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Energy Performance Analysis of Pelotint Dynamic Sun Responsive Thermochromic (SRT) Windows

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Energy Performance Analysis of Pelotint Dynamic Sun Responsive Thermochromic (SRT) Windows

by

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ABSTRACT

This study presents the energy performance test results of the Pleotint Sun Responsive Thermochromic (SRT) windows by using the Iowa Energy Center Energy Resource Station (ERS) test systems and data acquisition resources. The data includes experimental test results by using the ERS test, instrumentation and data acquisition resources. The experimental procedures were conducted under controlled environments.

The controlled environments consists of test rooms, office space, air handling units and air cooled chillers. The weather data were also collected at the facility and used for both experimental and simulation test procedures. The experimental performance results presented in this thesis for the SRT windows include the analysis of natural gas and electricity energy use for heating loads, cooling loads, pump energy, fan energy and lighting energy at the test room level.

Considering energy efficiency, the results of this study show that Pleotint SRT window technology can save more energy compared to Low-E dark tinted performance windows while still satisfying comfort level requirements. The results of the study show that most of the energy savings were from lighting energy compared to cooling and heating loads.

CHAPTER 1. INTRODUCTION

1.1 Motivation

The concerns about increasing fossil fuel prices, energy security, fluctuating climate conditions, have increased the demand for alternative energy resources and energy efficiency technologies. Alternative ways of saving energy lies in the applications of Energy Efficiency. Efficient energy use is to decrease the amount of energy that is required to provide products, services, performance and convenience. Buildings using energy efficiency use less energy, cost less to operate, improve comfort and save money for business and homeowners. According to the U.S. Department of Energy website, buildings use more energy than any other sector of the U.S. economy, consuming more than 70% of electricity and over 50% of natural gas. (DOE, 2012) The investments in energy efficiency yield cost savings, reduction in the peak demand, and a cleaner environment by reducing the carbon dioxide and harmful gas emissions. According to the U.S Department of Energy website, the near future goals for energy efficiency are to make homes and commercial buildings up to 60 to 70% more energy efficient than today's typical buildings by years 2020 to 2025 (DOE, 2012).

This thesis uses the basic concepts of thermodynamics, heat transfer and fundamentals of HVAC systems to evaluate the energy performance of the Pleotint SRT windows technology. The main purpose of this technology is to support more energy efficient buildings by reducing the demand on natural gas and electricity without sacrificing the environmental comfort settings. The study took place at Iowa

Energy Center's Energy Resource Station (ERS) which is located in Ankeny, Iowa. The Energy Resource Station, shown in Figure 1 is a training facility which is designed for the simultaneous testing and demonstration of multiple, full scale commercial building systems. The station is equipped with sophisticated instrumentation and electronic data acquisition systems to research programs, including Energy Efficiency Analysis.

Figure 1: Iowa Energy Center Energy Resource Station (ERS)

Energy Resource Station provided reliable experimental data throughout the Pleotint SRT performance window testing procedure.

1.2 Objective

The purpose of this work is to document the energy efficiency and performance of Pleotint SRT performance windows compared to the ERS high performance dark tinted insulating glass windows in a real world environment using ERS matched Test Room Pairs.

CHAPTER 2. Energy Resource Station Description

2.1 Site

The Energy Resource Station is located in Ankeny, Iowa with a latitude of 41.71 degrees North and a longitude of 93.61 degrees West. The building is a part of the DMACC Ankeny community college. The facility is located 937 ft above sea level.

2.2 Floor Plan and General Exterior Envelope

Energy Resource Station has a total floor area of 9,208 ft^2 and a building height of 15 ft. The building consists of three major areas; the general area, the A tests rooms and the B test rooms. The general area includes Media Center, Offices, Reception Space, East\West Vestibule, Computer Center, East\West Classrooms, Mechanical Room, Electrical Room, Communications Room, Storage Rooms and Restrooms. There are four A and four B test rooms. These test rooms are located as a pair on each side of the building. For each side of the building, these test rooms were built to be identical in construction and design specifications. Each test room has a floor area of approximately of 266 ft^2. The entire building floor is built from 4 inch concrete on a 4 inch layer of sand. The exterior construction layers for the building from outer layer to inward are precast concrete, metal stud walls insulated with fiberglass and gypsum board, vapor barrier, air space, rigid insulation. The percentages of glazing to the exterior wall area are; East Elevation (15%), West Elevation (16%), South Elevation (32%) and North Elevation (0%). The Elevation Sections, Floor Plan schematic and Room Sizes of Energy Resource Station can be seen in Figures 2 and 3 and Table 1.

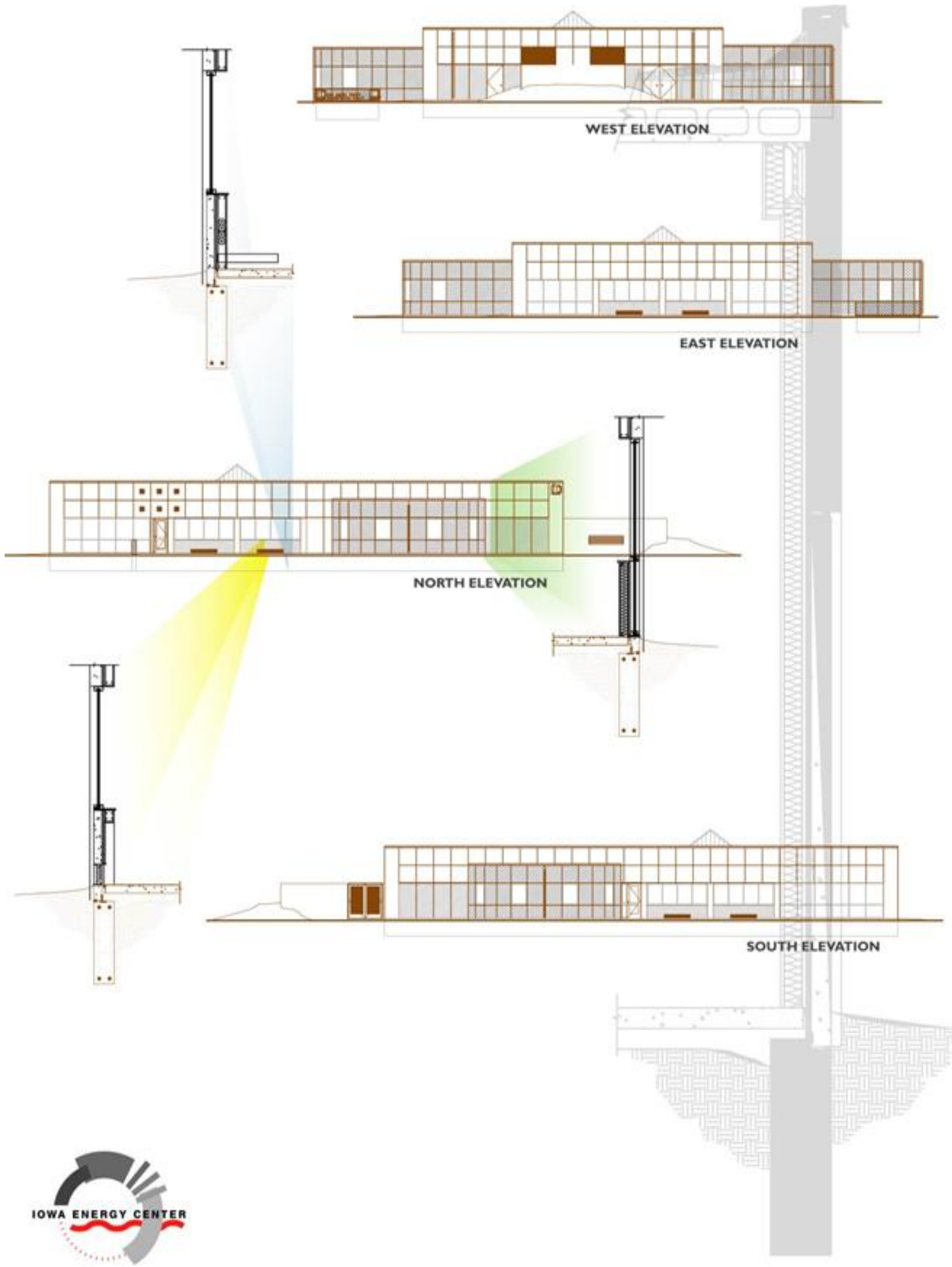

Figure 2: Elevations/Sections

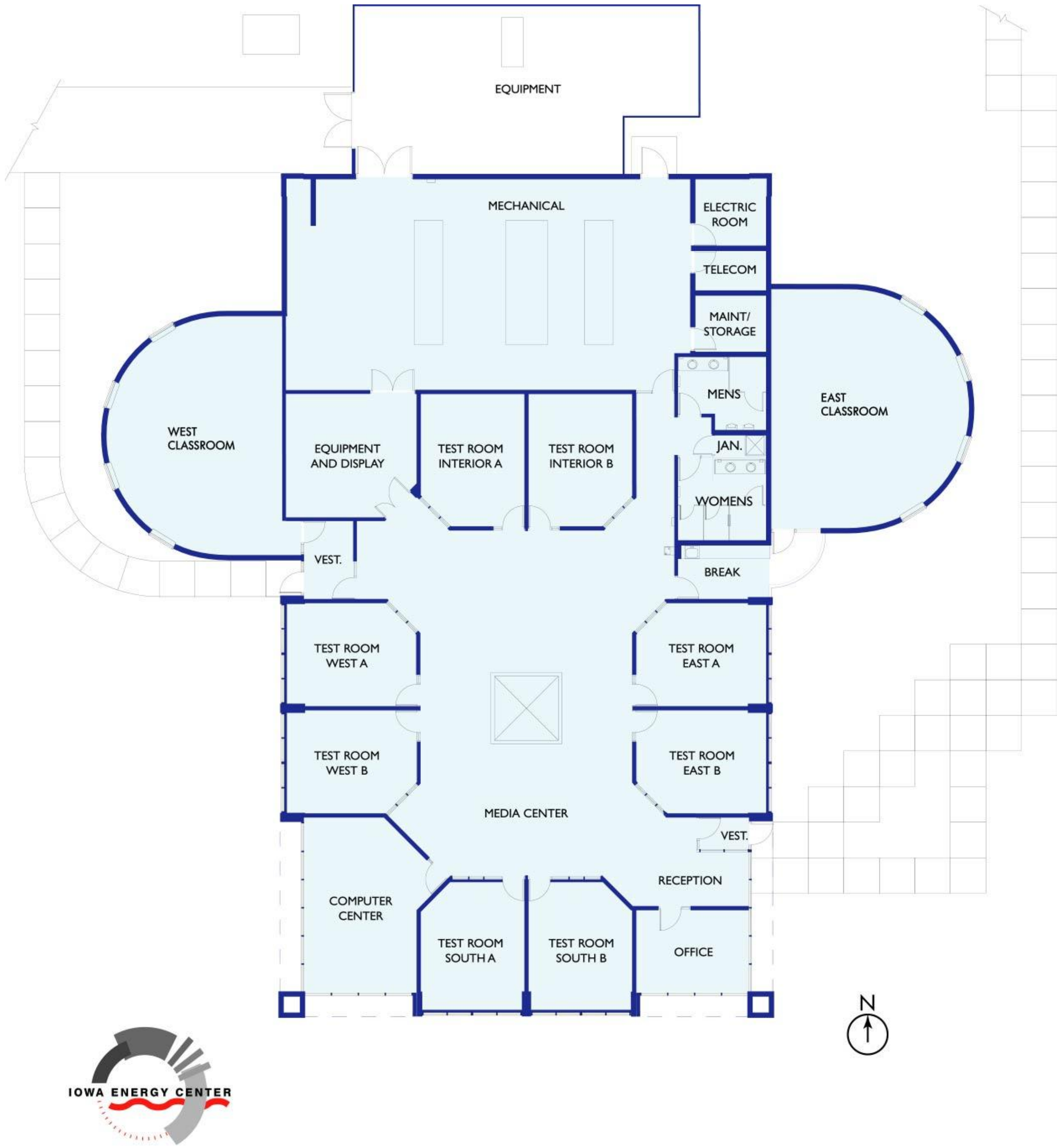

Figure 3: ERS Floor Plan

Table 1: Room Sizes

Room Type	Net Floor Area(ft^2)	Ceiling Height(ft)	Plenum Height(ft)	Exterior Wall(ft^2)	Window Area(ft^2)
Test Rooms:	266	8.5	5.5	137	74
East A/B	266	8.5	5.5	137	74
South A/B	266	8.5	5.5	137	74
West A/B	266	8.5	5.5	137	74
Interior A/B	266	8.5	5.5	0	0
General Service Areas:					
Mechanical Room	1764	14	0	1080	0
Storage Room	90	14	0	294	0
Communications Room	66	14	0	88	0
Electrical Room	110	14	0	119	0
Service Room	390	8	6	499	0
Display Room	316	8.5	5.5	0	0
East Classroom	769	9	1	762	70
West Classroom	769	9	1	762	70
East Vestibule	36	8.5	5.5	33	30
West Vestibule	85	8.5	5.5	125	30
Media Center	1888	10	4	0	0
Reception Area	178	8.5	5.5	75	40
East Office	197	8.5	5.5	238	136
West Office and Computer Center	415	8.5	5.5	383	197

2.3 Weather Station and Sensors

ERS has its own weather station and light sensors located on the exterior of the building shown in Figures 4, 5 and 6. The weather station and exterior sensors are capable of collecting real time data for the outside ambient conditions. The collected weather data includes the following parameters:

- Relative humidity.
- Outside air dry bulb temperature.
- Barometric pressure.
- Wind speed and direction.
- Long wave radiation.
- Total normal incidence and global horizontal solar flux.

Figure 4: ERS Weather Station

Figure 6: Solar Station

Figure 5: Exterior Lighting Sensors

There are exterior light sensors located on the east west and south side of the exterior wall to measure the quarter sphere sky dome and ground reflectance. There is a global light sensor located at the roof to measure the half sky dome. The collected real time weather data is stored in a computer as a TMY (Typical Meteorological Year) data format to be used for energy simulation purposes.

2.4 ERS Mechanical Equipment

The main mechanical system for the Energy Resource Station includes central heating, cooling plant and three air handling units. The heating plant consists of a natural gas fired hydronic boiler and circulating heating water pumps. The central cooling plant consists of three air cooled liquid chillers, a thermal energy storage tank and circulating chilled water pumps. The three air handling units will be discussed under HVAC Plan. The main mechanical system for the ERS can be seen in Figure 7.

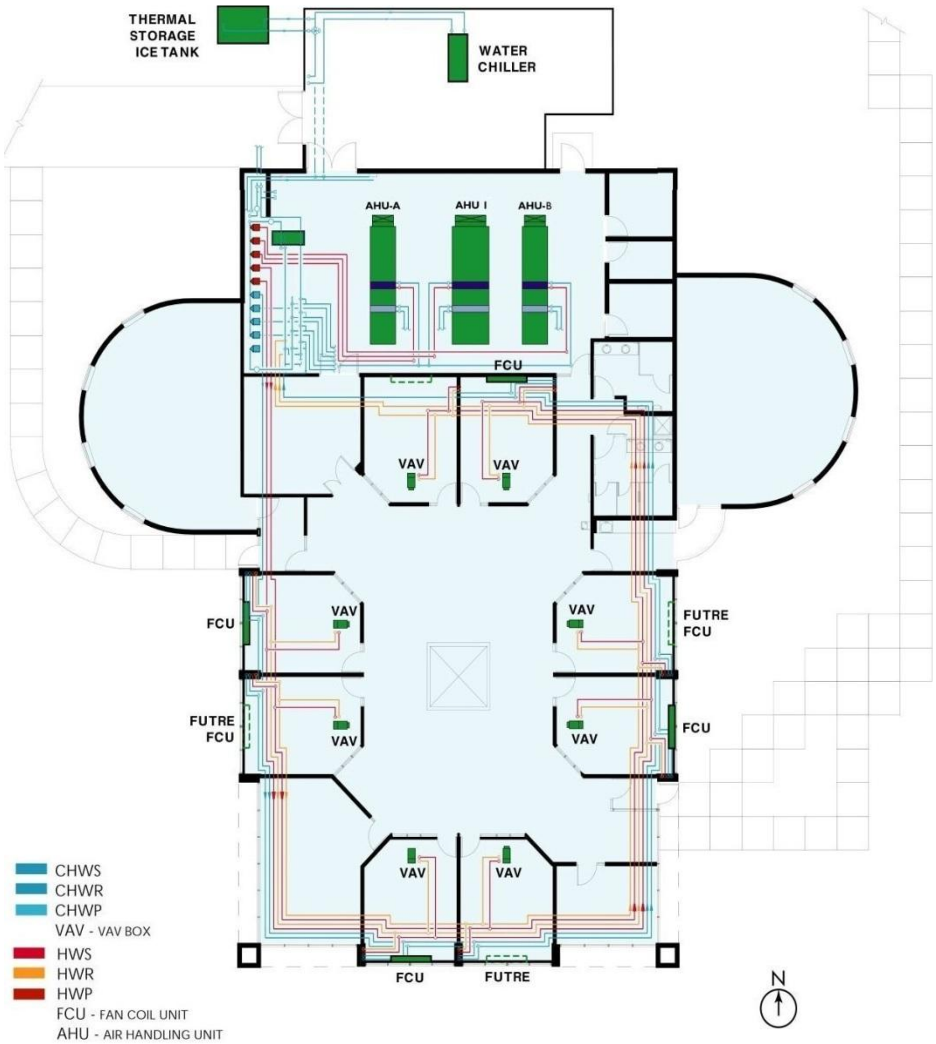

Figure 7: ERS Hydronic Floor Plan

2.4.1 Central Heating System

The central heating plant consists of a main hot water boiler which provides heating water to the HVAC equipment located in the test rooms and general areas. The heating water is provided through closed loops with the help of the heating water pumps.

Figure 8: Heating Water Boiler

The boiler which can be seen in Figure 8 uses natural gas as an energy source. The heating plant consists of five separate circulating pumps serving for the five separate heating loops. Two pumps serve as loop pumps for A and B test rooms. The other three pumps serve each air handling units. The air handling units will be discussed under Test Room HVAC Plan. The Heating Water Schematic, Boiler Design Specifications and Heating Water Pumps Design Specifications can be seen in Figure 9, Table 2 and Table 3.

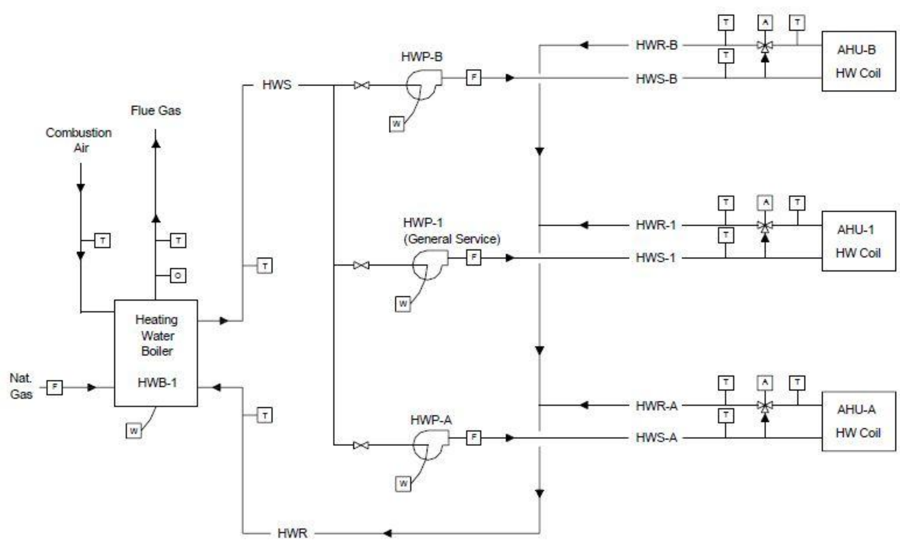

Figure 9: Heating Water Schematic

Table 2: Heating Water Boiler Design Specifications

Item	Heating Water Boiler
Boiler Type	Natural Gas Fired Hot Water
Maximum Capacity	930,000 BTU/hour
ASME Working Pressure	150 PSIG
Water Volume	23 Gallons
Control Range	50º to 220º F
Rated AFUE	92%

Table 3: Heating Water Pumps Design Specifications

Item	AHU Heating Coil Pumps	Loop A &B Pumps
Pump Type	In Line Centrifugal	In Line Centrifugal
Pump Head Pressure	11.3 PSI	21.7 PSI
Water Flow	21 GPM (AHU-A&B) 40 GPM (AHU-1)	24 GPM
Motor Horsepower	0.5 HP (AHU-A&B) 0.75 HP (AHU-1)	1 HP
Motor Speed Control	Fixed	Variable

2.4.2 Central Cooling System

The ERS central cooling system consists of three air cooled chillers, a thermal energy storage unit and multiple chilled water pumps serving to the HVAC equipment. The chillers named as ACCH-CH, ACCH-A and ACCH-B are located outside the building behind the mechanical room. Each chiller serves specific conditioned spaces. ACCH-CH serves chilled water to the three air handling units and fan coil units located in the test rooms. ACCH-A and ACCH-B are both identical and serve chilled water to A and B test rooms separately. In this study only Test 1.1 used ACCH-CH chiller to provide chilled water to both A and B test rooms. The thermal storage tank is also located outside the mechanical room. When the ACCH-CH is on ice mode, the purpose of the thermal storage tank is to form ice and store cooling energy which can be provided to the building as if required. The chillers and thermal storage tank can be seen in Figures 10 and 11.

Figure 10: Air Cooled Chillers from left to right ACCH-A, B and ACCH-CH

Figure 11: Thermal Storage Tank

There are total of seven chilled water pumps in the central cooling system, one loop pump for fan coil units, three primary pumps for chillers and three secondary pumps for air handling units. These pumps are located in the mechanical room. The chilled water pumps, chilled water schematics and equipment specifications can be seen in Figure 12-14 and Tables 4-6.

Figure 12: Chilled Water Pumps

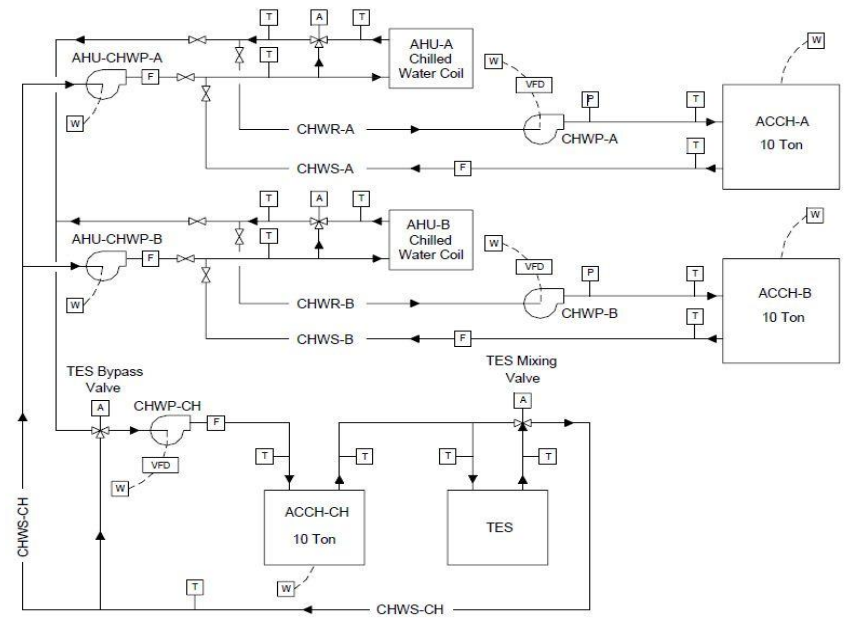

Figure 13: Chilled Water Schematic 1

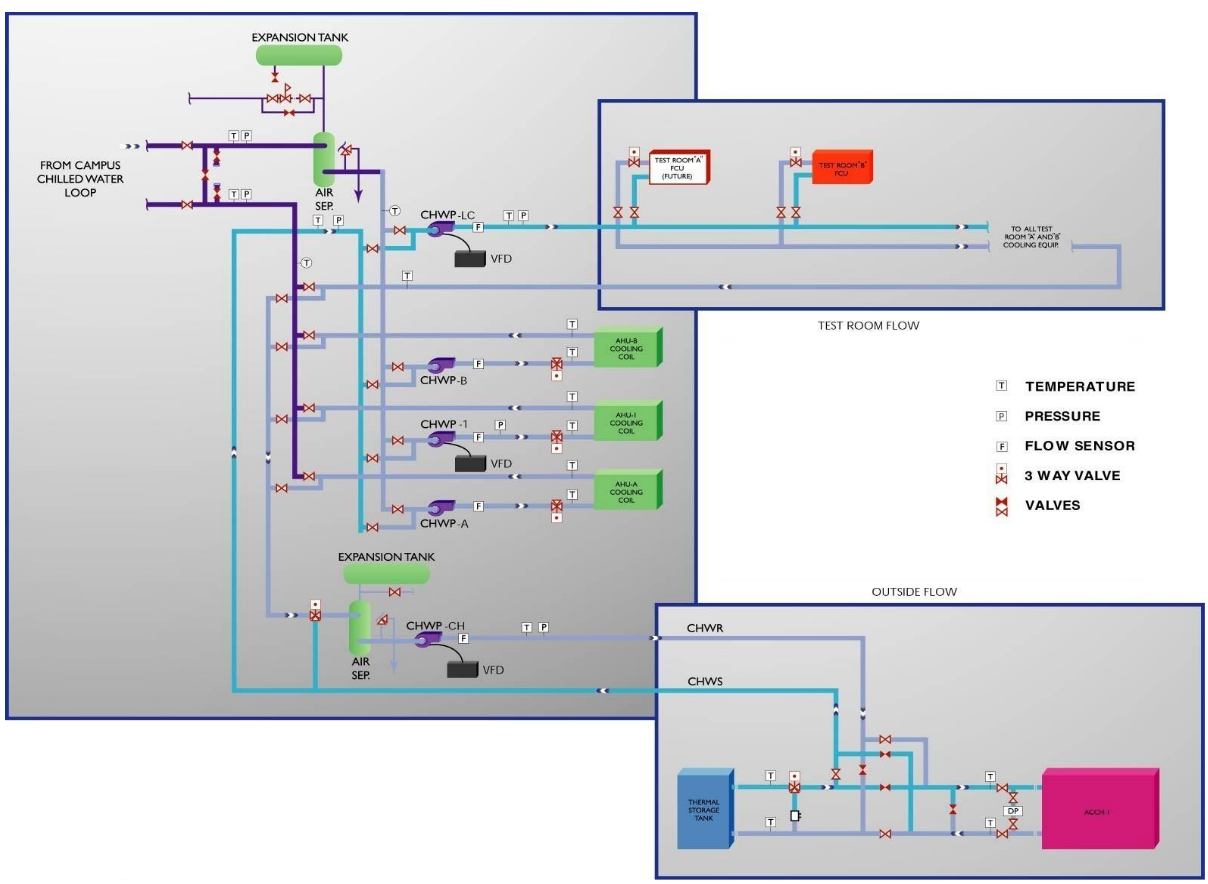

Figure 14: Chilled Water Schematic 2

Table 4: Chillers Design Specifications

Item	ACCH-A & ACCH-B	ACCH-CH
Chiller Type	Air Cooled Liquid	Air Cooled Liquid
Nominal Unit @ ARI Conditions	95ºF Entering Air Temp	95ºF Entering Air Temp
Capacity	9.8 Tons(34.3 KW)	9.6 Tons(33.8 KW)
Flow Rate	24 GPM	24 GPM
Leaving Water Temp	44 ºF	44ºF
Full Load EER	9.7 BTU/H Per Watt	10.6 BTU/H Per Watt
Integrated Part Load EER	12.2 BTU/H Per Watt	10.5 BTU/H Per Watt
Refrigerant Type	HCFC- 22	R-22
Heat Transfer Liquid	25% Propylene Glycol	25% Propylene Glycol
Electrical Specifications	460 Volt/ 3Phase/ 60 Hz	460 Volt/ 3Phase/ 60 Hz

Table 5: Thermal Energy Storage Design Specifications

Item	Thermal Energy Storage
Unit Type	Internal Melt Ice on Tube
Unit Size	96” X 66” X 83”
Maximum Latent Storage	125 Ton Hours
Number of Heat Exchangers	12 Each – U Shaped
Stored Cooling per Sq. Ft. Floor Space	3 Ton Hours

Table 6: Chilled Water Pump Design Specifications

Item	AHU Cooling Coil Pumps	Air Cooled Chiller Pumps	Chilled Water Loop Pump
Pump Type	In Line Centrifugal	In Line Centrifugal	In Line Centrifugal
Pump Head Pressure	11.3 PSI (AHU-A &B) 14.8 PSI (AHU-1)	21.7 PSI	21.7 PSI
Water Flow	28 PSI (AHU-A &B) 45 PSI (AHU-1)	24 GPM	24 GPM
Motor Horsepower	0.5 HP (AHU-A &B) 1 HP (AHU-1)	1.5 HP (ACCH-A&B) 1 HP (ACCH-CH)	1 HP 1 HP
Motor Speed Control	Fixed (AHU-A &B) Variable (AHU-1)	Variable	Variable

2.5 ERS Test Room HVAC Setup

The HVAC system for the Energy Resource Station can be divided into three major categories regarding their conditioned spaces. One system serves only for A test rooms, the second system serves only for the B test rooms (see Figure 15) and the remaining system serves for the general area. The HVAC system conditioning each test room includes an air handling unit (AHU) which is connected to four variable air volume (VAV) mixing boxes located in each of the four test room plenum spaces. Each A test room has two supply air diffusers being fed through the VAV boxes and one return grill. The equipment used on the B test rooms is identical. Additionally B test rooms include fan coil units which were not used in this study.

Figure 15: ERS Test Room Air Handling Unit B (AHU-B)

The main components for the AHU's are the supply air fans; return air fans; cooling and heating coils; heating and cooling control valves; exhaust air, recirculated air and outdoor air dampers; and the air duct system. The components of the air handling unit and ERS test room HVAC plan can be seen in Figures 16-18.

