FINAL TECHNICAL REPORT

Sunlight Responsive Thermochromic Window Systems

Project Title: Demonstration with Energy and Daylighting Assessment of Sunlight Responsive Thermochromic (SRT™) Window Systems

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Executive Summary

Pleotint, LLC was able to successfully extrude thermochromic interlayer for use in the fenestration industry. Pleotint has developed a thermochromic sytem that requires two thermochromic colors to make a neutral color when in the tinted state. These two colors were assembled into a single interlayer called a tri-layer prelam by Crown Operations for use in the glass lamination industry. Various locations, orientations, and constructions of thermochromic windows were studied with funds from this contract. Locations included Australia, California, Costa Rica, Indiana, Iowa, Mexico. Installed orientations included vertical and skylight glazing applications. Various constructions included monolithic, double pane, triple pane constructions.

A daylighting study was conducted at LinEl Signature. LinEl Signature has a conference room with a sylight roof system that has a west orientation. The existing LinEl Signature conference room had constant tint 40% VLT transparent skylights. Irradiance meters were installed on the interior and exterior sides of a constant tint skylight. After a month and a half of data collection, the irradiance meters were removed and the constant tint skylights were replaced with Pleotint thermochromic skylight windows. The irradiance meters were reinstalled in the same locations and irradiance data was collected. Both data sets were compared. The data showed that there was a linear relationship with exterior and interior irradiance for the existing constant tint skylights. The thermochromic skylights have a non-linear relationship. The thermochromic skylights were able to limit the amount of irradiance that passed through the thermochromic skylight.

A second study of the LinEl Signature conference was performed using EnergyPlus to calculate the amount of Illuminance that passed through constant tint skylights as compared to thermochromic skylights. The constant tint skylights transmitted Illuminance is 2.8 times higher than the thermochromic skylights during the months of May, June, July, August and 1.9 times higher than the thermochromic skylight during the months of March, April, September, October. Calculated illuminance levels were much more consistent as compared to the existing constant tint skylights installed at LinEl Signature. This allows for a more comfortable interior space in regard to glare discomfort and interior lighting control.

Lawrence Berkeley National Laboratory was contracted to characterize the performance of the thermochromic interlayer and thermochromic window systems. Thermochromic interlayer was characterized with spectrometer equipment. The thermochromic window systems were characterized using LBNL's Advanced Window Test Facility. A copy of the report can be found in the Appendix.

Iowa State University was contracted to compare thermochromic window technology to constant tint technology. Iowa State University conducted the testing at the Energy Resource Station (ERS). The ERS has the ability to simultaneously test side-by-side competing building technologies. The building is equipped with two identical air handling units, each with its own dedicated and identical chiller. One air handling unit supplies the four test rooms designated as the A rooms and the other unit serves the four test rooms designated as the B rooms. There is one A test room and one B test rooms arranged as pairs in a side-by-side design with each pair having a different exposure. There is a pair of test rooms that face the south, an east and west facing pair. Each of the test rooms is a mirror image of its match with identical construction. The rooms are unoccupied; however, the capability to impose false loads on the rooms exists. The false loads and room lighting can be scheduled to simulate various usage patterns. A copy of the report can be found in the Appendix.

GARD Analytics was contracted to compare EnergyPlus building simulations to the data recorded at the Iowa ERS. The goal of this research was to validate the building simulation software developed by the US Department of Energy. EnergyPlus is a whole building software package that includes thermochromic window system algorithms. The accuracy of these thermochromic window system algorithms were of special interest for this research. A copy of the report can be found in the Appendix.

1. Introduction

There are two compelling reasons to have a window in a building – daylight and a connection to the outdoors. Daylighting adds light to the building thus offsetting artificial lighting demands. A view of the outdoors will not contribute to energy savings of a building; however it does contribute to occupant well being. Although research is on-going, there are studies that indicate that when people have a view of the outdoors with natural lighting, reduced glare, and solar heat gain control; they not only feel better but are more productive. Windows exposed to direct sun however, need to have proper consideration given to the sun's contribution of heat and high Illuminance in buildings. These aspects of sunlight cause most of the unpleasant environmental effects in a building. Glass that can control the heat gain will reduce the cooling cost and offer a more pleasant environment for the building occupants. Almost all windows in buildings today have static or fixed transmission glass paired with other technologies such as interior or exterior shades. Regular and proper use of interior treatments is rare and exterior shades are expensive to install, maintenance intensive, and can be aesthetically undesirable. Static glass is tinted, coated or a combination of tint and coated glass. Glazing applications with this technology must determine a satisfactory compromise of visible light transmission and solar heat gain. After installation, the window's transmitted Illuminance is usually controlled with interior or exterior shades. This strategy often times breaks the connection to the outdoors and minimizes the value of the window.

Two technologies that have attempted to solve issues with using static transmission glass with shades are electrochromics and SPD (suspended particle device) glass. These technologies maintain a connection to the outdoors while allowing the user to change the visible light transmission of the window. The major downside to these technologies is the glass fabrication complexity and control system. Retrofit applications require some remodeling efforts to run power to the windows. In general wiring and control systems will drive up the cost of these technologies to a point where the cost benefit ratio prohibits investment. Finally if individual control is given to each office or room then energy management may be defeated. Complex control schemes that try to regulate the heat input will usually be overridden, become difficult to use or become a major maintenance issue. According to Rick Diamond and Mithra Moezzi, of LBNL in an article on Revealing Myths about People, Energy, and Buildings2:

> "**Myth #13. Installing energy retrofits or designing energy-efficient measures reduces energy use.** It is all too easy to assume that installing (or even specifying) energy retrofits will lead to energy savings. In practice, unless they are the right measures, installed carefully and operated correctly, there won't be any energy savings. We've seen solar collectors on the north side of the roof (the owner wanted them visible from the street). We've come across numerous daylight and occupancy sensors that were taped over or disabled by workers who didn't like them or understand their purpose. And we've seen numerous controls on HVAC systems disabled by the building managers, either because they were never commissioned to work properly, or because the operators wanted to be in control. With careful planning and commitment the energy efficient strategies can work, but we can't take for granted that they will work automatically. The difference between what is easy to recommend and what is likely to be installed and operated correctly cannot be ignored."

Pleotint has embarked on a novel approach to commercialize Sunlight Responsive Thermochromic, SRT™, windows. Pleotint integrates dynamic sunlight control, high insulation values and low solar heat gain together in a high performance window. Pleotint's innovative window product is an interlayer that can be used as a building block for architects and engineers to achieve the desired performance and aesthetic goals. Pleotint's product is able to leverage the existing glass fabricator infrastructure to produce thermochromic glazing designs. The Pleotint SRT window provides enhanced daylighting by allowing larger window to wall ratios and yet still meet or surpass energy codes. By allowing the glazing designer to choose various glass combinations and glass fabricators; it reduces the barrier to market for dynamic glazing. As an added benefit the laminated glass interlayer product can offer better sound reduction and safety. Glazing installers can install Pleotint SRT windows using traditional installation methods without the need to add controls or wires. These features of the product reduce cost and improve design flexibility.

2. Project Goals and Accomplishments

The primary project goal is to quantify the total energy usage and projected energy savings of thermochromic windows versus a conventional commercial grade double pane, fixed tint window incorporating a low emissivity coating in a vertical glazing. The second objective was to compare irradiance and Illuminance control of thermochromic sloped glazing to existing fixed tint windows at LinEl Signature. A third objective was to validate the EnergyPlus software accuracy using data collected from the energy study. A fifth objective is to install windows at test sites around the US in conjunction with Traco. A sixth objective will be to test the thermochromic laminates for sound reduction in various window configurations.

To accomplish the primary objective Pleotint will make film, Crown Operations will pre-laminate the film and Traco will laminate and assemble the IG units. After the thermochromic insulated glass units are constructed, they will be installed utilizing the Iowa Energy Center's Energy Resource Station (ERS). The ERS facility is equipped to monitor energy input, both HVAC and lighting, in identical side-by-side, pairs, of rooms facing East, South and West. The test will be two fold in that two different thermochromic window configurations will be tested against the fixed tint. There are two designs, a triple insulated glass package with the thermochromic pane in the middle and a double pane thermochromic window with the thermochromic pane on the outside, exposed to the elements. The rooms will be set up identically with automatic lighting control set for a fixed foot–candle illumination on the desk surface during working hours. Temperature in the room will be controlled between set points with night set back, closely simulating an actual office environment. The only variable in the test set up is the fixed tint windows in one set of rooms and the thermochromic windows in the other set of rooms. The test will be undertaken every other month, two weeks/month – one week for double pane and one week for triple pane, for a one year cycle to show actual energy used in a direct comparison to the traditional fixed tint windows. Testing every other month will allow a yearly savings to be extrapolated and conclusions made. Testing in all seasons and in a geographic location that has both heating and cooling loads will develop energy savings potential for all regions in the US.

The comparison of two different configurations of thermochromic windows to standard configuration fixed tint windows will demonstrate energy differences a double pane and triple pane will have on energy savings. An additional outcome will be what effect the wind and environment, at different times of the year, has on the performance of the exposed thermochromic pane. While a triple pane window has a higher insulation value, the double pane, being exposed to the elements, will allow more sunlight energy in during the winter, potentially offsetting the triple pane's higher insulation value in total energy savings.

2.1. Thermochromic Window and Skylight Preparation

Pleotint successfully completed the extrusion of thermochromic interlayer. Crown Operations was able to successfully complete the fabrication of a tri-layer prelam which consisted of Pleotint extruded orange interlayer/adhesion promoted polyethylene terephthalate/Pleotint extruded blue interlayer. The tri-layer prelam was successfully laminated between several different types of heat strengthened glass at Traco. Traco fabricated the thermochromic laminates into insulated glass units and shipped the insulated glass units to LBNL, Iowa Energy Resource Station, and LinEl Signature for testing and characterization.

Additionally Pleotint was able to ship thermochromic tri-layer prelam interlayer to two other glass fabricators in Australia and Mexico to fabricate windows for geographic locations outside the United States. Documentation and training were developed to help assist the glass fabricators with successful lamination of thermochromic laminates and fabrication of thermochromic insulated glass units.

2.2. Iowa State University Energy Resource Station Testing

See Appendix A for final report submitted by Iowa State University.

2.3. Thermochromic Skylight Testing

The purpose of this task was to quantify the difference between LinEl Signature's existing constant tint skylight windows and Pleotint's SRT skylight window system. This study was conducted at LinEl Signature taking advantage of their existing sloped glazing. The sloped glazing in their conference room has a west orientation with a 10 degree slope. Initial data was collected using a Micro Circuit Labs SDL-1 solar data logger. Irradiance measurement accuracy is ± 5%. The SDL-1 uses a silicon photodiode which has a spectral sensitivity from 400nm to 1100nm. This data logger is a self-contained solar energy meter that measures the sun's irradiance at user defined intervals. Two instruments were used to collect data. One meter was placed outdoors while the other meter was placed indoors. Both meters were mounted near the sloped glazing with the same 10 degree tilt as shown in Figure 1.

INDOOR METER OUTDOOR METER

Figure 1 LinEl Signature Irradiance Meter Mounting

Data for the existing LinEl Signature constant tint skylights was collected from September 8, 2011 to October 26, 2011. The recorded data was graphed comparing outdoor irradiance to indoor irradiance. As expected a significant linear correlation between indoor and outdoor irradiance was shown in Figure 2. This information confirmed that the existing windows installed in LinEl Signature's conference room were a fixed transmission glazing system.

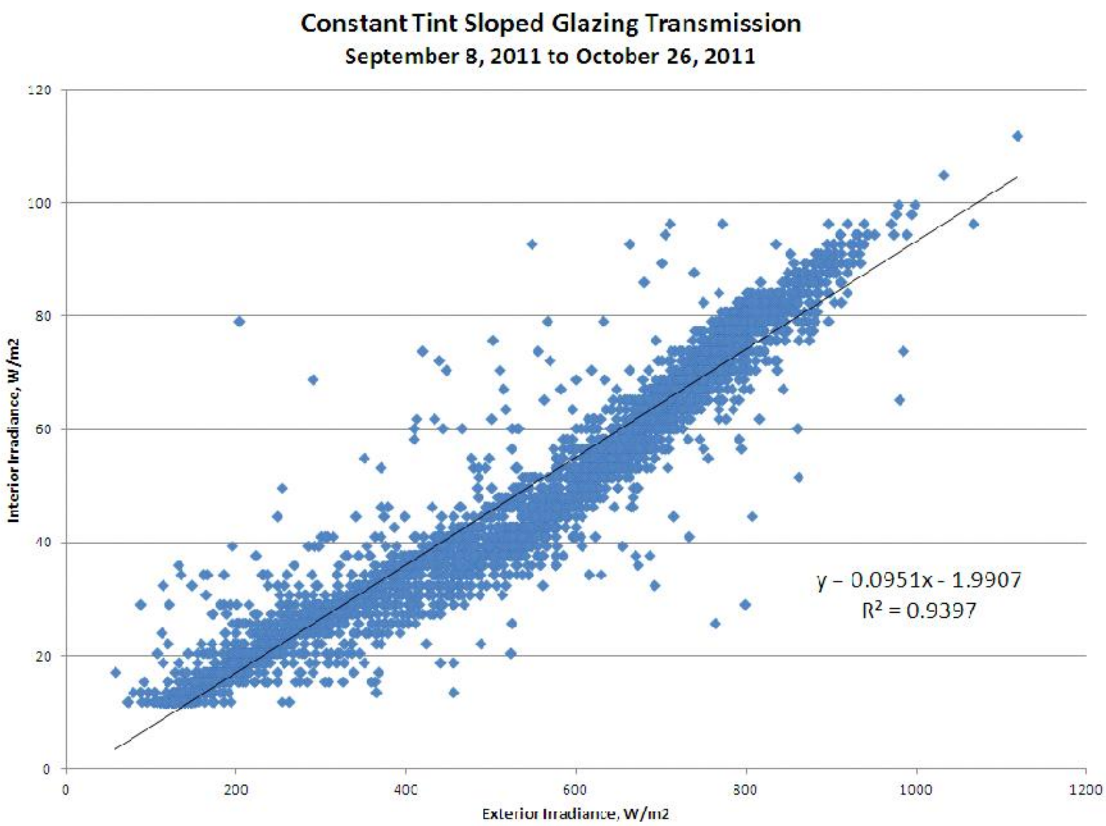

Figure 2 Constant Tint West Oriented Slope Glazing

After data collection for the constant tint windows was complete. On November 5, 2011 LinEl Signature removed the existing constant tint skylight windows and replaced them with Pleotint SRT skylight windows. A picture of the installed windows can be found in Figure 3. Data loggers used for the constant tint windows were remounted in the same position as they were for the constant tint irradiance monitoring. Data was collected from February 22, 2012 to March 22, 2012 and graphed comparing outdoor irradiance to indoor irradiance as shown in Figure 4. Additional data was to be collected from March 30, 2012 to May 16, 2012, however the outdoor irradiance data logger had a seal failure and destroyed the irradiance data logger.

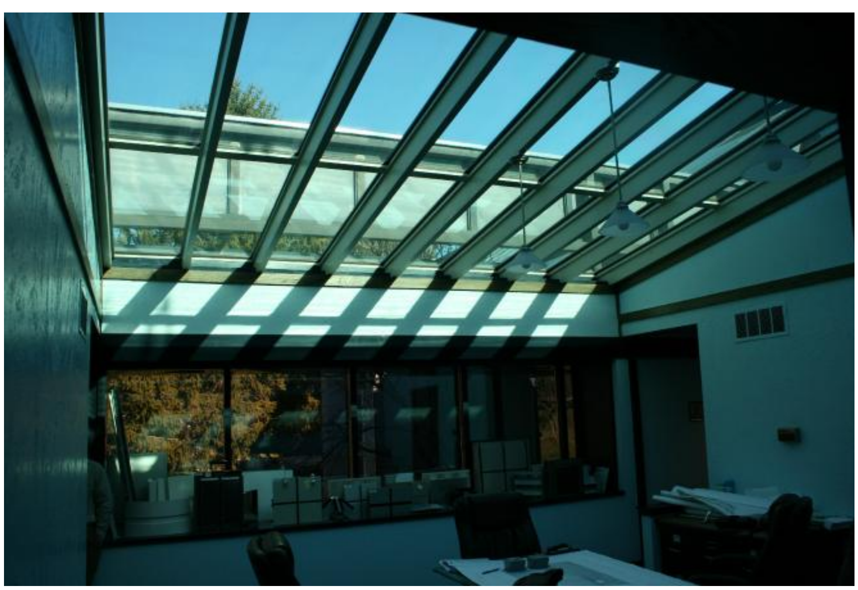

Figure 3 Installed Pleotint SRT Skylight Windows

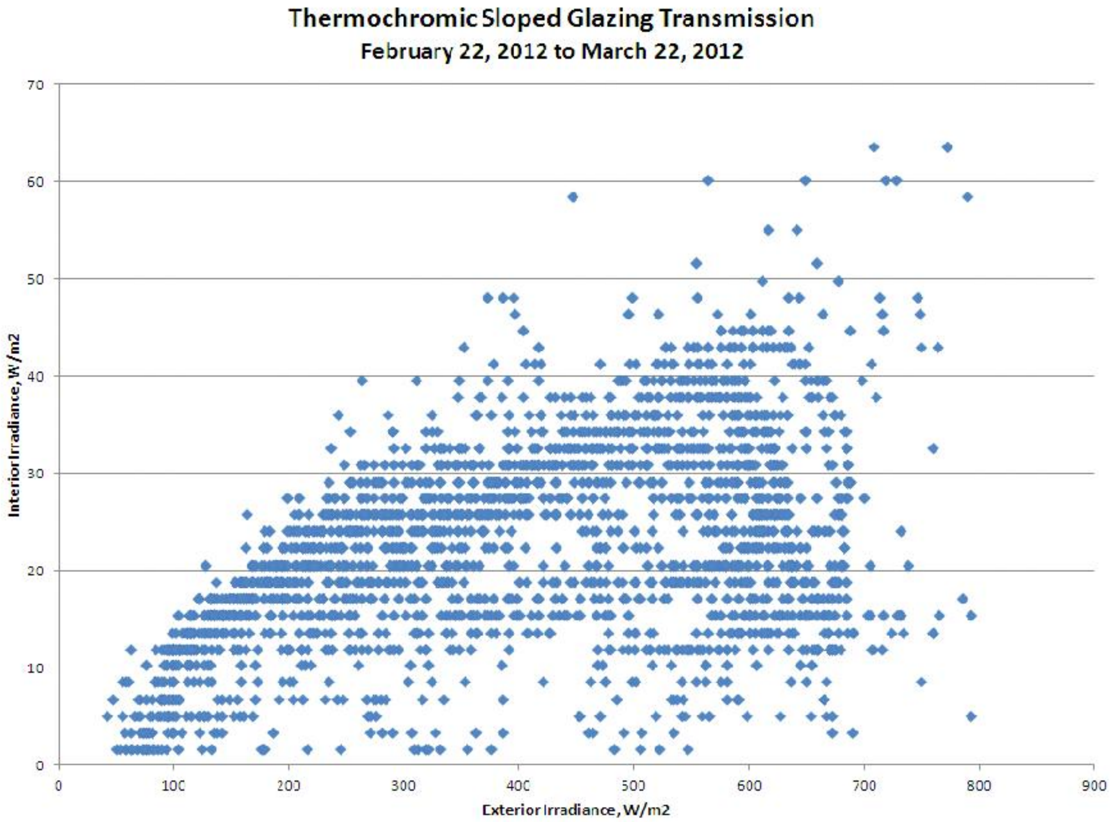

Figure 4 Thermochromic West Oriented Sloped Glazing

As can be seen in Figure 4, the thermochromic skylight was able to limit the amount of irradiance entering the LinEl Signature conference room. This is in contrast to the constant tint windows which continuously transmits a proportional amount of irradiance. This proportional amount of irradiance presents a problem to the building owner in that a static solar transmission must be selected for all environmental conditions. Dynamic glazing, on the other hand, offers the building owner a passive control device for dynamically altering solar transmission to accommodate variable environmental conditions.

A second analysis was deployed to investigate the impact thermochromic skylights have on room Illuminance as compared to constant tint skylights. A building simulation program called EnergyPlus version 6.0.0.023 was used to help with this analysis. EnergyPlus is a whole building energy simulation program that engineers, architects, and researchers use to model energy and water used in buildings. EnergyPlus models heating, cooling, lighting, ventilation, other energy flows, and water use. EnergyPlus calculates daylight factors by calculating daylight incident on a window which is separated into two components: (1) light that originates from the sky and reaches the window directly or by reflection from exterior surfaces; and (2) light that originates from the sun and reaches the window directly or by reflection from exterior surfaces. Light from the window reaches the workplane directly or via reflection from the interior surfaces of the room. For fixed sun position, sky condition and room geometry, the sky-related interior daylight will be proportional to the exterior horizontal illuminance, due to light from the sky. Similarly, the sun-related interior daylight will be proportional to the exterior horizontal solar Illuminance. More information regarding daylighting calculations can be found in EnergyPlus' Engineer Reference documentation. Iowa State University and GARD Analytics results of the EnergyPlus thermochromic algorithm accuracy can be found respectively in Appendix A and C of this final report. For more information regarding continued validation testing please refer to: http://apps1.eere.energy.gov/buildings/energyplus/energyplus_testing.cfm.

