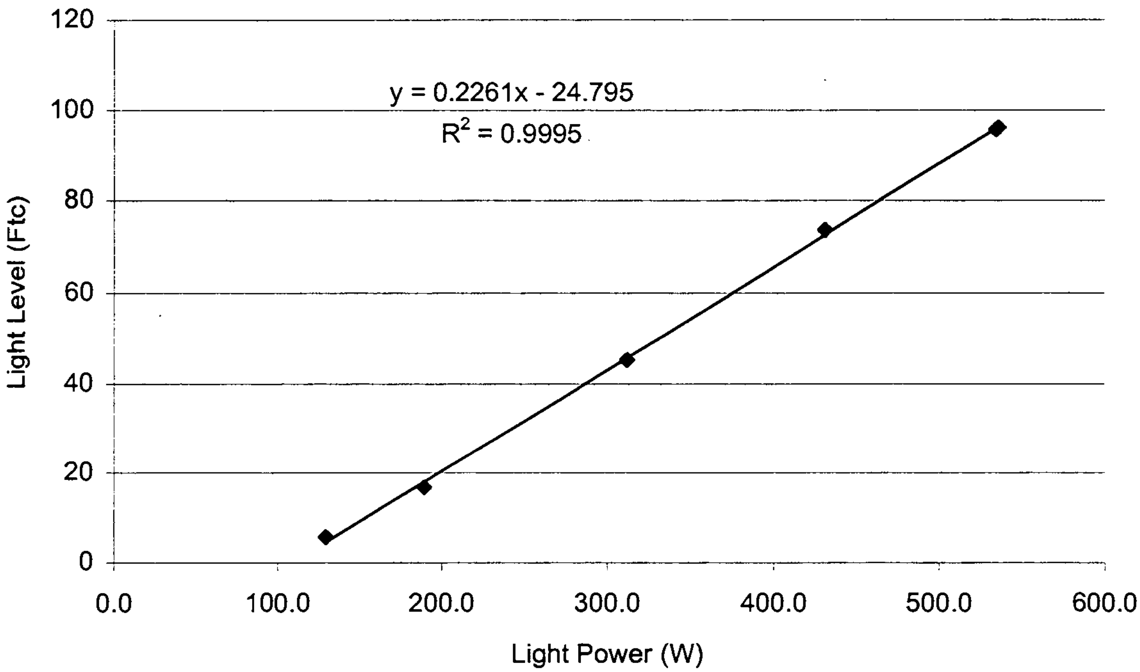

Figure C.1 Artificial illumination contribution calibration

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