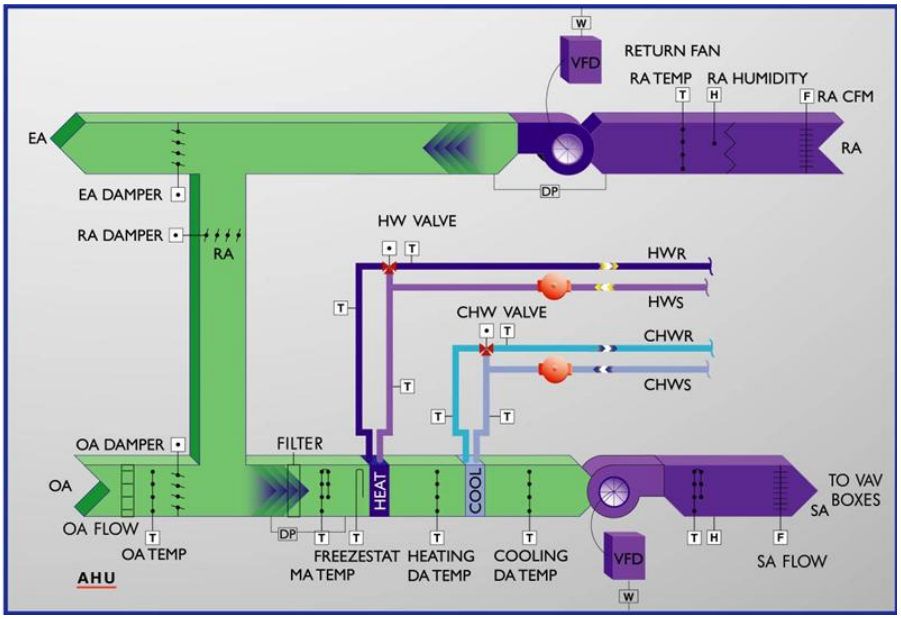

Figure 16: Air Handling Unit Schematic 1

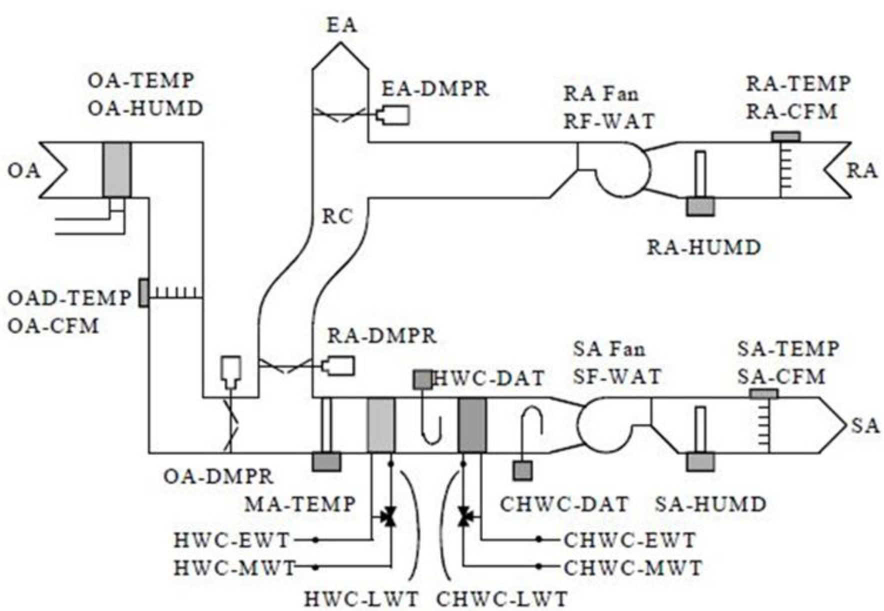

Figure 17: Air Handling Unit Schematic 2

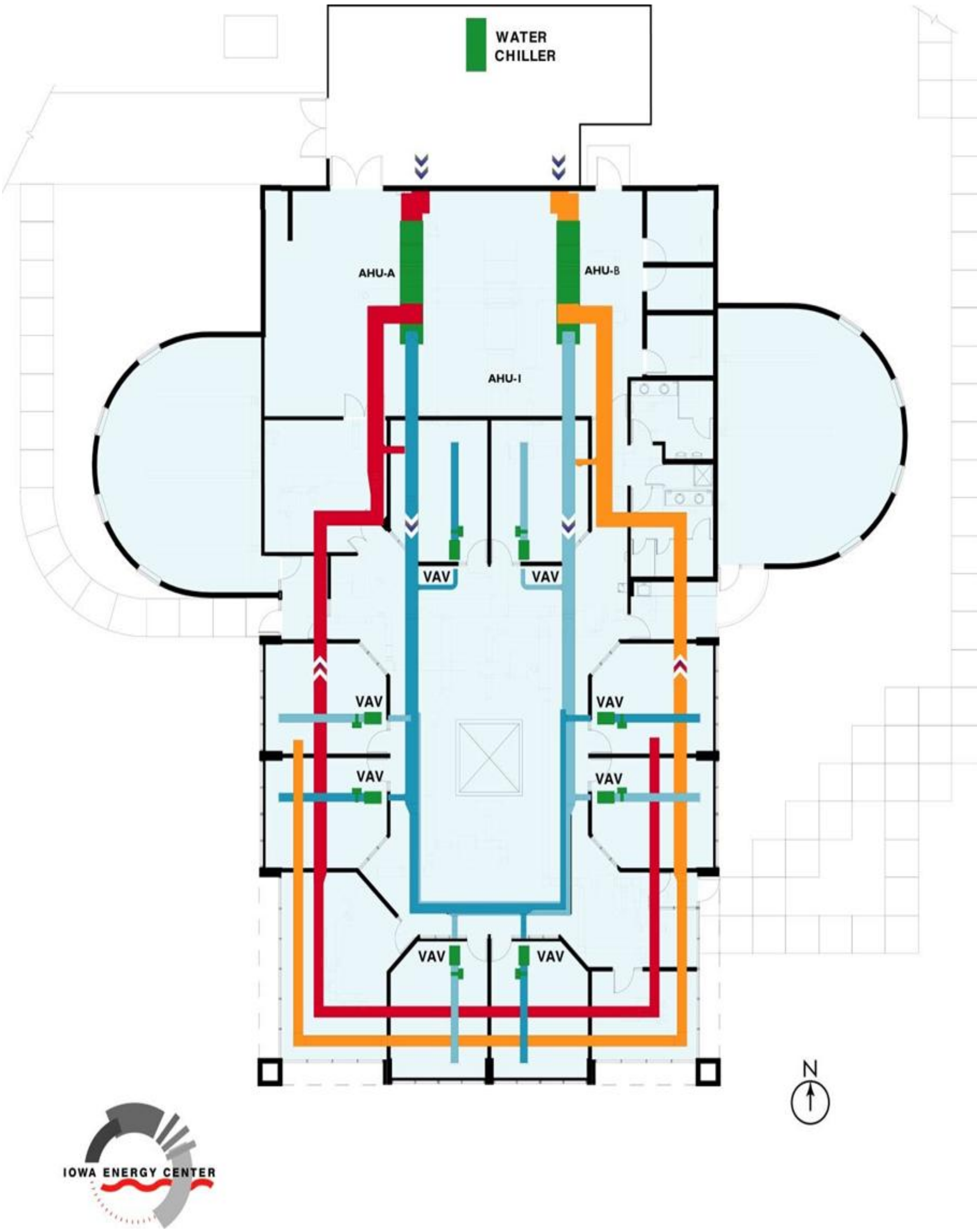

Figure 18: ERS Test Room HVAC Plan

The design specifications for the test room air handling units are shown in Table 7.

Table 7: Test Room Air Handling Unit Design Specifications

Item	AHU-A & AHU-B
Unit Configuration	Horizontal Draw Through
Total Design Supply Air Flow	3200 CFM
Preheat Coil – Outside Air	Heating Water 69 MBH 1 Row – 4.5 Sq. Ft. Face Area
Cooling Coil	Chilled Water 135 MBH 6 Row – 6.0 Sq. Ft. Face Area
Heating Coil	Heating Water 208 MBH 2 Row – 6.0 Sq. FT. Face Area
Supply Air Fan	Centrifugal Vertical Up Discharge 3.2 In WG – Total Static Pressure
Return Air Fan	Centrifugal Horizontal Discharge 1.25 In WG – Total Static Pressure

In addition to the main air handling equipment, there are data acquisition systems available to monitor the humidity, temperature, pressure, air flow and electric power of the air handling units. The variable air volume (VAV) systems located in the test rooms will be covered under the test room setup.

2.6 Test Room VAV System

Each test room is equipped with a single duct variable air volume box which is located in the unconditioned plenum space above the test room level. The temperatures in the test rooms are controlled by VAV reheat units. The reheat mechanism uses the hydronic reheat coil. The electric reheat coils were disabled for this study. The airflow from the VAV box is measured by a flow ring and differential pressure sensor which are located at the inlet of the unit. The airflow is rate is controlled by a VAV damper. The units in the exterior test rooms are the same. The interior test rooms have smaller units. Figures 19-20 and Table 8 show the VAV box schematic, test room HVAC partial plan and VAV design specifications.

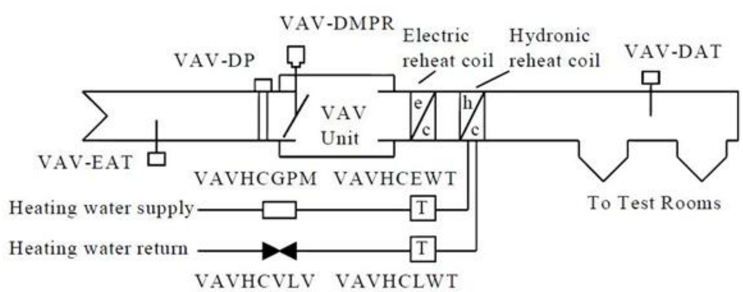

Figure 19: VAV Box Schematic

Table 8: VAV Box Design Specifications

Item	Exterior Test Rooms	Interior Test Rooms
Type	Single Duct	Single Duct
Inlet Size	9 inches	7 inches
Air Flow(Min-Max)	200 CFM - 1000CFM	80 CFM – 400 CFM
Hydronic Coil Flow Rate	3 GPM	2 GPM

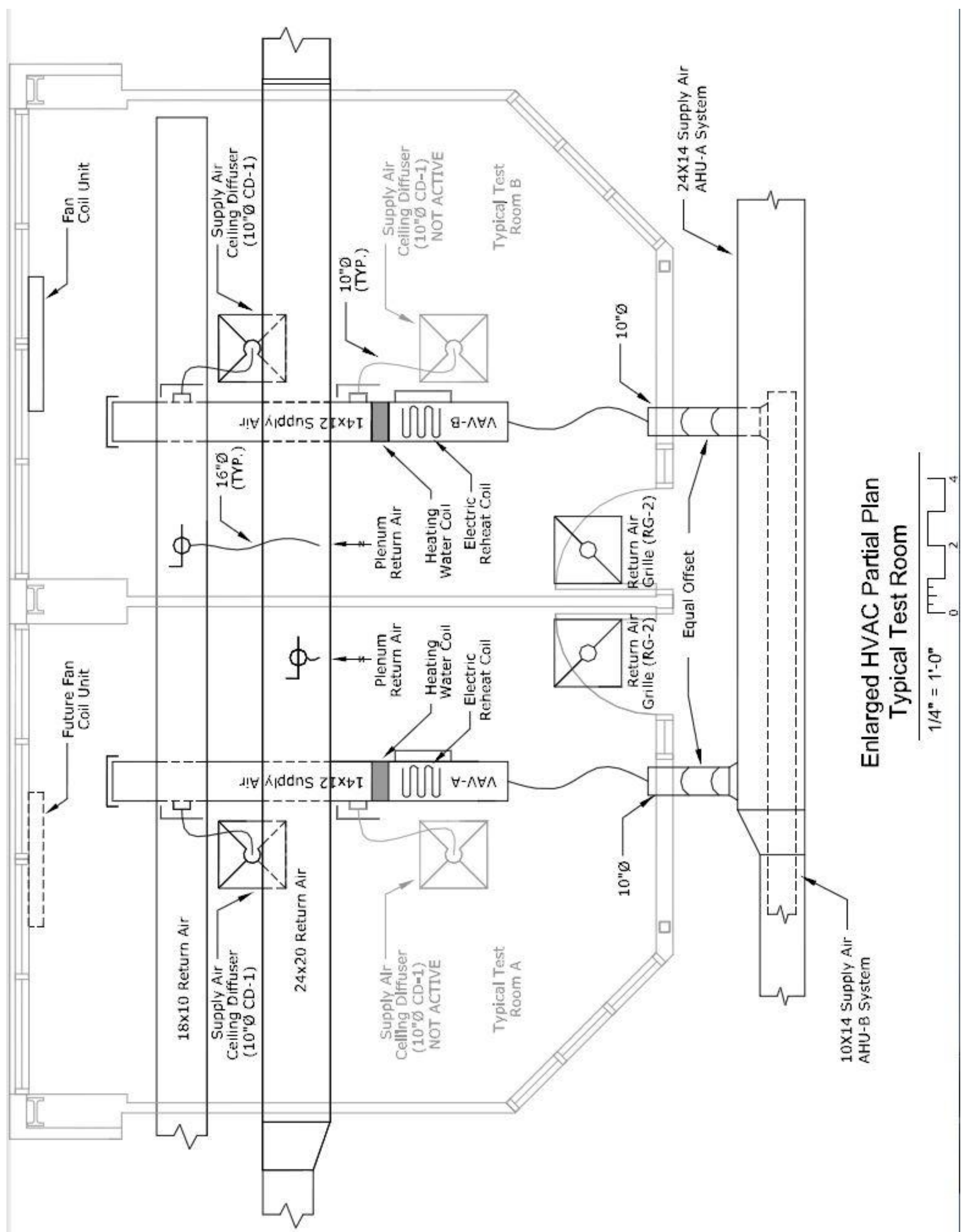

Figure 20: Test Room HVAC Partial Plan

CHAPTER 3. Test Room A and B setup

3.1 Test Room Floor and Layout Plan

Figure 21 shows test room lay out plan which includes the test equipment and sensors that were used in this study. The floor plan of Test Rooms East A and East B is shown in Figure 22. The remaining test rooms have a similar floor plan. Net floor area, exterior wall area and exterior window area are 266, 137 and 74 ft^2, respectively. All test rooms were also equipped with time lapse cameras to record the progress of the windows in action.

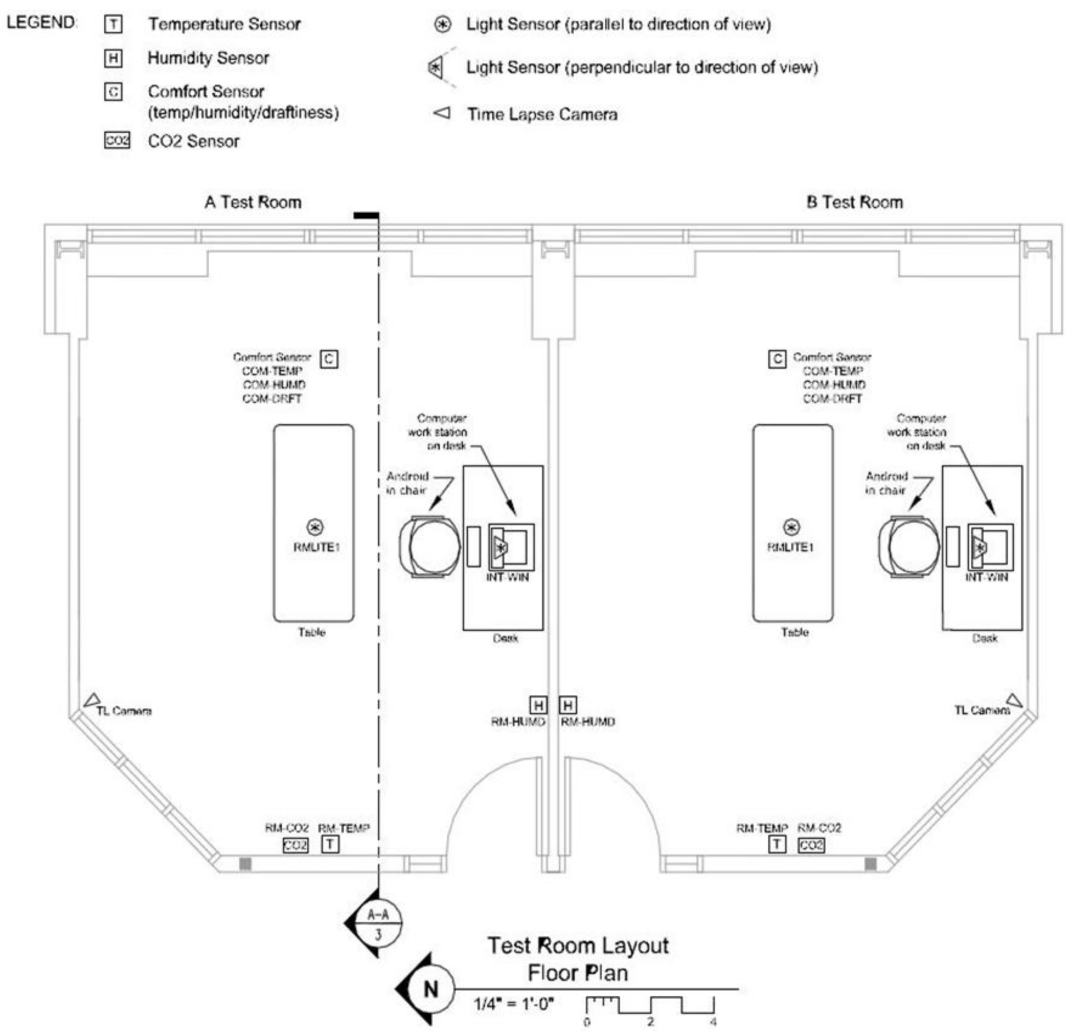

Figure 21: Test Room Layout Plan

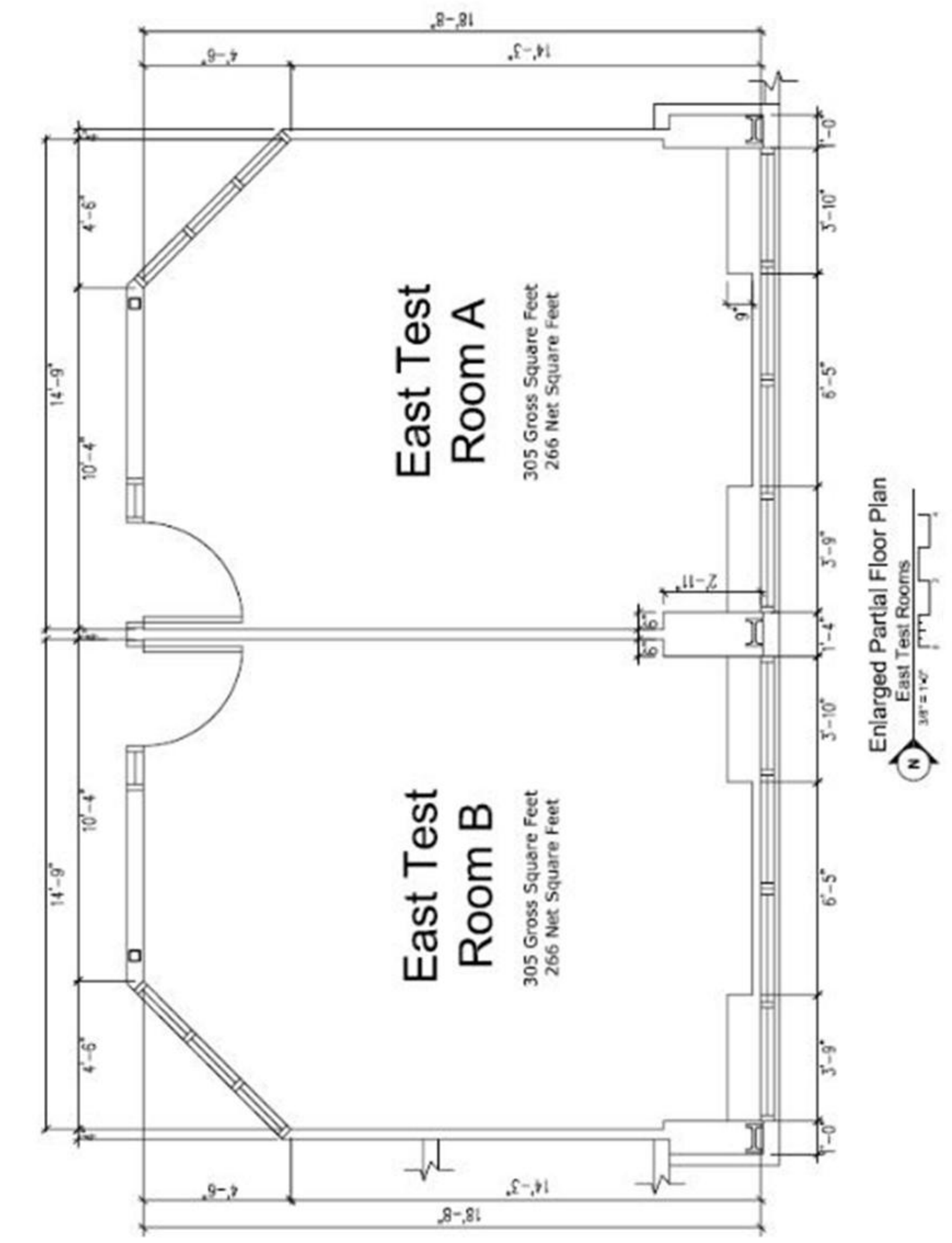

Figure 22: East A and East B Floor Plan

3.2 Test Rooms Exterior Envelope

There are total of eight test rooms located in the ERS. Two test rooms are located on the north interior side of the building and have no exterior walls or windows. These test rooms are called interior test rooms A and B. The remaining six test rooms each have one exterior wall with an exterior window section. The upper wall section construction layers are the same for all six exterior test rooms. Despite having the same lower wall section construction layers for the six test rooms, the B test rooms also include a fan coil unit installed in the center section. Test room exterior wall construction layers can be seen in Figure 23.

The construction layers for the test rooms can be categorized as follows:

- Layers for the exterior wall in the bottom of test rooms
- Layers for the exterior wall in the top of the test rooms
- Layers for the 1/8 inch interior glass partition wall
- Layers for the 6 inch interior partition wall
- Layers for the 4 inch interior partition wall
- Layers for the ceiling
- Layers for the roof

These layers are described from inside to outside. English units are used for the properties of the layers.

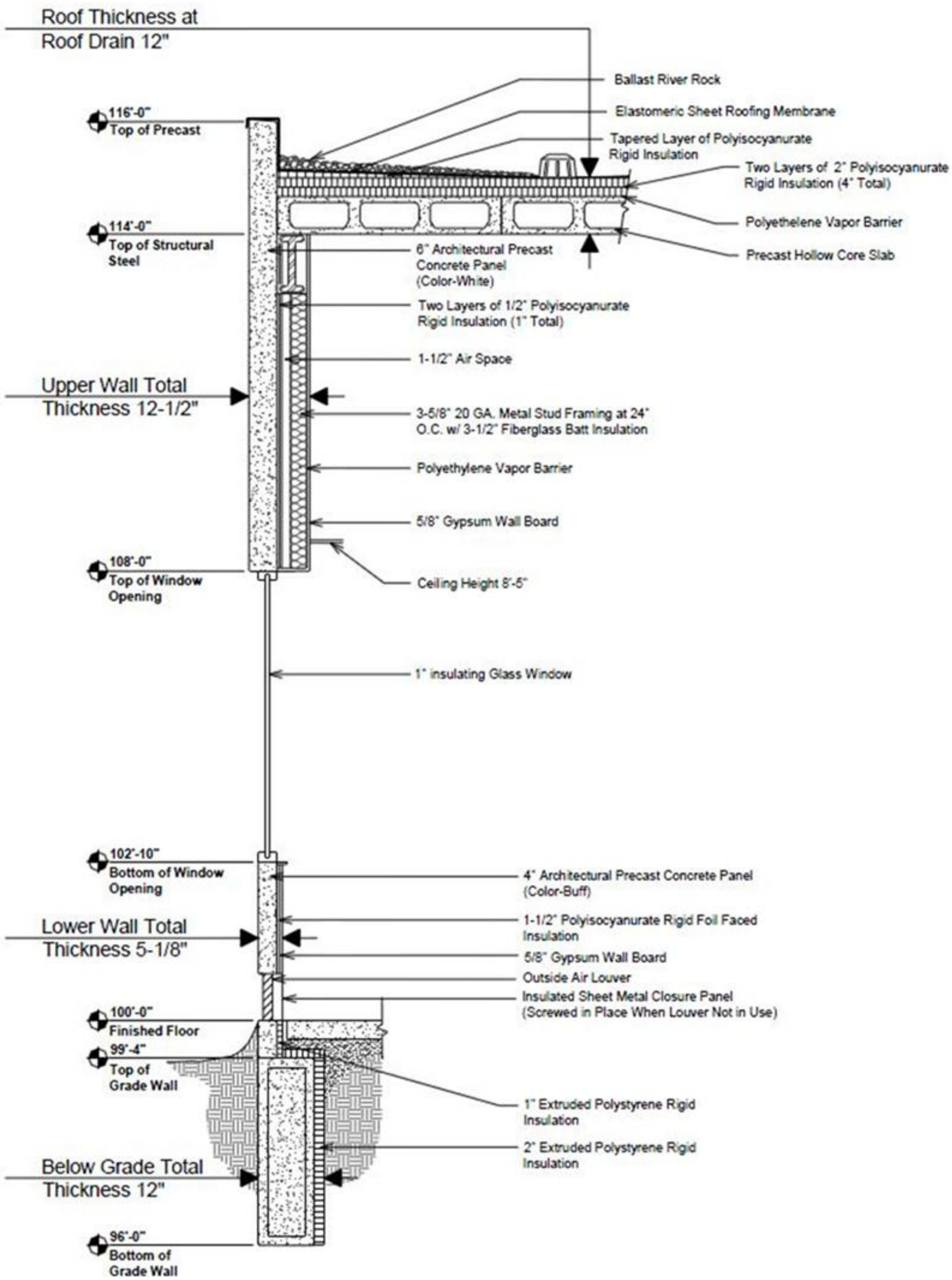

Figure 23: Test Room Exterior Wall Section

- T: thickness in inches
- K: conductivity in BTU/ hr-ft-ºF
- D: Density in lb/ft^2
- Cp: Specific heat in BTU/lb-ºF
- R: Thermal Resistance in hr-ft^2-ºF/BTU

Construction layer properties for the exterior wall of test rooms, floor of the test rooms and ceiling of the test rooms can be seen in Tables 9, 10, 11 and 12.

Table 9: Exterior wall in the bottom of the test room layers

Layers	T	K	D	Cp	R
Inside					
0.625'' gypsum board	0.63	0.0926	50	0.2	0.56
Vapor Barrier	NA	NA	NA	NA	0.06
0.375'' vertical air space	0.38	NA	NA	NA	0.90
1.5'' rigid insulation with foil face	1.5	0.0133	1.5	0.38	9.39
4'' precast concrete	4	0.7576	140	0.2	0.66
Outside					

Table 10: Exterior wall in the top of the test room layers

Layers	T	K	D	Cp	R
Inside					
0.625'' gypsum board	0.63	0.0926	50	0.2	0.56
0.375" vertical air space	0.38	NA	NA	NA	0.90
1''rigid insulation with foil face	1	0.0133	1.5	0.38	6.26
6'' precast concrete	6	0.7576	140	0.2	0.66
Outside					

Table 11: Floor of the test room layers

Layers	T	K	D	Cp	R
Carpet	NA	NA	NA	0.34	1.23
4'' heavy weight concrete	4	0.7576	140	0.2	0.44
2'' perimeter insulation	NA	NA	NA	NA	5

Table 12: Ceiling of the test room layers

Layers	T	K	D	Cp	R
Ceiling Tiles	0.75	0.033	18	0.32	1.89

Typical outside view of the test room exterior wall can be seen in Figure 24. The test rooms are divided in to two zones. These zones are named as test room level conditioned zone and unconditioned plenum zone. The ceiling height for the test rooms are 8.5 feet and the plenum height is 5.5 feet.

Figure 24: South A and B test room exterior walls

3.3 Test Rooms Exterior Window Setup

Exterior test room clear windows shown in Figure 25 are made of double glazed 0.25 inch clear insulating glass with a 0.5 inch air space in between. The window dimensions are roughly 5 feet high and 14.8 feet wide. The windows have 2 inch wide aluminum frames and dividers with thermal break. The top of the windows are 8 feet 2 inches above the ground. The glazing percentage is 47.6%. Table 13 shows the thermal properties of the test room clear windows. These windows were used in Normalization test procedure.

Figure 25: Test Room Clear Windows

Table 13: Clear Window Thermal Properties

Construction	1/4" (6mm) Clear glass 1/2" (13.2mm) airspace 1/4" (6mm) Clear Glass
Transmittance	
Visible Light:	81%
Reflectance	
ASHRAE U-Value Winter Nightime and Summer Daytime:	0.55 and 0.48 Btu/(hr.sqft.ºF)
Shading Coefficient:	0.85

For this study, clear windows are replaced by dark tinted performance windows in test rooms A and Pleotint SRT windows in test rooms B. These window properties will be discussed in Chapter 4 Experimental Procedure.

3.4 Test Room False Thermal Loads

3.4.1 Baseboard Heaters

All test rooms are equipped with two stage baseboard electric heater shown in Figure 26. In this study, these heaters are used to increase the internal load of the test rooms. They provide 100% sensible heating load and can be operated in three modes. Control modes, stages and the total power are shown on Table 14.

Figure 26: Test Room Baseboard Heaters

Table 13: Baseboard Design Specifications

Control Mode	Stage 1	Stage 2	Total Power (Watts)
1	OFF	OFF	0
2	ON	OFF	900
3	ON	ON	1800

3.4.2 Occupancy Loads

Figure 27: Android and Computer

All test rooms are equipped with occupancy loads, as shown in Figure 27, which simulate office equipment and people. Office equipment includes a sheet metal cylinder (android) and a desktop computer with a CRT screen. Androids simulate people activity and are equipped with a regulated solenoid valve CO_2 release system and a light bulb (150 Watts). This study does not include CO_2 production. Occupancy load specification is shown in Table 15.

Table 14: Occupancy Load Specifications

Control Mode	Capacity per Person	People Office Activity
CO_2 On	NA	Office Work
CO_2 Off	NA	Absent
People On	255 Btu/hr sensible (75 Watts per person)	Office Work
People Off	0 Btu/hr	Absent
Equipment On	42 Watts Computer 46 Watts Monitor	Office Work
Equipment Off	4 Watts Computer < 1 Watt Monitor	Absent

3.5 Test Room Lighting System and Sensors

The test rooms are equipped with direct lighting design using recessed; lighting fixtures installed in an acoustical lay in ceiling. Each of these 2 by 2 feet lighting fixtures have three U shaped T8 fluorescent tube lamb with a size of 31 watts. All the test room fixtures are equipped with dimmable ballasts. The lighting system has 2 stage lighting control. When both stages are on, with six fixtures, the lighting level in each test room is 85 foot candles. With only 4 lighting fixtures active the light level in the test rooms is 60 foot candles. Each of the exterior test rooms is equipped with six lighting fixtures. The interior test rooms only have four lighting fixtures. Figure 28 shows the test room reflected ceiling plan.

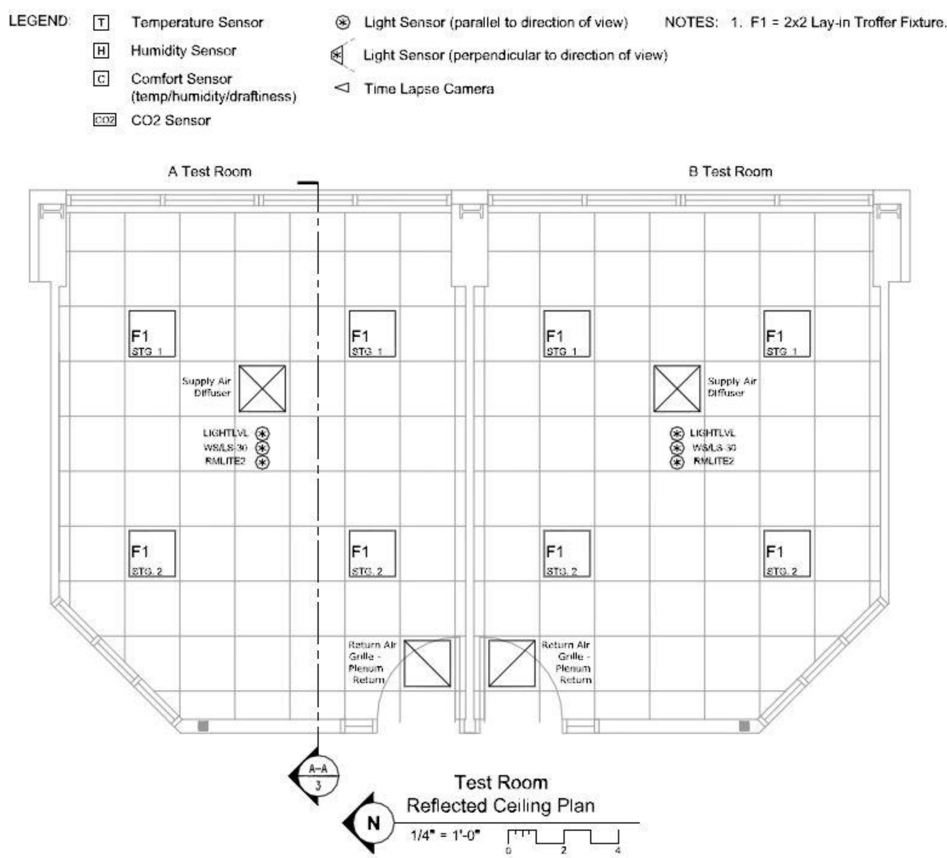

Figure 28: Test Room Reflected Ceiling Plan

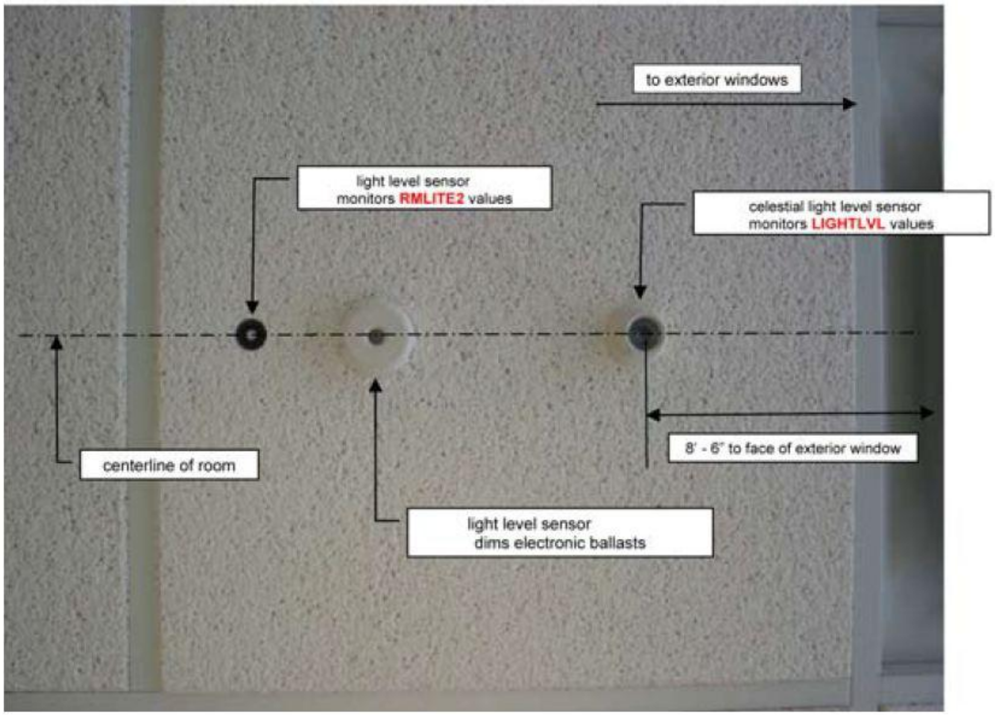

Figure 29: Lighting Sensors Mounted On Test Room Ceiling

Test room ceilings are equipped with three lighting sensors which can monitor the lighting level in the room. These sensors can be seen in Figure 29. In this study, additional lighting sensors were used to measure the light level in the room. The lighting sensor measuring the room light level is located on a table, which is 4 feet 2 inches above the test room floor, 9 feet 4.5 inches away from the test room windows and 7 feet 4 inches away from the test room side walls. There are other sensors located on a tripod comfort stand including comfort temperature and humidity sensors. These sensors can also be seen in Figure 30. Regarding the test room reflectance; test room carpets are gray fox colored, ceiling tiles are white, test room walls are polish gray and the tables are graphite colored. Test room lighting system has three control options which are local, DDC and manual control modes. Using DDC control, the building automation system and lighting sensors located in the test rooms are used to control the light level with dimmable ballasts. This study utilizes DDC control mode with on/off option. When the test room light level reaches 45 foot candles, the DDC control shuts down the test room lights to save energy. When the light level reaches critical (below set point) level, the DDC control turns the test room lights on. The set points for the test setup will be covered in Chapter 4.