A simple EnergyPlus building model was constructed in Google Sketchup to analyze the room Illuminance of both the constant tint skylight and thermochromic skylight as shown in Figure 5.

ISOMETRIC VIEW FRONT VIEW

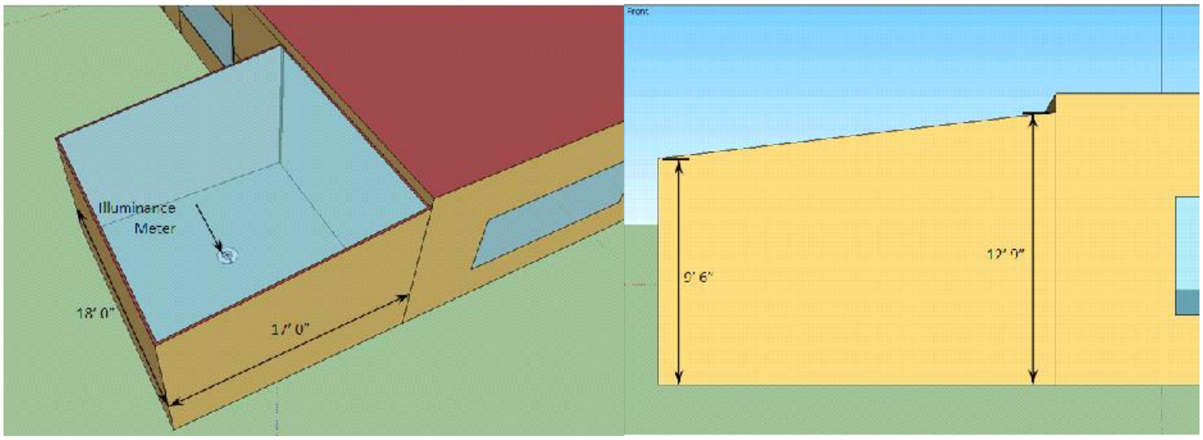

Figure 5 EnergyPlus Building Model of LinEl Signature West Conference Room

A daylighting control was placed in the center of the room 31.5" off from the floor. The daylighting control was set for a control type of continuous with a setpoint of 500 lux. The interior lighting for the west conference room was fluorescent lights with a design lighting level of 304 watts. Simulations used a time step of 20 using TMY3 weather file named USA_IN_Indianapolis.Intl.AP.724380_TMY.epw. Illuminance output was recorded for every time step for an entire year for both the constant tint and thermochromic skylights. The exact constant tint skylight window construction was unknown and therefore was approximated using 6mm Viracon LowE on Bronze (LBNL Window 6 ID 6061) 12.7mm air insulating space and 7.7mm clear glass laminate with Saflex^R 0.45" clear PVB. Overall IGU thickness is 26.053mm.

Table 1 LinEl Signature Constant Tint Skylight Model Center of Glass Properties

SHGC	0.283	Tvis	0.414
SC	0.325	Tsol	0.191
Rel. Heat Gain	68.9 BTU/hr*ft^2	Uvalue	0.423 BTU/hr*ft^2*F˚

Data based on performance metrics LBNL Window v6.3.9.0 and Optics v5.1 NFRC 100-2010 conditions/10˚ Tilt.

The thermochromic skylight construction is 6mm Solarban60 on clear glass (LBNL Window 6 ID 5284) 11.1 mm 90% argon/10% air insulated gas and a thermochromic glass laminate. The thermochromic glass laminate was constructed using 6mm Azuria (LBNL Window 6 ID 5036), Pleotint SRT interlayer, and 5mm Sungate500 on clear glass (LBNL Window 6 ID 5246). Overall IGU thickness is 28.3mm.

Table 2 LinEl Signature Thermochromic Skylight Model Center of Glass Properties

Laminate Temperature 10˚C			Laminate Temperature 65˚C	
SHGC	0.339	←Continuously Variable→	SHGC	0.322
SC	0.390	←Continuously Variable→	SC	0.370
Rel. Heat Gain	80.7 BTU/hr*ft^2	←Continuously Variable→	Rel. Heat Gain	76.8 BTU/hr*ft^2
Tvis	0.429	←Continuously Variable→	Tvis	0.09
Tsol	0.150	←Continuously Variable→	Tsol	0.035
		Uvalue 0.302 BTU/hr*ft^2*F˚		

Data based on performance metrics LBNL Window v6.3.9.0 and Optics v5.1 NFRC 100-2010 conditions/10˚ Tilt.

The graphed data generated an EnergyPlus simulation using TMY3 weather data for June 15 is shown in Figure 6. The graph shows how the dynamic visible light transmission of the thermochromic skylight affects the room Illuminance of the conference room. Both skylight windows start at approximately the same transmission point, however when solar irradiance strikes the thermochromic skylight, the thermochromic interlayer begins to tint and the room Illuminance is held more constant as compared to the constant tint skylight.

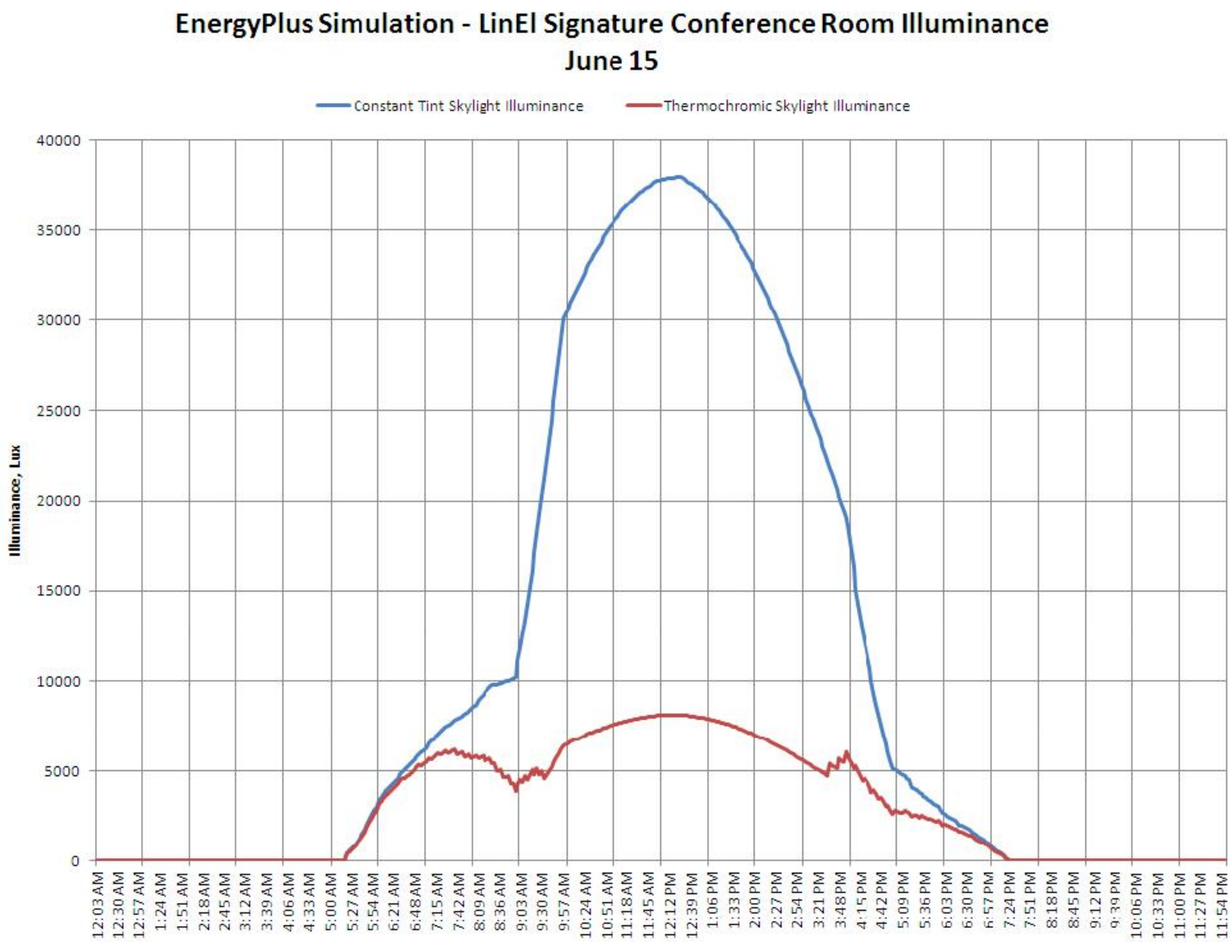

Figure 6 Constant Tint vs Thermochromic Skylight Interior Illuminance Comparison

Short of displaying every single day modeled with EnergyPlus, it is hard to understand the total impact of thermochromic as compared to constant tint skylights using this graphing methodology. Another approach to capturing the effect of dynamic glazing was undertaken. The analysis technique used a pivot table to sum all of the Illuminance results for each time step. The data was categorized for each month of a twelve month time period. The analysis was performed for both the thermochromic skylight and the constant tint models. The graphed results can be found in Figure 7. Comparing the months of November thru February to the rest of the year, it is apparent that the Illuminance is significantly lower. This is attributed to the amount of irradiance that is available during this portion of the year as shown in Figure 8.

As this daylight analysis shows, thermochromic glazing offers the building occupant a more consistent daylight level. The tables below show how the months of March, April, September, October and the months of May, June, July, August compare with the months of November, December, January, February. The constant tint skylight transmitted Illuminance is 2.8 times higher than the thermochromic skylight during the months of May, June, July, August and 1.9 times higher than the thermochromic skylight during the months of March, April, September, October.

Table 3 Constant Tint Aggregated Transmitted Illuminance

November, December, January, February	March, April, September, October	May, June, July, August
76,193,363 lux	278,843,503 lux	485,421,005 lux
	3.65 Higher	6.37 Higher

Table 4 Thermochromic Aggregated Transmitted Illuminance

November, December, January, February	March, April, September, October	May, June, July, August
67,599,653 lux	128,226,891 lux	152,387,223 lux
	1.90 Higher	2.25 Higher

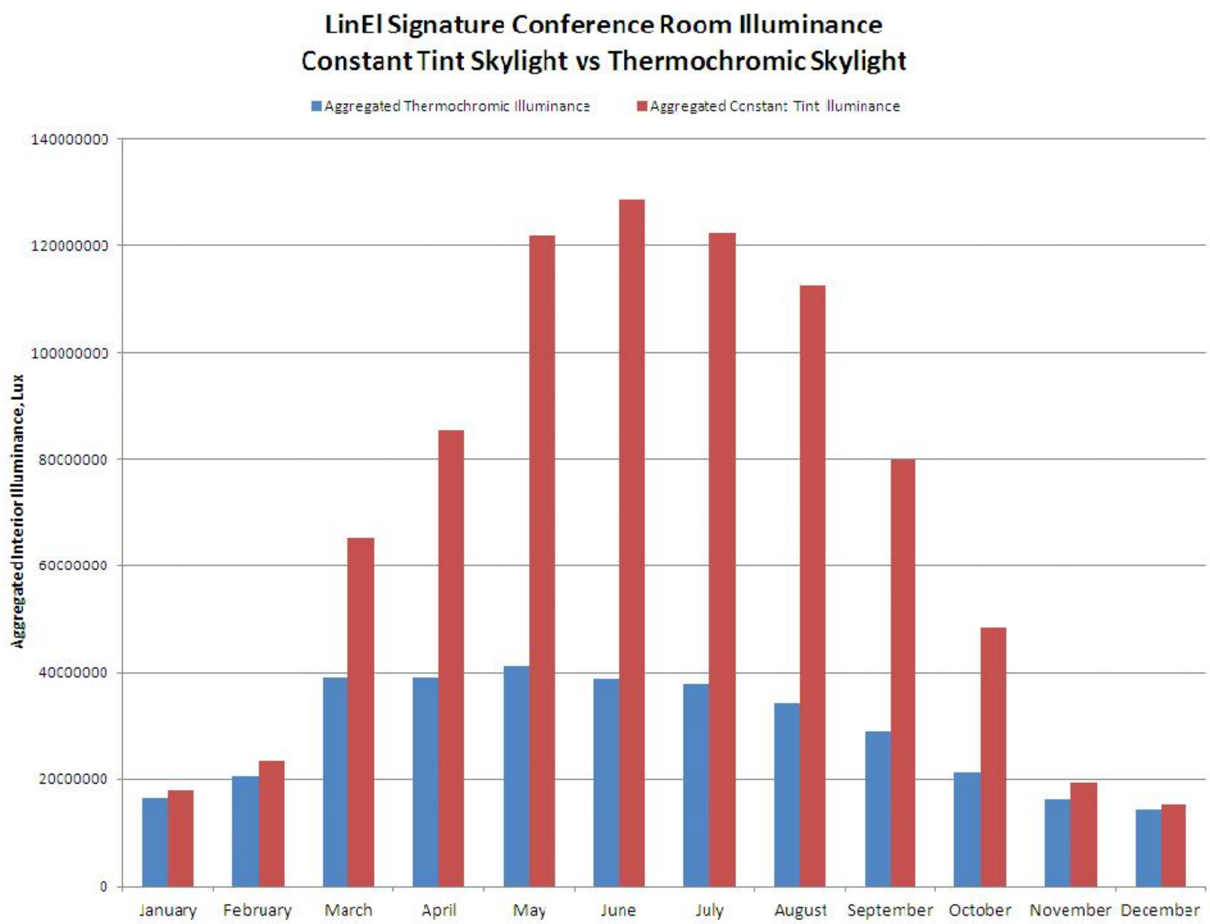

Figure 7 Aggregated Monthly Transmitted Illuminance Comparison

A building's lighting directly affects the comfort, mood, productivity, health, and safety of its occupants. Moreover glazing is the connecting link to the outdoors; it also directly affects the aesthetics and image of the building. Improved daylighting enhances visual comfort, reduces eye fatigue, and improves performance on visual tasks. Because costs associated with a building's occupants greatly outweigh other building costs, any daylighting change that improves the interior environment is worth investigating. Salary costs far outweigh the costs for daylighting in a typical office building, so even small improvements in worker productivity, absenteeism, or staff retention will quickly offset the costs of a well-executed glazing upgrade. Admittedly these effects are hard to quantify, but research efforts are helping to pin down the benefits.

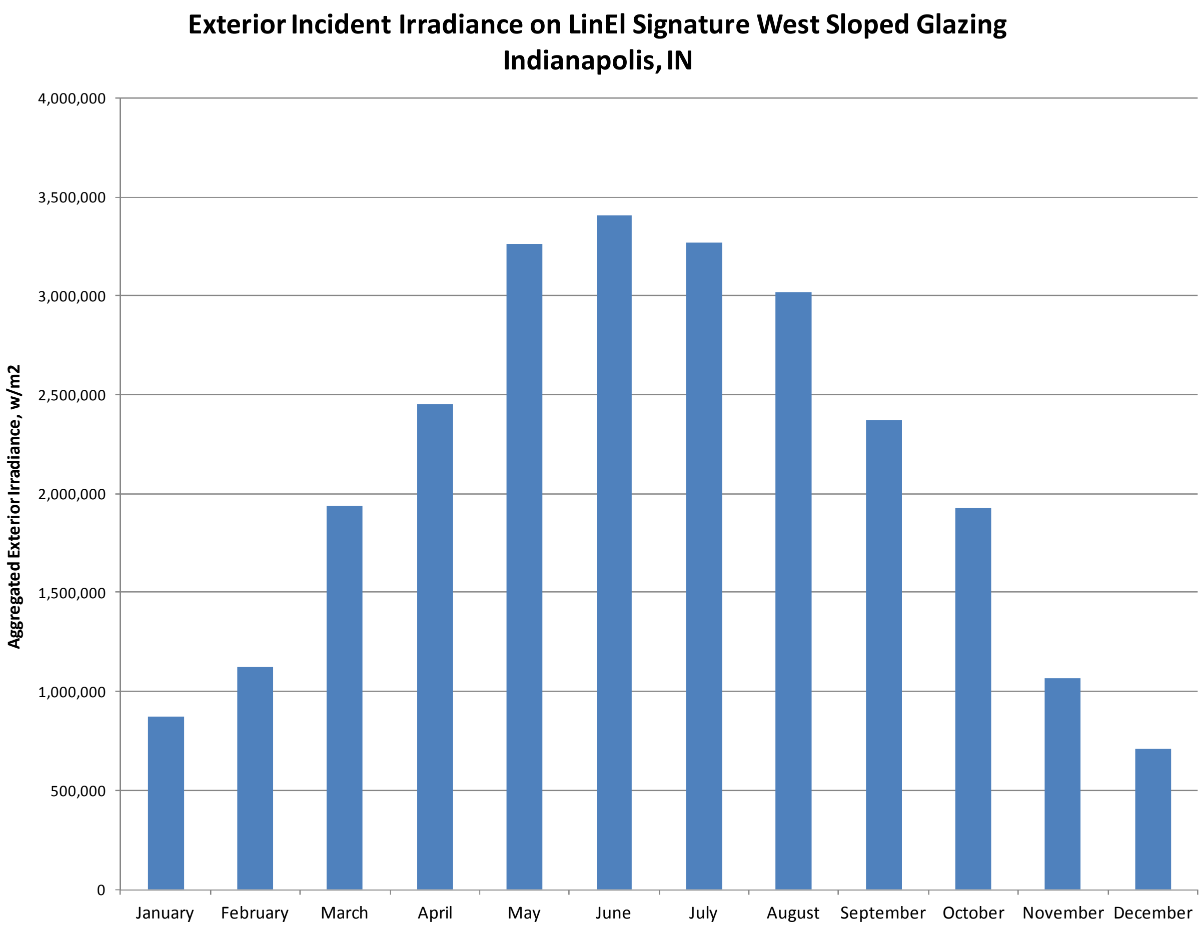

Figure 8 Exterior Irradiance

2.4. Lawrence Berkley National Laboratories Testing

See Appendix B for final report submitted by LBNL.

2.5. GARD Analytics EnergyPlus Modeling

See Appendix C for final report submitted by GARD Analytics.

2.6. Install SRT Windows in Various Climatic Sites

Jalisco, Mexico

Climate: January temperature averages 16 °C (60 °F). In June, the average is 23 °C (74 °F). Rainfall is heaviest between June and September. Average annual rainfall is 1.34 m (53 inches).

Installation Information: Retrofit application for storefront framing. Double pane insulated glass units with clear glass thermochromic laminate located as exterior pane. Interior pane has a soft coat low emissivity coating. Insulated glass units face west on first floor of a commercial building. Installation was completed in July, 2011.

Figure 9 Jalisco, Mexico

Dandenona Victoria, Australia

Climate: January through April, and October through December average temperatures are 10 °C (50.0 °F) to 20 °C (68.0 °F). May through September average temperatures are between 0 °C (32.0 °F) and 10 °C (50.0 °F). The warmest time of year is in February when it is 17.75 °C (64.0 °F) on average, but could get up to 22.9 °C (73.2 °F). The coldest time of year is in July when it is 5.9 °C (42.6 °F). The annual average rainfall is about 0.771 m (30 in).

Installation Information: New construction application with curtain wall framing. Double pane insulated glass units with tinted gray glass thermochromic laminate located as exterior pane. Interior pane has a soft coat low emissivity coating. Insulated glass units face east, north, and west on two-story commercial building. Installation was completed in December, 2011.

Figure 10 Dandenona Victoria, Australia

Houston, Texas

Climate: Subtropical and humid climate. Summer temperatures in Houston are at their hottest during July and August, when they can reach around 34 °C (93 °F). Winters in Houston are cool, with January being the coldest month. Daytime temperatures in January reach highs of around 16 °C (61 °F). Winter is Houston's wettest season. Average annual precipitation is 1.27 m (50 in).

Installation Information: Retrofit application for storefront framing. Double pane insulated glass units with clear and tinted thermochromic laminates located as exterior pane. Interior pane has a soft coat low emissivity coating. Thermochromic windows face west in manufacturing facility. Installation was completed in July, 2011.

Figure 11 Houston, TX

Costa Rica

Climate: tropical, situated between 8° and 11° North latitude, fairly close to the equator. The average annual temperature for most of the country lies between 21.7 °C (71 °F) and 27 °C (81 °F). The coolest months are from November through January, and the warmest from March through May. Rainfall patterns vary greatly across the country. Some locations receive over 6 m (216 in) of precipitation per year, while others receive under 1.5 m (48 in). Most of the total rainfall for any given site (about 70%) occurs on less than 15 days of a whole year, and will often be experienced as days of torrential downpour.