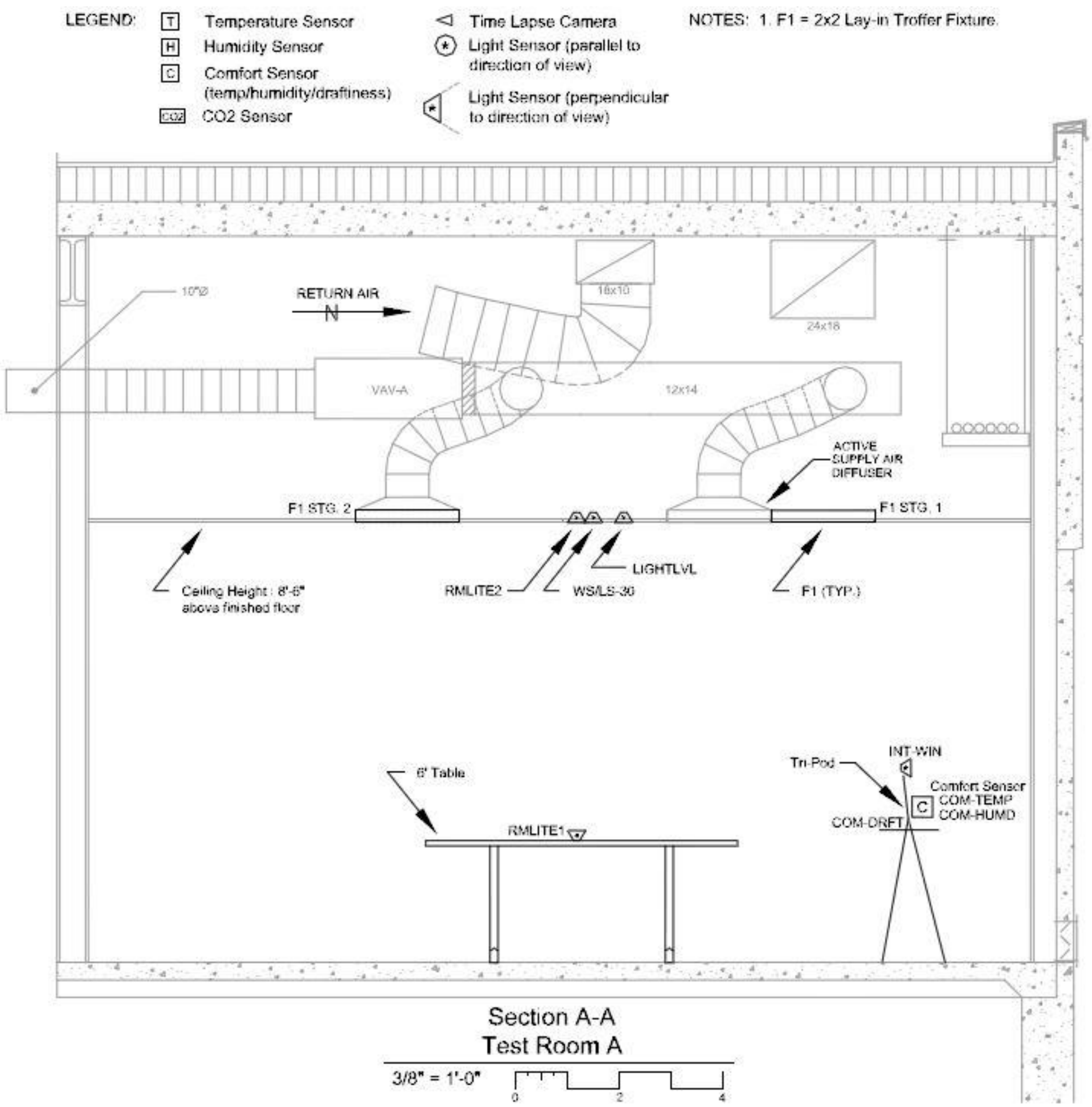

Figure 30: Test Room Section

Chapter 4 Test Procedure

4.1 Test Schedule

4.1.1 General Test Schedule

The Pleotint SRT window testing weekly schedule is designed to reflect a typical twelve hour, office occupancy schedule, which starts at 6 am in the morning and ends at 6 pm at night. This study does not include the unoccupied period which is between 6 pm to 6am. The schedule not only includes the business week days but also the weekends and holidays as well. Each test cycle has a duration about two weeks with an additional two days of setup and takedown for a total of sixteen days. The entire test procedure consists of six test cycles which were distributed throughout the year to study the performance behavior of the windows in different seasons of the year. The general test schedule is shown in Table 16.

Table 15: General Test Schedule

March Test 2011 (Test 1.1 and Test 1.2)
May Test 2011 (Test 2.1 and Test 2.2)
July Test 2011 (Test 3.1 and Test 3.2)
September Test 2011 (Test 4.1 and Test 4.2)
November Test 2011 (Test 5.1 and Test 5.2)
January Test 2012 (Test 6.1 and Test 6.2)

4.1.2 Test Room Thermostat Set Point Schedule

Test room thermostat set point schedule is shown in Figure 31. Heating and cooling set points were set to occupied and unoccupied values shown in Figure 31 during each test procedure. The study uses occupied heating and cooling temperature set points between 6:00 am until 18:00 pm.

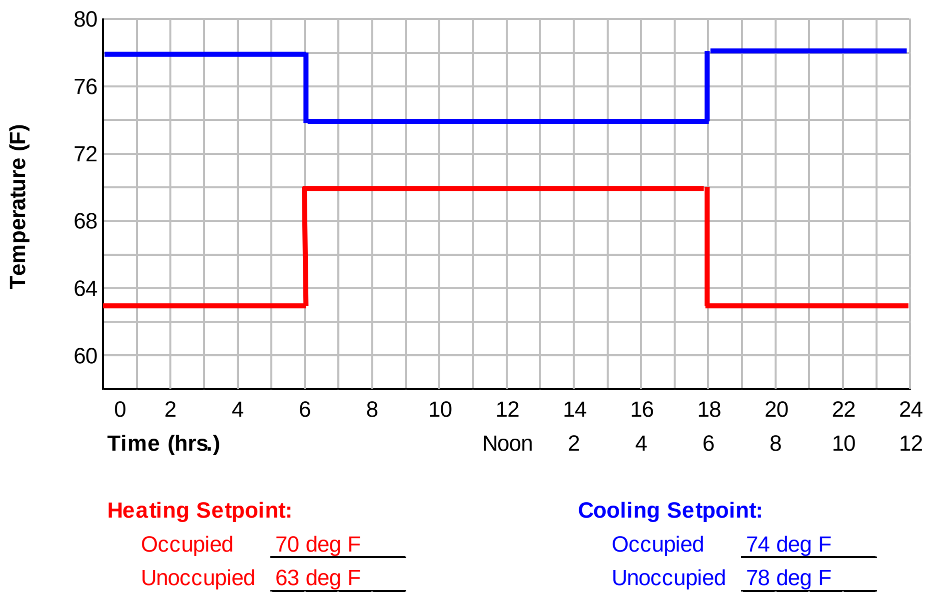

Figure 31: Test Room Thermostat Schedule

4.1.3 AHU System Control Mode Schedule

Figure 32 and Table 17 show the AHU system test schedule and control mode description.

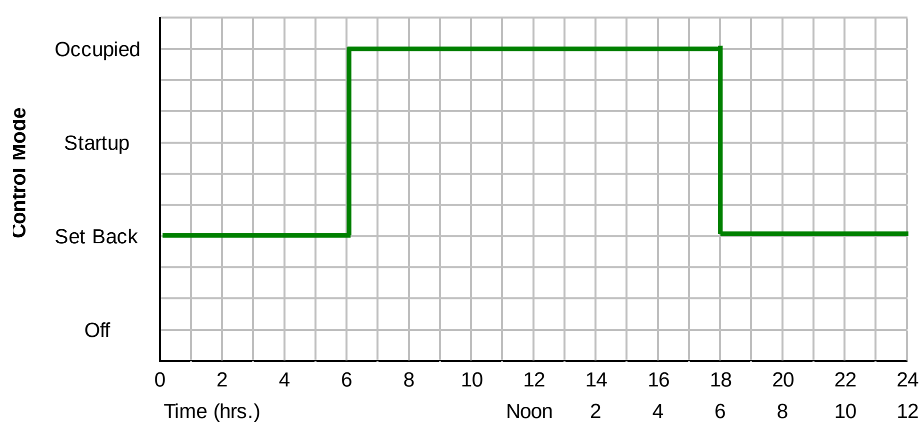

Figure 32: AHU System Control Mode Schedule

Table 16: AHU Control Mode Description

Control Mode	SA/RA Fan Operation	Test Room Temp Mode	Ventilation Outside Air Damper Operation	Control Mode Summary Explanation
Off	Off	Unoccupied	Closed	AHU fans positively off. Test room temperatures float. No heating and cooling available
Setback	Cycles	Unoccupied	Closed	AHU fans cycle on signal from min max test room temperature to prevent that temperature from exceeding the unoccupied set point. No outside air ventilation.
Startup	Continuous	Occupied	Closed	AHU fans operate continuously on 100% recirculated air to transition the test room temperature from unoccupied to occupied set point. Terminal heating coils activate for heat, VAV damper activate for cooling. No OA ventilation
Occupied	Continuous	Occupied	Available	AHU fan operates continuously to maintain SA temp set point. OA Ventilation provided as selected by OA mode control. VAV damper and terminal heating coil operate to maintain test room temperature set points.

4.1.4 Lighting and False Load Baseboard Heat Schedule

Figure 33: Lighting Schedule

Lighting schedule with two stages is shown in Figure 33. As it was mentioned in Chapter 3, the lighting control mode was set to DDC on/off during the schedule. In addition to two stages, exterior test rooms have two more lighting fixtures located in the middle of the test room, each with a size of 93 Watts.

- Stage 1: Two window side lighting fixtures each 93 Watts.
- Stage 2: Two door side lighting fixtures each 93 Watts.

Baseboard heat schedule is shown in Figure 34.

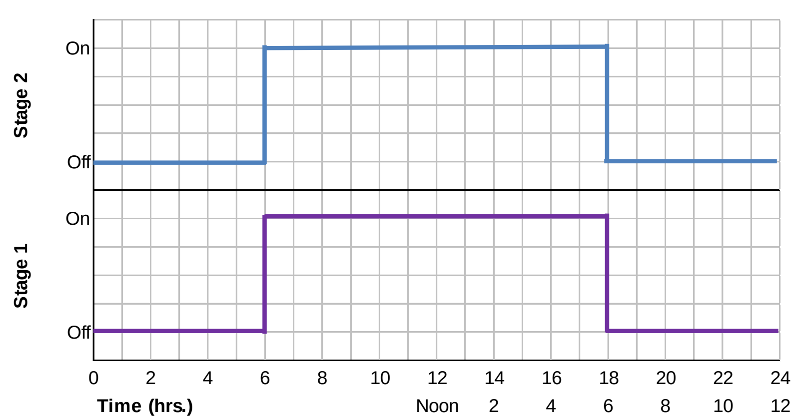

Figure 34: Baseboard Heat Schedule

March Test 2011 and May Test 2011 don't include baseboard heaters. Baseboard heaters were used to increase the internal sensible heating load of the test rooms starting on July Test 2011and ending on January Test 2012. As it was explained in Chapter 3, each stage is sized as 900 watts.

4.1.5 Internal Load Schedule

Internal load schedule is shown on Figure 35. Internal load specifications such as android and computer were covered on Table 15. Except the CO2 production, all internal loads stay active during the occupancy time period of 6 am to 6 pm. As it was mentioned earlier in Chapter 3, this study doesn't include CO2 production. The y axis on Figure 35 represents the number of occupants (people) and computers in each test room.

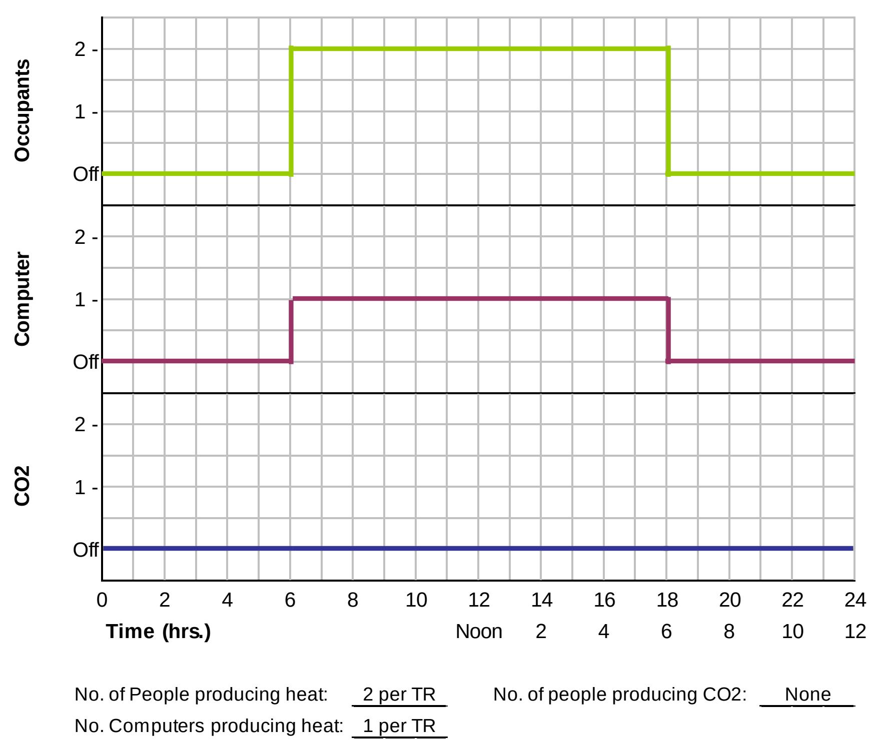

Figure 35: Internal Load Schedule

4.2 Performance Windows Specification and Installation

4.2.1 Dark Tinted High Performance Windows

In this study, test room exterior clear glazings were replaced with two different types of performance windows. These are Viracon Dark Tinted High Performance glazing and Pleotint SRT Performance glazing. The same frames were used for all cases. Test rooms A were equipped with Dark Tinted High Performance windows and Test rooms B were equipped with Pleotint SRT Performance windows. The specifications for Dark Tinted High Performance windows can be seen in Table 18.

Table 17: Viracon Low-E Dark Tinted Window Specifications

Construction	1/4" (6mm) VE3-55 #2
	1/2” (13.2mm) airspace
	1/4” (6mm) Clear Glass
Transmittance	
Visible Light:	23%
Solar Energy:	14%
Ultra Violet:	5%
Reflectance	
Visible Light Exterior and Interior:	6% and 15%
Solar Energy:	
ASHRAE U-Value Winter Nightime and Summer Daytime:	0.31 and 0.33 Btu/(hr.sqft.ºF)
Shading Coefficient:	0.26
Solar Factor (SHGC):	0.22

4.2.2 Pleotint SRT Performance Windows

Pleotint's SRT windows state that they effectively mix energy efficiency and comfort to deliver an outstanding experience. There were two different colors of Pleotint SRT windows used in this study. These were, Azuria and Clear colored Pleotint SRT windows. The structures for these two windows are as follows; Azuria colored Pleotint windows are made from 6 mm Azuria laminated to a 6mm clear with the Pleotint film. This laminate is made into an insulated glass unit with a 0.5" argon space (90% argon, 10 % air) and a 6mm Solarban 60, low E coating facing the argon space. The Azuria laminate faces the sun. The only difference for the Clear colored Pleotint windows is the laminated face is clear colored instead of Azuria colored. The Clear laminate faces the sun. The Pleotint SRT window system is shown in Figure 36.

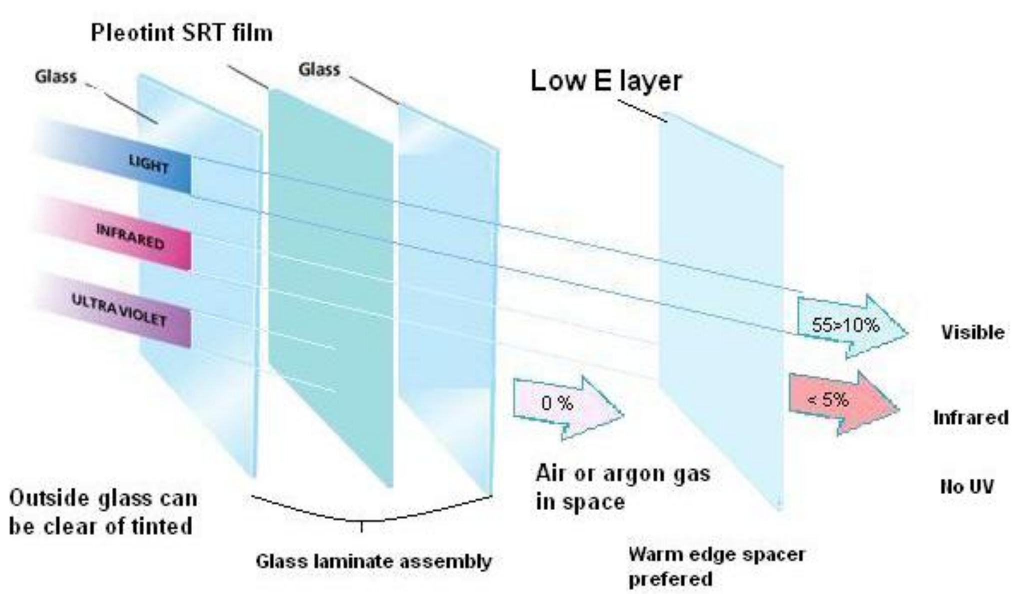

Figure 36: Pleotint SRT Window System

The main component of the SRT window systems is the lightly tinted thermochromic film. In the presence of direct sunlight the lightly tinted thermochromic film warms up and becomes darker. The darkened thermochromic film absorbs a significant portion of the direct sunlight shining on the window. The combination of the tinted film and special heat reflecting low E layer allows the window to block the heat load coming from outside into a building or structure. Without the direct sunlight, the darkened window becomes clear to allow more indirect sunlight. The graphical representation of the Pleotint SRT windows is shown in Figure 37 below.

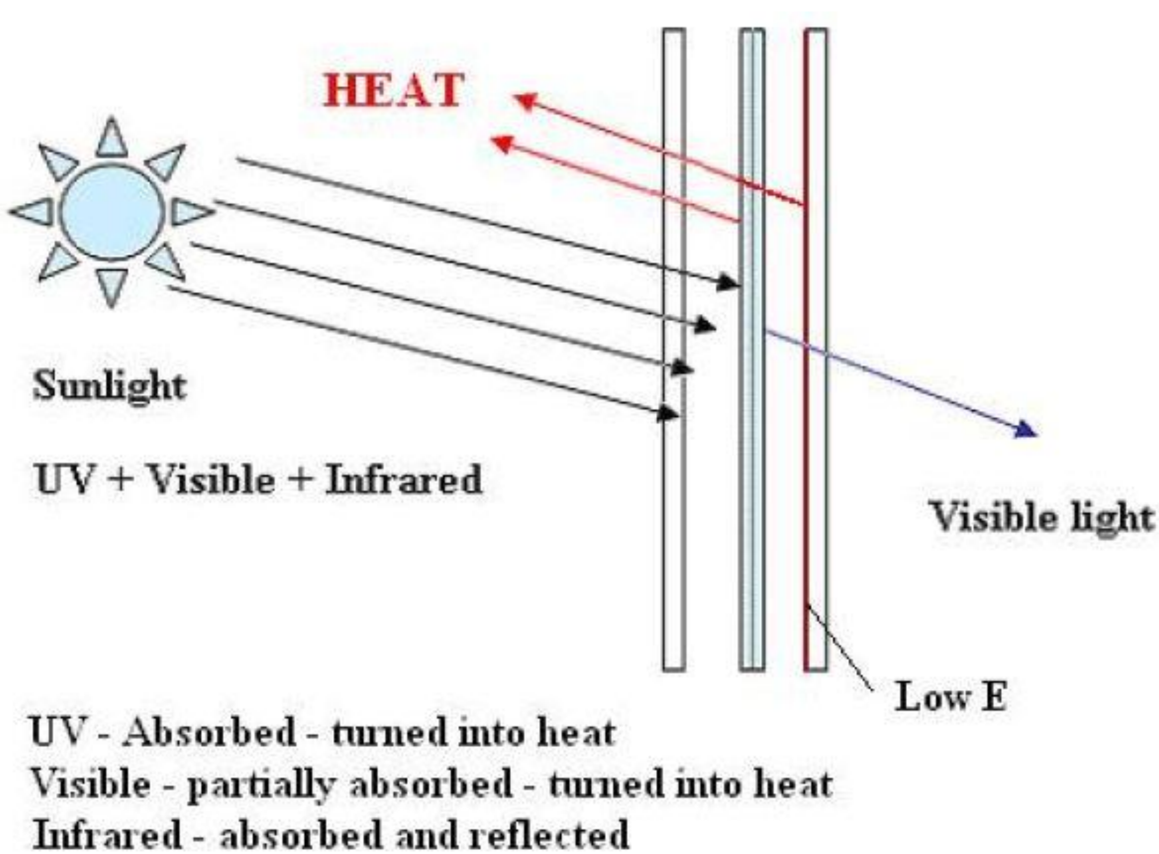

Figure 37: Pleotint SRT Window Panel

In this experiment, each of the three exterior test rooms East B, South B and West B which are installed with SRT windows, are also equipped with one additional type K thermocouple temperature sensor. The purpose of this sensor is to record the temperatures on the window by using National Instruments DAQ system. The thermocouple location is fixed for all three exterior test rooms. Thermocouple set up and location can be seen below on Figure 38.

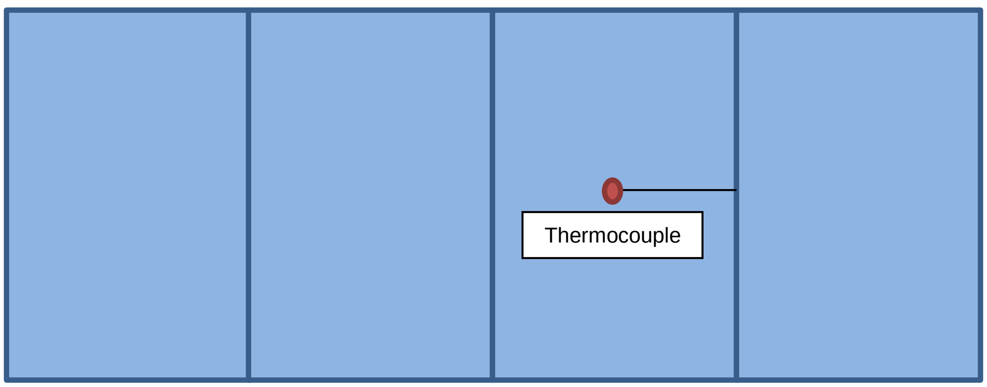

Figure 38: Thermocouple Setup Test Room Inside View

4.3 Equipment Set Points

4.3.1 Air Handling Units (AHU) A and B

System control mode: Both AHU A and AHU B were set to Night setback mode. Occupied start time was 06:00 am and stop time was 18:00. Setback start time was 18:00 and stop time was 06:00. **Outside Air Mode:** Outside minimum flow rate was set to 120 cfm. Minimum damper position was set to 0 % open. Economizer mode was disabled. **Return Fan Mode:** Speed tracking was set to 90% Speed of Supply Fan (SF) Speed. **System Settings:** Static pressure set point was 1.4 W.G. Supply air temperature was set to 55 ºF.

4.3.2 Test Rooms A and B Set Points

Room Temperature Set Points: Occupied time heating set point was set to 70ºF and cooling set point was 74ºF. Unoccupied time heating set point was set to 63ºF and cooling set point was 78 ºF. **Air Flow Rate Interior Test Rooms:** Minimum flow rate and maximum flow rate for occupied time was set to 200 and 400 cfm. Minimum flow rate and maximum flow rate for unoccupied time was set to 0 and 400 cfm. **Air Flow Rate Exterior Test Rooms:** Minimum flow rate and maximum flow rate for occupied time was set to 200 and 1000 cfm. Minimum flow rate and maximum flow rate for unoccupied time was set to 0 and 1000 cfm. **Terminal Heat Selection:** Hydronic coils were used for terminal heating. **Return Duct configuration:** Plenum return was used for return air. **Door Orientation:** All test room doors were closed and sealed.

4.3.3 Cooling System Set Points

Chilled Water Supply Set Up: AHU-A, AHU-B and AHU-1 use local supplied chilled water. **Chilled Water Pump Set Up:** Chilled water pump CH (CWP-CH) was set to 100% constant speed. **Local Chiller System:** The chillers were enabled. AHU-A uses ACCA (Chiller A), AHU-B uses ACCB (Chiller B) and AHU-1 uses ACCH (Chiller CH). **Valve Settings:** Ice Make Bypass valve was set to 70% open to air handler. Thermal storage tank was set to 100% open to tank.

4.3.4 Heating System Set Points

Boiler Thermostat Set Point: The set point was constant 120 ºF

4.4 Pleotint SRT Window Test Energy Consumption Evaluation

The types of energy used in this study were electricity and natural gas. Natural gas is used only for the boiler; however, electricity was used in all HVAC components and for lighting purposes. The energy consumption for this experiment is broken down in to main categories as Fan Energy, Pump Energy, Chiller Energy, Lighting Energy, System Cooling Energy, and System Heating Energy.

4.4.1 Fan Energy

Fan energy distribution is shown on Figure 39. As it was mentioned earlier, both Air Handling Units AHU- A and AHU- B are equipped with fans supplying and extracting conditioned air to the test rooms A and B. In addition to supply air fans, AHU-A and AHU-B are equipped with AHU outside air injection fans. These fans supply fresh outside air into both AHUs and then this air is mixed with some of the return air which is extracted from the test rooms through the return air duct system.

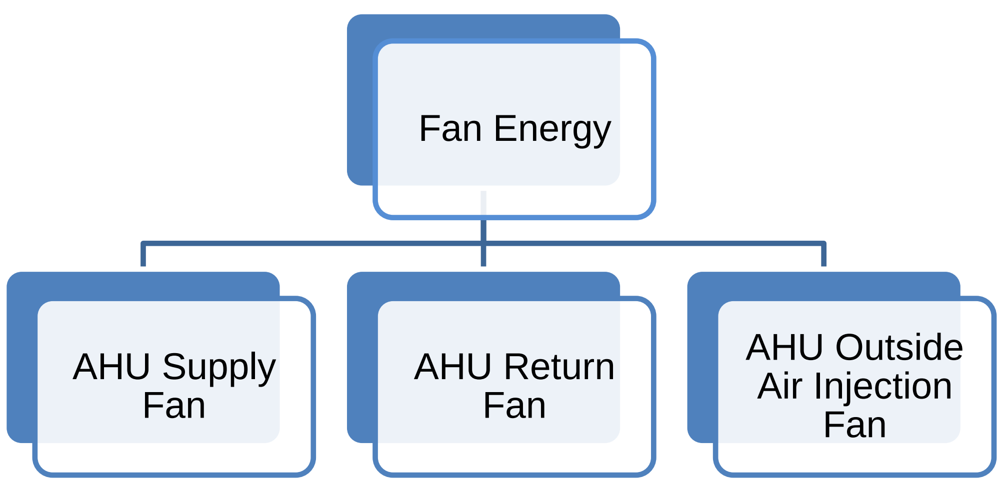

Figure 39: Fan Energy

Mixed outside and return air is reconditioned in the AHUs and supplied to the test rooms by AHU supply air fan. The volume of air coming from these fans is controlled by dampers. All fans require a belt drive electric motor which consumes electricity.

Fan Energy Calculation: Air handling unit fan energies are supplied from the programming computer which saves real time test data. The system data points for the fan energies are, SF-WAT for supply fan, RF-WAT for return fan and OAF-WAT for outside air injection fan. Since the units are in Watts (SI) the conversion factor of 3.412 was used to convert Watts to Btu per hour.

4.4.2 Pump Energy

Pumps shown in Figure 40 are used to circulate chilled or heating water through the pipes in a closed loop system. Three centrifugal pumps used in this study were Chiller-CH pump, AHU Chilled Water Pumps and Heating Water Loop Pumps.

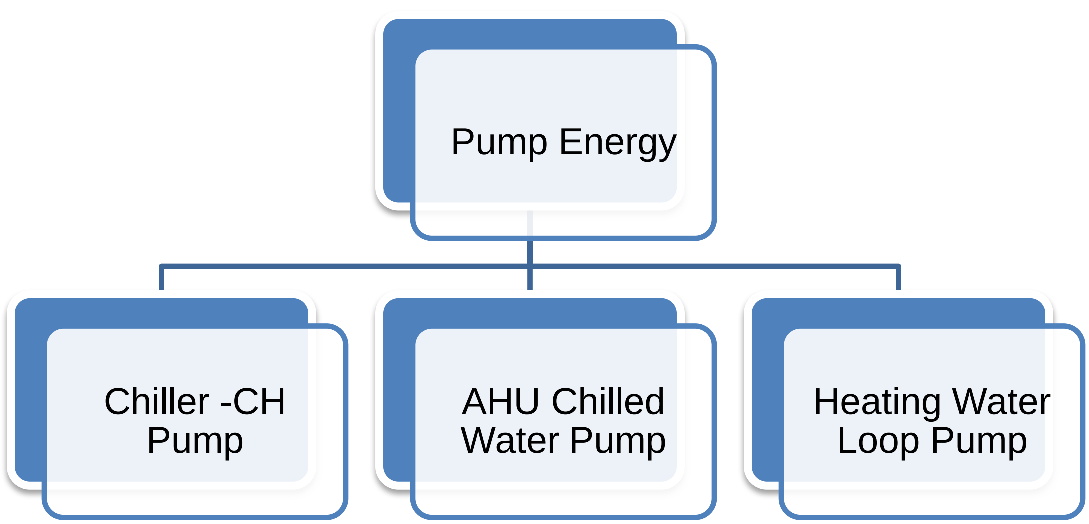

Figure 40: Pump Energy

March 2011 Test 1.1 uses Chiller-CH for both test rooms A and B, therefore that test takes Chiller-CH pumps into consideration. AHU-A and AHU-B have their own chilled water pumps which supply chilled water through test rooms A and test rooms B. The boiler supplies heating water to the test room VAV boxes hydronic reheat coils, by two separate closed loops which use two separate pumps. All pumps used in this study were electric powered centrifugal pumps. Pump energy distribution is shown in Figure 40.

Pump Energy Calculation: Pump energies are supplied from the programming computer which saves real time test data. The system data point for the pump energy is, CHWP-WAT for chilled water pumps, LAP-WAT and LBP-WAT for heating water loop A and B pumps. Since the units are in Watts (SI) the conversion factor of 3.412 was used to convert Watts to Btu per hour.

4.4.3 Chiller Energy

Chiller energy distribution is shown in Figure 41. Chiller-CH, ACCA and ACCB use electricity for operation.

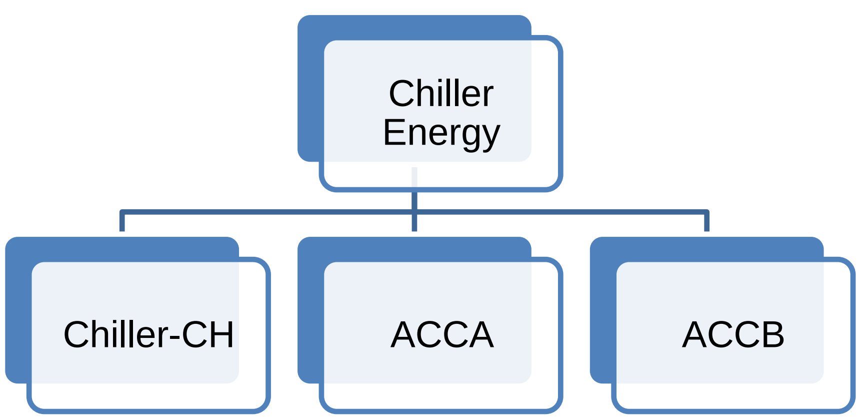

Figure 41: Chiller Energy

Chiller-CH supplies chilled water to general office areas, ACCA supplies chilled water to A test rooms and ACCB supplies chilled water to B test rooms.

Chiller Energy Calculation: Chiller energies are supplied from the programming computer which saves real time test data. The system data points for the chillers are ACCH-WAT for Chiller-CH, ACCA-WAT for Chiller ACCA and ACCB-WAT for Chiller ACCB. Since the units are in Watts (SI) the conversion factor of 3.412 was used to convert Watts to Btu per hour.

4.4.4 Lighting Energy

Test room lighting energy is provided by the electricity from the grid. Wattmeter's have an error percent of ±0.2%. Lighting energy distribution is shown in Figure 42.

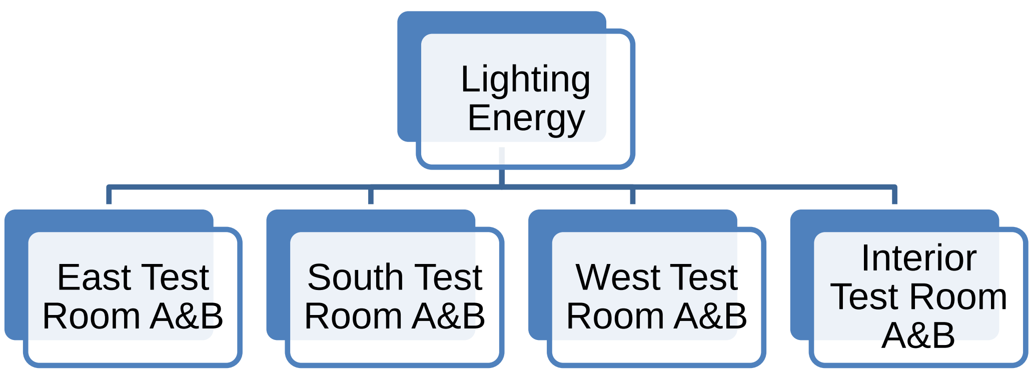

Figure 42: Lighting Energy

Lighting Energy Calculation: Lighting energies are supplied from the programming computer which saves real time test data. The system data point for the lighting energies are EALITWAT for East A , EBLITWAT for East B, WALITWAT for West A,WBLITWAT for West B, SALITWAT for South A, SBLITWAT for South B, IALITWAT for Interior A and IBLITWAT for Interior B Test Rooms.

4.4.5 System Cooling Energy

System cooling energy distribution is shown in Figure 43. System cooling energy consists of AHU cooling coil sensible heat and AHU cooling coil total heat.

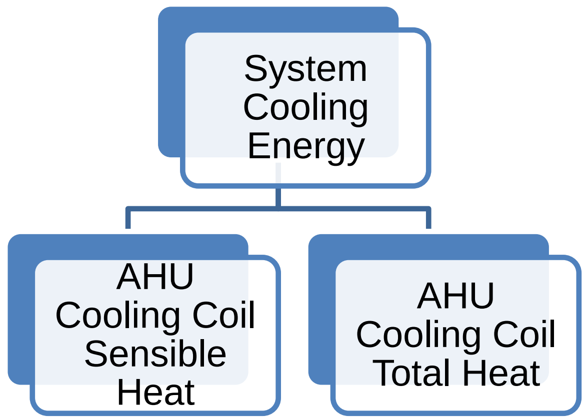

Figure 43: System Cooling Energy

System Cooling Energy Calculation: The AHU Chilled Water Coil (CHWC) flow is controlled by a 3-way valve with a constant flow Chilled Water Pump (CHWP) on the return side. Three Chilled Water temperatures are measured: Entering Water Temp (CHWC-EWT), Leaving Water Temp (CHWC-LWT) and Mixed Water Temp (CHWC-MWT). CHW Coil flow can be calculated from the flow and water temperatures. SA-TEMP and SA-HUMD are measured after the SA Fan. SA Fan Heat is added to the CHWC-DAT value.

AHU CHW Coil Sensible Heat (Btu/min) = 1.10 X CFM X TempDiff

Where, CFM is the air flow rate in cubic feet per minute and TempDiff is the difference between air temperatures before and after the coil (ºF). The value of 1.10

is dependent on the temperature and density of the air. For typical AHU supply air temps 1.10 is used, for standard air 1.08 is used. For critical calculations, actual values based on the temperature, moisture and density of the air should be calculated from the data set.

AHU CHW Coil Sensible Heat (Btu/min) =

= (1.10/60*SA-CFM*(CHWC-DAT - HWC-DAT)).

Where, HWC-DAT is the upstream entering air temperature of CHW coil. Conversion factor /60 used to calculate BTU/min to adjust the minute data from ERS TEST data set. Calculating AHU CHW Coil Total Heat based on waterside Flow and TempDiff measurements.

AHU CHW Coil Total Heat = 470 X GPM X TempDiff **.**

Where, GPM is the water/glycol flow rate through the coil in gallons per minute and TempDiff is the difference in water/glycol temperature entering and leaving coil. AHU CHW Coil Latent Heat is obtained by subtracting the AHU CHW Coil Sensible Heat from the CHW Coil Total Heat. Proportionally assign the Latent Heat Energy to each Test Room based on the Test Room air flow rate. The Chilled Water System Heat Transfer (HX) fluid is a 20% Propylene Glycol solution. The HX value is dependent on temperature, density and specific heat of the HX fluid. The HX value of <u>470</u> must be adjusted based on the glycol type, concentration and temperature.

AHU CHW Coil Total Heat (Btu/min) =

= (470/60*CHWP-GPM*(CHWC-EWT - CHWC-MWT)).

Conversion factor /60 used to calculate BTU/min to accommodate the minute data from ERS TEST data set. Resulting BTU is energy use per minute and requires adjustment for BTU/Hr, BTU/day or BTU per test period. The resulting value is negative which indicates cooling where the heat is being extracted from the system.

4.4.6 System Heating Energy

As seen on Figure 44, system heating energy is only consists of heating loop A and heating loop B energy.

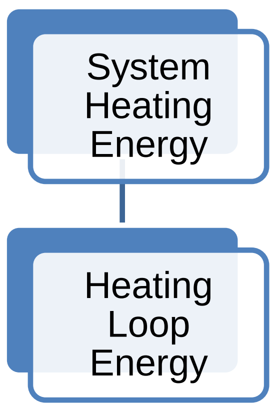

Figure 44: System Heating Energy

System Heating Energy Calculation (Heating Loop Energy): The AHU Heating Water Coil (HWC) flow is controlled by a 3-way valve with a constant flow Heating Water Pump (HWP) on the return side. Four Heating Water temperatures are measured: Loop A Supply Water Temp (LA-SWT), Loop B Supply Water Temp (LB-SWT), Loop A Return Water Temp (LA-RWT) and Loop B Return Water Temp (LB-RWT). Two Loop Pump Flow Rates are measured: Loop A Pump Flow Rate (LAP-GPM) and Loop B Pump Flow Rate (LBP-GPM).

Heating Water Loop Heating Energy = 500 X GPM X TempDiff .

Where GPM is Loop heating water flow rate and TemoDiff is the temperature difference of supply and return water temperatures. The Heating Water System Heat Transfer (HX) fluid is 100% treated water. For 100% water based systems an HX value of 500 is typical. The value is dependent on the temperature, density and specific heat of the heat transfer fluid. For glycol based systems the value must be adjusted based on the glycol type, concentration and temperature.

Heating Water Loop-A Heat Energy (Btu/min) =

= (500/60*LAP-GPM*(LA-SWT - LA-RWT)).

Heating Water Loop-B Heat Energy =

= (500/60*LBP-GPM*(LB-SWT - LB-RWT)).

Conversion factor /60 used to calculate BTU/min to accommodate the minute data from ERS TEST data set. Resulting BTU is energy use per minute and requires adjustment for BTU/Hr, BTU/day or BTU per test period.

4.4.7 Test Room Internal Loads

Internal Heat Gains from Test Rooms are androids, computers and false thermal loads (Baseboard Heaters). Number of androids, computers and number of false thermal loads are variable and defined in Test Setup.

Internal Load Calculations:

Occupant Heat Gain = Number Occupants x 75 W x 3.4 BTU/Hr-W.

OccGain (Btu/min) = (NumOcc * 75 * 3.4/60).

Computer Heat Gain = One Computer x 88 W x 3.4 BTU/Hr-W.

CompGain (Btu/min) = (NumComp * 84 * 3.4/60) + (4 * 3.4/60).

NumOcc is the number of occupants represented by each Android as designated by the Test Setup. NumComp is the number of computers designated by the Test Setup. Conversion factor /60 used to calculate BTU/min to accommodate the minute data from ERS TEST data set. Resulting BTU is energy use per minute and requires adjustment for BTU/Hr, BTU/day or BTU per test period.

False Load Heat Gain = Stages On x 880 W/Stage x 3.4 BTU/Hr-W

Occupant Heat Gain of 75 W / occupant is equivalent to 255 BTU/Hr Sensible Heat Gain. Computer Work Station includes a Computer and Monitor consuming 88 W when On and 4 W in Standby. Average capacity of baseboard heat stages is 880 watts. Measured capacity of individual stages varies between 860 and 900 watt.

4.4.8 Normalization

At the end of each test, both test room A and test room B windows were replaced with test room clear windows and continued the test procedure for two more extra days. There were total of six test cycles with six different normalization test results. The only difference for the normalization setup was replacing each test room exterior windows with test room clear windows. The main test setup remained the same as the Pleotint SRT windows test. With normalization, we were able to account for the errors in the test procedure. These errors were due to slight differences in construction and equipment, as well as systematic instrumentation errors. After each normalization test procedure, the normalization results were subtracted from the original test results to achieve the corrected data. Normalization lighting comparison example is shown in Appendix C.

4.4.9 Data Acquisition System

The Data Acquisition System consists of an Ethernet network which utilizes operator workstations to communicate with four network controller units. Each unit is user-programmed to provide supervisory functions of the secondary controllers and application specific controllers located on the local bus connected to that unit. Johnson Control Matasys system was used for control and data acquisition. The data was transferred to the programming computer, then, Matlab software was used by the programming computer to process and analyze the transferred test data. Data Acquisition System is shown in Figure 45**.**

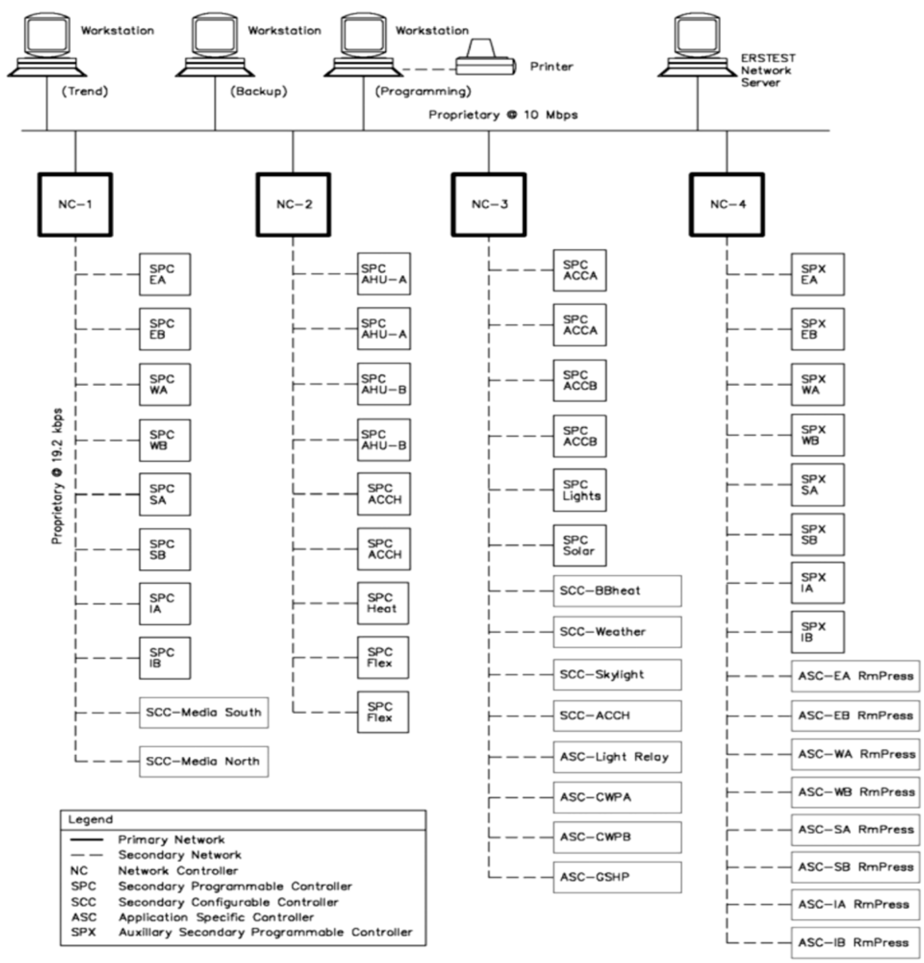

Figure 45: Data Acquisition System

Chapter 5 Pleotint SRT Window Test Results and Conclusion

5.1 Pleotint SRT Window Test Results

The test room setup and temperature set points were discussed in previous chapters. To reduce the interior load on the test rooms, the temperature set points of general office area and rest of the conditioned spaces were set to same values as the test rooms. With this setup and proper insulation, all thermal gains through the interior spaces and partition walls were minimized. Pleotint SRT window test overview is shown in Table 19.

Table 18: Pleotint SRT Window Test Overview

Test	Dates	Outside Air Average Temperature(ºF)	Global Horizontal Irradiance (Btu/day ft^2)
March 2011 Test 1.1	03/23/2011 - 04/10/2011	46.31	1250.54
March 2011 Test 1.2	04/12/2011 - 04/19/2011	46.97	906.07
May 2011 Test 2.1	05/24/2011 – 05/31/2011	66.58	1299.04
May 2011 Test 2.2	06/02/2011 – 06/12/2011	77.62	1508.49
July 2011 Test 3.1	07/29/2011 – 08/07/2011	84.54	1615.39
July 2011 Test 3.2	08/09/2011 08/15/2011	77.20	1936.32
September 2011 Test 4.1	09/28/2011 – 10/04/2011	67.19	1418.83
September 2011 Test 4.2	10/06/2011 – 10/12/2011	71.41	993.88
November 2011 Test 5.1	11/23/2011 – 11/30/2011	43.44	482.01
November 2011 Test 5.2	12/02/2011 – 12/09/2011	26.76	398.57
January 2012 Test 6.1	02/02/2012 – 02/08/2012	32.12	505.65
January 2012 Test 6.2	01/25/2012 – 01/31/2012	39.51	695.24

5.1.1 March Test 2011

In March Test 2011 Test 1.1, the exterior B test room windows were installed with azuria color Pleotint windows and exterior A test room windows were installed with dark tinted performance windows. Test 1.1 uses chiller CH for both A and B test rooms. Test 1.1 test didn't include the false thermal load (baseboard heaters) in the test setup. Test 1.1 daily average energy consumption is shown in Figure 45. In the "% Difference" column, negative sign "-" means B system uses less energy compared to the A system. The lighting energy total saving with B systems were 25.20%. Cooling and heating energy savings were 3.61% and 4.09% with the B system. The units are in BTU. Energy savings including chiller, pumps and fans can also be seen in Figure 46. March Test 1.1 total energy savings can be seen in Appendix A.

		System A Energy (BTU)	System B Energy (BTU)	% Difference	Normalization % Difference	Corrected % Difference
Fan Energy	AHU Supply Fan	20,048.80	20,587.57	2.69	2.36	
	AHU Return Fan	8,337.07	7,981.59	-4.26	-5.30	
	AHU Outside Air Injection Fan	5,934.38	5,280.63	-11.02	-10.54	
	Total Fan Energy	34,320.25	33,849.79	-1.37	-1.78	0.41
Pump Energy	Chiller-CH Pump	36,723.24	35,353.70	-3.73	0.00	
	AHU Chilled Water Pump	0.00	0.00			
	Heating Water Loop Pump	18,636.74	18,015.65	-3.33	1.10	
	Total Pump Energy	55,359.98	53,369.35	-3.60	0.82	-4.42
Chiller Energy	Chiller-CH	78,965.68	76,322.58	-3.35	0.00	
	ACCA / ACCB	0.00	0.00			
	Total Chiller Energy	78,965.68	76,322.58	-3.35	0.86	-4.21
Lighting Energy	East Test Room	8,436.37	4,254.51	-49.57	-14.45	-35.12
	South Test Room	7,534.64	4,768.29	-36.72	-2.37	-34.35
	West Test Room	9,109.90	5,475.91	-39.89	-8.60	-31.29
	Interior Test Room	14,659.48	14,754.76	0.65	0.68	-0.03
	Total Lighting Energy	39,740.38	29,253.48	-26.39	-4.83	-25.20
System Cooling Energy	AHU Cooling Coil Sensible Heat	-184,538.85	-184,580.10	0.02	-1.92	
	AHU Cooling Coil Total Heat	-179,284.29	-172,819.05	-3.61	0.00	-3.61
System Heating Energy	Heating Loop Energy	110,584.46	104,322.53	-5.66	-1.57	
	Total Heating Energy	110,584.46	104,322.53	-5.66	-1.57	-4.09
Total HVAC Electricity Used	Fan+Pump+Chiller	168,645.91	163,541.72	-3.03	0.23	-3.26
Total Building Electricity Used	Fan+Pump+Chiller+Lighting	208,386.29	192,795.20	-7.48	-0.77	-6.71

Figure 46: Test 1.1 Average Daily Energy Consumption

South A and B test room lighting comparison for the Test 1.1 and date 03/23/2011 is shown in Figure 47. This test date was chosen to be a cloudy test date which was supported by the weather data. On this graph, left side y axis represents room light level which is measured from the lighting sensor located on the tables inside the test rooms. The right side y axis represents lighting energy in watts. The x axis represents time in minutes. From the test room setup, the minimum light level was specified as 45 foot candles. The lighting dimming control, adjusts test room lights depending on the minimum light level requirement for the test rooms. The interpretation of the graph is as follows: During the early morning, since there is no natural day light, the lights turn on to set the light level of 45 foot candles for the test room. This explains the lighting wattage spikes in Figure 47 during the morning. During the day, the sun provides natural day light and the dimming control adjusts the lights according to the light level reading from the lighting sensor located on the table, this results in the fluctuating light level and lighting wattage curves as seen from Figure 47. When the natural lighting provides 45 foot candles or even more lighting, the dimming control shuts down the test room lighting fixtures. From Figure 47, on 03/23/2011, it can be seen that South B test room lighting wattage curves are below South A test room lighting wattage curves. This indicates that South B test room was saving lighting energy. Test 1.2 to Test 6.2 selected sunny and cloudy day lighting comparisons can be seen on Appendix B.

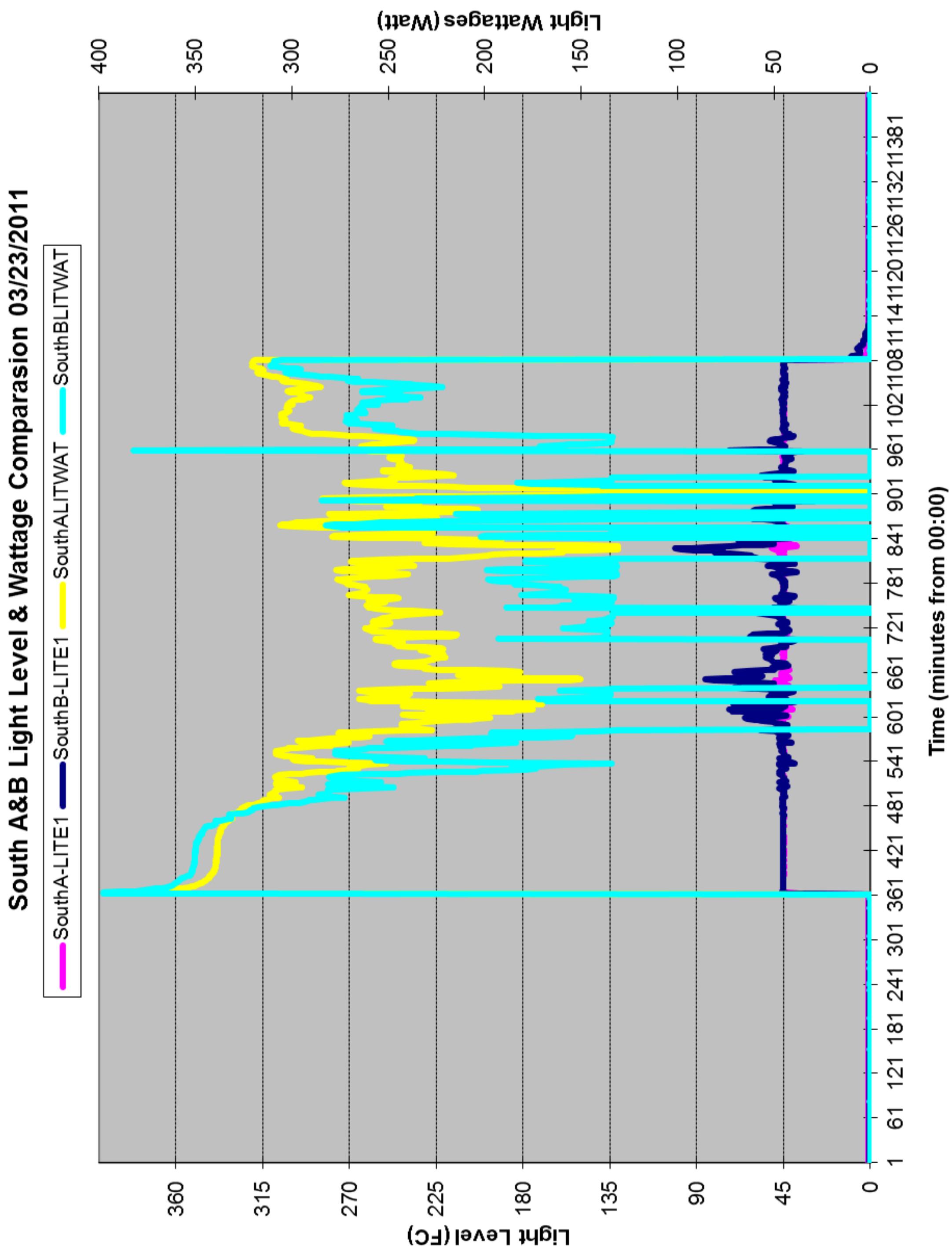

Figure 47: South A&B Test Room Lighting Comparisons on a Cloudy Day

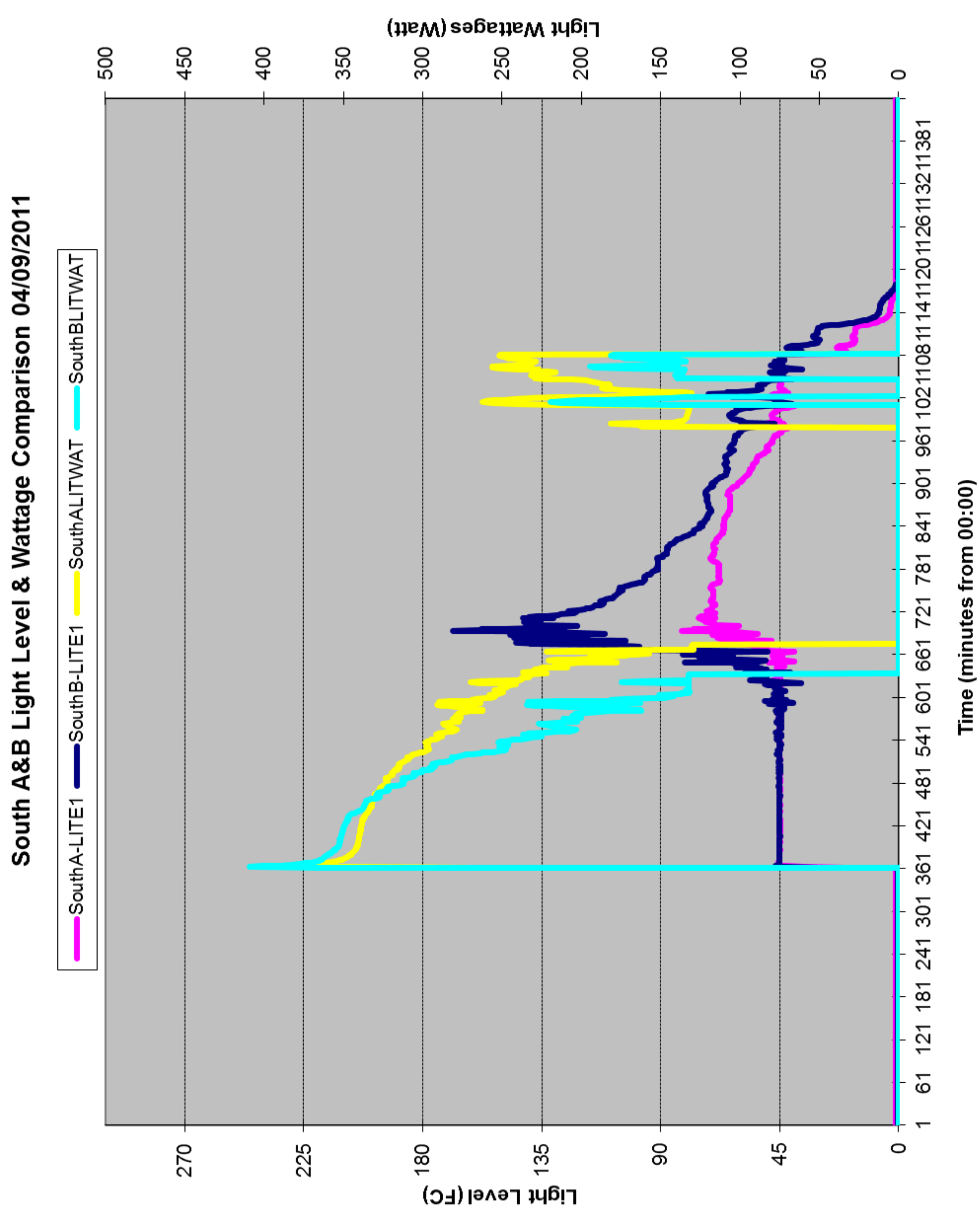

Figure 48: South A&B Test Room Lighting Comparisons on a Sunny Day

South A and B test room lighting comparison for the Test 1.1 and date 04/09/2011 is shown in Figure 48. Compared with the previous Figure 47, this test date was chosen to be a sunny day. As it can be seen from Figure 48, system B saves more lighting energy and transmits more natural day light in to the test room. The light level for south B test room is higher.

In March Test 2011 Test 1.2, the exterior B test room windows were installed with clear color Pleotint windows and exterior A test room windows were installed with dark tinted performance windows. Starting with Test 1.2, the system uses chillers ACCA for A and ACCB for B test rooms. The 0.00 for the Chiller-CH Pump indicates that Chiller CH was inactive for this test. March Test 1.2 didn't include the false thermal load (baseboard heaters) in the test setup. Test 1.2 average daily energy consumption is shown in Figure 49. March Test 1.2 total energy savings can be seen in Appendix A.

		System A Energy (BTU)	System B Energy (BTU)	% Difference	Normalization % Difference	Corrected % Difference
Fan Energy	AHU Supply Fan	20,120.18	20,311.26	0.95	2.36	
	AHU Return Fan	8,500.58	8,003.51	-5.85	-5.30	
	AHU Outside Air Injection Fan	5,941.87	5,330.73	-10.29	-10.54	
	Total Fan Energy	34,562.63	33,645.50	-2.65	-1.78	-0.87
Pump Energy	Chiller-CH Pump	0.00	0.00	Na	Na	
	AHU Chilled Water Pump	18,933.59	19,045.51	0.59	0.66	
	Heating Water Loop Pump	10,246.41	10,146.09	-0.98	1.10	
	Total Pump Energy	29,179.99	29,191.61	0.04	0.82	-0.78
Chiller Energy	Chiller-CH	0.00	0.00	Na	Na	
	ACCA / ACCB	88,040.45	87,076.92	-1.09	0.86	
	Total Chiller Energy	88,040.45	87,076.92	-1.09	0.86	-1.95
Lighting Energy	East Test Room	10,057.17	5,948.97	-40.85	-14.45	-26.40
	South Test Room	9,643.13	6,111.04	-36.63	-2.37	-34.26
	West Test Room	10,170.99	6,152.46	-39.51	-8.60	-30.91
	Interior Test Room	14,727.19	14,829.38	0.69	0.68	0.01
	Total Lighting Energy	44,598.48	33,041.86	-25.91	-4.83	-22.89
System Cooling Energy	AHU Cooling Coil Sensible Heat	-190,573.96	-183,672.99	-3.62	-1.92	
	AHU Cooling Coil Total Heat	-185,355.10	-165,907.51	-10.49	-9.28	-1.21
System Heating Energy	Heating Loop Energy	113,444.21	95,574.82	-15.75	-1.57	
	Total Heating Energy	113,444.21	95,574.82	-15.75	-1.57	-14.18
Total HVAC Electricity Used	Fan+Pump+Chiller	151,783.07	149,914.03	-1.23	0.23	-1.46
Total Building Electricity Used	Fan+Pump+Chiller+Lighting	196,381.56	182,955.89	-6.84	-0.77	-6.07

Figure 49: Test 1.2 Average Daily Energy Consumption

5.1.2 May Test 2011

In May Test 2011 Test 2.1, the exterior B test room windows were installed with azuria color Pleotint windows and exterior A test room windows were installed with dark tinted performance windows. In May Test 2011 Test 2.2, the exterior B test room windows were installed with clear color tinted Pleotint windows and exterior A test room windows were installed with dark tinted performance windows. Test 2.1 and Test 2.2 use chillers ACCA for A and ACCB for B test rooms. Both Test 2.1 and Test 2.2 didn’t include the false thermal load (baseboard heaters) in the test setup. Test 2.1 and 2.2 daily average energy consumptions are shown in Figure 50 and in Figure 51.