Installation Information: Retrofit application for sliding doors. Monothic laminates with clear glass pyrolytic low emmisivity coatings on both exterior and interior surfaces. Laminates will face west in third story resort building facing the ocean. Installation is scheduled for January 20, 2012.

Figure 12 Costa Rica

2.7. SRT Window Sound Reduction Testing

Pleotint, LLC contracted Architectural Testing, Inc. to conduct sound transmission loss tests on insulating glass units. Architectural Testing, Inc is accredited by the International Accreditation Service, Inc. under the specific test methods listed under lab code TL-144, in accordance with the recognized International Standard ISO/IEC 17025:2005. The STC (Sound Transmission Class) rating was calculated in accordance with ASTM E 413. The OITC (Outdoor-Indoor Transmission Class) was calculated in accordance with ASTM E 1332. A summary of the results is listed below are from Architectural Testing, Inc. Report No. B1385.03-113-11. Tests were conducted on July 29, 2011 and August 26, 2011.

Table 5 Summary of Acoustic Test Results

Data File Number	Sample Identification Number	STC	OITC
B1385.03A	Acoustic Test 1	38	31
B1385.03B	Acoustic Test 2	37	30
B1385.03C	Acoustic Test 3	38	31
B1385.03D	Acoustic Test 4	37	31
B1385.03E	Acoustic Test 5	36	29

Sample Descriptions

The insulating glass units were sampled and they will be retained by Architectural Testing for four years. Units size for all five samples were 34” by 76”.

Sample Identification Number: Acoustic Test 1

Table 6 Acoustic Test 1 Sample

Overall Measured Thickness		27.76mm (1.093”)	
Total Weight		67.3kg (148lbs)	
Exterior Glass	**Exterior Sheet**	**Interlayer**	**Interior Sheet**
Measured Thickness	5.72mm (0.225”)	1.02mm (0.040”)	4.67mm (0.184”)
Material	Heat Strengthened	Pleotint SRT	Heat Strengthened
Air Space	11.68mm (0.460”)		
Spacer Type	Aluminum		
Interior Glass	**Sheet**		
Measured Thickness	4.67mm (0.184”)		
Material	Heat Strengthened		

Sample Identification Number: Acoustic Test 2

Table 7 Acoustic Test 2 Sample

Overall Measured Thickness		26.66mm (1.050”)	
Total Weight		62.7kg (138lbs)	
Exterior Glass	**Exterior Sheet**	**Interlayer**	**Interior Sheet**
Measured Thickness	4.67mm (0.184”)	1.02mm (0.040”)	4.67mm (0.184”)
Material	Heat Strengthened	Pleotint SRT	Heat Strengthened
Air Space	11.63mm (0.458”)		
Spacer Type	Aluminum		
Interior Glass	**Sheet**		
Measured Thickness	4.67mm (0.184”)		
Material	Heat Strengthened		

Sample Identification Number: Acoustic Test 3

Table 8 Acoustic Test 3 Sample

Overall Measured Thickness		28.88mm (1.137”)	
Total Weight		68.2kg (150lbs)	
Exterior Glass	**Exterior Sheet**	**Interlayer**	**Interior Sheet**
Measured Thickness	5.72mm (0.225”)	1.02mm (0.040”)	4.67mm (0.184”)
Material	Heat Strengthened	Pleotint SRT	Heat Strengthened
Air Space	12.80mm (0.504”)		
Spacer Type	Aluminum		
Interior Glass	**Sheet**		
Measured Thickness	4.67mm (0.184”)		
Material	Heat Strengthened		

Sample Identification Number: Acoustic Test 4

Table 9 Acoustic Test 4 Sample

Overall Measured Thickness		28.01mm (1.103")	
Total Weight		63.6kg (140lbs)	
Exterior Glass	**Exterior Sheet**	**Interlayer**	**Interior Sheet**
Measured Thickness	4.67mm (0.184")	1.02mm (0.040")	4.67mm (0.184")
Material	Heat Strengthened	Pleotint SRT	Heat Strengthened
Air Space	12.98mm (0.511")		
Spacer Type	Aluminum		
Interior Glass	**Sheet**		
Measured Thickness	4.67mm (0.184")		
Material	Heat Strengthened		

Sample Identification Number: Acoustic Test 5

Table 10 Acoustic Test 5 Sample

Overall Measured Thickness		38.71mm (1.524")	
Total Weight		86.4kg (190lbs)	
Exterior Glass	**Sheet**		
Measured Thickness	4.67mm (0.184")		
Material	Heat Strengthened		
Air Space	6.22mm (0.245")		
Spacer Type	Aluminum		
Middle Glass	**Exterior Sheet**	**Interlayer**	**Interior Sheet**
Measured Thickness	4.67mm (0.184")	1.02mm (0.040")	4.67mm (0.184")
Material	Heat Strengthened	Pleotint SRT	Heat Strengthened
Air Space	12.78mm (0.503")		
Spacer Type	Aluminum		
Interior Glass	**Sheet**		
Measured Thickness	4.67mm (0.184")		
Material	Heat Strengthened		

Test Methods: The acoustical tests were conducted in accordance with the following:

ASTM E 90-09, *Standard Test Method for Laboratory Measurement of Airborne Sound Transmission Loss of Building Partitions.*

ASTM E 413-10, *Classification for Rating Sound Insulation.*

ASTM E 1332-10a, *Standard Classification for Rating Outdoor-Indoor Sound Attenuation.*

ASTM E 2235-04, *Standard Test Method for Determination of Decay Rates for Use in Sound Insulation Test Methods.*

Test Equipment: The equipment used to conduct these tests meets the requirements of ASTM E 90. The microphones were calibrated before conducting sound transmission loss tests. The test equipment and test chamber specifications can be found in Table 11 and 12 respectively.

Table 11 ATI Acoustical Test Equipment

Instrument	Manufacturer	Model	Description	ATI Number	Date of Calibration
Analyzer	Hewlett Packard	HB35670A	Real time analyzer	Y002929	06/14/11
Data Acquisition Unit	Agilent	34970A	Data Acquisition Unit	62211	07/13/11
Receive Room Microphone	GRAS	40 AR	½" Microphone	Y003246	08/17/10
Source Room Microphone	GRAS	40 AR	½" Microphone	Y003245	08/17/10
Receive Room Preamplifier	GRAS	26 AK	½" Preamplifier	Y003249	08/17/10
Source Room Preamplifier	GRAS	26 AK	½" Preamplifier	Y003248	08/17/10
Microphone Calibrator	Bruel & Kjaer	Type 4228	Pistonphone Calibrator	Y002816	02/17/11
Noise Source	Delta Electronics	SNG-1	Noise Generator	Y002181	N/A
Equalizer	Rane	RPE 228	Programmable Equalizer	Y002180	N/A
Power Amplifiers	Crown	Xti 2000	Two, Amplifiers	005769 005770	N/A
Receive Room Loudspeakers	Renkus-Heinz, Inc.	Trap Jr./9	Two, Loudspeakers	Y001784 Y001785	N/A
Source Room Loudspeakers	Renkus-Heinz, Inc.	Trap Jr./9	Two, Loudspeakers	Y002649 Y002650	N/A
Receive Room Environmental Indicator	Vaisala	HMW60Y	Temperature and Humidity Sensor	005066	08/20/10
Source Room Environmental Indicator	Vaisala	HMW60Y	Temperature and Humidity Sensor	Y002652	09/15/10
Weather Station	Davis Instruments	VantagePRO 6150C	Weather Station	Y003257	05/16/11
Torque Wrench	Armstrong	64-031	Torque Wrench	Y003311	05/10/11

Table 12 Acoustical Test Chamber Specifications

	Volume	**Decription**
Receive Room	234m^3 (8,291.3ft^3)	Rotating vane and stationary diffusers Temperature and humidity controlled Isolation pads under the floor.
Source Room	206.6m^3 (7,296.3ft^3)	Stationary diffusers only Temperature and humidity controlled.
	Maximum Size	Description
TL Test Opening	4.27m (14ft) wide by 3.05m (10ft) high	Vibration break between source and receive rooms.

Sample Installation: Sound transmission loss tests were initially performed on a filler wall that was designed to test 40” by 86” and 80” by 86” specimens. The filler wall achieved an STC rating of 67. The specimen plug was removed from the filler wall assembly, and a custom adapter plug was constructed to reduce the test opening size to fit the glass and the mounting apparatus. The adapter plug consisted of a double 2 x 4 wood stud wall with three layers of 5/8” gypsum board covering both sides. The double wood stud wall was insulated with two layers of 3-1/2” thick fiberglass insulation. The glass panels were held in place on both sides with 1-1/2” by 1-1/2” steel angle, lined with ½” wide by 1/8” thick, closed cell foam gasket tape. This configuration isolated the glass from the steel angle and the test opening. The steel angle was held together with eighteen (18) bolts, and the gasket was compressed using plastic nuts. A torque wrench was set to 16-inch pounds and was used to tighten the nuts onto the bolts compressing the foam gasket onto the glass. The interior side of the glass, when installed, was approximately 1-1/2” from being flush with the receiving room side of the filler wall. A dense neoprene gasket and duct seal were used to seal the custom adapter plug to the inside perimeter of the filler wall opening. A stethoscope was used to check for any abnormal air leaks before the test.

Figure 13 Sound Apparatus

Test Procedure: One background noise sound pressure level and five sound absorption measurements were conducted at each of the five microphone positions under ambient conditions. Two Sound Pressure Level (SPL) measurements were made simultaneously in both rooms, at each of the five microphone positions. The air temperature and relative humidity conditions were monitored and recorded during the background, absorption, source, and receive room measurements. The glass temperature was monitored and recorded, before and after the source and receiving room SPL measurement.

APPENDICES

Appendix A. Iowa State University Final Technical Report

DEMONSTRATION WITH ENERGY AND DAYLIGHTING ASSESSMENTS OF SUNLIGHT RESPONSIVE THERMOCHROMIC (SRT) WINDOW SYSTEMS

Final Technical Report
September 2012

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This material is based upon work supported by the Pleotint, LLC
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EXECUTIVE SUMMARY

Pleotint LLC's Sunlight Responsive Thermochromic Windows adapts (absorbing suns energy and reducing the light transmission) to the changing sun angle on a vertical window as the earth rotates. The Pleotint SRT film laminated between two panes of glass blocks the sun's harmful ultraviolet rays, and reduces solar heat gains, visible light transmission, and glare. This demonstration project assesses building energy and daylighting performance for two different models of Pleotint SRT windows ("Azuria" and "Green") comparing to standard low-e dark tinted windows in a light commercial building environment under typical central Iowa weather conditions. The overall test was conducted in six cycles during a one-year period. Each cycle consisted of at least 7 days of comparison testing for each of the Pleotint window models.

Normalized testing results show that on yearly average, the Pleotint SRT Green windows can save approximately **4%** total building electricity compared to standard low-e dark tinted windows, while the Pleotint SRT Azuria windows used approximately **the same** total electricity. The tests were implemented in a facility and setup so that 11% of the total building electricity was used for lighting in the perimeter rooms with windows. Most of the energy savings were from lighting energy: **15%** (south) ~ **27%** (west) savings for SRT Azuria windows, and **37%** (south) ~ **42%** (west) savings on lighting energy for SRT Green windows. Thermal (heating and cooling) energy savings were not apparent from this project testing.

A building energy simulation model for this test was first built using DesignBuilder software and then modified and run under EnergyPlus environment because the special SRT window's properties cannot be modeled in DesignBuilder. Simulation model results were compared and calibrated using the actual data from the "normalization" tests. The calibrated model's accuracies on total electricity are -2.2% and +4.5% respectively for the two test energy systems. Simulation runs under six cycles of actual comparison testing conditions show that the Pleotint SRT Green windows can save approximately **3.7%** total electricity compared to standard low-e dark tinted windows, while the Pleotint SRT Azuria windows can save **2.1%** total electricity. Most of the energy savings were also from lighting energy: **14%** (south) ~ **31%** (west) savings for SRT Azuria windows, and **35%** (south) ~ **51%** (west) savings for SRT Green windows. Thermal (heating and cooling) energy savings were not significant. These simulation results match the actual normalized testing comparison results fairly well.

The calibrated simulation model also runs a full-year simulation using typical Des Moines, Iowa weather data. Annual total electricity consumption simulation results show that Pleotint SRT Green windows can save **3.7% ~ 4.3%** building electric energy under different internal load conditions, and the Pleotint SRT Azuria windows can save **2.1% ~ 3.9%** building electric energy.

1. INTRODUCTION

1.1. Background

In buildings, windows are one of the most important components in deciding heating and cooling loads and therefore overall building energy use. Properly designed and selected windows provide occupant comfort while minimizing the heating and cooling energy required for the building. Energy flows through windows via solar radiation, thermal conduction/convection/radiation, and air flow (ventilation and/or infiltration). Among these factors, solar radiation usually is the biggest factor. Nowadays, commercial buildings often use double-pane low-emissivity (low-e) coatings and gas fills as standard windows for increased window thermal resistance (R-value) and reduced solar heat gain coefficient (SHGC) compared to traditional clear glass windows.

Normal windows have fixed properties (U-value, R-value, solar heat gain coefficient, etc.) Since the 1990s, a new type of window called electrochromic window was studied and later become commercially available [1] [2]. Electrochromic windows can be darkened or lightened electronically via a small voltage applied (or reversed) to the windows. This technology gives the capability of controlling the amount of light and heat that pass through the windows and presents an opportunity for the windows to be used as energy-saving devices. However, a complicated control mechanism is usually needed.

Another type of window that can passively change properties automatically, depending on the solar and temperature conditions, started to emerge in recent years [2]. Pleotint, LLC recently developed a Sunlight Responsive Tinting ("SRT™") window that can passively tint the window automatically when there is direct sunlight, without using any control devices. These windows block the sun's rays and reduce the sun's heat and glare under direct sunlight, while allowing more visible light when there is no direct sunlight. Pleotint claims that SRT windows have multiple energy benefits:

- Maximizing daylighting - visible light transmission of 50-55% - less artificial light needed.
- Reduce direct solar heat gain – SHGC as low as 0.13 – less air-conditioning needed.
- Reduce building energy required at peak demand thus lowering the peak demand charge.
- On new construction – reduce the size of HVAC equipment because of lowered heating/cooling demand.

Other benefits include improving building occupant comfort and health and sun protection to reduce fading damage, etc. These were not the focus of this project.

Figure 1 shows the Pleotint SRT Window basic structure and Table 1 shows the typical performance properties for one model.

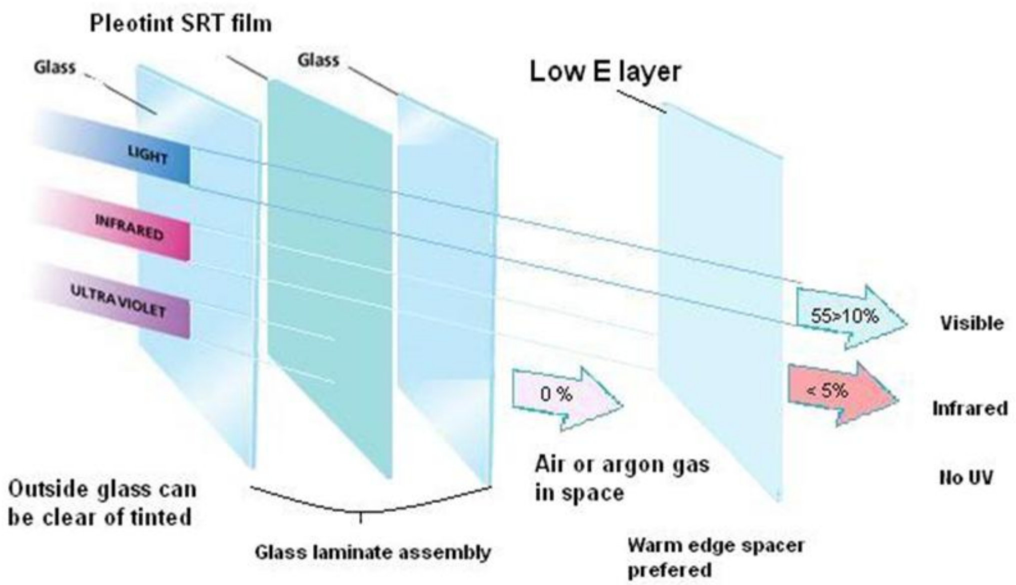

Figure 1. Pleotint SRT Window System

Table 1. Typical SRT Window Performance

Performance	@ 25 Deg C	@ 65 Deg C
Total Visible	50%	12%
Total Solar	17%	5%
Fading Factor	28%	8%
Solar Heat Gain	0.29	0.13
Shading Coefficient	0.33	0.15
Relative Heat Gain	220 w/m^2	109 w/m^2
U-factor	0.24	
R-value	4.2	

*Figure 1 and data in Table 1 are provided by Pleotint, LLC. Table 1 data is based on 5mm clear glass/SRT film/5mm clear glass-12 mm argon-6mm Solarban 70xl glass.

While the above window properties at certain temperatures can be measured in a lab environment, there was a need to do a test to evaluate and validate SRT window energy performance over a year cycle in a real building environment, especially to compare with current commercially available and commonly used standard low-e dark tinted windows. This project is part of a research project funded by the Department of Energy to demonstrate and assess energy and daylighting performance for Pleotint SRT windows in a light commercial office building environment in typical Midwest weather conditions (near Des Moines, Iowa).

1.2. Objectives

The objectives for this project are as follows:

a. Conduct a year-round, real-world, side-by-side comparison test for two different double pane models ("Azuria" and "Green") of SRT windows to compare with conventional commercial grade double pane, fixed dark tinted windows incorporating a low-E coating. The test will be undertaken every other month, two weeks/month – one week for double pane "Azuria" SRT windows and one week for double pane "Green" SRT windows, in a light commercial office building environment.
b. Demonstrate thermochromic window energy performance under various conditions to quantify total energy usage by analyzing and performing thermal and electrical system energy evaluations based on testing data.
c. Build and validate/calibrate a building energy simulation model for the comparison testing setup so simulation model results can later be used to extrapolate energy performance of other locations or weather based on standard weather data files.

1.3. Iowa Energy Center Energy Resource Station

The Iowa Energy Center Energy Resource Station (ERS, Figure 2) is located in Ankeny, Iowa, with a latitude of 41.71 degrees North and a longitude of 93.61 degrees West, and is 937 ft. above sea level. The building is part of the Des Moines Area Community College (DMACC) Ankeny campus, and was built for the purposes of examining various energy-efficiency measures and demonstrating innovative heating, ventilating, and air-conditioning (HVAC) concepts. The facility has a total floor area of 9,208 ft^2 and a building height of 15 ft. The facility has laboratory-testing capabilities combined with real building characteristics. The distinct feature of four matched pairs of test rooms allow for side-by-side comparisons of systems in real time and in a controlled environment.

To achieve the unique ability to simultaneously test side-by-side, the building is equipped with two identical air handling units, each with its own dedicated and identical chiller. One air handling unit supplies the four test rooms designated as the A rooms and the other unit serves the four test rooms designated as the B rooms. There is one A test room and one B test room arranged as pairs in a side-by-side design with each pair having a different exposure (Figure 3). There is a pair of test rooms that face the south, an east and west facing pair, and an interior pair of test rooms with no exterior exposure. Each of the test rooms is a mirror image of its match with identical construction. Detailed dimensional data on the individual rooms are shown on Table 2, which itemizes the floor, wall and window square footages and the ceiling and plenum heights for all the above referenced rooms. The rooms are unoccupied; however, the capability to impose false loads on the rooms exists. The false loads and room lighting can be scheduled to simulate various usage patterns. The A and B test rooms are individually controlled by a commercially available energy management and control system. The control system is well instrumented with near-research and commercial grade sensors installed. This system is capable of accurately controlling and monitoring operating conditions with over 1100 data points.

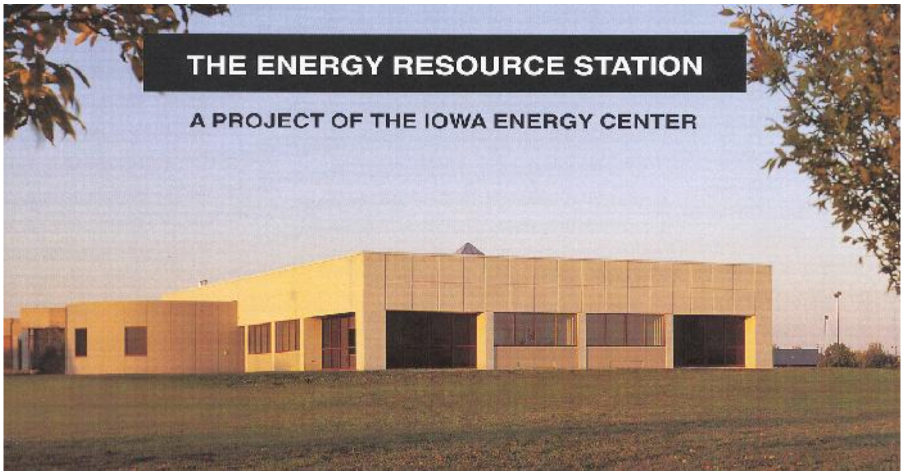

Figure 2. Iowa Energy Center Energy Resource Station

Table 2. Test Room Sizes

Room Designation	Net Floor Area, (ft^2)	Ceiling Height (ft)	Plenum Height, (ft)	Exterior Wall (ft^2)	Window Area (ft^2)
East A/B	266	8.4	5.5	137	74
South A/B	266	8.4	5.5	137	74
West A/B	266	8.4	5.5	137	74
Interior A/B	266	8.4	5.5	0	0

In addition, the geographical location of the building itself provides annual outside air temperature and humidity extremes that represent the majority of the climate zones. Testing equipment under high relative humidity conditions or extreme cold temperatures is possible due to seasonality of the Iowa climate.

Figure 3. Energy Resource Station Floor Plan

2. BUILDING ENVELOPE, TEST ROOM LAYOUT, AND TEST HVAC SYSTEM

2.1. Building Envelope

The general construction of the ERS is a structural steel frame building with precast concrete panels that are insulated on the interior. The floor is a slab-on-grade construction. All rooms are finished. Partition walls are metal stud frame construction with gypsum wall board. The ceilings are suspended lay-in acoustical tile in all rooms except in the mechanical area which is exposed structure.

The floor of the building is constructed of 4 inch concrete on a 4 inch layer of sand. The exterior wall envelope is constructed of white, gray and buff colored architectural precast concrete panels. These panels are either 6 inches or 4 inches thick depending on location. The construction layers inward from the precast concrete panels generally consist of rigid insulation, air space, vapor barrier, metal stud walls insulated with fiberglass, and gypsum wall board. Each elevation with the exception of the north has windows.

The exterior walls of the six test rooms located on the east, south and west sides of the facility are constructed of a lower wall area, a window section and an upper wall area. The lower wall area has a height of 3 feet and is divided into three vertical components consisting of two side sections and a center section. The upper wall area construction layers are the same in all six exterior test rooms. A picture of south test room exterior is shown in Figure 4, and a detailed drawing of the construction layers for the center wall section of a typical test room is shown in Figure 5.

Figure 4. South Testroom Exterior Elevation

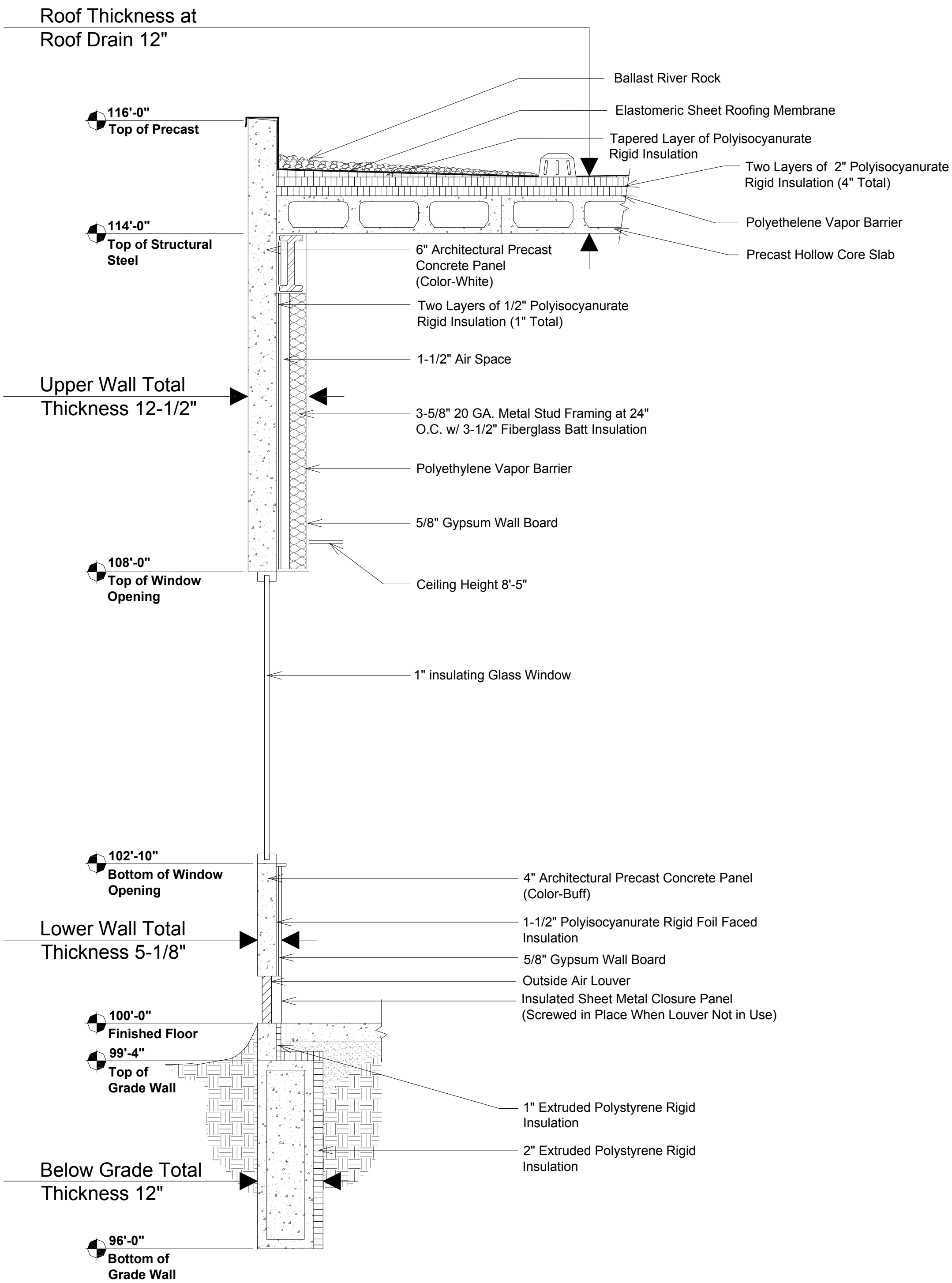

Figure 5. Typical Testroom Center Wall Section

The interior walls of each test room extend to the roof to isolate it from the adjacent test room and the general areas of the building. The interior walls are either a standard 3-5/8" metal stud partition wall with 5/8" gypsum board or, where there are structural columns located, a 6" metal stud wall with 5/8" gypsum board. The insulation in the interior walls of the test rooms is 1/2 lb. open-celled polyicynene spray foam insulation. The walls separating the test rooms from the media center include a partial glass section to allow vision into the test rooms and daylight into the center media area of the building. This glass section is made up of single glazed 1/4" inch clear insulating safety glass and measures 7' high by 6' wide. There are nine equal sections with aluminum frames and thermal breaks. For this research project, all glass sections are fully covered with 5/8" gypsum board from inside the room (Figure 6 & Figure 7) to prevent general lighting from the center of the facility (not part of the eight test zones) from affecting the test rooms. These boards also have similar surface reflectivity compared to other test room interior surfaces. Each test room has a standard hollow-core metal door.

Figure 6. Glass Section View From Outside of Testrooms

Figure 7. Glass Section View From Inside of Testrooms

The roof structure of the Energy Resource Station is flat with a tapered insulation system to allow for drainage of water through the roof drains. The construction layers of the main portion of the roof, including the test rooms, are composed of the following layers from interior to exterior; 8” precast hollow core slab, vapor barrier, 4” of rigid polyisocyanurate insulation, a tapered layer of insulation (varies from 0-5”), elastomeric roofing membrane and rock ballast.

The windows’ properties and setup for this project will be discussed in Chapter 3.

2.2. Test Room Layout and Reflected Ceiling Plan

As shown in Figure 3 in Chapter 1, there are four test rooms in each set of A and B rooms for a total of eight test rooms (East-A, East-B, South-A, South-B, West-A, West-B, Interior-A, Interior-B). The test room layout is in matched side-by-side pairs of A and B test rooms with the location of each pair having its own directional exposure. The A rooms are identical in construction specifications to the corresponding B room, except that they are in mirror image.

Figure 8 shows a typical pair of A & B testrooms’ layout for this project. A desktop computer with display is set on a desk along one side of each room, with a self-made “Android” simulating sensible heat generated by office staff in the front of the desk. In addition, there is a two-stage baseboard heater that can generate false internal load in each of the test rooms when needed (not shown in Figure 8).

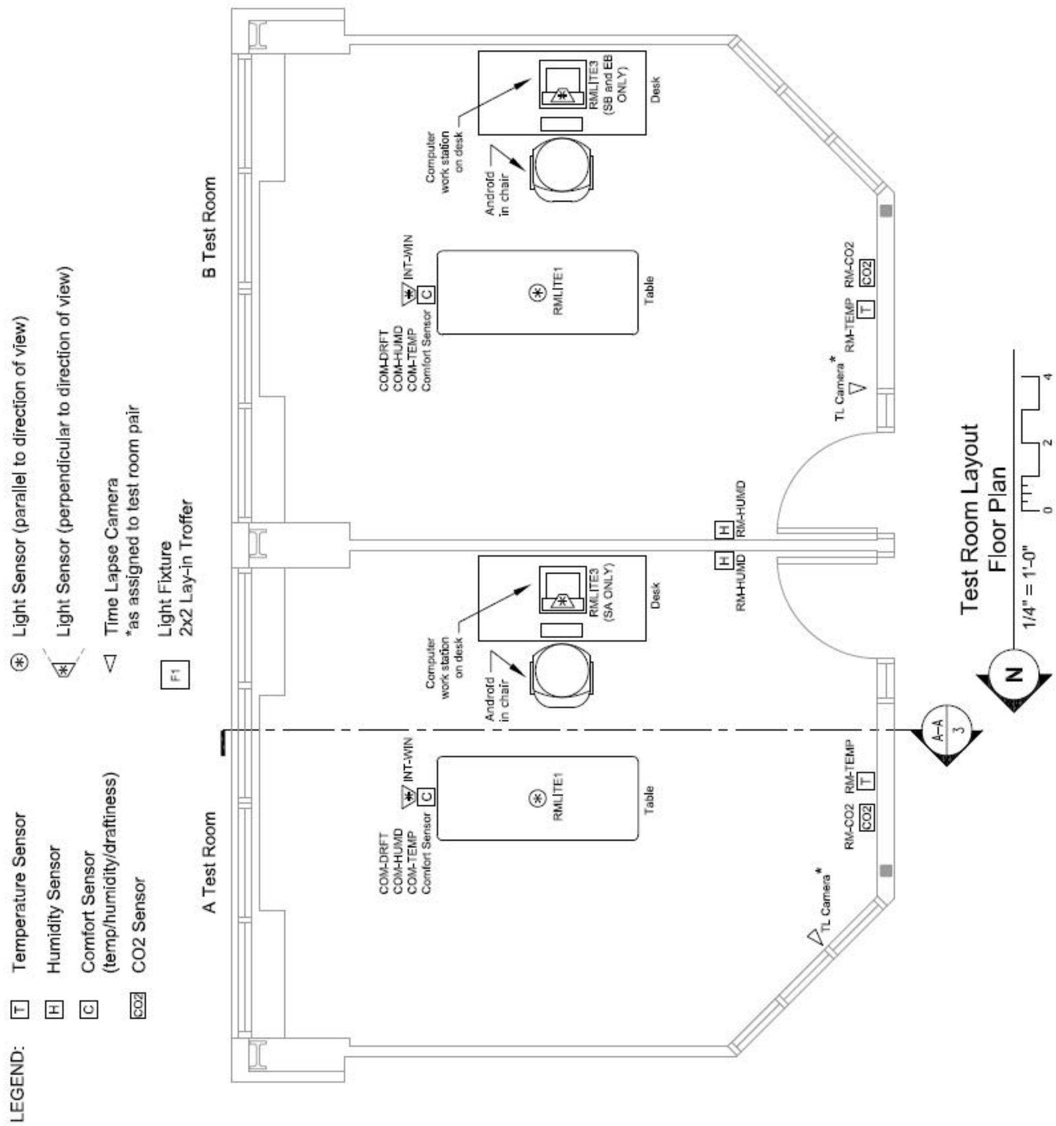

Figure 8. A & B Testroom Layout

The lighting fixture type installed in the test rooms is a recessed grid troffer measuring 2' x 2'. Each fixture is equipped with three U-shaped T8 fluorescent tube lamps sized at nominal 31 watts each. All the test room fixtures have dimmable ballasts. There are a total of six lights in each test room, and they are set up for 2-stage lighting. Figure 9 shows the reflected ceiling plan for a typical testroom. Each exterior testroom was equipped with a high-resolution web-camera to record snapshots of the test room at 10-minute intervals from *5:00am to 8:00pm* each testing day.

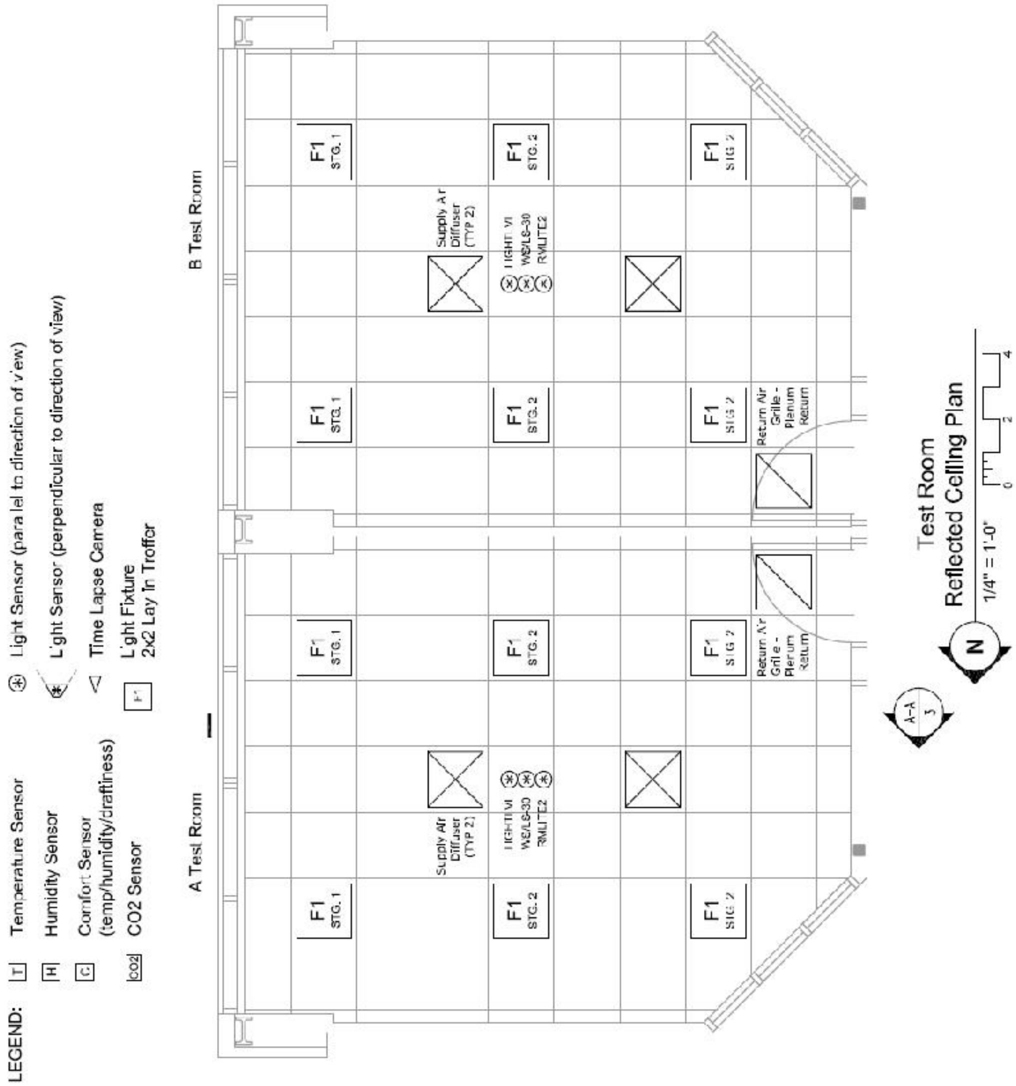

Figure 9. A & B Test Room Reflected Ceiling Plan

2.3. Test Room Internal Loads

There are four types of controllable internal loads in each test room – lighting load, people sensible heat load, office equipment load, and false thermal load generated by the baseboard heater. These loads can be scheduled ON or OFF via the ERS building automation system. The nominal capacities of these loads are listed in Table 3 to Table 6. The lighting load capacities listed in Table 3 are dimmable lighting power with 100% output (full power and brightness).

Table 3. Test Room Lighting Load

Room Designation	Stage 1 (Watt)	Stage 2 (Watt)	Total (Watt)
East A/B	186	372	558
South A/B	186	372	558
West A/B	186	372	558
Interior A/B	186	186	372

Table 4. People Sensible Load

Room Designation	Android (Watt)
East A/B	150
South A/B	150
West A/B	150
Interior A/B	150

Table 5. Equipment Load

Room Designation	Computer and Display (Watt)
East A/B	88
South A/B	88
West A/B	88
Interior A/B	88

Table 6. False Load (Baseboard Heater)

Room Designation	Stage 1 (Watt)	Stage 2 (Watt)	Total (Watt)
East A/B	900	900	1800
South A/B	900	900	1800
West A/B	900	900	1800
Interior A/B	900	900	1800

2.4. Test HVAC System

2.4.1. Overview

ERS Test System includes HVAC mechanical system for the heating, ventilating, and air-conditioning of the eight test rooms and building automation system to measure and control this mechanical equipment, and collect testing data.

The primary HVAC mechanical system at the ERS consists of a central heating and cooling plant servicing two test systems air handling units and another unit for general service areas (media center, classrooms, and offices). A natural gas fired hydronic boiler and circulating pumps make up the central heating plant. The central cooling plant has three air cooled liquid chillers, a thermal energy storage unit and circulating pumps. These plants supply chilled or heating water, as required, to the air handling units and test room mechanical equipment including variable-air-volume (VAV) terminal units. The graphic in Figure 10 provides an overview of the Test HVAC System layout plan.

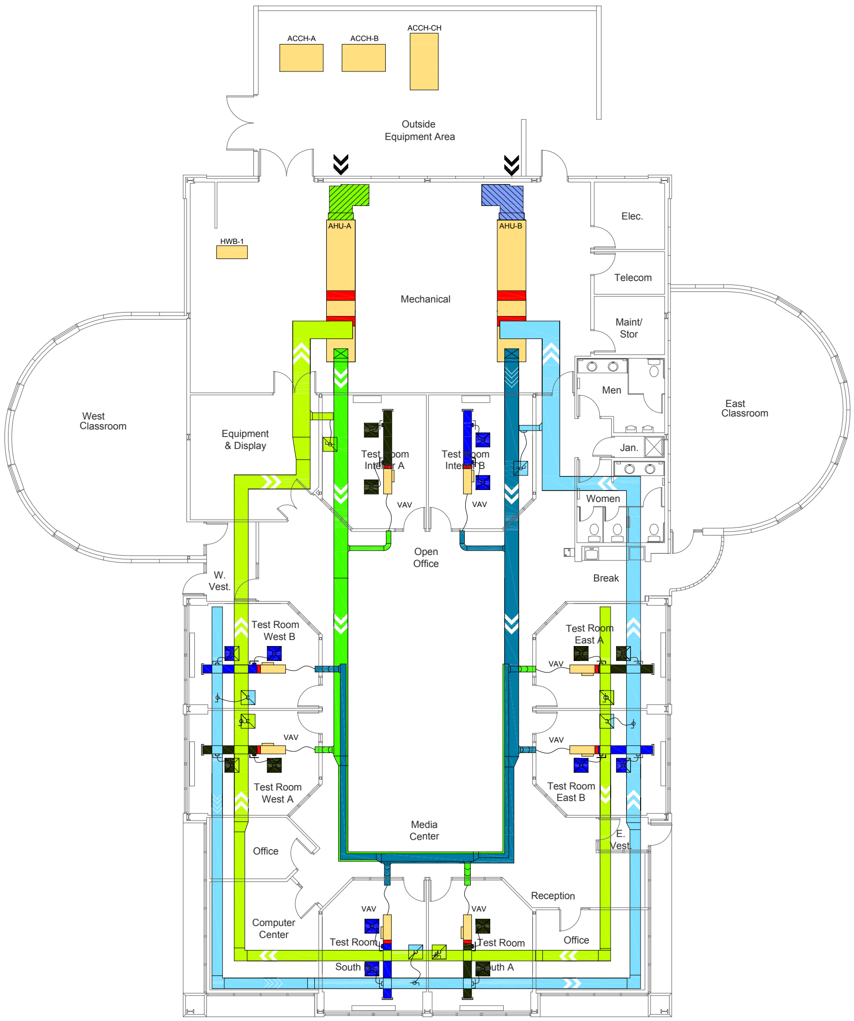

Figure 10. A&B Test HVAC System Layout

2.4.2. Air Handling Units

The test room system air handling units (AHU) are central station units that are identical in model and size. The unit designated AHU-A serves the four A test rooms and AHU-B the four B test rooms. The design intent of utilizing the central station modular type air handling units for the ERS test rooms was to permit versatility and adaptability. The modular components of the units, as well as the easy accessibility of those components, allow for the removal of existing sections and reinstallation of alternate test specific equipment. The two AHUs are single-duct VAV system units that mainly move air by their supply and return fans, all controlled by variable frequency drives. Table 7 shows the main specifications of the test system AHUs, and Figure 11 and Figure 12 illustrate the AHUs.