		System A Energy (BTU)	System B Energy (BTU)	% Difference	Normalization % Difference	Corrected % Difference
Fan Energy	AHU Supply Fan	21,758.57	22,138.87	1.75	3.72	
	AHU Return Fan	9,852.43	9,495.28	-3.63	-1.27	
	AHU Outside Air Injection Fan	5,829.85	5,920.31	1.55	13.03	
	Total Fan Energy	37,440.85	37,554.46	0.30	3.87	-3.57
Pump Energy	Chiller-CH Pump	0.00	0.00	Na	Na	
	AHU Chilled Water Pump	18,934.92	18,908.96	-0.14	-0.98	
	Heating Water Loop Pump	11,284.41	11,123.62	-1.42	1.66	
	Total Pump Energy	30,219.33	30,032.58	-0.62	-0.03	-0.59
Chiller Energy	Chiller-CH	0.00	0.00	Na	Na	
	ACCA / ACCB	119,262.23	116,360.60	-2.43	-0.57	
	Total Chiller Energy	119,262.23	116,360.60	-2.43	-0.57	-1.86
Lighting Energy	East Test Room	8,833.42	5,659.91	-35.93	-9.83	-26.10
	South Test Room	10,010.02	6,403.01	-36.03	-0.16	-35.87
	West Test Room	9,866.33	6,713.28	-31.96	-2.32	-29.64
	Interior Test Room	14,747.46	14,853.74	0.72	0.86	-0.14
	Total Lighting Energy	43,457.23	33,629.93	-22.61	-1.06	-21.55
System Cooling Energy	AHU Cooling Coil Sensible Heat	-216,653.18	-193,682.56	-10.60	-9.72	
	AHU Cooling Coil Total Heat	-226,705.31	-209,104.84	-7.76	-4.67	-3.09
System Heating Energy	Heating Loop Energy	63,242.38	55,581.71	-12.11	2.49	
	Total Heating Energy	63,242.38	55,581.71	-12.11	2.49	-14.60
Total HVAC Electricity Used	Fan+Pump+Chiller	186,922.41	183,947.63	-1.59	0.36	-1.95
Total Building Electricity Used	Fan+Pump+Chiller+Lighting	230,379.64	217,577.56	-5.56	0.20	-5.76

Figure 50: Test 2.1 Average Daily Energy Consumption

		System A Energy (BTU)	System B Energy (BTU)	% Difference	Normalization % Difference	Corrected % Difference
Fan Energy	AHU Supply Fan	21,508.22	22,660.18	5.36	3.72	
	AHU Return Fan	9,686.59	9,687.86	0.01	-1.27	
	AHU Outside Air Injection Fan	5,798.81	6,435.43	10.98	13.03	
	Total Fan Energy	36,993.62	38,783.46	4.84	3.87	0.97
Pump Energy	Chiller-CH Pump	0.00	0.00	Na	Na	
	AHU Chilled Water Pump	18,914.75	18,802.79	-0.59	-0.98	
	Heating Water Loop Pump	10,330.28	9,709.45	-6.01	1.66	
	Total Pump Energy	29,245.04	28,512.25	-2.51	-0.03	-2.47
Chiller Energy	Chiller-CH	0.00	0.00	Na	Na	
	ACCA / ACCB	146,771.26	145,186.56	-1.08	-0.57	
	Total Chiller Energy	146,771.26	145,186.56	-1.08	-0.57	-0.51
Lighting Energy	East Test Room	8,102.09	2,983.05	-63.18	-9.83	-53.35
	South Test Room	8,412.81	3,611.93	-57.07	-0.16	-56.90
	West Test Room	8,743.37	4,031.13	-53.90	-2.32	-51.58
	Interior Test Room	14,740.02	14,865.86	0.85	0.86	0.00
	Total Lighting Energy	39,998.29	25,491.97	-36.27	-1.06	-35.21
System Cooling Energy	AHU Cooling Coil Sensible Heat	-235,849.03	-212,457.11	-9.92	-9.72	
	AHU Cooling Coil Total Heat	-258,115.04	-249,968.91	-3.16	-4.67	1.52
System Heating Energy	Heating Loop Energy	24,333.68	17,322.26	-28.81	2.49	
	Total Heating Energy	24,333.68	17,322.26	-28.81	2.49	-31.30
Total HVAC Electricity Used	Fan+Pump+Chiller	213,009.92	212,482.26	-0.25	0.36	-0.61
Total Building Electricity Used	Fan+Pump+Chiller+Lighting	253,008.21	237,974.23	-5.94	0.20	-6.14

Figure 51: Test 2.2 Average Daily Energy Consumption

5.1.3 July Test 2011

In July Test 2011 Test 3.1, the exterior B test room windows were installed with azuria color Pleotint windows and exterior A test room windows were installed with dark tinted performance windows. In July Test 2011 Test 3.2, the exterior B test room windows were installed with clear color tinted Pleotint windows and exterior A test room windows were installed with dark tinted performance windows. Test 3.1 and Test 3.2 use chillers ACCA for A and ACCB for B test rooms. Both Test 3.1 and Test 3.2 included the false thermal load (baseboard heaters) in the test setup. Test room supply air and return air flow rate were increased as a result of the active false thermal loads in each test room. However, when the false thermal loads were active, test rooms didn’t require heating energy. The 0.00 values in the heating loop energy indicate that, there was no heating load required for the test rooms. Test 3.1 and 3.2 daily average energy consumptions are shown in Figure 52 and in Figure 53.

		System A Energy (BTU)	System B Energy (BTU)	% Difference	Normalization % Difference	Corrected % Difference
Fan Energy	AHU Supply Fan	43,765.13	41,934.25	-4.18	-15.09	
	AHU Return Fan	13,472.75	13,590.76	0.88	-7.14	
	AHU Outside Air Injection Fan	5,738.84	5,331.17	-7.10	-8.11	
	Total Fan Energy	62,976.72	60,856.17	-3.37	-12.89	9.52
Pump Energy	Chiller-CH Pump	0.00	0.00	Na	Na	Na
	AHU Chilled Water Pump	18,484.27	18,550.62	0.36	0.00	
	Heating Water Loop Pump	1,405.82	1,478.95	5.20	5.68	
	Total Pump Energy	19,890.09	20,029.57	0.70	0.40	0.30
Chiller Energy	Chiller-CH	0.00	0.00	Na	Na	Na
	ACCA / ACCB	294,002.76	295,505.45	0.51	-9.81	
	Total Chiller Energy	294,002.76	295,505.45	0.51	-9.81	10.32
Lighting Energy	East Test Room	6,348.61	5,292.57	-16.63	1.91	-18.55
	South Test Room	6,713.03	5,619.51	-16.29	3.44	-19.73
	West Test Room	6,792.71	5,845.44	-13.95	15.15	-29.09
	Interior Test Room	11,826.89	11,872.44	0.39	0.57	-0.18
	Total Lighting Energy	31,681.24	28,629.96	-9.63	2.47	-12.10
System Cooling Energy	AHU Cooling Coil Sensible Heat	-542,696.79	-505,828.60	-6.79	-11.65	
	AHU Cooling Coil Total Heat	-598,990.39	-617,425.11	3.08	-9.76	12.84
System Heating Energy	Heating Loop Energy	0.00	0.00	Na	Na	
	Total Heating Energy	0.00	0.00	Na	Na	Na
Total HVAC Electricity Used	Fan+Pump+Chiller	376,869.57	376,391.19	-0.13	-9.87	9.74
Total Building Electricity Used	Fan+Pump+Chiller+Lighting	416,095.46	412,955.58	-0.75	-9.25	8.49

Figure 52: Test 3.1 Average Daily Energy Consumption

		System A Energy (BTU)	System B Energy (BTU)	% Difference	Normalization % Difference	Corrected % Difference
Fan Energy	AHU Supply Fan	41,015.60	38,930.90	-5.08	-15.09	
	AHU Return Fan	12,911.93	12,843.78	-0.53	-7.14	
	AHU Outside Air Injection Fan	5,809.61	5,360.75	-7.73	-8.11	
	Total Fan Energy	59,737.14	57,135.43	-4.36	-12.89	8.53
Pump Energy	Chiller-CH Pump	0.00	0.00	Na	Na	Na
	AHU Chilled Water Pump	18,469.50	18,613.19	0.78	0.00	
	Heating Water Loop Pump	1,410.60	1,483.64	5.18	5.68	
	Total Pump Energy	19,880.09	20,096.83	1.09	0.40	0.69
Chiller Energy	Chiller-CH	0.00	0.00	Na	Na	Na
	ACCA / ACCB	246,275.64	220,905.04	-10.30	-9.81	
	Total Chiller Energy	246,275.64	220,905.04	-10.30	-9.81	-0.50
Lighting Energy	East Test Room	5,024.65	2,636.42	-47.53	1.91	-49.44
	South Test Room	5,378.74	2,465.25	-54.17	3.44	-57.61
	West Test Room	5,653.45	2,941.02	-47.98	15.15	-63.13
	Interior Test Room	10,571.48	10,627.11	0.53	0.57	-0.04
	Total Lighting Energy	26,628.32	18,669.80	-29.89	2.47	-32.35
System Cooling Energy	AHU Cooling Coil Sensible Heat	-520,438.81	-478,912.61	-7.98	-11.65	
	AHU Cooling Coil Total Heat	-519,476.99	-488,514.34	-5.96	-9.76	3.80
System Heating Energy	Heating Loop Energy	0.00	0.00	Na	Na	
	Total Heating Energy	0.00	0.00	Na	Na	Na
Total HVAC Electricity Used	Fan+Pump+Chiller	325,892.87	298,137.30	-8.52	-9.87	1.35
Total Building Electricity Used	Fan+Pump+Chiller+Lighting	363,157.50	324,455.21	-10.66	-9.25	-1.41

Figure 53: Test 3.2 Average Daily Energy Consumption

5.1.4 September Test 2011

In September Test 2011 Test 4.1, the exterior B test room windows were installed with azuria color Pleotint windows and exterior A test room windows were installed with dark tinted performance windows. In September Test 2011 Test 4.2, the exterior B test room windows were installed with clear color tinted Pleotint windows and exterior A test room windows were installed with dark tinted performance windows. Test 4.1 and Test 4.2 use chillers ACCA for A and ACCB for B test rooms. Both Test 4.1 and Test 4.2 included the false thermal load (baseboard heaters) in the test setup. Test 4.1 and 4.2 daily average energy consumptions are shown in Figure 54 and in Figure 55.

		System A Energy (BTU)	System B Energy (BTU)	% Difference	Normalization % Difference	Corrected % Difference
Fan Energy	AHU Supply Fan	37,583.47	33,602.99	-10.59	-14.04	
	AHU Return Fan	11,990.58	11,344.10	-5.39	-7.06	
	AHU Outside Air Injection Fan	5,877.23	5,410.76	-7.94	-8.66	
	Total Fan Energy	55,451.28	50,357.85	-9.19	-12.04	2.86
Pump Energy	Chiller-CH Pump	0.00	0.00	Na	Na	Na
	AHU Chilled Water Pump	18,684.67	18,719.72	0.19	0.77	
	Heating Water Loop Pump	1,379.21	1,471.49	6.69	5.21	
	Total Pump Energy	20,063.88	20,191.21	0.63	1.08	-0.44
Chiller Energy	Chiller-CH	0.00	0.00	Na	Na	Na
	ACCA / ACCB	186,552.08	156,226.67	-16.26	-11.52	
	Total Chiller Energy	186,552.08	156,226.67	-16.26	-11.52	-4.74
Lighting Energy	East Test Room	7,966.83	7,556.95	-5.14	-17.69	12.55
	South Test Room	5,260.28	8,592.15	63.34	-14.00	77.34
	West Test Room	8,080.21	6,640.51	-17.82	-3.61	-14.20
	Interior Test Room	14,711.95	14,779.87	0.46	-8.77	9.23
	Total Lighting Energy	36,019.27	37,569.48	4.30	-11.69	16.00
System Cooling Energy	AHU Cooling Coil Sensible Heat	-460,314.46	-411,908.25	-10.52	-9.39	
	AHU Cooling Coil Total Heat	-427,963.14	-372,278.76	-13.01	-12.56	-0.45
System Heating Energy	Heating Loop Energy	0.00	0.00	Na	Na	
	Total Heating Energy	0.00	0.00	Na	Na	Na
Total HVAC Electricity Used	Fan+Pump+Chiller	262,067.24	226,775.72	-13.47	-10.61	-2.86
Total Building Electricity Used	Fan+Pump+Chiller+Lighting	298,086.50	264,345.20	-11.32	-5.77	-5.55

Figure 54: Test 4.1 Average Daily Energy Consumption

		System A Energy (BTU)	System B Energy (BTU)	% Difference	Normalization % Difference	Corrected % Difference
Fan Energy	AHU Supply Fan	37,261.48	35,125.38	-5.73	-14.04	
	AHU Return Fan	11,853.89	11,732.87	-1.02	-7.06	
	AHU Outside Air Injection Fan	5,817.75	5,357.36	-7.91	-8.66	
	Total Fan Energy	54,933.12	52,215.61	-4.95	-12.04	7.09
Pump Energy	Chiller-CH Pump	0.00	0.00	Na	Na	Na
	AHU Chilled Water Pump	18,693.30	18,803.77	0.59	0.77	
	Heating Water Loop Pump	1,377.81	1,469.34	6.64	5.21	
	Total Pump Energy	20,071.11	20,273.11	1.01	1.08	-0.07
Chiller Energy	Chiller-CH	0.00	0.00	Na	Na	Na
	ACCA / ACCB	203,860.74	175,426.12	-13.95	-11.52	
	Total Chiller Energy	203,860.74	175,426.12	-13.95	-11.52	-2.43
Lighting Energy	East Test Room	8,647.78	4,703.40	-45.61	-17.69	-27.92
	South Test Room	6,507.50	4,741.08	-27.14	-14.00	-13.15
	West Test Room	8,451.96	4,655.42	-44.92	-3.61	-41.30
	Interior Test Room	14,702.93	14,775.12	0.49	-8.77	9.26
	Total Lighting Energy	38,310.16	28,875.02	-24.63	-11.69	-12.93
System Cooling Energy	AHU Cooling Coil Sensible Heat	-468,465.65	-429,512.18	-8.32	-9.39	
	AHU Cooling Coil Total Heat	-445,603.90	-403,913.36	-9.36	-12.56	3.21
System Heating Energy	Heating Loop Energy	0.00	0.00	Na	Na	
	Total Heating Energy	0.00	0.00	Na	Na	Na
Total HVAC Electricity Used	Fan+Pump+Chiller	278,864.97	247,914.84	-11.10	-10.61	-0.49
Total Building Electricity Used	Fan+Pump+Chiller+Lighting	317,175.14	276,789.86	-12.73	-5.77	-6.96

Figure 55: Test 4.2 Average Daily Energy Consumption

5.1.5 November Test 2011

In November Test 2011 Test 5.1, the exterior B test room windows were installed with azuria color Pleotint windows and exterior A test room windows were installed with dark tinted performance windows. In November Test 2011 Test 5.2, the exterior B test room windows were installed with clear color tinted Pleotint windows and exterior A test room windows were installed with dark tinted performance windows. Test 5.1 and Test 5.2 use chillers ACCA for A and ACCB for B test rooms. Both Test 5.1 and Test 5.2 included the false thermal load (baseboard heaters) in the test setup. Test 5.1 and 5.2 daily average energy consumptions are shown in Figure 56 and in Figure 57.

		System A Energy (BTU)	System B Energy (BTU)	% Difference	Normalization % Difference	Corrected % Difference
Fan Energy	AHU Supply Fan	26,313.97	25,022.26	-4.91	-11.69	
	AHU Return Fan	9,321.53	9,270.23	-0.55	-13.95	
	AHU Outside Air Injection Fan	6,190.64	5,600.32	-9.54	-8.57	
	Total Fan Energy	41,826.14	39,892.81	-4.62	-12.03	7.41
Pump Energy	Chiller-CH Pump	0.00	0.00	Na	Na	Na
	AHU Chilled Water Pump	29,632.67	28,291.10	-4.53	0.86	
	Heating Water Loop Pump	1,795.72	1,824.22	1.59	24.73	
	Total Pump Energy	31,428.39	30,115.32	-4.18	2.64	-6.82
Chiller Energy	Chiller-CH	0.00	0.00	Na	Na	Na
	ACCA / ACCB	98,747.40	85,611.19	-13.30	-13.93	
	Total Chiller Energy	98,747.40	85,611.19	-13.30	-13.93	0.62
Lighting Energy	East Test Room	8,280.95	6,835.13	-17.46	-0.40	-17.06
	South Test Room	5,962.96	5,781.70	-3.04	1.51	-4.55
	West Test Room	8,496.25	6,328.44	-25.51	-3.88	-21.63
	Interior Test Room	11,064.74	11,098.81	0.31	0.48	-0.17
	Total Lighting Energy	33,804.90	30,044.09	-11.13	-0.67	-10.46
System Cooling Energy	AHU Cooling Coil Sensible Heat	-290,769.46	-258,433.93	-11.12	-8.10	
	AHU Cooling Coil Total Heat	-272,368.69	-235,601.25	-13.50	-12.97	-0.53
System Heating Energy	Heating Loop Energy	7,791.07	8,368.40	7.41	Na	Na
	Total Heating Energy	7,791.07	8,368.40	7.41	Na	Na
Total HVAC Electricity Used	Fan+Pump+Chiller	172,001.93	155,619.32	-9.52	-11.53	2.01
Total Building Electricity Used	Fan+Pump+Chiller+Lighting	218,255.76	197,057.12	-9.71	-8.12	-1.59

Figure 56: Test 5.1 Average Daily Energy Consumption

		System A Energy (BTU)	System B Energy (BTU)	% Difference	Normalization % Difference	Corrected % Difference
Fan Energy	AHU Supply Fan	23,872.21	22,609.12	-5.29	-11.69	
	AHU Return Fan	8,729.18	8,591.61	-1.58	-13.95	
	AHU Outside Air Injection Fan	6,349.05	5,698.92	-10.24	-8.57	
	Total Fan Energy	38,950.44	36,899.66	-5.27	-12.03	6.76
Pump Energy	Chiller-CH Pump	0.00	0.00	Na	Na	Na
	AHU Chilled Water Pump	18,200.66	18,460.37	1.43	0.86	
	Heating Water Loop Pump	2,711.60	2,458.53	-9.33	24.73	
	Total Pump Energy	20,912.26	20,918.90	0.03	2.64	-2.61
Chiller Energy	Chiller-CH	0.00	0.00	Na	Na	Na
	ACCA / ACCB	73,662.90	65,086.08	-11.64	-13.93	
	Total Chiller Energy	73,662.90	65,086.08	-11.64	-13.93	2.28
Lighting Energy	East Test Room	8,837.32	6,534.87	-26.05	-0.40	-25.65
	South Test Room	7,498.98	6,337.23	-15.49	1.51	-17.00
	West Test Room	9,004.64	6,280.62	-30.25	-3.88	-26.37
	Interior Test Room	11,052.75	11,091.83	0.35	0.48	-0.13
	Total Lighting Energy	36,393.70	30,244.55	-16.90	-0.67	-16.23
System Cooling Energy	AHU Cooling Coil Sensible Heat	-229,625.07	-202,162.42	-11.96	-8.10	
	AHU Cooling Coil Total Heat	-213,327.86	-179,719.70	-15.75	-12.97	-2.79
System Heating Energy	Heating Loop Energy	16,712.92	15,472.08	-7.42	Na	Na
	Total Heating Energy	16,712.92	15,472.08	-7.42	Na	Na
Total HVAC Electricity Used	Fan+Pump+Chiller	133,525.59	122,904.64	-7.95	-11.53	3.58
Total Building Electricity Used	Fan+Pump+Chiller+Lighting	181,575.25	161,987.52	-10.79	-8.12	-2.67

Figure 57: Test 5.2 Average Daily Energy Consumption

5.1.6 January Test 2012

In January Test 2012 Test 6.1, the exterior B test room windows were installed with clear color Pleotint windows and exterior A test room windows were installed with dark tinted performance windows. In January Test 2012 Test 6.2, the exterior B test room windows were installed with azuria color Pleotint windows and exterior A test room windows were installed with dark tinted performance windows. Test 6.1 and Test 6.2 use chillers ACCA for A and ACCB for B test rooms. Both Test 6.1 and Test 6.2 included the false thermal load (baseboard heaters) in the test setup. Test 6.1 and 6.2 daily average energy consumptions are shown in Figure 58 and in Figure 59.

		System A Energy (BTU)	System B Energy (BTU)	% Difference	Normalization % Difference	Corrected % Difference
Fan Energy	AHU Supply Fan	23,160.54	22,570.80	-2.55	-3.29	
	AHU Return Fan	8,428.11	8,416.39	-0.14	-2.70	
	AHU Outside Air Injection Fan	5,967.29	5,393.22	-9.62	-10.37	
	Total Fan Energy	37,555.94	36,380.41	-3.13	-4.16	1.03
Pump Energy	Chiller-CH Pump	0.00	0.00	Na	Na	Na
	AHU Chilled Water Pump	17,546.54	17,693.92	0.84	-0.95	
	Heating Water Loop Pump	2,391.18	2,517.68	5.29	2.71	
	Total Pump Energy	19,937.72	20,211.60	1.37	0.06	1.32
Chiller Energy	Chiller-CH	0.00	0.00	Na	Na	Na
	ACCA / ACCB	78,135.52	71,191.50	-8.89	-10.68	
	Total Chiller Energy	78,135.52	71,191.50	-8.89	-10.68	1.79
Lighting Energy	East Test Room	6,752.29	5,175.12	-23.36	6.35	-29.70
	South Test Room	6,319.14	5,224.52	-17.32	4.44	-21.77
	West Test Room	7,217.07	5,040.53	-30.16	2.33	-32.49
	Interior Test Room	9,803.64	9,836.42	0.33	0.57	-0.23
	Total Lighting Energy	30,092.14	25,276.59	-16.00	1.93	-17.93
System Cooling Energy	AHU Cooling Coil Sensible Heat	-239,752.75	-214,051.11	-10.72	-13.07	
	AHU Cooling Coil Total Heat	-222,799.21	-198,149.77	-11.06	-15.39	4.32
System Heating Energy	Heating Loop Energy	15,555.22	16,137.56	3.74	3.23	
	Total Heating Energy	15,555.22	16,137.56	3.74	3.23	0.51
Total HVAC Electricity Used	Fan+Pump+Chiller	135,629.18	127,783.51	-5.78	-6.97	1.18
Total Building Electricity Used	Fan+Pump+Chiller+Lighting	177,600.22	163,163.34	-8.13	-5.81	-2.32

Figure 58: Test 6.1 Average Daily Energy Consumption

		System A Energy (BTU)	System B Energy (BTU)	% Difference	Normalization % Difference	Corrected % Difference
Fan Energy	AHU Supply Fan	25,928.86	25,701.29	-0.88	-3.29	
	AHU Return Fan	9,138.53	9,265.70	1.39	-2.70	
	AHU Outside Air Injection Fan	6,175.58	5,610.68	-9.15	-10.37	
	Total Fan Energy	41,242.98	40,577.68	-1.61	-4.16	2.54
Pump Energy	Chiller-CH Pump	0.00	0.00	Na	Na	Na
	AHU Chilled Water Pump	18,441.45	18,579.63	0.75	-0.95	
	Heating Water Loop Pump	2,911.24	3,160.17	8.55	2.71	
	Total Pump Energy	21,352.69	21,739.80	1.81	0.06	1.76
Chiller Energy	Chiller-CH	0.00	0.00	Na	Na	Na
	ACCA / ACCB	92,636.42	83,615.24	-9.74	-10.68	
	Total Chiller Energy	92,636.42	83,615.24	-9.74	-10.68	0.94
Lighting Energy	East Test Room	6,972.54	4,544.40	-34.82	6.35	-41.17
	South Test Room	5,280.42	4,154.83	-21.32	4.44	-25.76
	West Test Room	7,597.91	4,458.75	-41.32	2.33	-43.65
	Interior Test Room	10,497.09	10,534.81	0.36	0.57	-0.21
	Total Lighting Energy	30,347.96	23,692.79	-21.93	1.93	-23.86
System Cooling Energy	AHU Cooling Coil Sensible Heat	-270,985.58	-251,403.23	-7.23	-13.07	
	AHU Cooling Coil Total Heat	-254,430.09	-235,530.02	-7.43	-15.39	7.96
System Heating Energy	Heating Loop Energy	16,210.90	16,146.55	-0.40	3.23	
	Total Heating Energy	16,210.90	16,146.55	-0.40	3.23	-3.63
Total HVAC Electricity Used	Fan+Pump+Chiller	155,232.08	145,932.71	-5.99	-6.97	0.98
Total Building Electricity Used	Fan+Pump+Chiller+Lighting	196,824.22	178,042.25	-9.54	-5.81	-3.74

Figure 59: Test 6.2 Average Daily Energy Consumption

5.2 Total Cooling Load Comparison

Total cooling loads for each test are shown in the previous figures and Appendix A. To analyze the performance of the Pleotint windows in more detail regarding the total cooling loads, sunny days from three random test dates were chosen. The chosen days are as follows:

- Test 5.1,Date 11/29/2011
- Test 6.1, Date 02/06/2012
- Test 1.2, Date 04/12/2011

For those days above, the Matlab normalization program was executed for each hour of the day starting from 06:00 ending at 18:00. At the end of each hour, the data was recorded and the figures were provided. The Y axis in the figures indicates the total cooling load for A and B test rooms. The X axis indicates the time. The data at 07:00 indicates the total cooling load collected between 06:00 am and 07:00 am time period. The values for the cooling loads are in BTU/Hr. Since the heat is taken out from the system, the cooling load values are negative. Total cooling load comparisons for the selected days are shown in Figure 60 to Figure 62. The figures show that the B systems save cooling energy compared to the A systems.

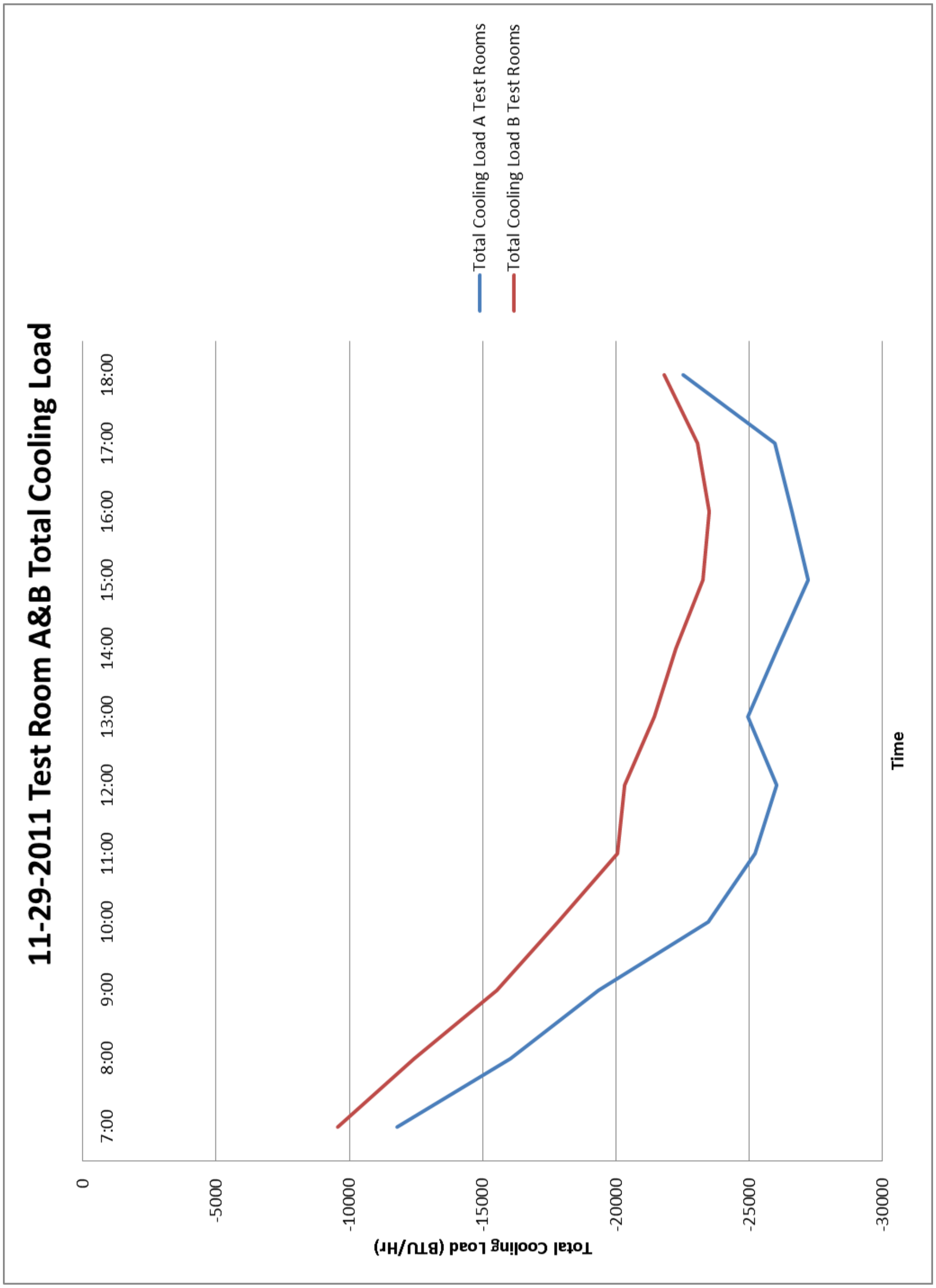

Figure 60: Test 5.1 Sunny Test Day Total Cooling Load Comparison

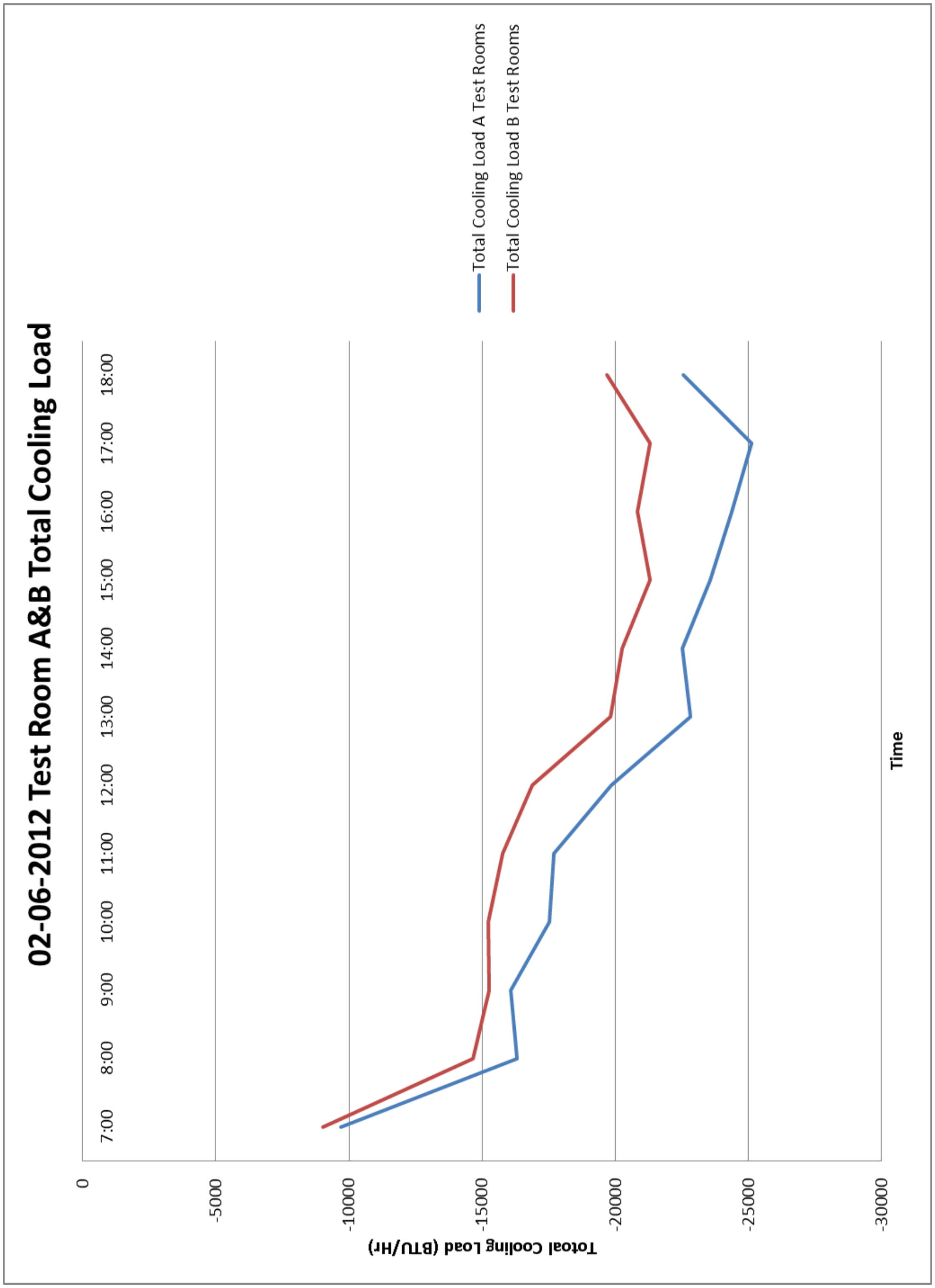

Figure 61: Test 6.1 Sunny Test Day Total Cooling Load Comparison

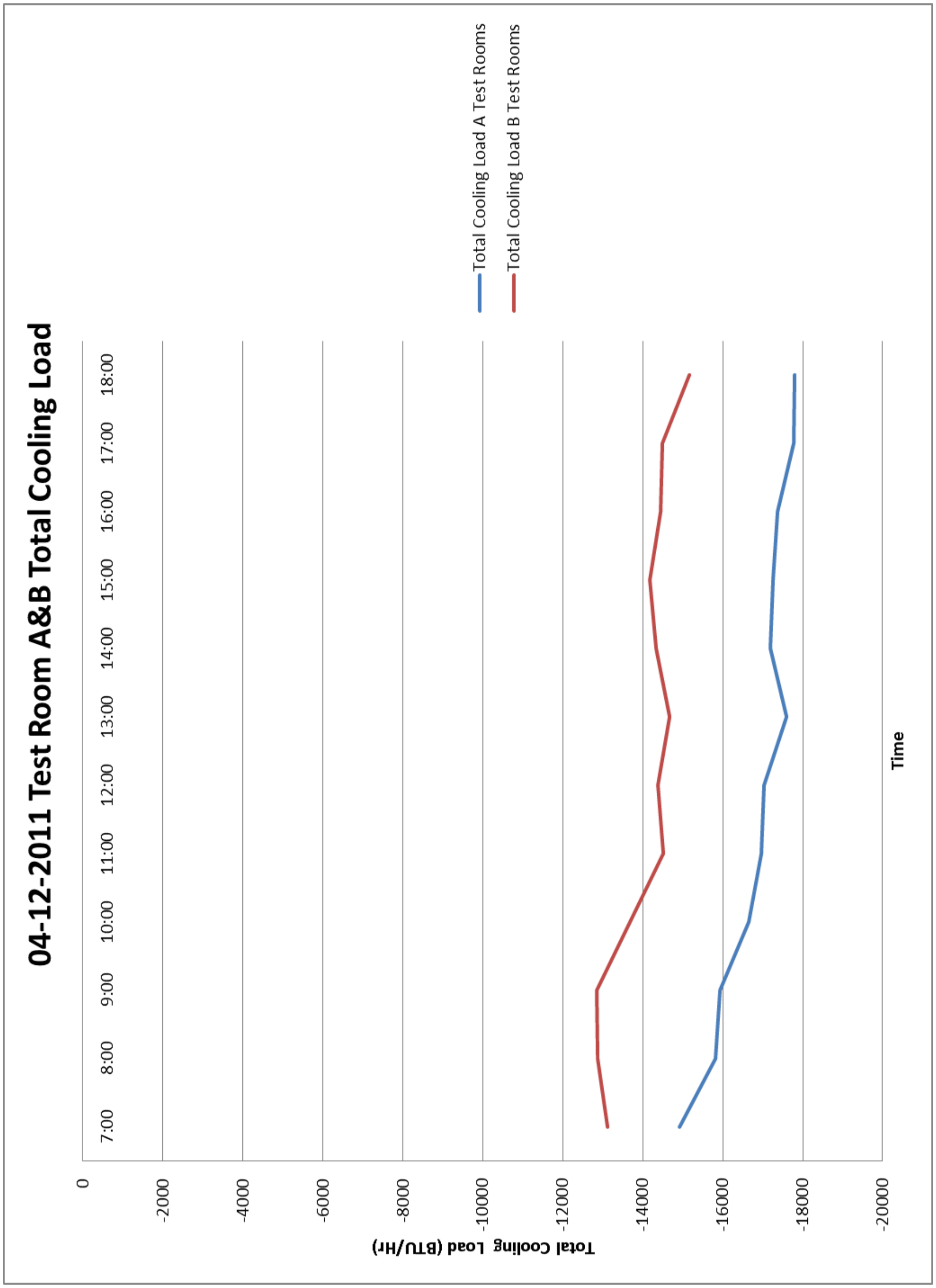

Figure 62: Test 1.2 Sunny Test Day Total Cooling Load Comparison

5.3 Summary

Both azuria and clear color Pleotint SRT performance windows in the B test rooms proved to save more energy than the dark tinted low-e performance windows in the A test rooms. Total lighting and HVAC energy comparison are shown on Table 20.