Figure 11. Test System Air Handling Unit

Table 7. Air Handling Unit Design Specifications

Design Item	AHU-A and 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 3.20 In. WG – Total Static Pressure
Return Air Fan	Centrifugal, Horizontal Discharge 1.25 In. WG – Total Static Pressure

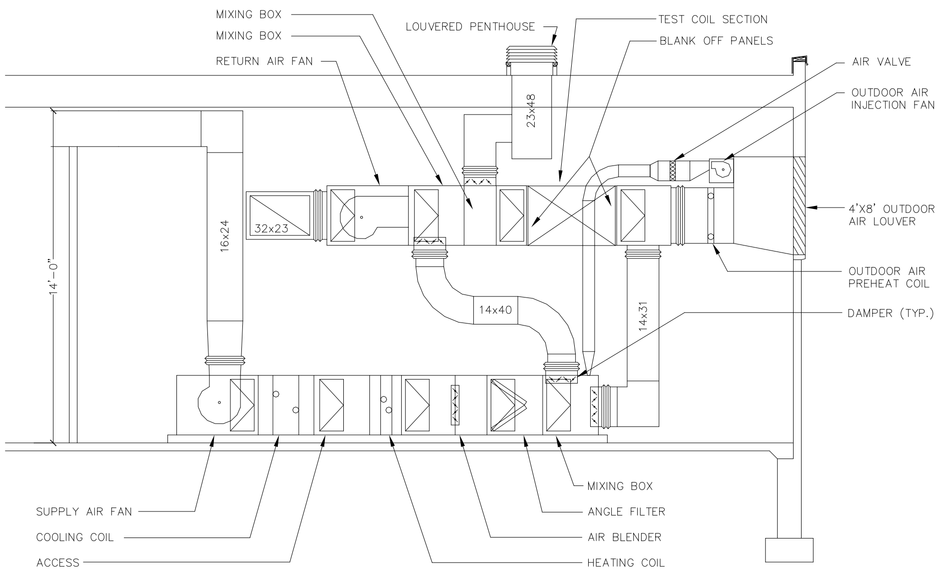

Figure 12. Air Handling Unit Section

For each test system AHU, a speed-adjustable outdoor air injection fan and air valve combination provides an alternative way to control outside air when only a minimum amount of outside air volume is required and not appropriate for the conventional outside air damper and outside air flow station to accurately measure and control. Necessary air and water temperatures, air and water flow sensors, as well as wattage meters are installed in different sections of the AHU so energy and heat transfer can be measured or calculated.

2.4.3. Testroom Terminal Units

For each testroom, a single-duct pressure-independent VAV terminal unit (pictured in Figure 13) was used to control the air volume into the room through two supply diffusers. It can also provide the reheat (via hydronic coil or electric coil) if needed. A typical pair of testrooms' HVAC partial plan is illustrated in Figure 14. It can be seen that the positions of the supply and return duct work for each pair of testrooms are symmetrically identical. Plenum return was used in this project and the test room's return air damper was automatically adjusted to maintain zero room pressure compared to the common media center space. The models of the six VAV units for the exterior rooms (EA, EB, SA, SB, WA, WB) are identical, and the two VAV units for the two interior rooms (IA, IB) are smaller in size and capacity. Main specifications for these units are listed in Table 8. For this research, hydronic reheat coils (and corresponding control valves) were used for reheat, even though the electrical coils were also available on these units.

Figure 13. Variable-Air-Volume Terminal Unit

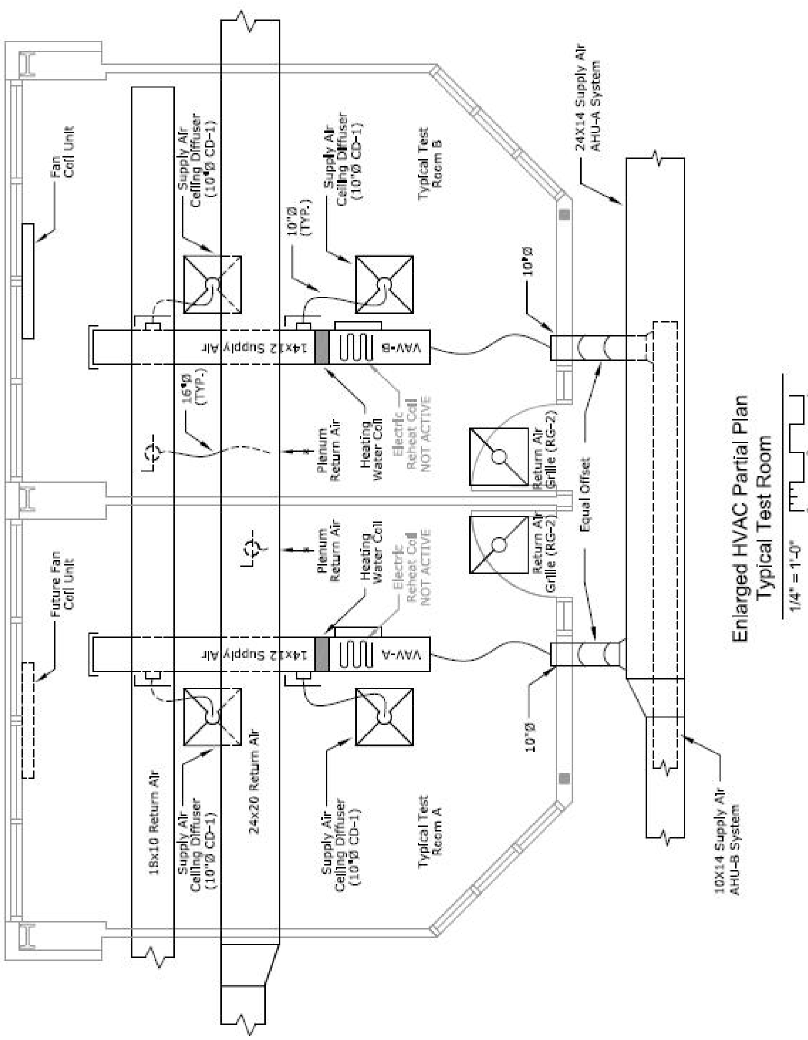

Figure 14. A & B Test Room HVAC Partial Plan

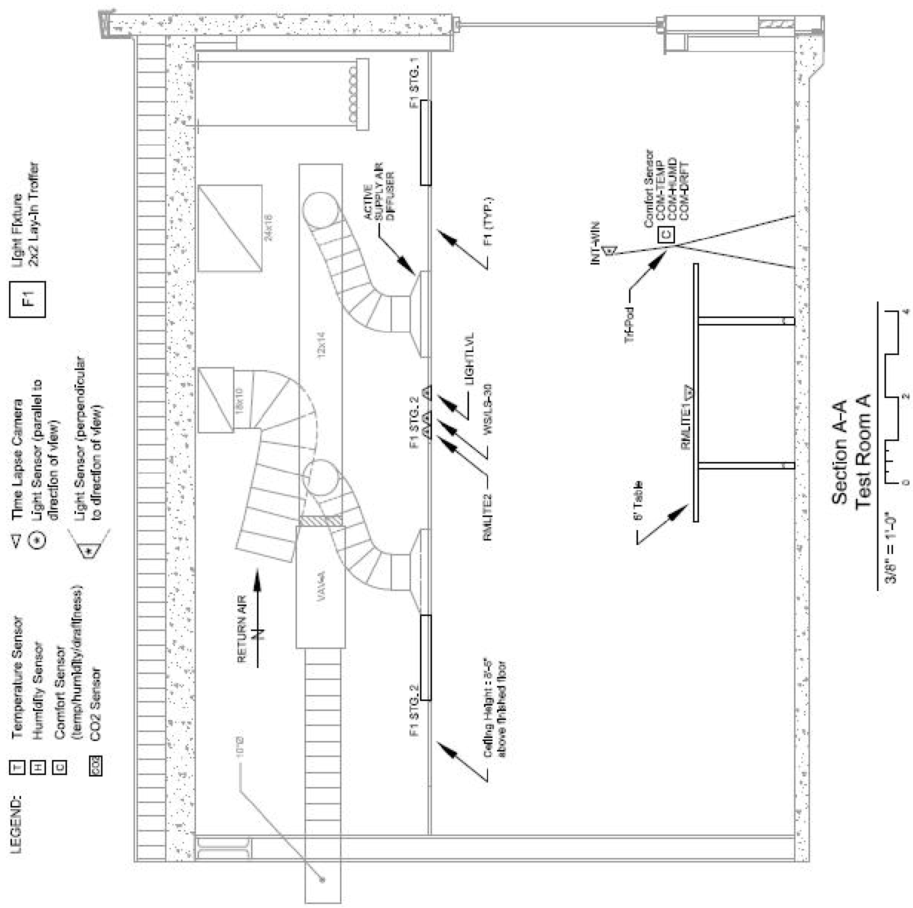

Figure 15. A & B Test Room HVAC Section Plan

Table 8. Variable-Air-Volume Terminal Unit Specifications

Design Item	Exterior Test Rooms	Interior Test Rooms
Unit Type	Single Duct, Pressure Independent	Single Duct, Pressure Independent
Inlet Size	9 Inches	7 Inches
Air Flow – Min / Max	200 CFM / 1000 CFM	80 CFM / 400 CFM
Hydronic Coil Flow Rate	3.0 GPM	1.0 GPM
Electric Coil Capacity	5.0 kW	2.0 kW
Electric Coil # of Stages / kW per Stage	3 Stages / 1.67 kW per Stage	2 Stages / 1.00 kW per Stage

Major data recorded are entering and leaving air and water temperatures, air flows for VAV boxes, and water flows of hydronic heating coils. Lighting wattages and light levels at different locations are also recorded.

2.4.4. Central Heating Plant

A natural gas fired hot water boiler (Figure 16, also referred to as HWB-1 as shown in Figure 17) is the main component of the heating plant. There are a total of five in-line circulating pumps for the heating plant that make up the five separate heating circuits of the plant. Three pumps provide water to the coils in the three air handling units. The other two are loop pumps that serve terminal heating equipment including VAV terminal units' hydronic coils in the A and B test rooms (shown in Figure 17). The loop A pump serves four A test rooms, while the loop B pump serves four B test rooms. Table 9 lists the design specifications for the boiler and Table 10 shows the design specifications for the heating water pumps.

Figure 16. Natural Gas-Fired Boiler

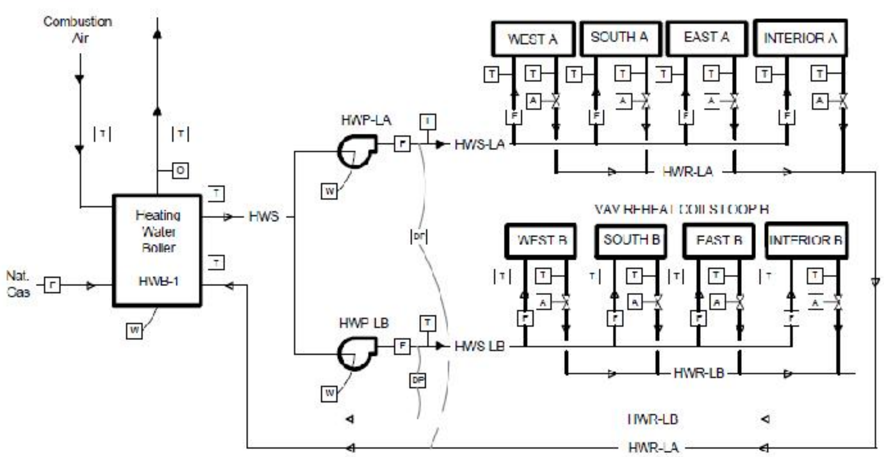

Figure 17. Heating Water System Schematic

Table 9. Heating Water Boiler Design Specifications

Design Item	Boiler HWB-1
Boiler Type	Natural Gas Fired Hot Water
Maximum Capacity	930,000 BTU/H
ASME Working Pressure	150 PSIG
Water Volume	23 Gallons
Control Range	50° to 220° F
Rated AFUE	92%

Table 10. Heating Water Pumps Design Specifications

Design Item	AHU Heating Coil Pumps	Loop A & Loop B Pumps
Pump Type	In-Line Centrifugal	In-Line Centrifugal
Pump Head Pressure	11.3 PSI	21.7 PSI
Water Flow	21.0 GPM (AHU-A & B) 40.0 GPM (AHU-1)	24.0 GPM
Motor Horsepower	0.50 HP (AHU-A & B) 0.75 HP (AHU-1)	1.00 HP
Motor Speed Control	Fixed	Variable

2.4.5. Central Cooling Plant

There are three air-cooled chillers (ACCH-CH, ACCH-A, and ACCH-B in Figure 18) each with nominal ten-ton capacity located outside the equipment area on the north side of the ERS building. Figure 19 illustrates the chilled water system schematic that is relevant to this project. Test Systems AHU-A and AHU-B were provided with chilled water from either dedicated chillers, ACCH-A and ACCH-B, or by common chiller ACCH-CH. The chiller ACCH is used for projects that require matched chilled water supply temperature to both AHUs and that one chiller has enough cooling capability for both AHUs. The ACCH-A and ACCH-B are identical and provide the option of a dedicated chilled water circuit for each set of test rooms when separate chiller wattages are needed and cooling capability for each system may exceed 10 tons. Table 11 shows the chillers' design specifications.

There are seven in-line circulating pumps in the central cooling plant, all located in the mechanical equipment room (Figure 19 shows five of the pumps that are relevant to this test). The thermal energy storage tank is installed partially underground just outside of the facility and used with ACCH-CH to provide smoother chilled water supply temperature. It is an internal melt ice-on-tube type of unit. All chilled water pumps run at a fixed speed (therefore near constant chilled water flow rates as all chilled water valves are three-way control valves) during this project, even though some of them can be controlled using variable frequency drives. Table 12 shows these pumps' design specifications.

Figure 18. Chillers

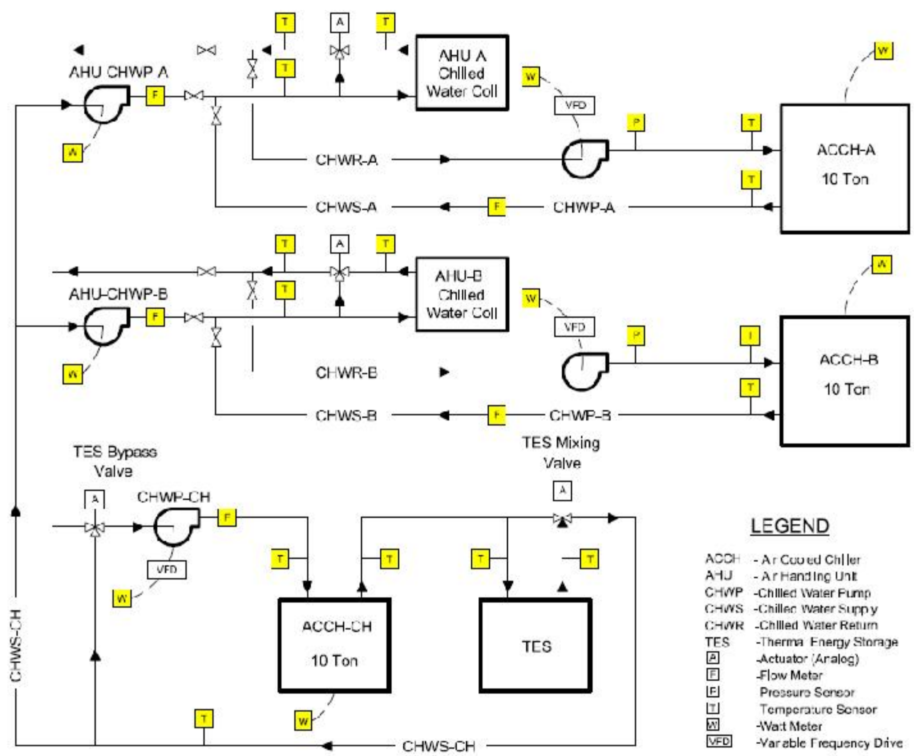

Figure 19. Chilled Water System Schematic

Table 11. Chillers Design Specifications

Design Item	Test Room Chillers ACCH-A & ACCH-B	General Service Chiller ACCH-CH
Chiller Type	Air Cooled Liquid	Air Cooled Liquid
Chiller Serves	System A / System B	General Service / System A / System B
Nominal Unit @ ARI Conditions	95°F Entering Air Temperature	95°F Entering Air Temperature
Capacity	9.8 Tons (34.3 KW)	9.6 Tons (33.8 KW)
Flow Rate	24.0 GPM	24.0 GPM
Leaving Water Temp	44.0°F	44.0°F
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
Refrigerant Circuits	1 Refrigerant Circuit	1 Refrigerant Circuit
Heat Transfer Fluid	25% Propylene Glycol	25% Propylene Glycol
Electrical Characteristics	460 Volt / 3 Phase / 60 Hertz	460 Volt / 3 Phase / 60 Hertz

Table 12. Chilled Water Pumps Design Specifications

Design 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	28.0 GPM (AHU-A & B) 45.0 GPM (AHU-1)	24.0 GPM	24.0 GPM
Motor Horsepower	0.50 HP (AHU-A & B) 1.00 HP (AHU-1)	1.50 HP (ACCH-A & B) 1.00 HP (ACCH-CH)	1.00 HP
Motor Speed Control	Fixed (AHU-A & B) Variable (AHU-1)	Variable	Variable

3. PLEOTINT WINDOWS AND TEST PROTOCALS

3.1. Clear Window and Low-E Dark Tinted Window

The exterior windows in the test room for a typical research project conducted at ERS are double-glazed 1/4 inch clear insulating glass with 1/2 inch air space ("clear" window). The overall rough opening for the windows in each test room measure 5 feet high by 14.8 feet wide. The windows have 2" wide aluminum frames with 2" wide mullions. There are no exterior shading devices utilized. For this research project, standard low-e dark tinted windows were installed in one of the two independent test systems ("A" test system) as "control" or "benchmark". Since each test system includes one East, one South, one West and one Interior test room, there were a total of 12 panes of standard low-e dark tinted windows installed (4 panes installed in each of the three exterior test rooms). The clear and standard low-e dark tinted window thermal properties are listed in Table 13.

Table 13. Clear and Low-E Window Thermal Properties

Test Room	Type	Color	Height by Width ft x ft	Overall U Value Summer Btu/h · ft^2 · °F	Overall U Value Winter Btu/h · ft^2 · °F	Visible Transmittance	Shading Co-efficient
Base Clear Windows	Annealed Insulated	Clear	rough opening 5' x 14' window size (4 each) 55" x 39" (nominal)	0.55	0.48	81%	0.85
Alternate Standard Performance (Dark Tint) Windows	Annealed Insulated	Dark Tint	rough opening 5' x 14' window size (4 each) 55" x 39" (nominal)	0.33	0.31	23%	0.26

3.2. Pleotint Windows

Two different models of Pleotint windows were tested in this project and both were compared with the standard low-e dark tinted window. One Pleotint model is an aqua-blue window – "Azuria" model, and the other model is a light-green colored window – "Green" model. Both models are double-pane windows and appear clear if there is no direct solar exposure. The "Azuria" model seems darker than the "Green" model under similar strong direct solar conditions. Figure 1 in Chapter 1 shows the basic structure of Pleotint windows.

3.3. Test Protocols

For this research project, a side-by-side system comparison approach was used for testing Pleotint SRT windows in comparison with the standard low-e dark tinted windows. The testing was conducted in a light-commercial-office-building-type research testing and demonstration facility – Iowa Energy Center Energy Resource Station.

3.3.1. Test Cycles and Sub-Tests

To cover a one-year period of testing, the test was implemented in six test "cycles", with the first cycle starting on March 23, 2011. Each cycle was approximately two months apart, and consisted of 2 sub-tests: sub-test 1 was for "Azuria" windows to compare with standard low-e windows, and sub-test 2 was for "Green" SRT windows to compare with standard low-e windows. Each sub-test covered at least 7 continuous days of testing, and could be longer depending on factors like facility test schedule and window installers' availability. Table 14 illustrates the test dates for each test cycle and sub-tests.

Table 14. Test Cycles and Sub-Test Dates

Test Cycles	Sub-Tests	Test Dates	Windows
1	1.1	03/23/2011 – 04/10/2011	"Azuria" vs. Low-E
	1.2	04/12/2011 – 04/19/2011	"Green" vs. Low-E
2	2.1	05/24/2011 – 05/31/2011	"Azuria" vs. Low-E
	2.2	06/2/2011 – 06/12/2011	"Green" vs. Low-E
3	3.1	07/29/2011 – 08/07/2011	"Azuria" vs. Low-E
	3.2	08/09/2011 – 08/15/2011	"Green" vs. Low-E
4	4.1	09/28/2011 – 10/04/2011	"Azuria" vs. Low-E
	4.2	10/06/2011 – 10/12/2011	"Green" vs. Low-E
5	5.1	11/23/2011 – 11/30/2011	"Azuria" vs. Low-E
	5.2	12/02/2011 – 12/08/2011	"Green" vs. Low-E
6	6.1	02/02/2012 – 02/08/2012	"Azuria" vs. Low-E
	6.2	01/25/2012 – 01/31/2012	"Green" vs. Low-E

3.3.2. Normalization Test

Since this test was done in a real building environment, mismatch did exist for the side-by-side test systems due to many factors such as building design and construction differences, instrumentation accuracies, etc. Therefore the testing results needed to discount the "system errors" when both systems are setup the same. A two-day "normalization" test was implemented at the end of each test cycle to find out the percentage errors between the two independent systems.

The setup for the normalization tests was the same as the test cycles that immediately preceded them, except both A and B testroom windows were replaced with "Base Clear Windows" described in Section 3.1. The successful normalization test dates for each test cycles are listed in Table 15 below.

Table 15. Normalization Test Dates

Test Cycles	Sub-Tests	Test Dates	Windows
1	1.1&1.2	04/21/2011 – 04/22/2011	Clear vs. Clear
2	2.1&2.2	06/14/2011 – 06/15/2011	Clear vs. Clear
3	3.1&3.2	08/20/2011 – 08/23/2011	Clear vs. Clear
4	4.1&4.2	10/15/2011 – 10/16/2011	Clear vs. Clear
5	5.1&5.2	12/14/2011	Clear vs. Clear
6	6.1&6.2	02/11/2012 – 02/12/2012	Clear vs. Clear

3.3.3. Test Room Setup

Four A testrooms and four B testrooms were setup the same with the exception of the windows for the exterior rooms. Three A exterior rooms were installed with standard low-e windows during all testing cycles, and three B exterior rooms were installed with Pleotint SRT windows (refer to Table 14 for specific models for each sub-test).

The testroom layout is illustrated in Section 2.2, Figure 8. Each testroom simulated an office room with two staff and one computer. The two working staff were simulated by a self-made “Android” with 150 watt light bulb inside. The computers (about 88 watts each) and androids can be scheduled ON/OFF based on occupancy schedule. A high resolution web-camera was installed in a corner of each room and recorded snapshot photos once every 10 minutes from *5:00am to 8:00pm* for a comparison of the visual lighting condition inside the room. However, the occupancy period for each testing day was from *6:00am to 6:00pm*. The room temperature heating and cooling setpoint for all eight test rooms was a constant 70 Deg F and 74 Deg F, respectively, during all test cycles, as illustrated in Figure 19.

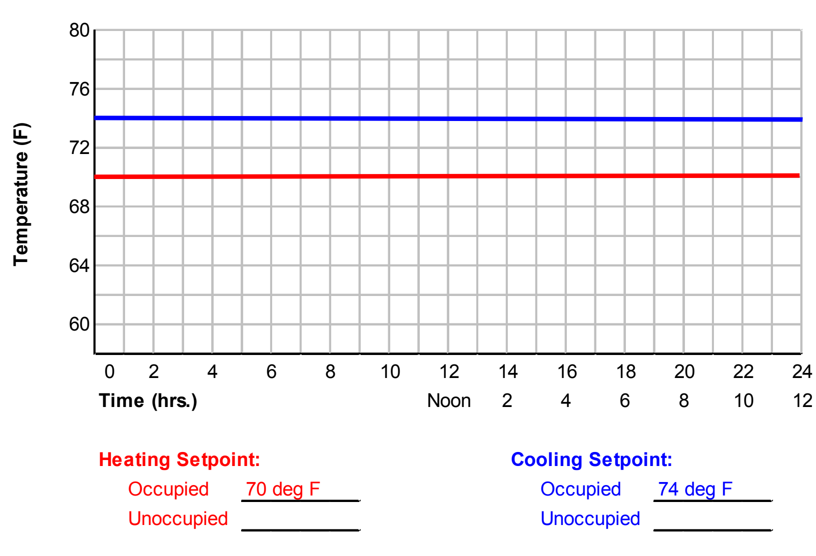

Figure 20. Room Temperature Setpoint Schedule

The internal loads for this project include: lighting, people and computer, and false load simulated by baseboard heaters. These internal loads were scheduled according to Figure 21 ~ Figure 24.

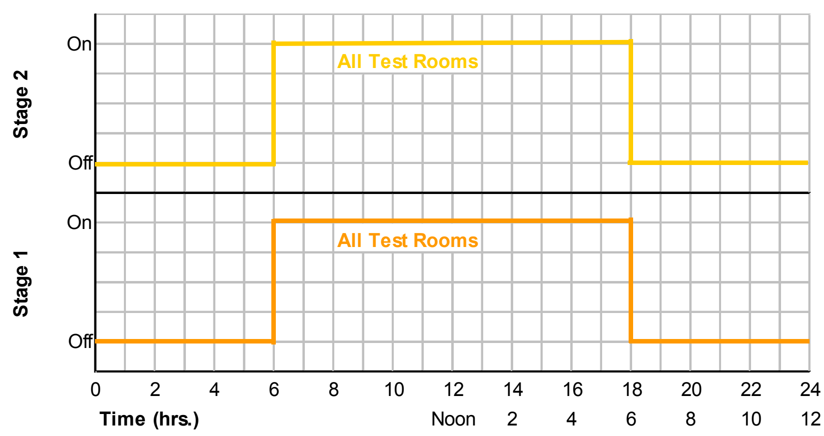

Figure 21. Lighting Schedule

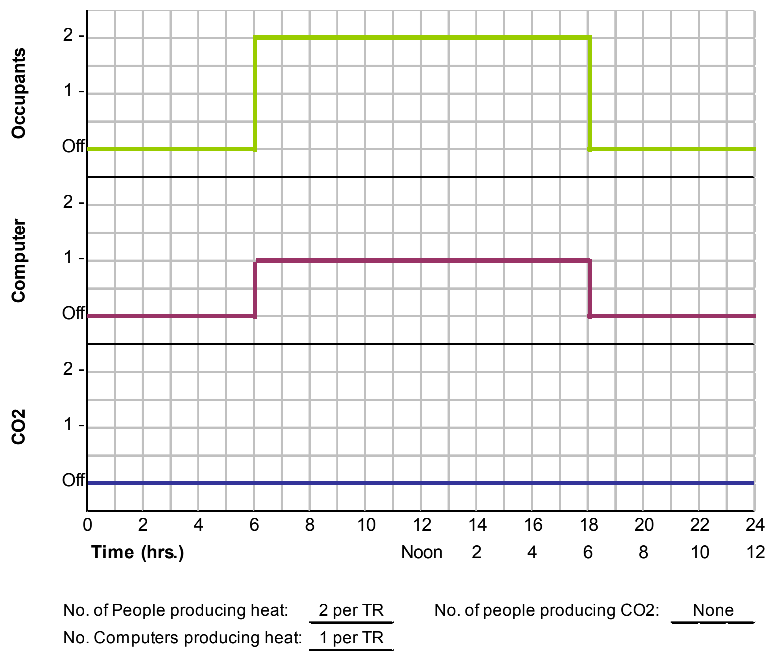

Figure 22. People and Computer Schedule

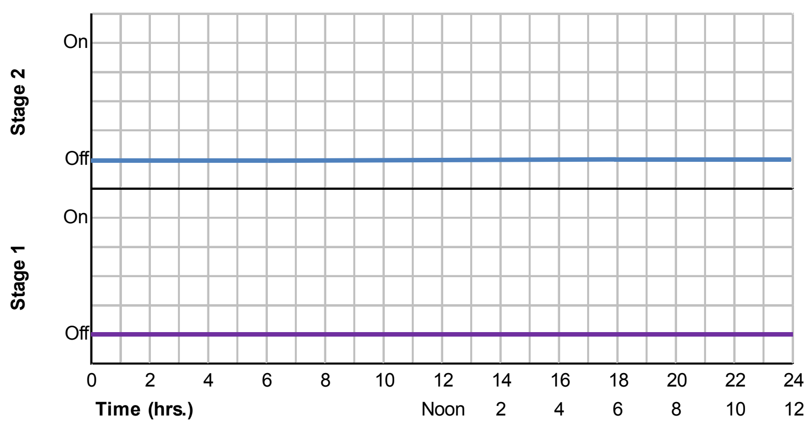

Figure 23. False Baseboard Heat Load Schedule (Test Cycle 1 ~ 2)

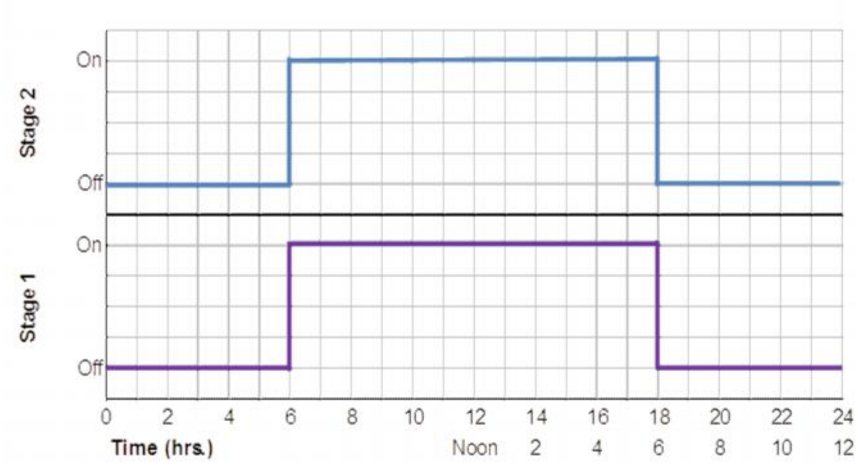

Figure 24. False Baseboard Heat Load Schedule (Test Cycle 3 ~ 6)

The lights in the six exterior A and B testrooms were controlled by the building automation system as continuous linear dimming/off control – meaning the lights could be automatically turned ON/OFF depending on the lighting conditions inside the room, even though these lights were scheduled ON/OFF based on the lighting schedule in Figure 21. For each exterior test room, the dimming control set point was set at 45 foot-candles and the light sensor was placed on the table surface (surface height: 2 feet and 4.5 inches) in the middle of the room. For detailed light control sequence descriptions, please refer to Appendix E.

Since there are no windows for the two interior rooms, the lights in Interior-A and Interior-B rooms were simply ON/OFF with constant full power based on the schedule in Figure 20. The nominal full power output wattages for each room is listed in Table 3 in Chapter 2.

The occupants (150 watts) and Computers (88 watts) were schedule ON/OFF at the same time from *6:00am to 6:00pm* as indicated in Figure 22.

Initially there was no false baseboard heat load planned in all test cycles. The baseboards in the testrooms were turned on starting from Test Cycle 3 because the first two test cycle preliminary results revealed that the cooling loads were too small to make the test HVAC system have significant variance in air flow rates. This is due to the initial HVAC system design being based on clear windows in all testrooms and one baseboard heat stage ON in each of the testrooms, and both standard low-e and Pleotint windows reduced the solar radiation into the rooms significantly. After discussion with a Pleotint representative, two-stage baseboard heat schedules were added for Test Cycle 3 to test Cycle 6 (Figure 24).

3.3.4. Test HVAC System Setup

The heating and cooling of the four A test rooms was provided by air handling unit A (AHU-A), and four single-duct Variable-Air-Volume (VAV) terminal units - one in each of the A test rooms. Similarly, the four B test rooms were conditioned by air handling unit B (AHU-B), and four single-duct Variable-Air-Volume (VAV) terminal units. For Test 1.1 only, the chilled water was provided by the common chiller ACCH-CH. The air handling units ran in recirculation mode with 120 CFM constant outside air for each system provided by the outside air injection fan for accurate outside air measurement and control. For all following sub-tests, Chiller ACCH-A provided chilled water to AHU-A, and Chiller ACCH-B provided chilled water to AHU-B. The boiler HWB-1 provided heating water to both A and B systems. For system schematics and equipment specifications, please see Section 2.4.

The two air handling units' control mode is illustrated in Figure 25. They were enabled ON/OFF from *6:00am to 6:00pm*. The air handling unit supply air temperature setpoint was set at a constant 55 Deg F, and the static pressure setpoint was set at 1.4" W.C. for both AHUs and during all test cycles and sub-tests.

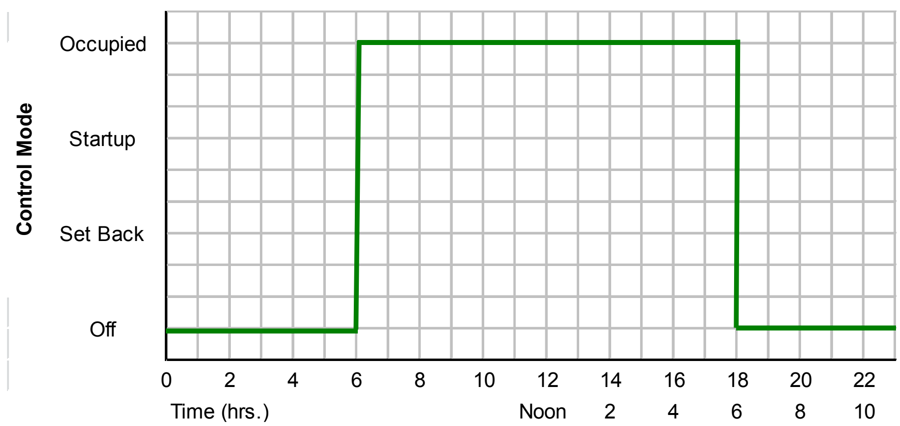

Figure 25. Air Handling Units Control Mode Schedule

All chillers, boilers, chilled water pumps and heating water loop pumps (for VAV reheat) were controlled by the test building automation system automatically, thus would be turned on as necessary and completely shut off when there is no heating/cooling load, or in the unoccupied period after 6:00pm (until the next day 6:00am). The boiler output temperature was set at 120 Deg F, and the three chillers' temperature set points were set at 42 Deg F.

3.3.5. Test Data Collection

About 600 data points in the test system were trended at 1-minute intervals by the ERS building automation system. Proprietary software was used to process the original raw database format to easy-to-use ASCII format. An in-house developed MATLAB program was used to evaluate energy performance of the two independent energy systems from the processed system data.

Three additional special temperature data points were recorded using thermocouples embedded in SRT windows facing different orientations. One thermocouple was embedded in East-B, one in South-B, and one in West-B testroom SRT windows as illustrated in Figure 26. This was to measure the temperatures inside the SRT windows. National Instruments data acquisition system was used to collect these temperature data at 1-minute intervals.

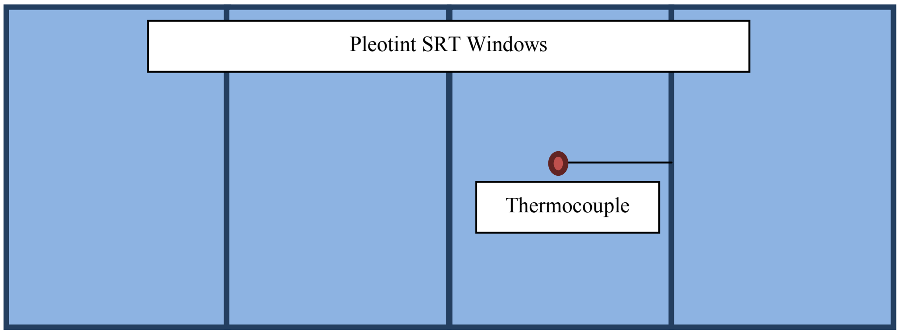

Figure 26. Thermocouple Embedded inside the SRT Windows

Snapshots of testroom conditions from inside the rooms were recorded at 10-minute intervals for the six exterior test rooms using high resolution web-cameras and a commercial video recording software. Room names and time stamps were automatically added on the snapshots when they were taken.

3.3.6. Performance Evaluation

The testing facility (Energy Resource Station) only uses two types of energy: natural gas for boiler HWB-1, and electricity for all other system components. The end-use electric energy was evaluated at system level as well as at sub-category level such as fans, pumps, chillers, and lighting – all separately counted for A and B systems. The natural gas usage was not evaluated because there is only one boiler to provide reheat for the whole building. However, the natural gas usage percentage difference between the A and B system can be estimated by the heating loop energy, because only the heating loop A and B used hot water during the project testing period.

Thermal energy use (heating and cooling energy) was evaluated at the air handling unit cooling coil for cooling, and heating water loop level for re-heat energy. Since the air handling unit provided a constant 55 Deg F supply air and ran in recirculation mode, neither air handling unit heating coil was activated during the testing periods, thus no heating energy was evaluated for AHU-A and AHU-B.

Because dimming control was used in exterior test rooms, daylighting comparison between Pleotint SRT windows vs. standard low-e was done by comparing lighting energy for each pair of A and B system exterior testrooms. Light levels were also compared at different solar conditions for those rooms. Detailed evaluations are reported in Chapter 4.

4. ENERGY AND DAYLIGHTING ASSESSMENT

4.1. Building Electric Energy Assessment

4.1.1. Building Electric Energy Subcategories

The total electric energy use in the testing facility includes five subcategories:

a. Chiller Energy
b. Fan Energy
c. Pump Energy
d. Interior Lighting Energy
e. Interior Equipment

The energy to power the control equipment and instrumentation was omitted. No other types of electric energy were consumed during the testing periods.

The total of a, b, and c is called **HVAC System Electric Energy**, and the total of a, b, c and d is called **Building Electric Energy** (Figure 27). Subcategory "Interior Equipment" includes artificial internal loads (people simulated by androids, computers, equipment simulated by baseboard heaters) were constant during the occupied periods and were the same for both A and B systems. These loads were not counted in the building electric energy comparison for this project.

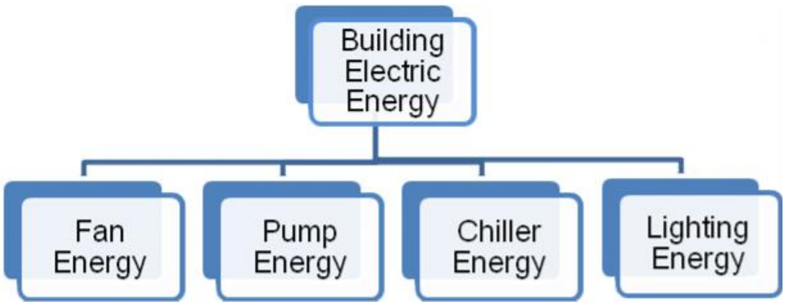

Figure 27. Composition of Building Electric Energy

For chillers ACCH-CH, ACCH-A, and ACCH-B (Figure 28), c*hiller energy* refers to energy used by the whole chiller package (compressor, condenser fan, controls, etc.) Each of the three chillers' energy was measured separately.

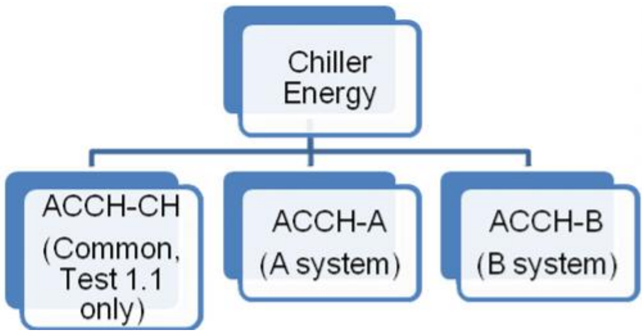

Figure 28. Composition of Chiller Energy

All sub-tests except Test 1.1 used ACCH-A and ACCH-B watt-hour measurements to compare chiller energy for A and B systems. Measured chiller energy for ACCH-CH in Test 1.1 was proportionally divided based on the ratio of sensible cooling loads of A and B systems to estimate the chiller energy for A and B systems, since chiller ACCH-CH was used as the common chiller in that test setup.