Table 19: Total Lighting and HVAC Energy Comparison Without Normalization

Test	Total Lighting Energy (BTU)		Total HVAC Electricity (BTU)	
	A Test Rooms	B Test Rooms	A Test Rooms	B Test Rooms
1.1	755,067.	555,816	3,204,272	3,107,293
1.2	356,788	264,335	1,214,265	1,199,312
2.1	347,658	269,039	1,495,379	1,471,581
2.2	359,985	229,428	1,917,089	1,912,340
3.1	316,812	286,300	3,768,696	3,763,912
3.2	186,398	130,689	2,281,250	2,086,961
4.1	252,135	262,986	1,834,471	1,587,430
4.2	268,171	202,125	1,952,055	1,735,404
5.1	270,439	240,353	1,376,015	1,244,955
5.2	291,150	241,956	1,068,205	983,237
6.1	210,645	176,936	949,404	894,485
6.2	212,436	165,850	1,086,625	1,021,529
Total	3,617,534 ± 0.2%	3,025,812 ± 0.2%	22,147,726 ± 0.2%	21,008,439 ± 0.2%

As it is shown in Table 20, B test rooms using the Pleotint SRT windows, used 3,025,812 BTU total lighting energy and 22,008,438 BTU total HVAC electricity. This compares to the, A test rooms, using the low-e dark tinted performance windows, which used 3,617,534 BTU total lighting energy and 22,147,725 BTU total HVAC electricity. Without the correction factor normalization data applied, the Pleotint SRT performance windows saved 16 % in lighting energy and 5 % in total HVAC electricity.

Test	Daily Average Lighting Energy (Btu/Day)		Daily Average HVAC Electricity (Btu/Day)		Daily Average Lighting Energy (Btu/Day)	Daily Average HVAC Electricity (Btu/Day)
	A Test Rooms	B Test Rooms	A Test Rooms	B Test Rooms	(B-A) % Difference	(B-A) % Difference
1.1	39,740	31,173	168,646	163,154	-21.5	-3.2
1.2	44,598	34,391	151,783	149,565	-22.8	-1.5
2.1	43,457	34,091	186,922	183,279	-21.5	-1.9
2.2	39,998	25,917	213,010	211,720	-35.20	-0.6
3.1	31,681	27,848	376,870	413,576	-12.1	9.7
3.2	26,628	18,013	325,893	330,292	-32.4	1.3
4.1	36,019	41,782	262,067	254,572	16	-2.8
4.2	38,310	33,355	278,865	277,493	-12.9	-0.5
5.1	33,805	30,271	172,002	175,454	-10.4	2.0
5.2	36,394	30,488	133,526	138,302	-16.2	3.6
6.1	30,092	24,697	135,629	137,232	-17.9	1.2
6.2	30,348	23,108	155,232	156,746	-23.8	0.9
Total	431,070	355,134	2,560,445	2,591,385	-17.6 ± 0.2%	1.2 ± 0.2%

Figure 63: Test Summary With Normalization

Test summary with the correction factor is shown in Figure 63. According to the test results, both azuria and clear color Pleotint SRT performance windows saved 17% on lighting energy.

Though, Pleotint SRT windows saved more energy than low-e dark tinted performance windows, they are not perfect. There had been some test days when the azuria color Pleotint performance windows failed to save lighting energy. Figure 62 Test 4.1 sunny day 10/02/2011 shows an example of lighting energy saving failure for South B test room, which was equipped with azuria color Pleotint SRT performance windows.

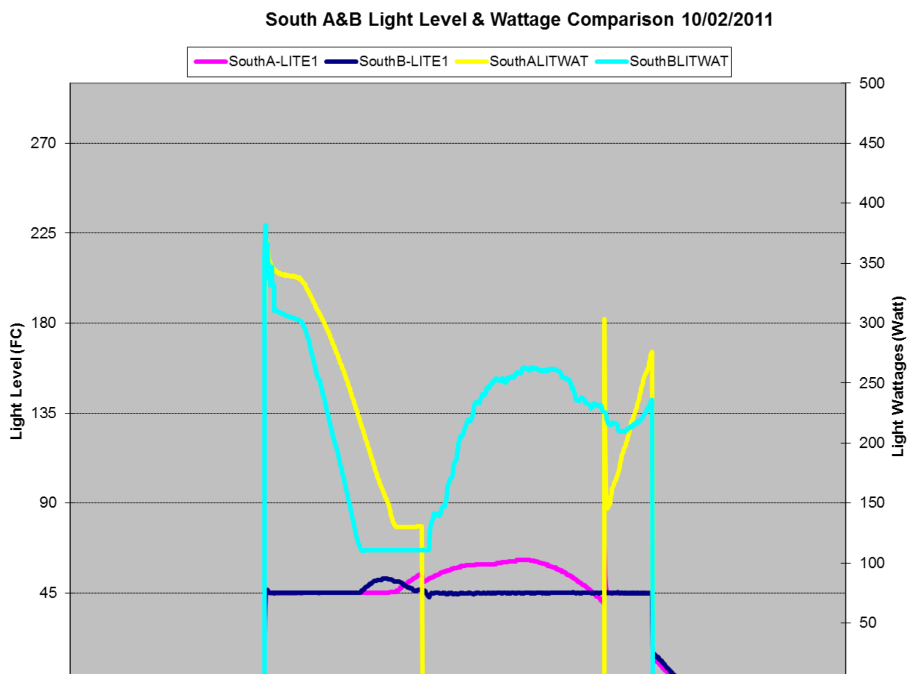

Figure 64: 10/02/2011 South Test Room Lighting Comparison

From Figure 64, it can be seen that the B system is saving energy during the morning, however in the afternoon South A test room lights were turned off with the dimming control due to sufficient natural day lighting in to the test room but South B test room lights continued to be on and the wattage kept increasing. The observation on that test day showed that the azuria color Pleotint SRT windows were darker than usual and couldn’t transmit enough natural day lighting in to the test room. The reason for this phenomenon seems to be related with the location of the sun which caused more direct sunlight for the south test rooms. Direct solar irradiance for the test day 10/02/2011 is shown on Figure 65.

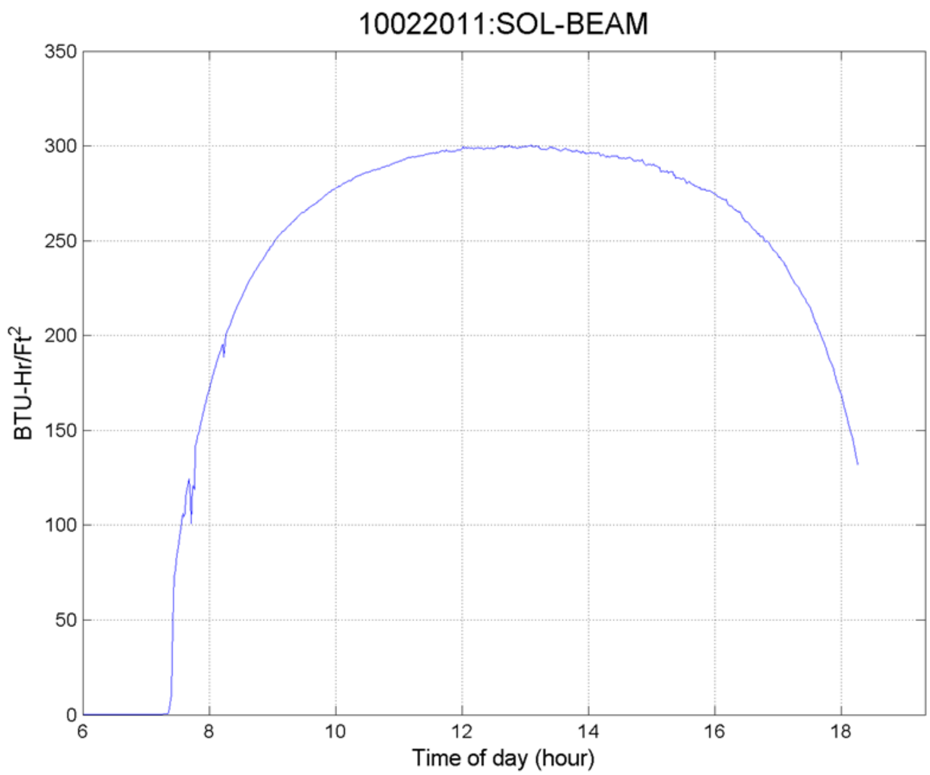

Figure 65: Direct Solar Irradiance

5.4 Conclusions

Most of the energy savings were not only in total HVAC electricity usage (fans, pumps, chillers) but also in lighting energy as well. In fact, both azuria and clear color Pleotint SRT performance windows had the most energy savings in lighting electricity. Overall, B test rooms equipped with azuria and clear color Pleotint SRT performance windows saved 17 % in lighting energy with the daily normalization corrections applied. However, without the normalization correction, Pleotint SRT performance windows saved 16% in lighting and 5 % in total HVAC electricity. To take the fully advantage of the Pleotint SRT windows technology, it is recommended that the occupied spaces should be equipped with dimming controlled lighting systems. Figure 66 shows the lighting savings for both A and B test rooms with dimming lighting control compared to without dimming lighting control. Both systems saved significant amount of lighting energy with the dimming control lighting systems.

Test	Daily Average Lighting Energy (Btu/Day)		Daily Average Lighting No Dimming Control (Btu/Day)		Daily Average Lighting Energy (Btu/Day)	Daily Average Lighting Energy (Btu/Day)
	A Test Rooms	B Test Rooms	A Test Rooms	B Test Rooms	(A Dimming - A Without Dimming)% Difference	(B Dimming - B Without Dimming) % Difference
1.1	39,740	31,173	99,073	99,073	-149	-218
1.2	44,598	34,391	99,073	99,073	-122	-188
2.1	43,457	34,091	99,073	99,073	-128	-191
2.2	39,998	25,917	99,073	99,073	-148	-282
3.1	31,681	27,848	99,073	99,073	-213	-256
3.2	26,628	18,013	99,073	99,073	-272	-450
4.1	36,019	41,782	99,073	99,073	-175	-137
4.2	38,310	33,355	99,073	99,073	-159	-197
5.1	33,805	30,271	99,073	99,073	-193	-227
5.2	36,394	30,488	99,073	99,073	-172	-225
6.1	30,092	24,697	99,073	99,073	-229	-301
6.2	30,348	23,108	99,073	99,073	-226	-329
Total	431,070	355,134	1,188,876	1,188,876	-176 ± 0.2%	-234 ± 0.2%

Figure 66: Dimming Control vs Without Dimming Control

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Appendix A. Pleotint Windows Testing Total Energy Performance Results

		System A Energy (BTU)	System B Energy (BTU)	% Difference	Normalization % Difference	Corrected % Difference
Fan Energy	AHU Supply Fan	380,927.19	391,163.75	2.69	2.36	
	AHU Return Fan	158,404.36	151,650.17	-4.26	-5.30	
	AHU Outside Air Injection Fan	112,753.13	100,332.04	-11.02	-10.54	
	Total Fan Energy	652,084.68	643,145.96	-1.37	-1.78	0.41
Pump Energy	Chiller-CH Pump	697,741.52	671,720.33	-3.73	0.00	
	AHU Chilled Water Pump	0.00	0.00			
	Heating Water Loop Pump	354,098.14	342,297.41	-3.33	1.10	
	Total Pump Energy	1,051,839.66	1,014,017.74	-3.60	0.82	-4.42
Chiller Energy	Chiller-CH	1,500,347.91	1,450,128.98	-3.35	0.00	
	ACCA / ACCB	0.00	0.00			
	Total Chiller Energy	1,500,347.91	1,450,128.98	-3.35	0.86	-4.21
Lighting Energy	East Test Room	160,291.00	80,835.76	-49.57	-14.45	-35.12
	South Test Room	143,158.10	90,597.55	-36.72	-2.37	-34.35
	West Test Room	173,088.09	104,042.26	-39.89	-8.60	-31.29
	Interior Test Room	278,530.04	280,340.47	0.65	0.68	-0.03
	Total Lighting Energy	755,067.23	555,816.04	-26.39	-4.83	-21.56
System Cooling Energy	AHU Cooling Coil Sensible Heat	-3,506,238.22	-3,507,021.92	0.02	-1.92	
	AHU Cooling Coil Total Heat	-3,406,401.60	-3,283,561.96	-3.61	0.00	-3.61
System Heating Energy	Heating Loop Energy	2,101,104.82	1,982,128.08	-5.66	-1.57	
	Total Heating Energy	2,101,104.82	1,982,128.08	-5.66	-1.57	-4.09
Total HVAC Electricity Used	Fan+Pump+Chiller	3,204,272.25	3,107,292.69	-3.03	0.23	-3.26
Total Building Electricity Used	Fan+Pump+Chiller+Lighting	3,959,339.48	3,663,108.73	-7.48	-0.77	-6.71

Figure 67: Test 1.1 Total Energy Consumption

		System A Energy (BTU)	System B Energy (BTU)	% Difference	Normalization % Difference	Corrected % Difference
Fan Energy	AHU Supply Fan	160,961.47	162,490.06	0.95	2.36	
	AHU Return Fan	68,004.61	64,028.11	-5.85	-5.30	
	AHU Outside Air Injection Fan	47,534.95	42,645.86	-10.29	-10.54	
	Total Fan Energy	276,501.03	269,164.03	-2.65	-1.78	-0.87
Pump Energy	Chiller-CH Pump	0.00	0.00	Na	Na	
	AHU Chilled Water Pump	151,468.68	152,364.10	0.59	0.66	
	Heating Water Loop Pump	81,971.26	81,168.75	-0.98	1.10	
	Total Pump Energy	233,439.94	233,532.85	0.04	0.82	-0.78
Chiller Energy	Chiller-CH	0.00	0.00	Na	Na	
	ACCA / ACCB	704,323.61	696,615.38	-1.09	0.86	
	Total Chiller Energy	704,323.61	696,615.38	-1.09	0.86	-1.95
Lighting Energy	East Test Room	80,457.38	47,591.79	-40.85	-14.45	-26.40
	South Test Room	77,145.04	48,888.32	-36.63	-2.37	-34.26
	West Test Room	81,367.91	49,219.70	-39.51	-8.60	-30.91
	Interior Test Room	117,817.53	118,635.04	0.69	0.68	0.01
	Total Lighting Energy	356,787.86	264,334.85	-25.91	-4.83	-22.89
System Cooling Energy	AHU Cooling Coil Sensible Heat	-1,524,591.64	-1,469,383.94	-3.62	-1.92	
	AHU Cooling Coil Total Heat	-1,482,840.83	-1,327,260.11	-10.49	-9.28	-1.21
System Heating Energy	Heating Loop Energy	907,553.64	764,598.59	-15.75	-1.57	
	Total Heating Energy	907,553.64	764,598.59	-15.75	-1.57	-14.18
Total HVAC Electricity Used	Fan+Pump+Chiller	1,214,264.58	1,199,312.26	-1.23	0.23	-1.46
Total Building Electricity Used	Fan+Pump+Chiller+Lighting	1,571,052.44	1,463,647.11	-6.84	-0.77	-6.07

Figure 68: Test 1.2 Total Energy Consumption

		System A Energy (BTU)	System B Energy (BTU)	% Difference	Normalization % Difference	Corrected % Difference
Fan Energy	AHU Supply Fan	174,068.54	177,110.93	1.75	3.72	
	AHU Return Fan	78,819.45	75,962.23	-3.63	-1.27	
	AHU Outside Air Injection Fan	46,638.79	47,362.48	1.55	13.03	
	Total Fan Energy	299,526.78	300,435.64	0.30	3.87	-3.57
Pump Energy	Chiller-CH Pump	0.00	0.00	Na	Na	
	AHU Chilled Water Pump	151,479.38	151,271.65	-0.14	-0.98	
	Heating Water Loop Pump	90,275.29	88,988.95	-1.42	1.66	
	Total Pump Energy	241,754.67	240,260.60	-0.62	-0.03	-0.59
Chiller Energy	Chiller-CH	0.00	0.00	Na	Na	
	ACCA / ACCB	954,097.82	930,884.81	-2.43	-0.57	
	Total Chiller Energy	954,097.82	930,884.81	-2.43	-0.57	-1.86
Lighting Energy	East Test Room	70,667.39	45,279.24	-35.93	-9.83	-26.10
	South Test Room	80,080.13	51,224.07	-36.03	-0.16	-35.87
	West Test Room	78,930.63	53,706.26	-31.96	-2.32	-29.64
	Interior Test Room	117,979.67	118,829.88	0.72	0.86	-0.14
	Total Lighting Energy	347,657.82	269,039.45	-22.61	-1.06	-21.55
System Cooling Energy	AHU Cooling Coil Sensible Heat	-1,733,225.41	-1,549,460.46	-10.60	-9.72	
	AHU Cooling Coil Total Heat	-1,813,642.47	-1,672,838.70	-7.76	-4.67	4.67
System Heating Energy	Heating Loop Energy	505,939.02	444,653.66	-12.11	2.49	
	Total Heating Energy	505,939.02	444,653.66	-12.11	2.49	-14.60
Total HVAC Electricity Used	Fan+Pump+Chiller	1,495,379.27	1,471,581.05	-1.59	0.36	-1.95
Total Building Electricity Used	Fan+Pump+Chiller+Lighting	1,843,037.09	1,740,620.50	-5.56	0.20	-5.76

Figure 69: Test 2.1 Total Energy Consumption

		System A Energy (BTU)	System B Energy (BTU)	% Difference	Normalization % Difference	Corrected % Difference
Fan Energy	AHU Supply Fan	193,574.02	203,941.61	5.36	3.72	
	AHU Return Fan	87,179.27	87,190.70	0.01	-1.27	
	AHU Outside Air Injection Fan	52,189.28	57,918.85	10.98	13.03	
	Total Fan Energy	332,942.57	349,051.16	4.84	3.87	0.97
Pump Energy	Chiller-CH Pump	0.00	0.00	Na	Na	
	AHU Chilled Water Pump	170,232.77	169,225.13	-0.59	-0.98	
	Heating Water Loop Pump	92,972.56	87,385.09	-6.01	1.66	
	Total Pump Energy	263,205.33	256,610.22	-2.51	-0.03	-2.47
Chiller Energy	Chiller-CH	0.00	0.00	Na	Na	
	ACCA / ACCB	1,320,941.36	1,306,679.00	-1.08	-0.57	
	Total Chiller Energy	1,320,941.36	1,306,679.00	-1.08	-0.57	-0.51
Lighting Energy	East Test Room	72,918.78	26,847.48	-63.18	-9.83	-53.35
	South Test Room	75,715.31	32,507.37	-57.07	-0.16	-56.90
	West Test Room	78,690.34	36,280.16	-53.90	-2.32	-51.58
	Interior Test Room	132,660.19	133,792.71	0.85	0.86	0.00
	Total Lighting Energy	359,984.62	229,427.72	-36.27	-1.06	-35.21
System Cooling Energy	AHU Cooling Coil Sensible Heat	-2,122,641.27	-1,912,114.00	-9.92	-9.72	
	AHU Cooling Coil Total Heat	-2,323,035.37	-2,249,720.21	-3.16	-4.67	1.52
System Heating Energy	Heating Loop Energy	219,003.11	155,900.35	-28.81	2.49	
	Total Heating Energy	219,003.11	155,900.35	-28.81	2.49	-31.30
Total HVAC Electricity Used	Fan+Pump+Chiller	1,917,089.26	1,912,340.38	-0.25	0.36	-0.61
Total Building Electricity Used	Fan+Pump+Chiller+Lighting	2,277,073.88	2,141,768.10	-5.94	0.20	-6.14

Figure 70: Test 2.2 Total Energy Consumption

		System A Energy (BTU)	System B Energy (BTU)	% Difference	Normalization % Difference	Corrected % Difference
Fan Energy	AHU Supply Fan	437,651.28	419,342.45	-4.18	-15.09	
	AHU Return Fan	134,727.52	135,907.62	0.88	-7.14	
	AHU Outside Air Injection Fan	57,388.40	53,311.67	-7.10	-8.11	
	Total Fan Energy	629,767.20	608,561.74	-3.37	-12.89	9.52
Pump Energy	Chiller-CH Pump	0.00	0.00	Na	Na	Na
	AHU Chilled Water Pump	184,842.73	185,506.19	0.36	0.00	
	Heating Water Loop Pump	14,058.17	14,789.48	5.20	5.68	
	Total Pump Energy	198,900.90	200,295.67	0.70	0.40	0.30
Chiller Energy	Chiller-CH	0.00	0.00	Na	Na	Na
	ACCA / ACCB	2,940,027.56	2,955,054.52	0.51	-9.81	
	Total Chiller Energy	2,940,027.56	2,955,054.52	0.51	-9.81	10.32
Lighting Energy	East Test Room	63,486.12	52,925.68	-16.63	1.91	-18.55
	South Test Room	67,130.32	56,195.08	-16.29	3.44	-19.73
	West Test Room	67,927.07	58,454.40	-13.95	15.15	-29.09
	Interior Test Room	118,268.90	118,724.43	0.39	0.57	-0.18
	Total Lighting Energy	316,812.41	286,299.59	-9.63	2.47	-12.10
System Cooling Energy	AHU Cooling Coil Sensible Heat	-5,426,967.88	-5,058,286.04	-6.79	-11.65	
	AHU Cooling Coil Total Heat	-5,989,903.86	-6,174,251.11	3.08	-9.76	12.84
System Heating Energy	Heating Loop Energy	0.00	0.00	Na	Na	
	Total Heating Energy	0.00	0.00	Na	Na	Na
Total HVAC Electricity Used	Fan+Pump+Chiller	3,768,695.66	3,763,911.93	-0.13	-9.87	9.74
Total Building Electricity Used	Fan+Pump+Chiller+Lighting	4,160,954.63	4,129,555.84	-0.75	-9.25	8.49

Figure 71: Test 3.1 Total Energy Consumption

		System A Energy (BTU)	System B Energy (BTU)	% Difference	Normalization % Difference	Corrected % Difference
Fan Energy	AHU Supply Fan	287,109.18	272,516.30	-5.08	-15.09	
	AHU Return Fan	90,383.50	89,906.45	-0.53	-7.14	
	AHU Outside Air Injection Fan	40,667.28	37,525.28	-7.73	-8.11	
	Total Fan Energy	418,159.96	399,948.03	-4.36	-12.89	8.53
Pump Energy	Chiller-CH Pump	0.00	0.00	Na	Na	Na
	AHU Chilled Water Pump	129,286.49	130,292.35	0.78	0.00	
	Heating Water Loop Pump	9,874.17	10,385.47	5.18	5.68	
	Total Pump Energy	139,160.66	140,677.82	1.09	0.40	0.69
Chiller Energy	Chiller-CH	0.00	0.00	Na	Na	Na
	ACCA / ACCB	1,723,929.48	1,546,335.26	-10.30	-9.81	
	Total Chiller Energy	1,723,929.48	1,546,335.26	-10.30	-9.81	-0.50
Lighting Energy	East Test Room	35,172.58	18,454.91	-47.53	1.91	-49.44
	South Test Room	37,651.18	17,256.78	-54.17	3.44	-57.61
	West Test Room	39,574.13	20,587.14	-47.98	15.15	-63.13
	Interior Test Room	74,000.37	74,389.74	0.53	0.57	-0.04
	Total Lighting Energy	186,398.26	130,688.57	-29.89	2.47	-32.35
System Cooling Energy	AHU Cooling Coil Sensible Heat	-3,643,071.66	-3,352,388.25	-7.98	-11.65	
	AHU Cooling Coil Total Heat	-3,636,338.93	-3,419,600.37	-5.96	-9.76	3.80
System Heating Energy	Heating Loop Energy	0.00	0.00	Na	Na	
	Total Heating Energy	0.00	0.00	Na	Na	Na
Total HVAC Electricity Used	Fan+Pump+Chiller	2,281,250.10	2,086,961.11	-8.52	-9.87	1.35
Total Building Electricity Used	Fan+Pump+Chiller+Lighting	2,542,102.48	2,271,186.45	-10.66	-9.25	-1.41

Figure 72: Test 3.2 Total Energy Consumption

		System A Energy (BTU)	System B Energy (BTU)	% Difference	Normalization % Difference	Corrected % Difference
Fan Energy	AHU Supply Fan	263,084.31	235,220.92	-10.59	-14.04	
	AHU Return Fan	83,934.03	79,408.67	-5.39	-7.06	
	AHU Outside Air Injection Fan	41,140.64	37,875.35	-7.94	-8.66	
	Total Fan Energy	388,158.98	352,504.94	-9.19	-12.04	2.86
Pump Energy	Chiller-CH Pump	0.00	0.00	Na	Na	Na
	AHU Chilled Water Pump	130,792.67	131,038.02	0.19	0.77	
	Heating Water Loop Pump	9,654.46	10,300.43	6.69	5.21	
	Total Pump Energy	140,447.13	141,338.45	0.63	1.08	-0.44
Chiller Energy	Chiller-CH	0.00	0.00	Na	Na	Na
	ACCA / ACCB	1,305,864.55	1,093,586.67	-16.26	-11.52	
	Total Chiller Energy	1,305,864.55	1,093,586.67	-16.26	-11.52	-4.74
Lighting Energy	East Test Room	55,767.80	52,898.64	-5.14	-17.69	12.55
	South Test Room	36,821.94	60,145.08	63.34	-14.00	77.34
	West Test Room	56,561.47	46,483.55	-17.82	-3.61	-14.20
	Interior Test Room	102,983.65	103,459.06	0.46	-8.77	9.23
	Total Lighting Energy	252,134.86	262,986.33	4.30	-11.69	16.00
System Cooling Energy	AHU Cooling Coil Sensible Heat	-3,222,201.20	-2,883,357.76	-10.52	-9.39	
	AHU Cooling Coil Total Heat	-2,995,741.97	-2,605,951.34	-13.01	-12.56	-0.45
System Heating Energy	Heating Loop Energy	0.00	0.00	Na	Na	
	Total Heating Energy	0.00	0.00	Na	Na	Na
Total HVAC Electricity Used	Fan+Pump+Chiller	1,834,470.66	1,587,430.06	-13.47	-10.61	-2.86
Total Building Electricity Used	Fan+Pump+Chiller+Lighting	2,086,605.52	1,850,416.39	-11.32	-5.77	-5.55

Figure 73: Test 4.1 Total Energy Consumption

		System A Energy (BTU)	System B Energy (BTU)	% Difference	Normalization % Difference	Corrected % Difference
Fan Energy	AHU Supply Fan	260,830.38	245,877.66	-5.73	-14.04	
	AHU Return Fan	82,977.24	82,130.07	-1.02	-7.06	
	AHU Outside Air Injection Fan	40,724.23	37,501.54	-7.91	-8.66	
	Total Fan Energy	384,531.85	365,509.27	-4.95	-12.04	7.09
Pump Energy	Chiller-CH Pump	0.00	0.00	Na	Na	Na
	AHU Chilled Water Pump	130,853.08	131,626.38	0.59	0.77	
	Heating Water Loop Pump	9,644.68	10,285.39	6.64	5.21	
	Total Pump Energy	140,497.76	141,911.77	1.01	1.08	-0.07
Chiller Energy	Chiller-CH	0.00	0.00	Na	Na	Na
	ACCA / ACCB	1,427,025.19	1,227,982.84	-13.95	-11.52	
	Total Chiller Energy	1,427,025.19	1,227,982.84	-13.95	-11.52	-2.43
Lighting Energy	East Test Room	60,534.43	32,923.83	-45.61	-17.69	-27.92
	South Test Room	45,552.47	33,187.55	-27.14	-14.00	-13.15
	West Test Room	59,163.72	32,587.91	-44.92	-3.61	-41.30
	Interior Test Room	102,920.53	103,425.85	0.49	-8.77	9.26
	Total Lighting Energy	268,171.15	202,125.14	-24.63	-11.69	-12.93
System Cooling Energy	AHU Cooling Coil Sensible Heat	-3,279,259.53	-3,006,585.26	-8.32	-9.39	
	AHU Cooling Coil Total Heat	-3,119,227.29	-2,827,393.54	-9.36	-12.56	3.21
System Heating Energy	Heating Loop Energy	0.00	0.00	Na	Na	
	Total Heating Energy	0.00	0.00	Na	Na	Na
Total HVAC Electricity Used	Fan+Pump+Chiller	1,952,054.80	1,735,403.88	-11.10	-10.61	-0.49
Total Building Electricity Used	Fan+Pump+Chiller+Lighting	2,220,225.95	1,937,529.02	-12.73	-5.77	-6.96

Figure 74: Test 4.2 Total Energy Consumption

		System A Energy (BTU)	System B Energy (BTU)	% Difference	Normalization % Difference	Corrected % Difference
Fan Energy	AHU Supply Fan	210,511.73	200,178.11	-4.91	-11.69	
	AHU Return Fan	74,572.23	74,161.80	-0.55	-13.95	
	AHU Outside Air Injection Fan	49,525.14	44,802.57	-9.54	-8.57	
	Total Fan Energy	334,609.10	319,142.48	-4.62	-12.03	7.41
Pump Energy	Chiller-CH Pump	0.00	0.00	Na	Na	Na
	AHU Chilled Water Pump	237,061.37	226,328.79	-4.53	0.86	
	Heating Water Loop Pump	14,365.76	14,593.74	1.59	24.73	
	Total Pump Energy	251,427.13	240,922.53	-4.18	2.64	-6.82
Chiller Energy	Chiller-CH	0.00	0.00	Na	Na	Na
	ACCA / ACCB	789,979.19	684,889.52	-13.30	-13.93	
	Total Chiller Energy	789,979.19	684,889.52	-13.30	-13.93	0.62
Lighting Energy	East Test Room	66,247.63	54,681.02	-17.46	-0.40	-17.06
	South Test Room	47,703.70	46,253.63	-3.04	1.51	-4.55
	West Test Room	67,969.96	50,627.53	-25.51	-3.88	-21.63
	Interior Test Room	88,517.92	88,790.51	0.31	0.48	-0.17
	Total Lighting Energy	270,439.21	240,352.69	-11.13	-0.67	-10.46
System Cooling Energy	AHU Cooling Coil Sensible Heat	-2,326,155.65	-2,067,471.43	-11.12	-8.10	
	AHU Cooling Coil Total Heat	-2,178,949.54	-1,884,809.99	-13.50	-12.97	-0.53
System Heating Energy	Heating Loop Energy	62,328.59	66,947.22	7.41	Na	Na
	Total Heating Energy	62,328.59	66,947.22	7.41	Na	Na
Total HVAC Electricity Used	Fan+Pump+Chiller	1,376,015.42	1,244,954.53	-9.52	-11.53	2.01
otal Building Electricity Used	Fan+Pump+Chiller+Lighting	1,746,046.06	1,576,456.99	-9.71	-8.12	-1.59