Fan energy includes supply fans and return fans of AHU-A and AHU-B and outside injection fans for both AHUs (Figure 29). The wattages were also measured separately for each fan.

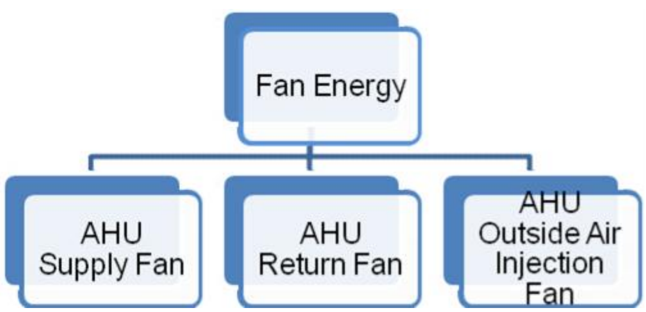

Figure 29. Composition of Fan Energy

Pump energy is the summation of energy for chilled water pumps and heating water loop pumps (Figure 30). All sub-tests except Test 1.1 used chilled water pumps CHWP-A and CHWP-B watt-hour measurements to compare for A and B systems. Measured chiller water pump energy for CHWP-CH in Test 1.1 was proportionally divided based on the ratio of cooling loads of A and B systems to estimate the chiller water pump energy for A and B systems, since the pump was used to provide chilled water for both systems. As explained in an earlier section, the heating water pumps for AHU-A and AHU-B were not activated during any of the sub-tests so they were not included in the analysis.

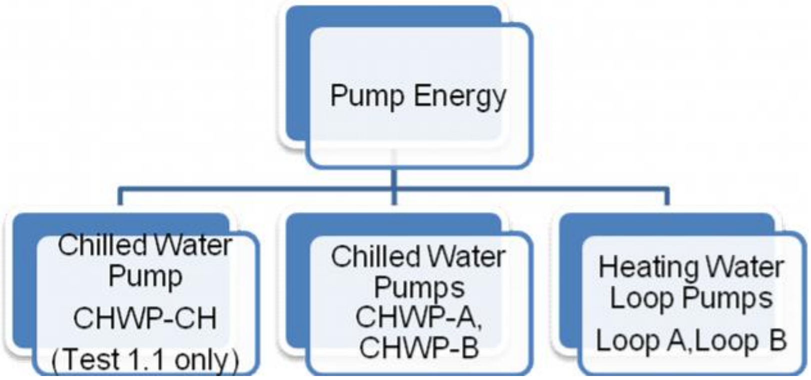

Figure 30. Composition of Pump Energy

Interior lighting energy (or simply lighting energy, since there is no exterior lighting involved in this project) were measure separately for each of the test rooms. Six exterior testrooms (East-A, East-B, South-A, South-B, West-A, West-B) used linear dimming/off control, and two interior rooms used ON/OFF control since there are no windows installed in those rooms.

4.1.2. Actual Daily Average Building Electric Energy Comparison

For Test Cycles 1 through 6, the actual average daily electric energy of the A and B systems was calculated for each sub-test. The average daily electric energy of A and B systems for the whole year were then derived from the six average daily electric energy values to account for the Pleotint window performance at different seasons. The comparison of Pleotint SRT Azuria windows vs. standard low-e windows is illustrated in Figure 31. The comparison of Pleotint SRT Green windows vs. standard low-e windows is illustrated in Figure 32. The detailed actual average daily energy comparison results for these sub-tests are listed in Appendix A: Table A. 1.1 to Table A.6.2.

It can be seen from Figure 31 and Figure 32 that both Pleotint SRT Azuria and Green models used less electric energy than the standard low-e windows. These actual comparison test results were based on the assumption that both A and B systems would perform exactly the same under the same setup and weather conditions. However, for a real building, many factors affect its final electric energy measurements and calculations – building envelope construction, HVAC system design and install, instrumentation and data acquisition system accuracy and stability, among others. It is therefore impractical to assume that A and B systems' electric energy is identical when the setups are the same. The normalization tests were performed to find out the difference between A and B systems under the same setup and weather conditions.

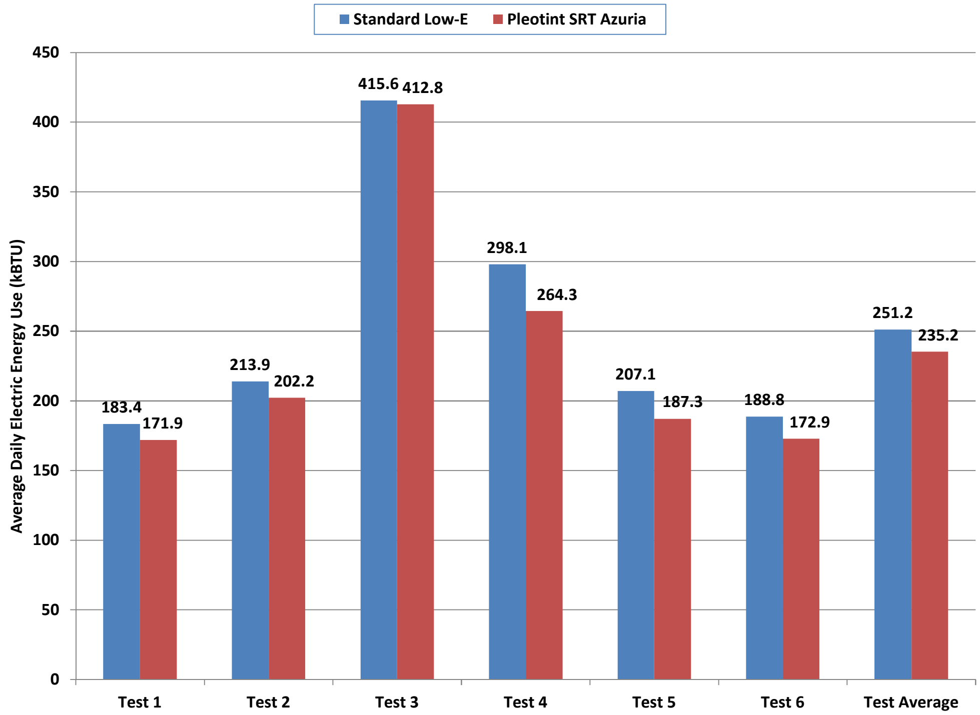

Figure 31. Actual Electric Energy: Pleotint SRT Azuria vs. Standard Low-E

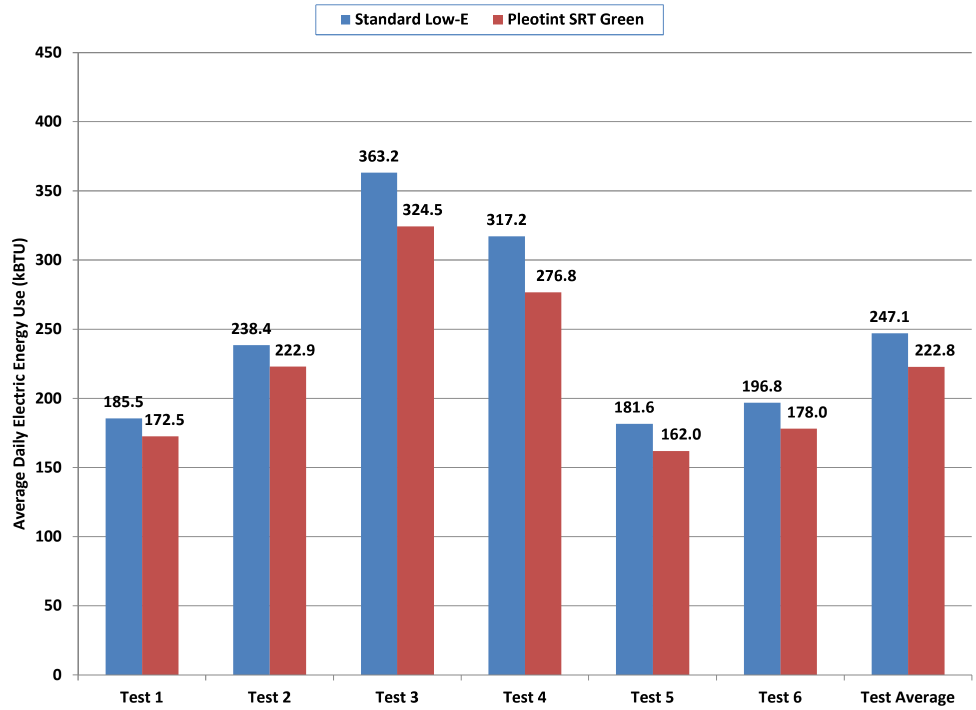

Figure 32. Actual Electric Energy: Pleotint SRT Green vs. Standard Low-E

4.1.3. Building Electric Energy Normalization

Average daily electric energy comparison results for normalization of A and B systems were calculated based on six normalization tests and are shown in Figure 33. The building electric energy percentage of differences between A and B for each test cycle are listed in Table 16.

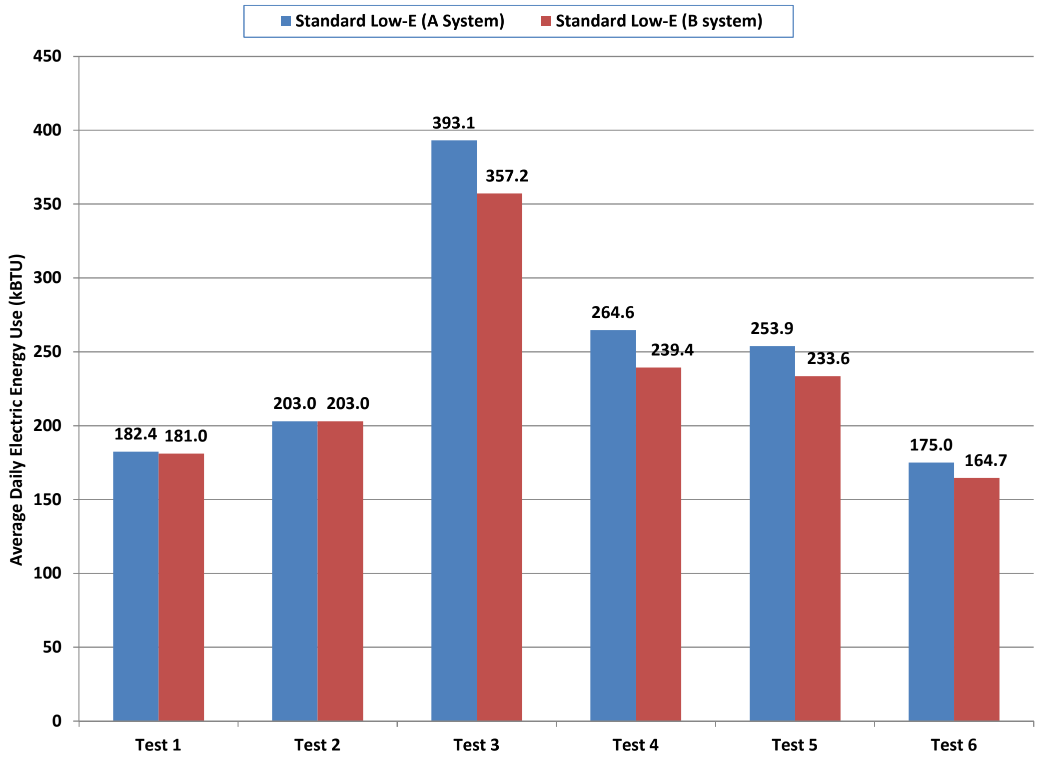

Figure 33. Building Electric Energy: Normalization Results

Table 16. Building Electric Energy Normalization Differences

Test Cycles	Average Percent Difference (System A as reference)
1	-0.77%
2	0.00%
3	-9.13%
4	-9.51%
5	-8.00%
6	-5.89%

It can be seen that the percentage of difference increased for test cycles 3~6 comparing to test cycles 1 and 2. Two factors may have affected this: 1) each of the three exterior A testrooms (East-A, South-A, and West-A) were installed with a unit ventilator by the window side at the end of test cycle 2, for the purpose of implementing another research project immediately following each of the test cycles 3~6. The inside-covers for the pre-constructed wall openings connecting unit ventilators to the outside air were removed. 2) increased internal load (simulated by nominal 1800-watt baseboard heaters in each of the eight testrooms) for both A and B systems made systems run at higher air flow rate, therefore testroom infiltration rates, uncertainties for instrumentation and data acquisition system may be different.

4.1.4. Lighting Normalization

To accurately compare lighting levels and lighting energy use under different window configurations, matching the performance of each pair of test rooms with the same windows is essential. The light levels and lighting wattages matched up very well from normalization tests where both A and B systems were installed with clear windows (Figure 34 to Figure 36).

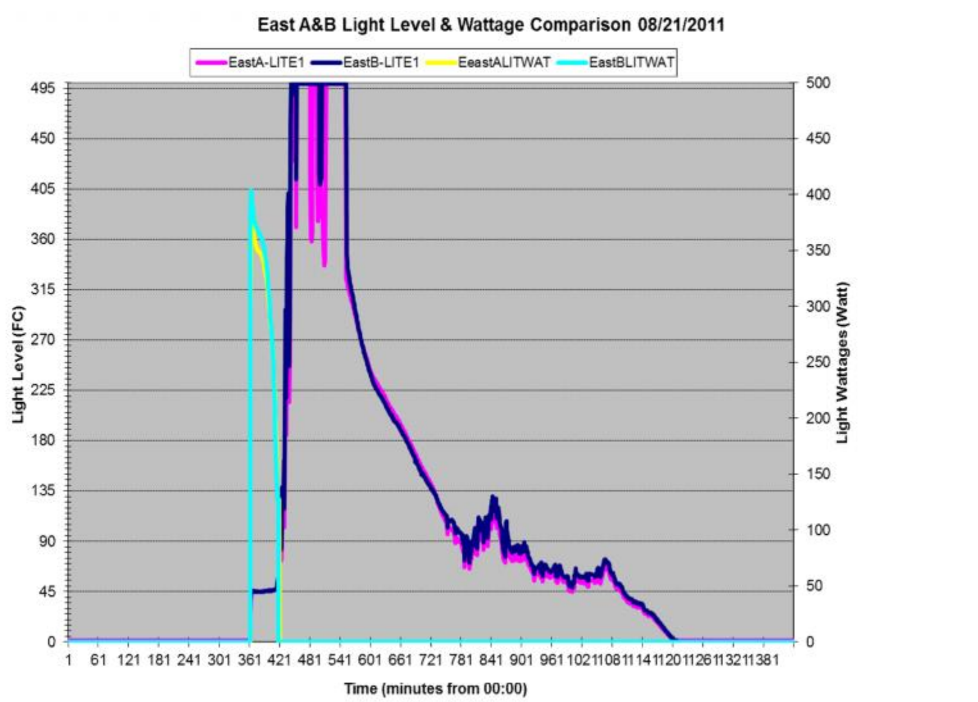

Figure 34. Lighting Normalization in East Rooms

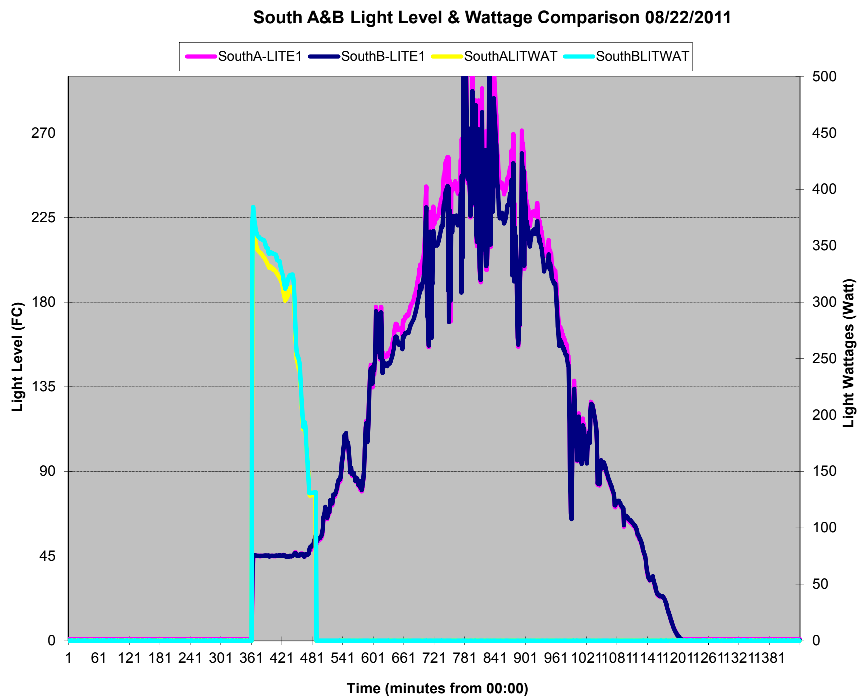

Figure 35. Lighting Normalization in South Rooms

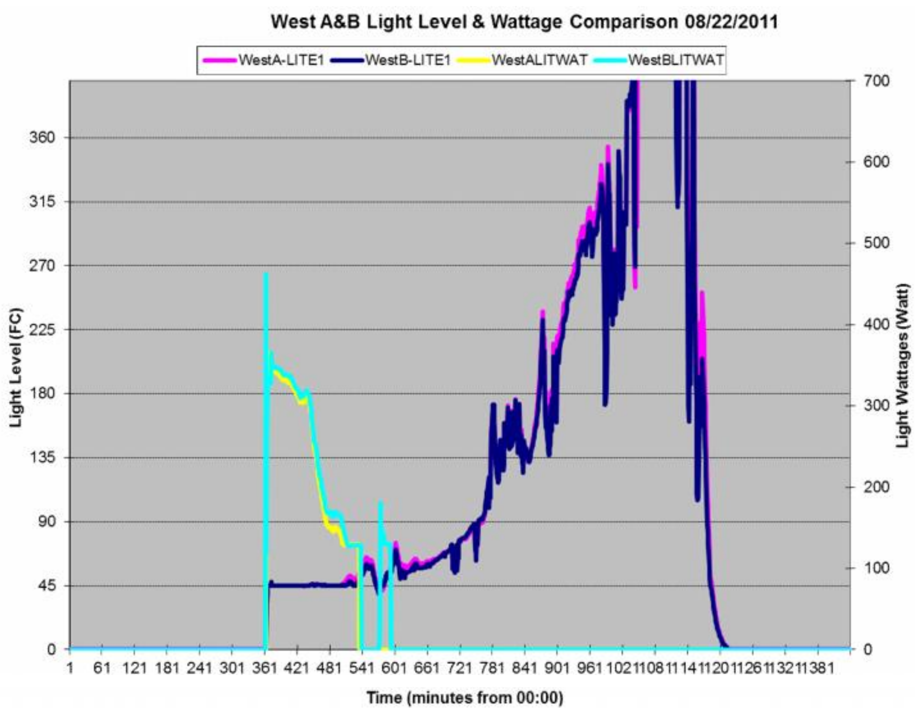

Figure 36. Lighting Normalization in West Rooms

Table 17 shows the percentage of differences on lighting energy for each pair of exterior test rooms for test cycles 1~6 normalization tests. The differences were most likely caused by solar angle difference, sensor accuracy, and exact locations of the light sensors placed on the table, etc. These percentages of errors were discounted when evaluating the Pleotint vs. standard low-e windows' lighting energy comparisons.

Table 17. Lighting Energy Normalization Differences

Test Cycles	East Rooms	South Rooms	West Rooms
1	-14.45%	-2.37%	-8.60%
2	-9.66%	-0.30%	-2.49%
3	1.92%	3.44%	15.14%
4	-1.27%	12.31%	1.92%
5	-0.40%	1.51%	-3.90%
6	6.35%	4.44%	2.32%

4.1.5. Normalized Daily Average Building Electric Energy Comparison

For a fair comparison, the actual daily average electric energy for the B system at each test cycle was discounted by the daily average normalization percentage of difference between A and B systems as shown in Table 16. The comparison of Pleotint SRT Azuria vs. standard low-e windows after normalization is illustrated in Figure 37. The comparison of Pleotint SRT Green vs. standard low-e windows after normalization is illustrated in Figure 38.