Figure 75: Test 5.1 Total Energy Consumption

		System A Energy (BTU)	System B Energy (BTU)	% Difference	Normalization % Difference	Corrected % Difference
Fan Energy	AHU Supply Fan	190,977.71	180,872.99	-5.29	-11.69	
	AHU Return Fan	69,833.43	68,732.89	-1.58	-13.95	
	AHU Outside Air Injection Fan	50,792.37	45,591.37	-10.24	-8.57	
	Total Fan Energy	311,603.51	295,197.25	-5.27	-12.03	6.76
Pump Energy	Chiller-CH Pump	0.00	0.00	Na	Na	Na
	AHU Chilled Water Pump	145,605.25	147,682.94	1.43	0.86	
	Heating Water Loop Pump	21,692.80	19,668.24	-9.33	24.73	
	Total Pump Energy	167,298.05	167,351.18	0.03	2.64	-2.61
Chiller Energy	Chiller-CH	0.00	0.00	Na	Na	Na
	ACCA / ACCB	589,303.19	520,688.65	-11.64	-13.93	
	Total Chiller Energy	589,303.19	520,688.65	-11.64	-13.93	2.28
Lighting Energy	East Test Room	70,698.56	52,278.92	-26.05	-0.40	-25.65
	South Test Room	59,991.85	50,697.80	-15.49	1.51	-17.00
	West Test Room	72,037.12	50,244.99	-30.25	-3.88	-26.37
	Interior Test Room	88,422.03	88,734.65	0.35	0.48	-0.13
	Total Lighting Energy	291,149.56	241,956.36	-16.90	-0.67	-16.23
System Cooling Energy	AHU Cooling Coil Sensible Heat	-1,837,000.57	-1,617,299.35	-11.96	-8.10	
	AHU Cooling Coil Total Heat	-1,706,622.87	-1,437,757.62	-15.75	-12.97	-2.79
System Heating Energy	Heating Loop Energy	133,703.32	123,776.67	-7.42	Na	Na
	Total Heating Energy	133,703.32	123,776.67	-7.42	Na	Na
Total HVAC Electricity Used	Fan+Pump+Chiller	1,068,204.75	983,237.08	-7.95	-11.53	3.58
Total Building Electricity Used	Fan+Pump+Chiller+Lighting	1,452,601.99	1,295,900.17	-10.79	-8.12	-2.67

Figure 76: Test 5.2 Total Energy Consumption

		System A Energy (BTU)	System B Energy (BTU)	% Difference	Normalization % Difference	Corrected % Difference
Fan Energy	AHU Supply Fan	162,123.75	157,995.58	-2.55	-3.29	
	AHU Return Fan	58,996.76	58,914.76	-0.14	-2.70	
	AHU Outside Air Injection Fan	41,771.06	37,752.53	-9.62	-10.37	
	Total Fan Energy	262,891.57	254,662.87	-3.13	-4.16	1.03
Pump Energy	Chiller-CH Pump	0.00	0.00	Na	Na	Na
	AHU Chilled Water Pump	122,825.80	123,857.42	0.84	-0.95	
	Heating Water Loop Pump	16,738.24	17,623.76	5.29	2.71	
	Total Pump Energy	139,564.04	141,481.18	1.37	0.06	1.32
Chiller Energy	Chiller-CH	0.00	0.00	Na	Na	Na
	ACCA / ACCB	546,948.67	498,340.51	-8.89	-10.68	
	Total Chiller Energy	546,948.67	498,340.51	-8.89	-10.68	1.79
Lighting Energy	East Test Room	47,266.04	36,225.86	-23.36	6.35	-29.70
	South Test Room	44,233.99	36,571.66	-17.32	4.44	-21.77
	West Test Room	50,519.47	35,283.72	-30.16	2.33	-32.49
	Interior Test Room	68,625.47	68,854.92	0.33	0.57	-0.23
	Total Lighting Energy	210,644.97	176,936.16	-16.00	1.93	-17.93
System Cooling Energy	AHU Cooling Coil Sensible Heat	-1,678,269.24	-1,498,357.77	-10.72	-13.07	
	AHU Cooling Coil Total Heat	-1,559,594.47	-1,387,048.38	-11.06	-15.39	4.32
System Heating Energy	Heating Loop Energy	108,886.54	112,962.90	3.74	3.23	
	Total Heating Energy	108,886.54	112,962.90	3.74	3.23	0.51
Total HVAC Electricity Used	Fan+Pump+Chiller	949,404.28	894,484.56	-5.78	-6.97	1.18
Total Building Electricity Used	Fan+Pump+Chiller+Lighting	1,243,201.56	1,142,143.41	-8.13	-5.81	-2.32

Figure 77: Test 6.1 Total Energy Consumption

		System A Energy (BTU)	System B Energy (BTU)	% Difference	Normalization % Difference	Corrected % Difference
Fan Energy	AHU Supply Fan	181,502.05	179,909.05	-0.88	-3.29	
	AHU Return Fan	63,969.71	64,859.92	1.39	-2.70	
	AHU Outside Air Injection Fan	43,229.09	39,274.79	-9.15	-10.37	
	Total Fan Energy	288,700.85	284,043.76	-1.61	-4.16	2.54
Pump Energy	Chiller-CH Pump	0.00	0.00	Na	Na	Na
	AHU Chilled Water Pump	129,090.15	130,057.39	0.75	-0.95	
	Heating Water Loop Pump	20,378.66	22,121.19	8.55	2.71	
	Total Pump Energy	149,468.81	152,178.58	1.81	0.06	1.76
Chiller Energy	Chiller-CH	0.00	0.00	Na	Na	Na
	ACCA / ACCB	648,454.91	585,306.65	-9.74	-10.68	
	Total Chiller Energy	648,454.91	585,306.65	-9.74	-10.68	0.94
Lighting Energy	East Test Room	48,807.79	31,810.79	-34.82	6.35	-41.17
	South Test Room	36,962.92	29,083.79	-21.32	4.44	-25.76
	West Test Room	53,185.38	31,211.28	-41.32	2.33	-43.65
	Interior Test Room	73,479.63	73,743.64	0.36	0.57	-0.21
	Total Lighting Energy	212,435.72	165,849.50	-21.93	1.93	-23.86
System Cooling Energy	AHU Cooling Coil Sensible Heat	-1,896,899.04	-1,759,822.61	-7.23	-13.07	
	AHU Cooling Coil Total Heat	-1,781,010.65	-1,648,710.11	-7.43	-15.39	7.96
System Heating Energy	Heating Loop Energy	113,476.32	113,025.85	-0.40	3.23	
	Total Heating Energy	113,476.32	113,025.85	-0.40	3.23	-3.63
Total HVAC Electricity Used	Fan+Pump+Chiller	1,086,624.57	1,021,528.99	-5.99	-6.97	0.98
Total Building Electricity Used	Fan+Pump+Chiller+Lighting	1,377,769.51	1,246,295.74	-9.54	-5.81	-3.74

Figure 78: Test 6.2 Total Energy Consumption

Appendix B. Test Room Lighting Comparisons for Selected Test Days

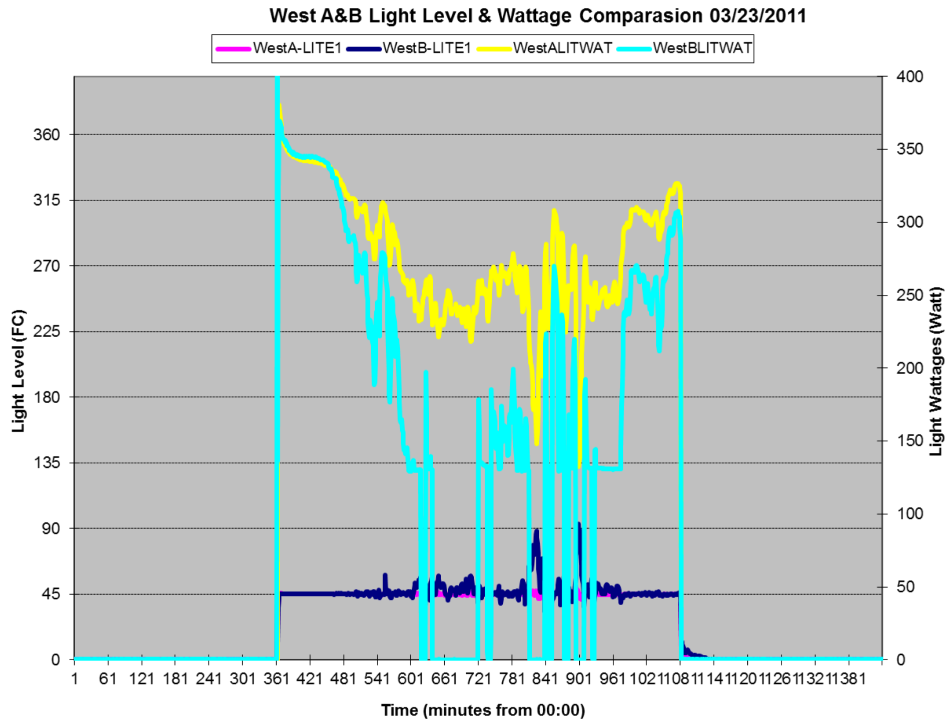

Figure 79: Test 1.1 Cloudy Day West A&B Lighting Comparison

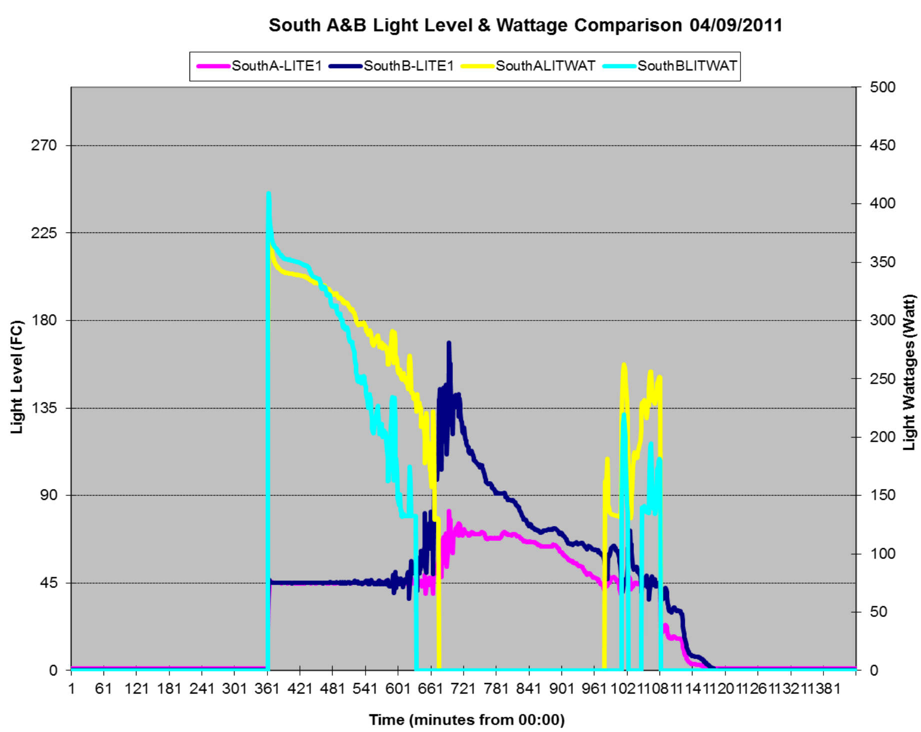

Figure 80: Test 1.1 Sunny Day South A&B Lighting Comparison

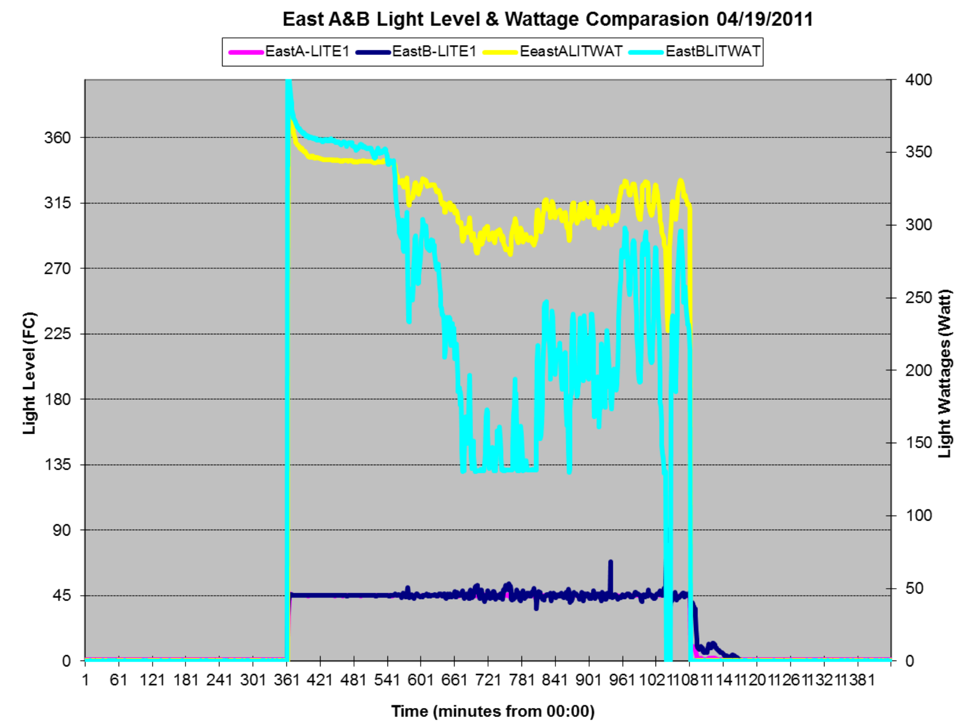

Figure 82: Test 1.2 Cloudy Day East A&B Lighting Comparison

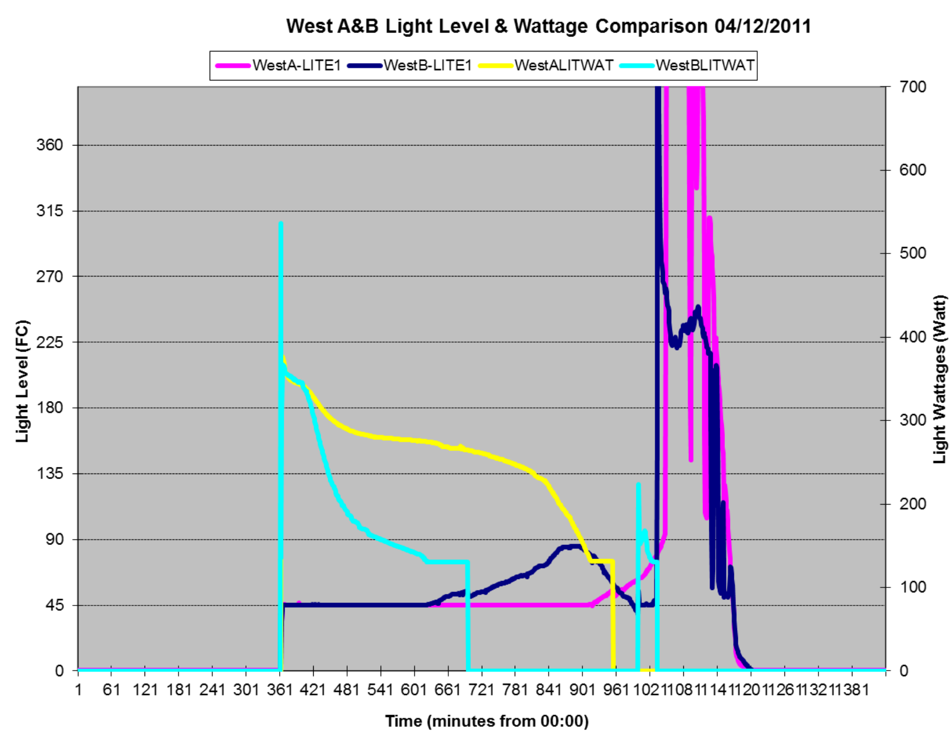

Figure 81: Test 1.2 Sunny Day West A&B Lighting Comparison

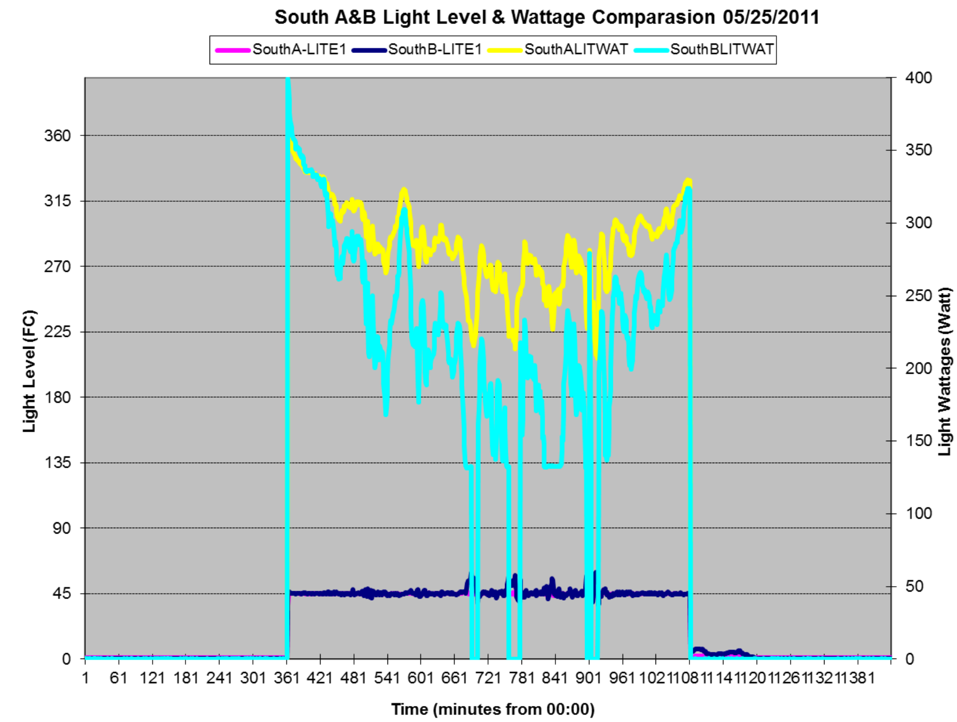

Figure 84: Test 2.1 Cloudy Day South A&B Lighting Comparison

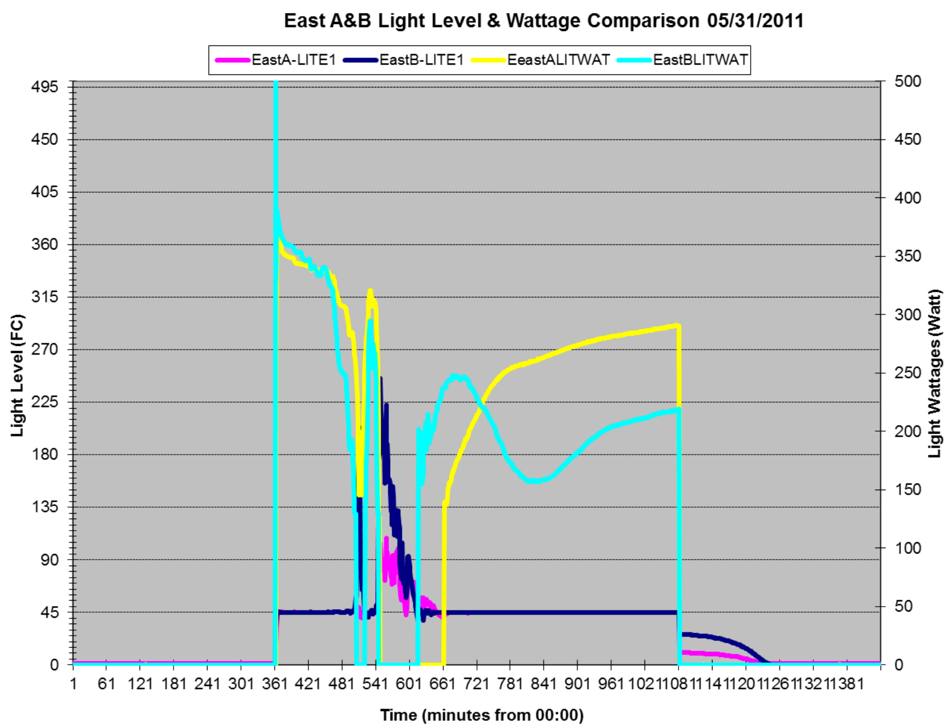

Figure 83: Test 2.1 Sunny Day East A&B Lighting Comparison

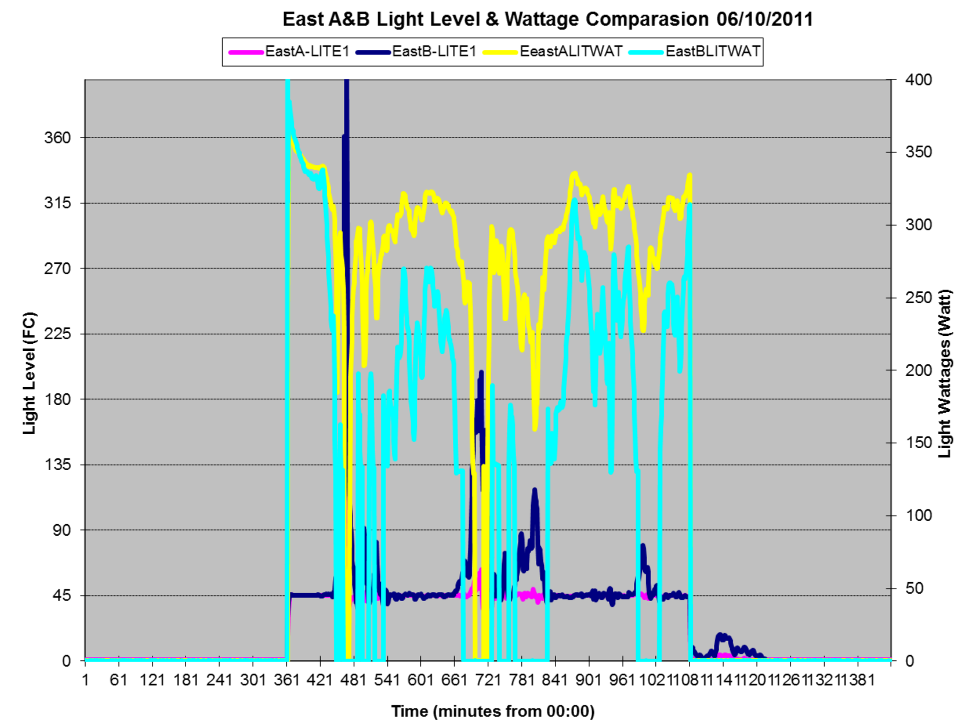

Figure 86: Test 2.2 Cloudy Day East A&B Lighting Comparison

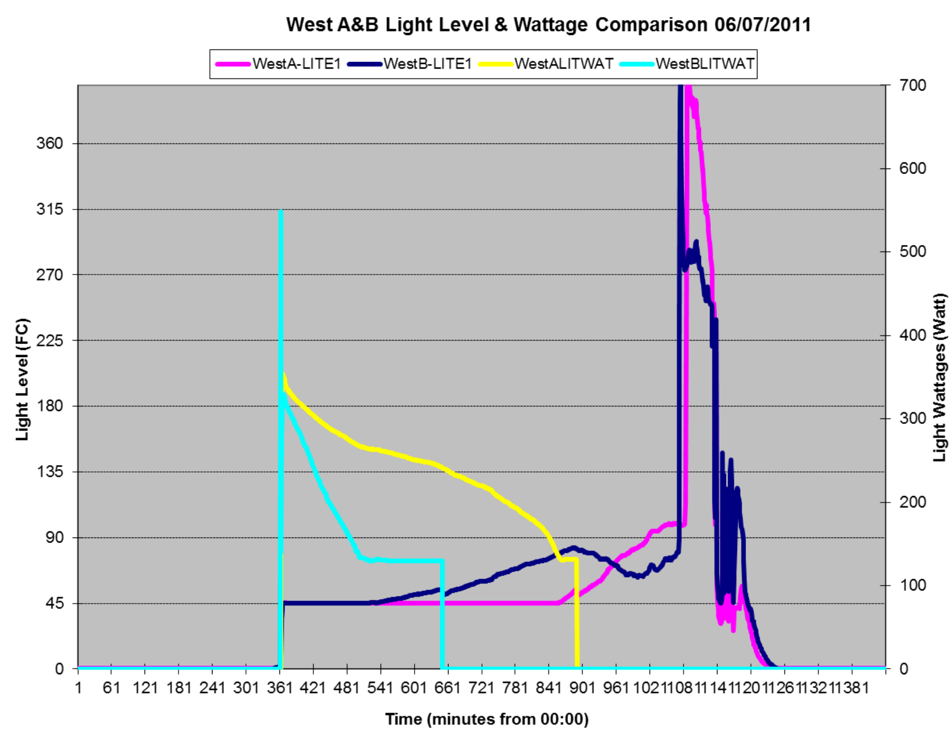

Figure 85: Test 2.2 Sunny Day West A&B Lighting Comparison

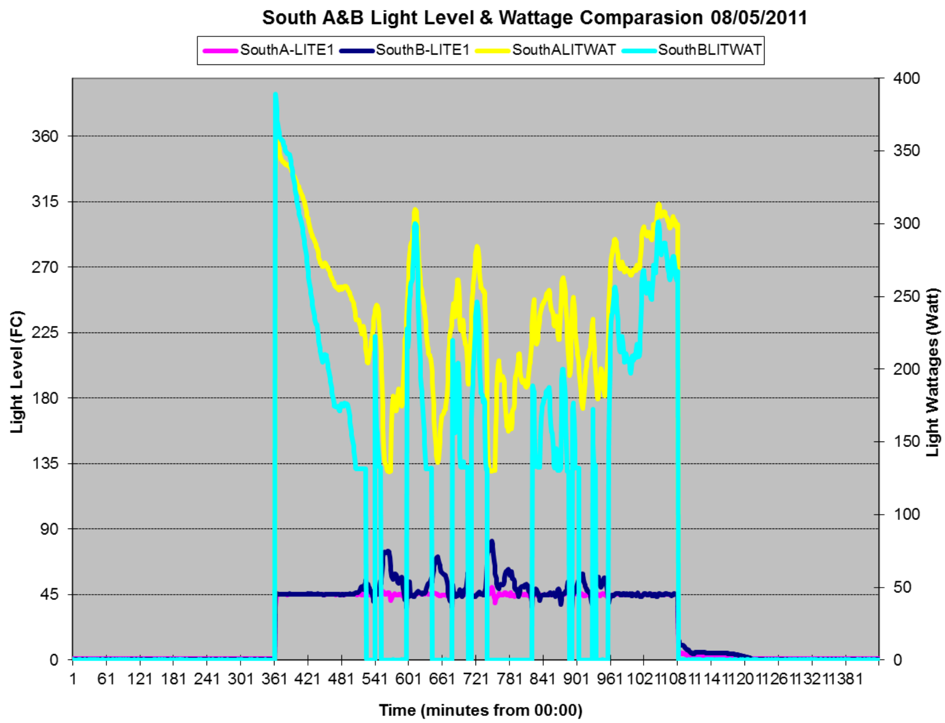

Figure 87: Test 3.1 Cloudy Day South A&B Lighting Comparison

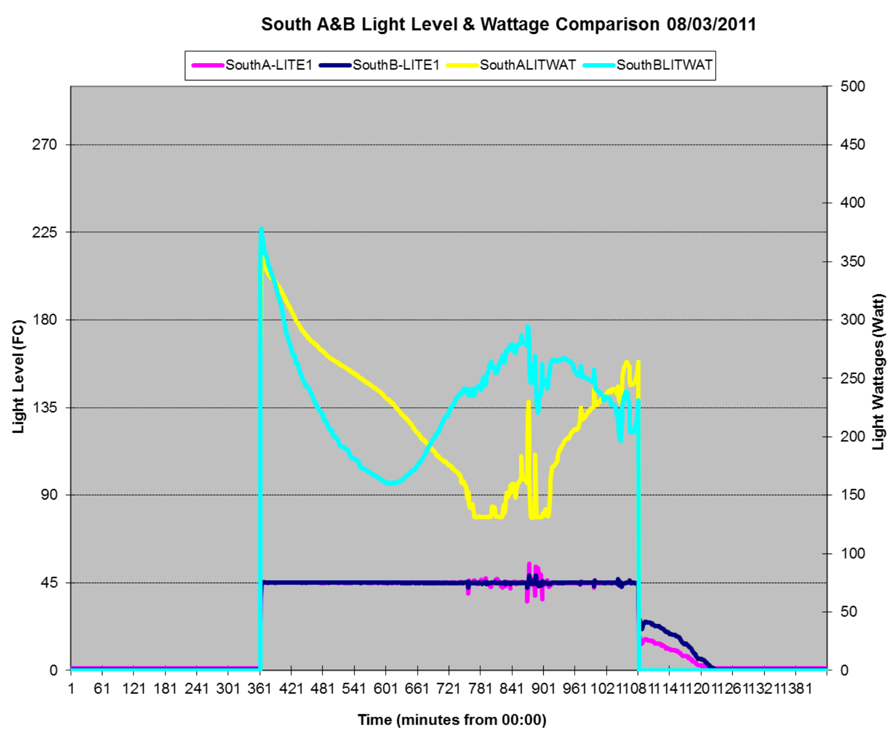

Figure 88: Test 3.1 Sunny Day South A&B Lighting Comparison

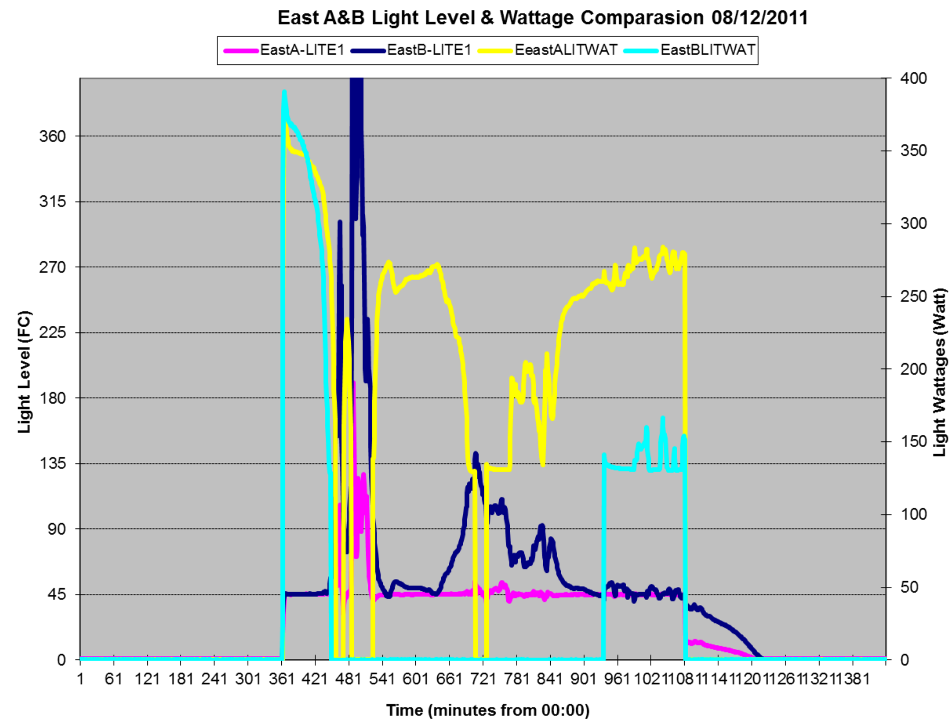

Figure 89: Test 3.2 Cloudy Day East A&B Lighting Comparison

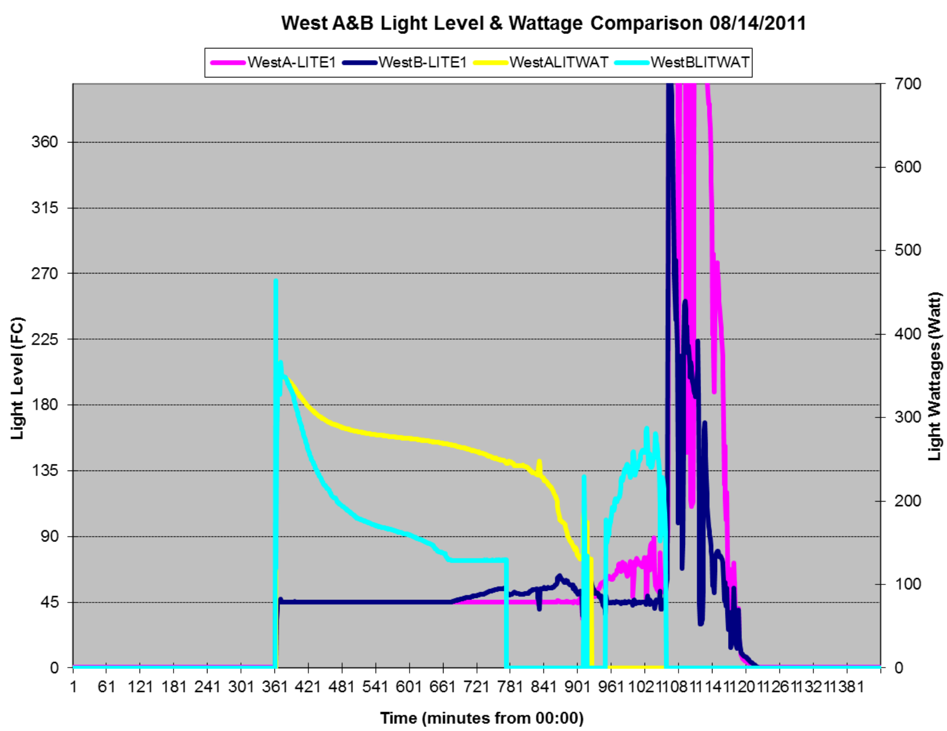

Figure 90: Test 3.2 Sunny Day West A&B Lighting Comparison

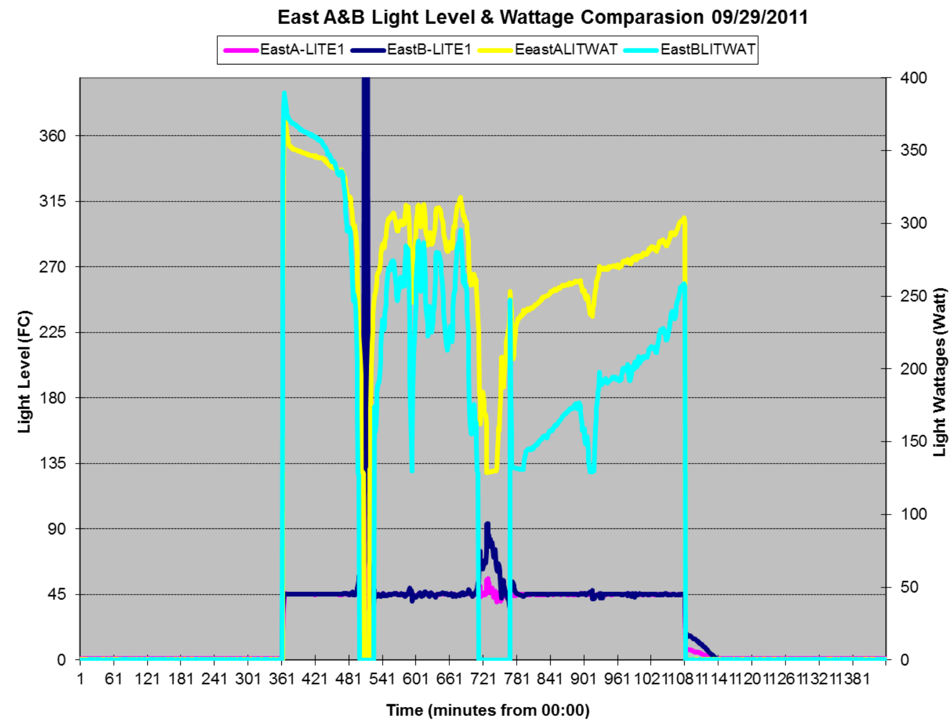

Figure 91: Test 4.1 Cloudy Day East A&B Lighting Comparison

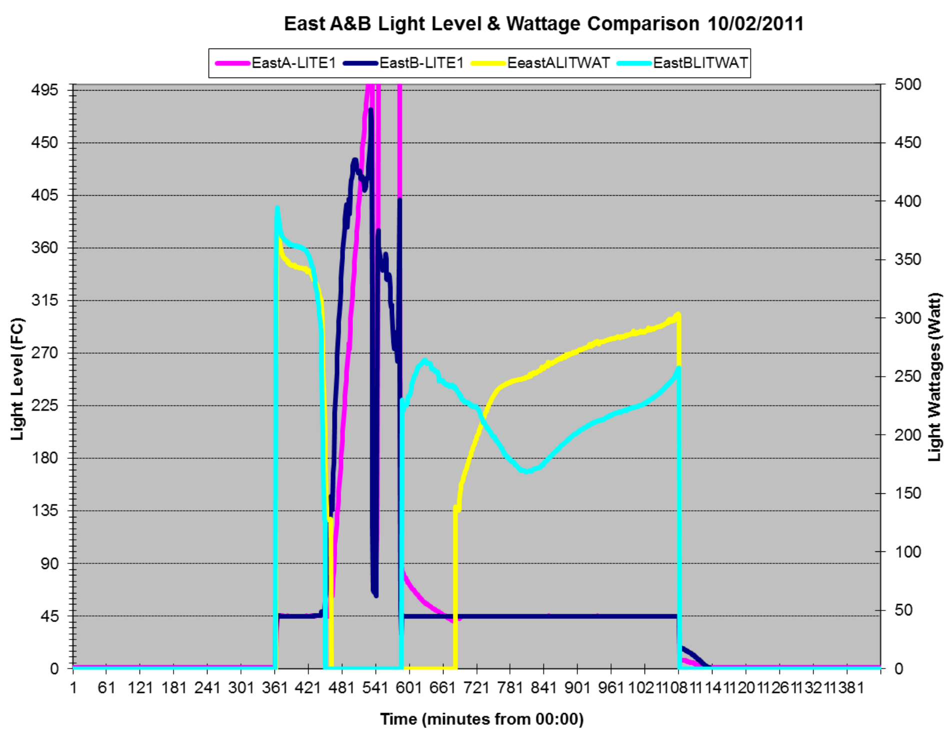

Figure 92: Test 4.1 Sunny Day East A&B Lighting Comparison

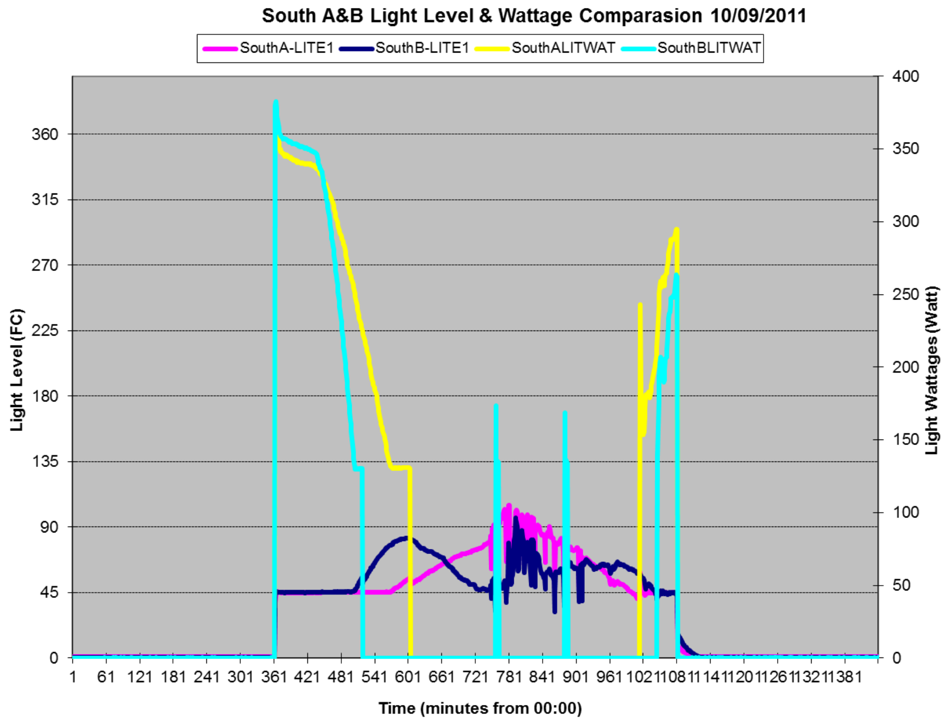

Figure 93: Test 4.2 Sunny Day South A&B Lighting Comparison

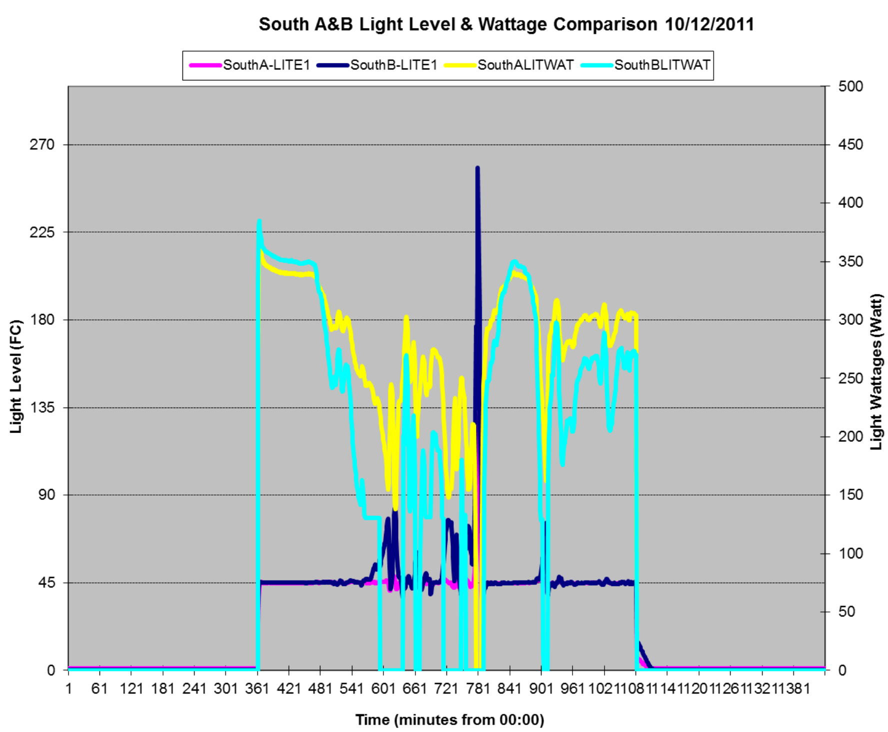

Figure 94: Test 4.2 Cloudy Day South A&B Lighting Comparison

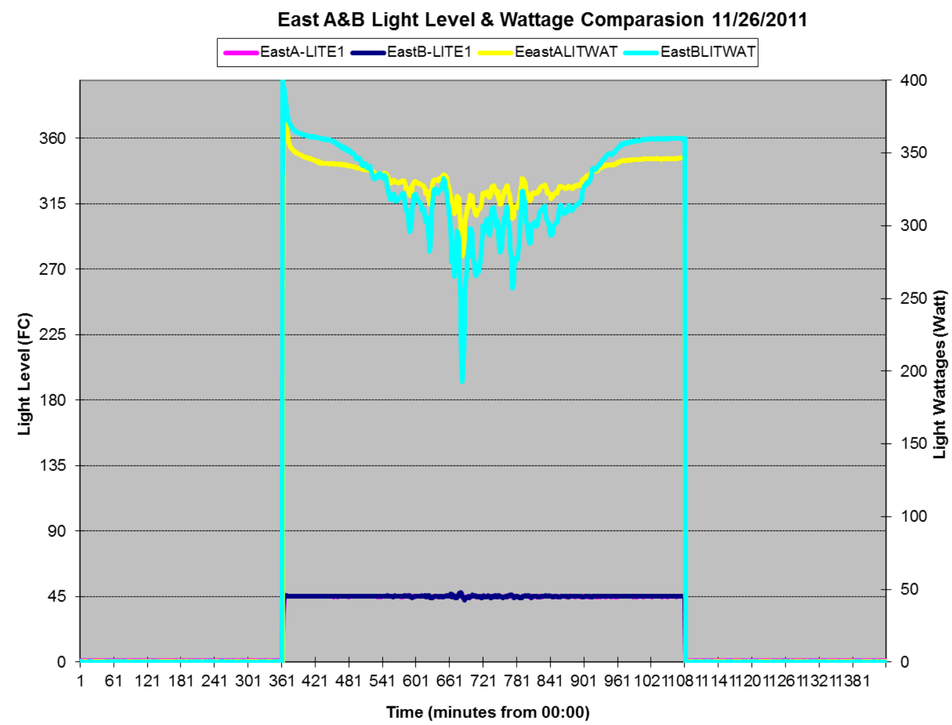

Figure 95: Test 5.1 Cloudy Day East A&B Lighting Comparison

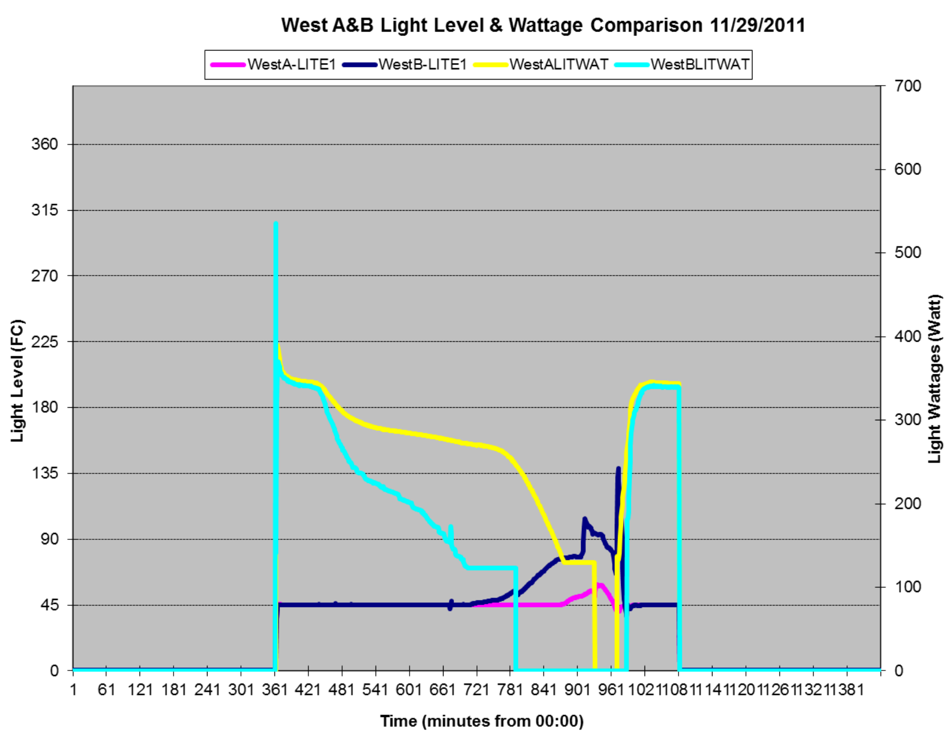

Figure 96: Test 5.1 Sunny Day West A&B Lighting Comparison

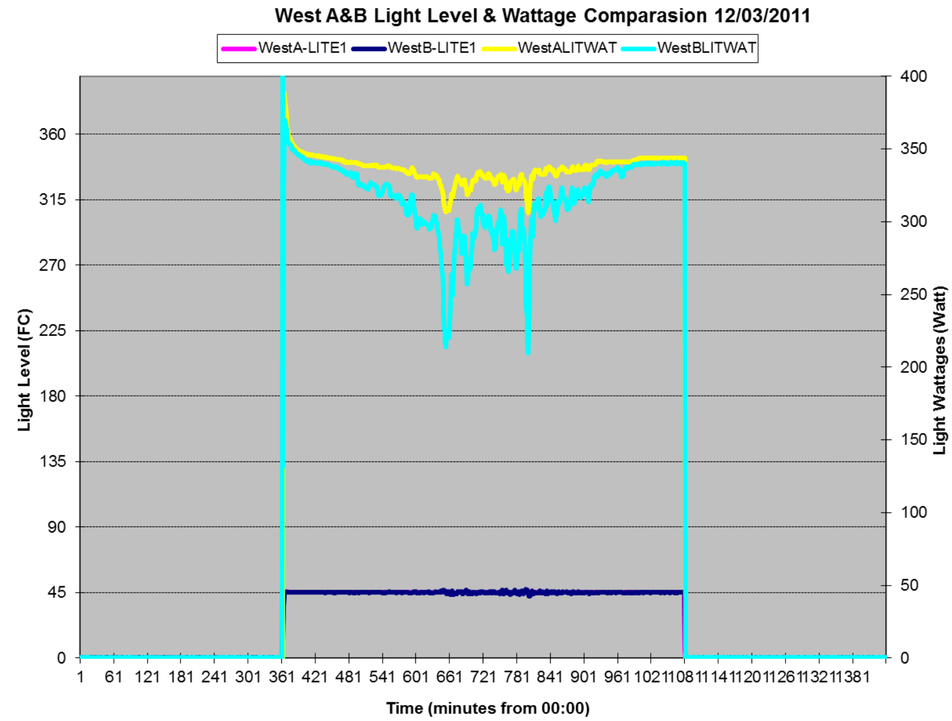

Figure 97: Test 5.2 Cloudy Day West A&B Lighting Comparison

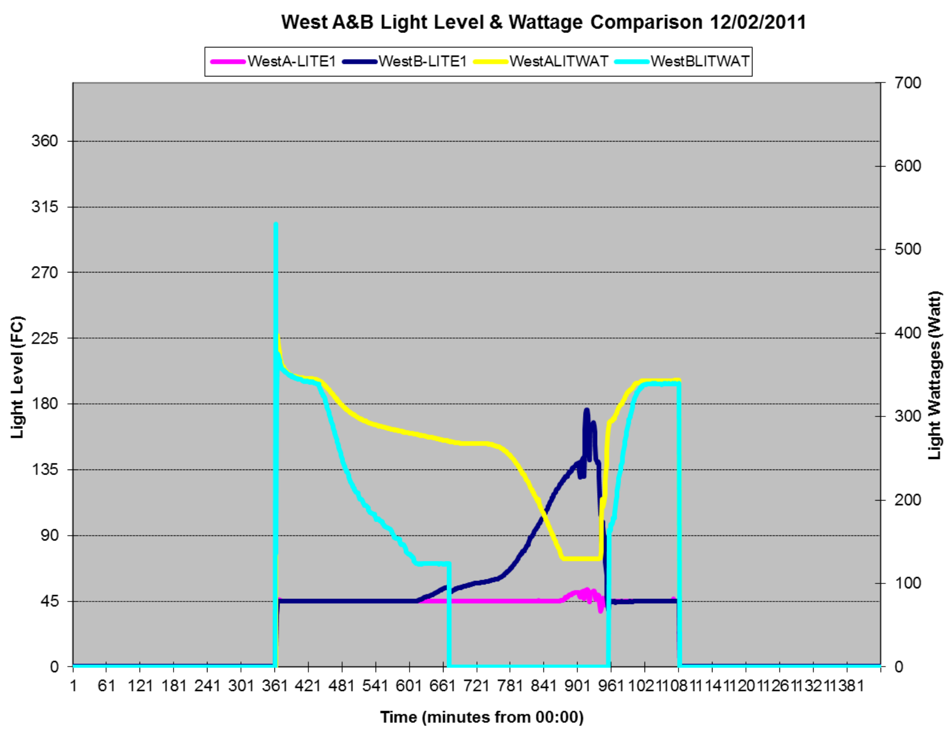

Figure 98: Test 5.2 Sunny Day West A&B Lighting Comparison

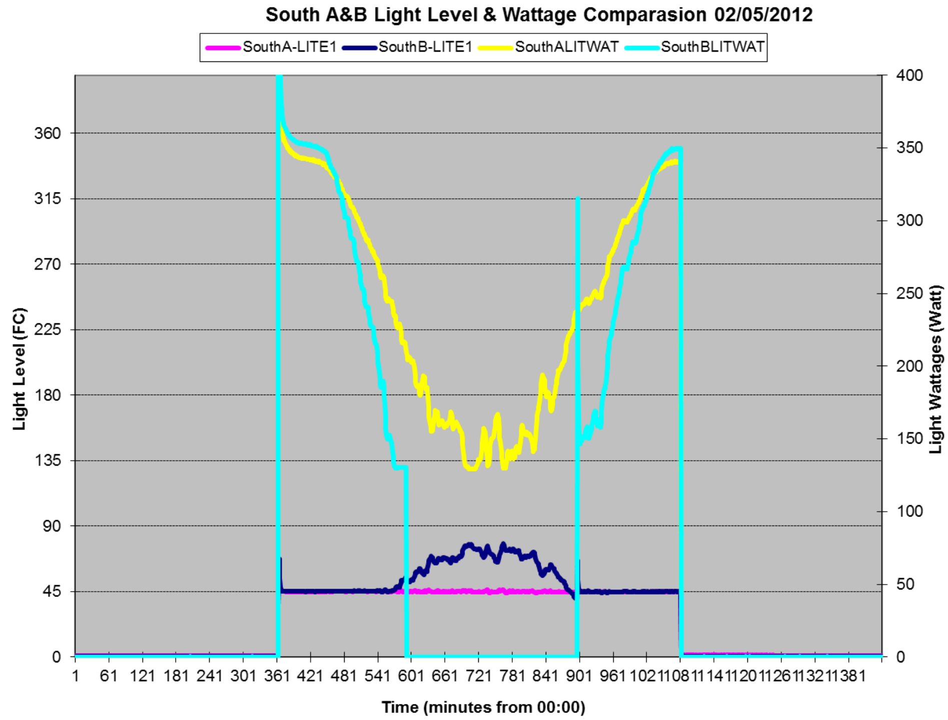

Figure 99: Test 6.1 Cloudy Day South A&B Lighting Comparison

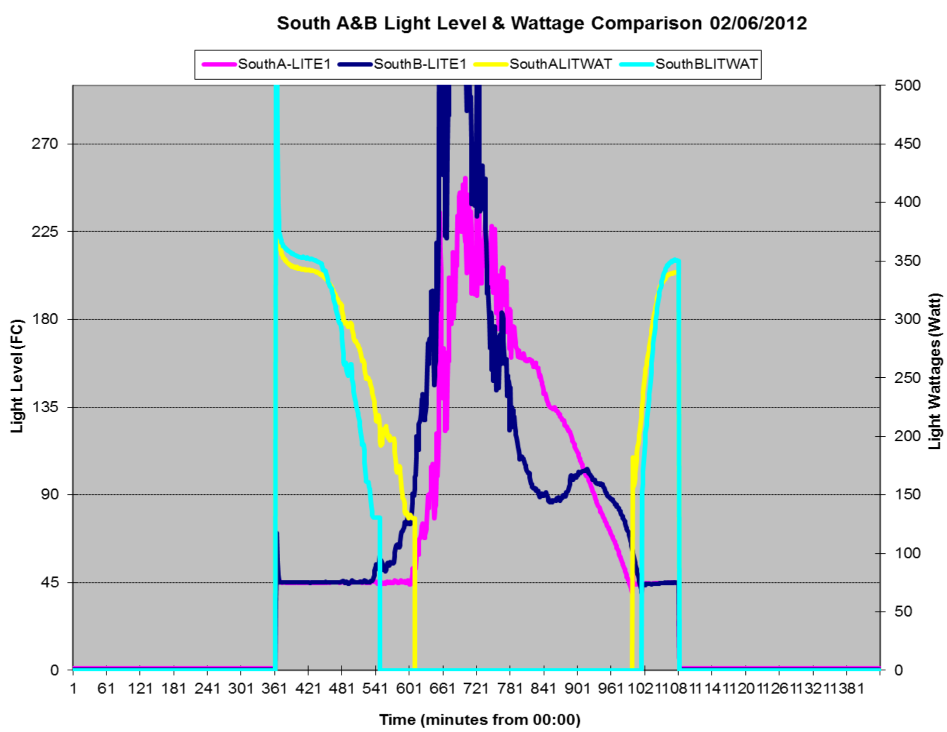

Figure 100: Test 6.1 Sunny Day South A&B Lighting Comparison

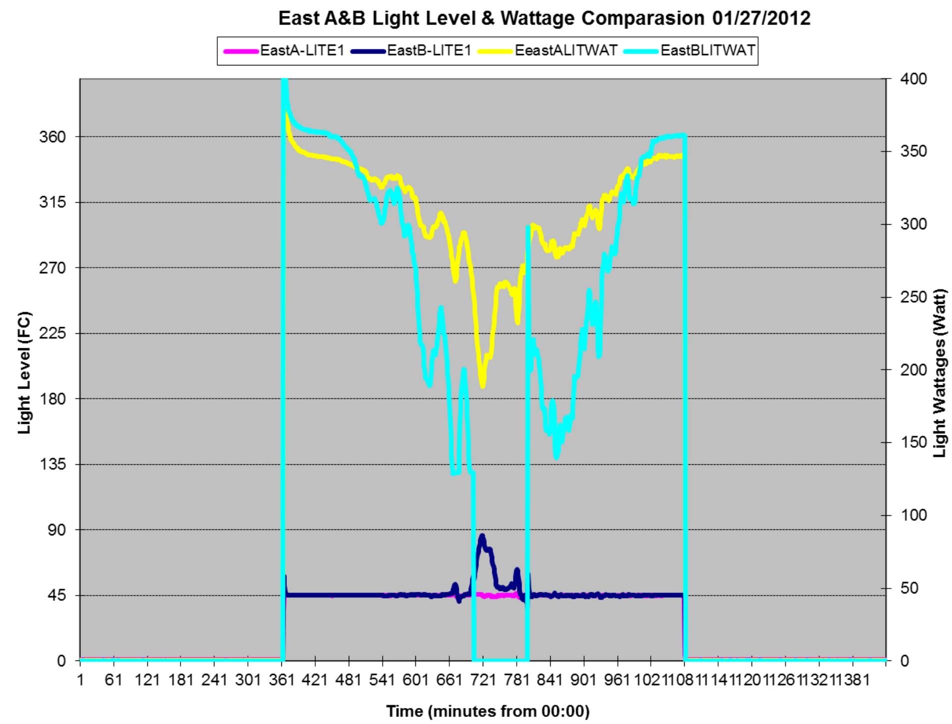

Figure 101: Test 6.2 Cloudy Day East A&B Lighting Comparison

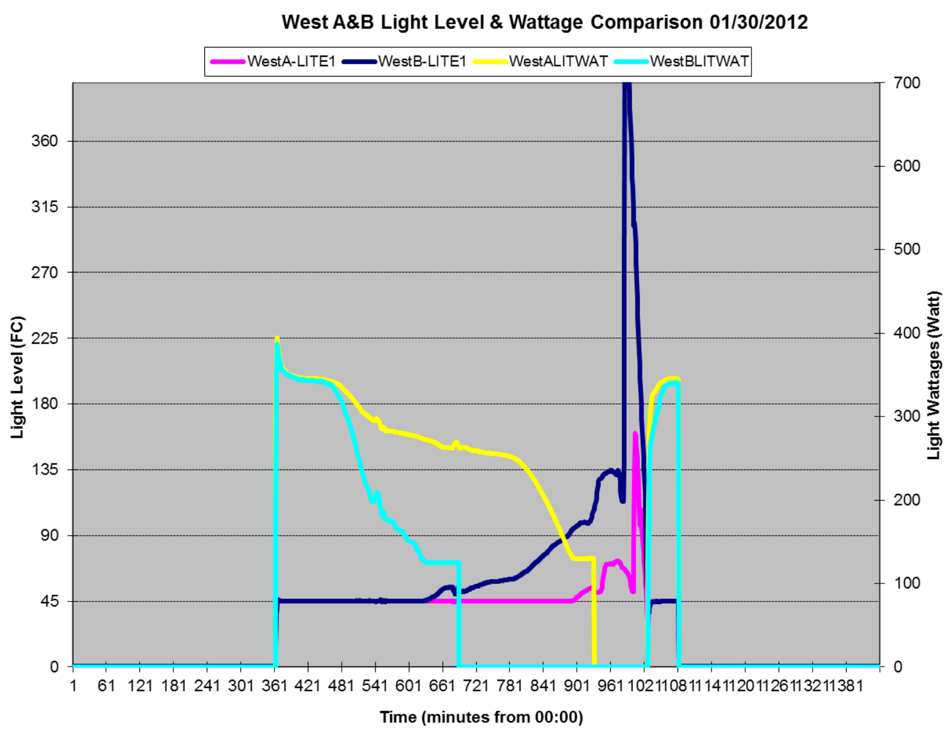

Figure 102: Test 6.2 Sunny Day West A&B Lighting Comparison

Appendix C. Normalization Test Room Lighting Comparison Examples

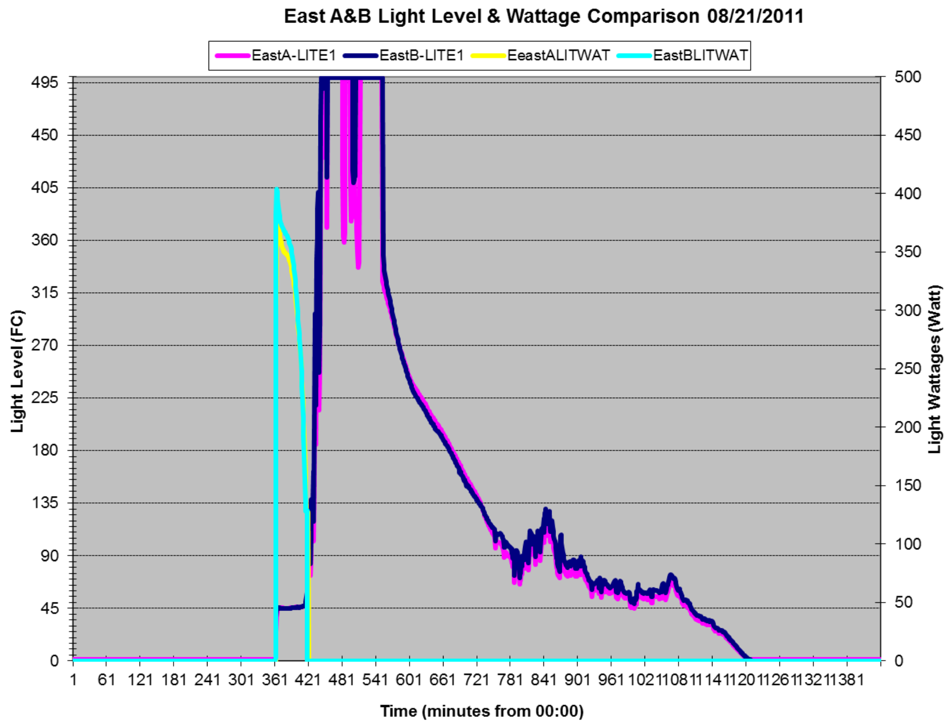

Figure 103: 08/21/2011 Lighting Comparison

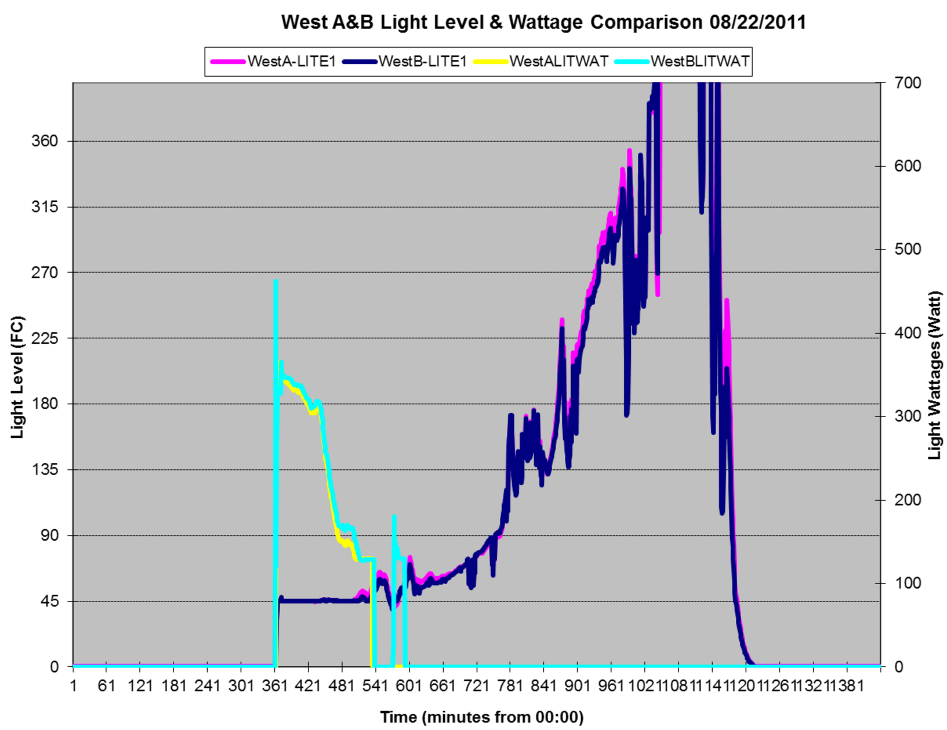

Figure 104: 08/22/2011 Lighting Comparison