Averaging over 6 cycle periods, the Pleotint SRT Azuria windows' net effect on total building energy is negligible (251.5 kBTU/day vs. 251.2 kBTU/day, with Pleotint SRT Azuria **+0.14%**), and the Pleotint SRT Green windows' saved about **4.00%** (247.1 kBTU/day vs.237.5 kBTU/day) total electricity. Overall, the Pleotint SRT Green model did better in terms of energy savings compared to the Pleotint SRT Azuria model. From these two figures, the Pleotint windows did better in almost all seasons except the hottest periods (August/September). The reason is that Pleotint SRT windows (especially the Azuria model) became too dark when exposed to strong direct sunlight and very high outside air temperatures, and actually required the dimming control to turn on the lights in the rooms with higher percentage of outputs, while in rooms installed with standard low-e windows the lights were off or lower dimming outputs were enough. Some examples are shown in Section 4.3 daylighting assessment.

It is worth noting that the above results only apply to the testing facility under weather conditions during the testing periods. The results may change for other buildings, locations, and weather conditions.

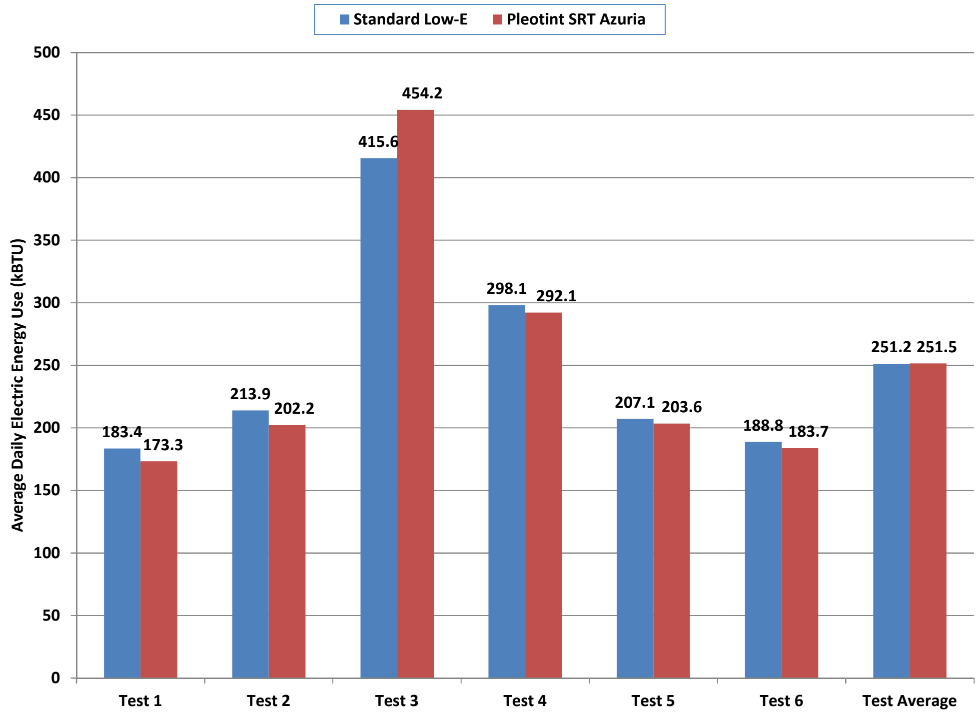

Figure 37. Normalized Electric Energy: Pleotint SRT Azuria vs. Standard Low-E

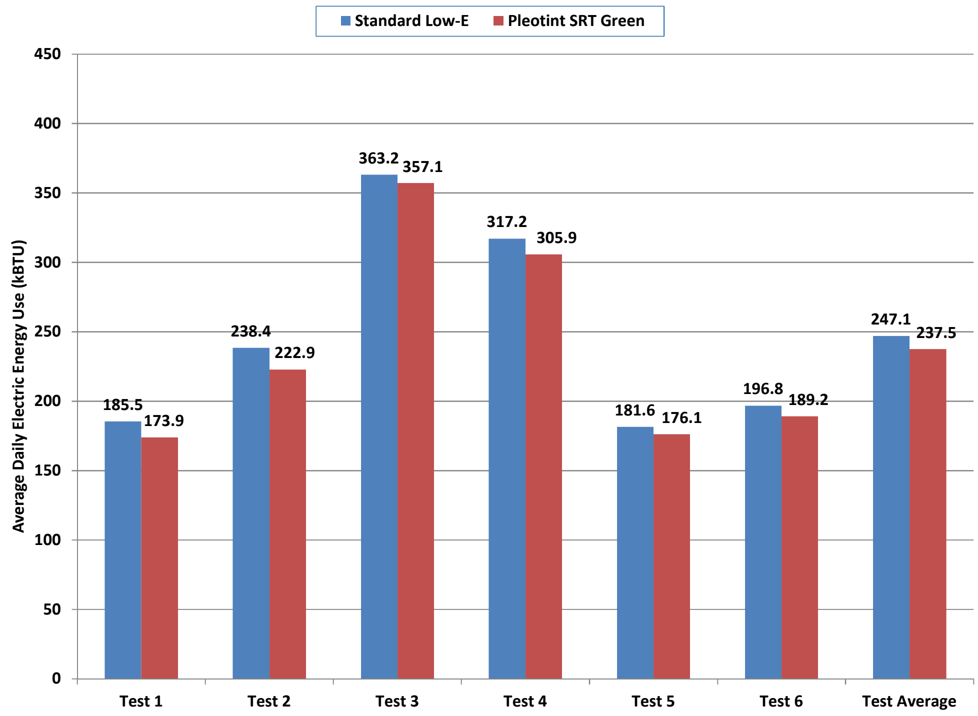

Figure 38. Normalized Electric Energy: Pleotint SRT Green vs. Standard Low-E

4.2. HVAC System Electric Energy Assessment

HVAC system electric energy includes fan energy, pump energy (chilled water and heating water pumps), and chiller energy. Table 18 shows the normalization error for HVAC electric energy at each test cycle. For the normalized average daily building electric energy comparison between Pleotint SRT windows and standard low-e windows, Figure 39 and 40 show similar trends comparing with the total building electric energy comparison figures. On average, HVAC system energy differences are small (standard low-e vs. Pleotint SRT Azuria windows 209.6 kBTU/day vs. 215.2 kBTU/day, with Pleotint SRT Azuria **+2.67%,** and the standard low-e vs. Pleotint SRT Green windows 205.5 kBTU/day vs.206.6 kBTU/day, with Pleotint SRT Green **+0.53%).** Similarly, the biggest negative impact on energy was on hottest days with strong direct solar exposure (Test 3 August/September periods).

Table 18. HVAC Electric Energy Normalization Differences

Test Cycles	Difference (A as reference)
1	0.23%
2	0.15%
3	-9.75%
4	-10.59%
5	-11.36%
6	-7.06%

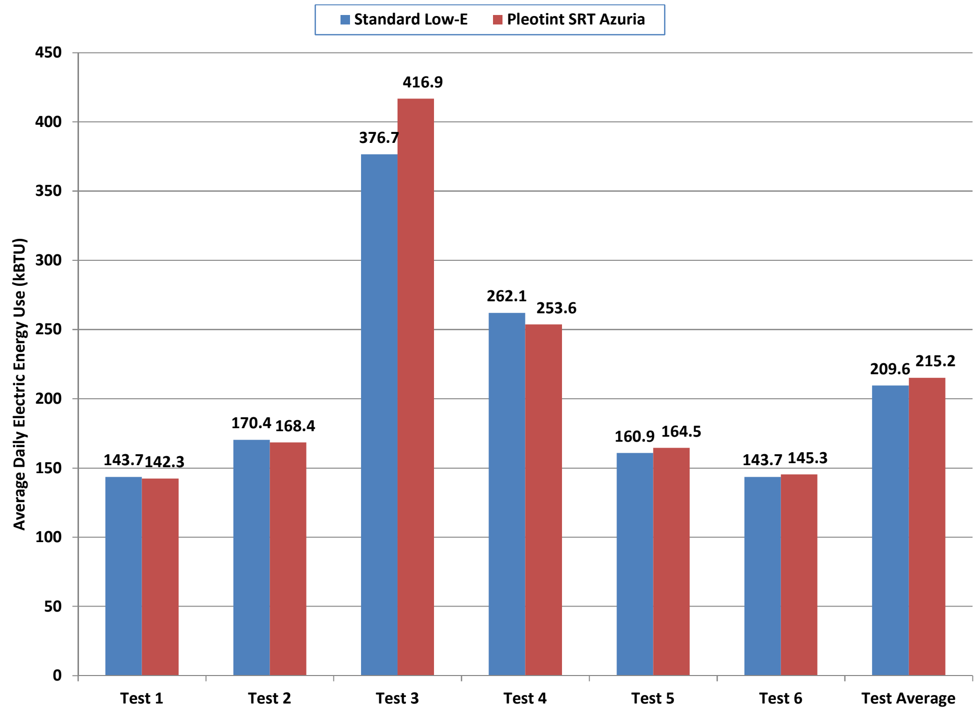

Figure 39. Normalized HVAC Electric Energy: Pleotint SRT Azuria vs. Standard Low-E

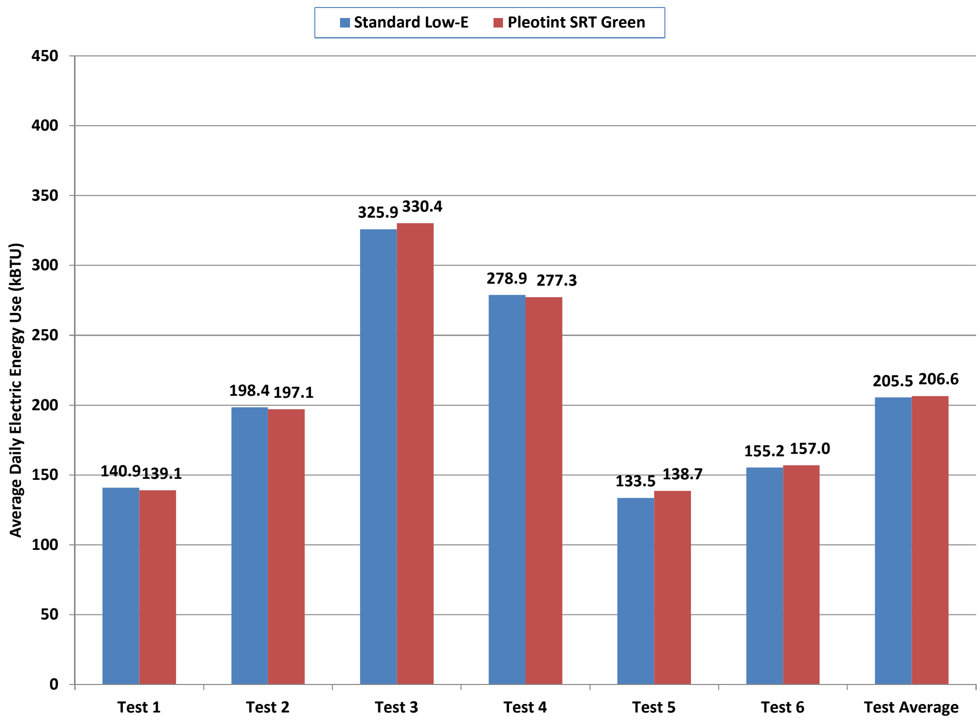

Figure 40. Normalized HVAC Electric Energy: Pleotint SRT Green vs. Standard Low-E

4.3. Daylighting Assessment

4.3.1. Daylighting Energy Comparisons

During the testing cycles 1 ~ 6, lighting energy consisted of 13%~14% of total building electric energy for system A (with standard low-e windows installed). Excluding the constant lighting for the interior test room, the lighting energy in exterior rooms for system A contributed to about 9% of total building electric energy. Lighting energy savings with Pleotint SRT windows installed in these exterior rooms were apparent and significant (Figure 41 ~ Figure 46).

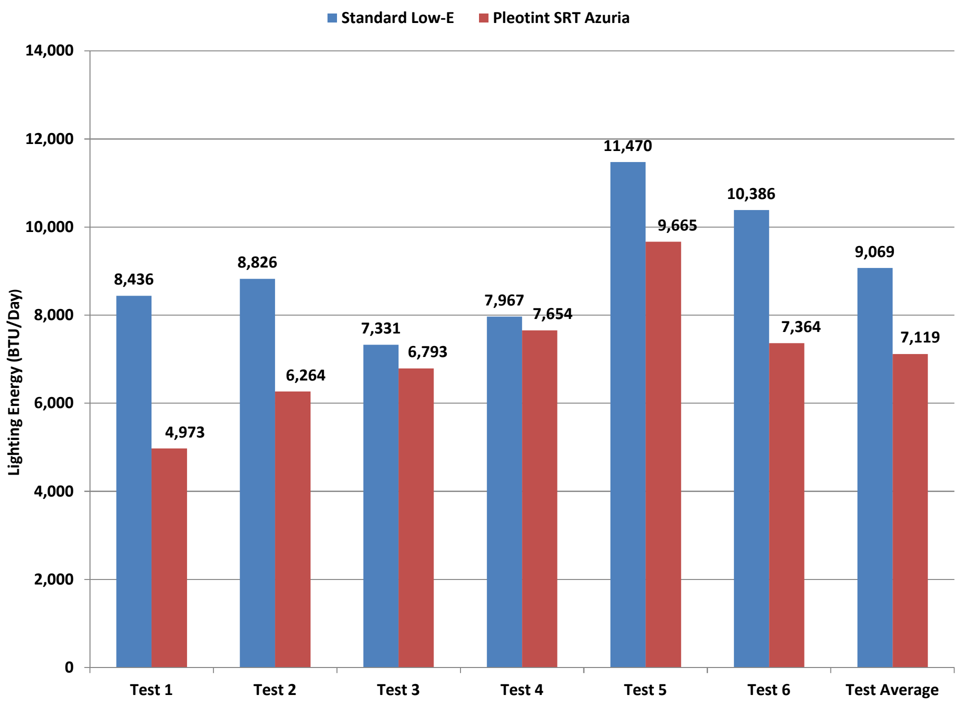

Figure 41. Normalized Lighting Energy (East): Pleotint SRT Azuria vs. Standard Low-E

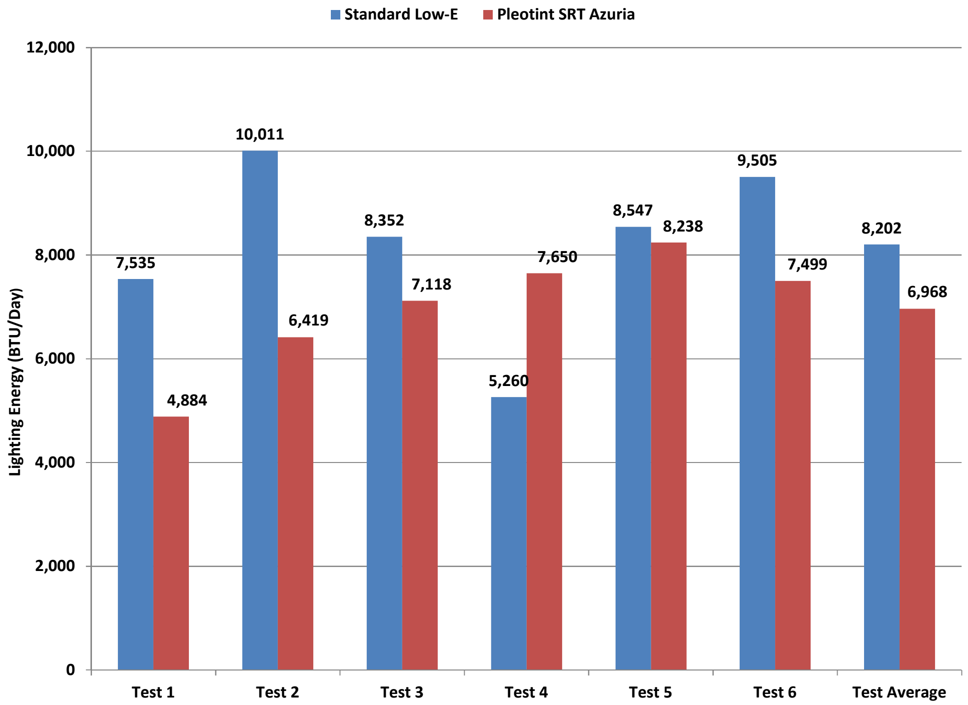

Figure 42. Normalized Lighting Energy (South): Pleotint SRT Azuria vs. Standard Low-E

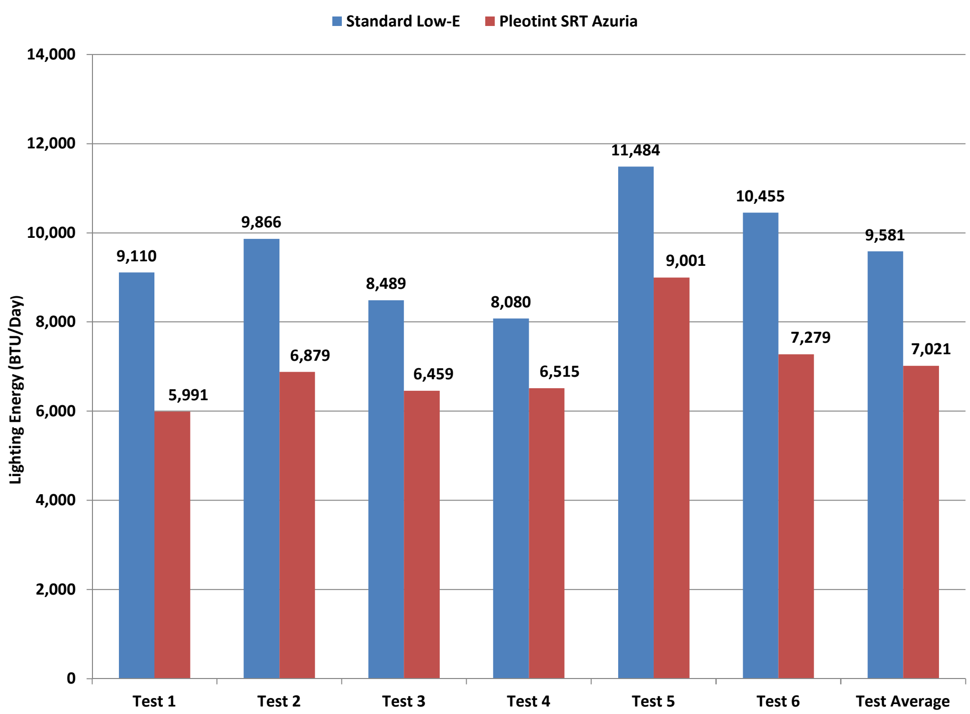

Figure 43. Normalized Lighting Energy (West): Pleotint SRT Azuria vs. Standard Low-E

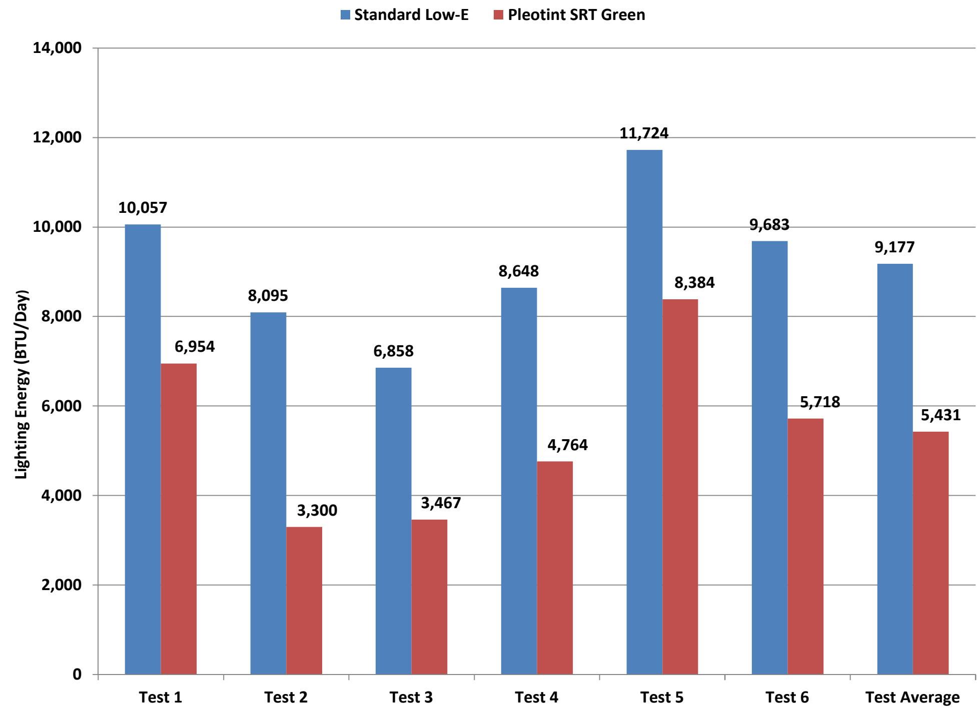

Figure 44. Normalized Lighting Energy (East): Pleotint SRT Green vs. Standard Low-E

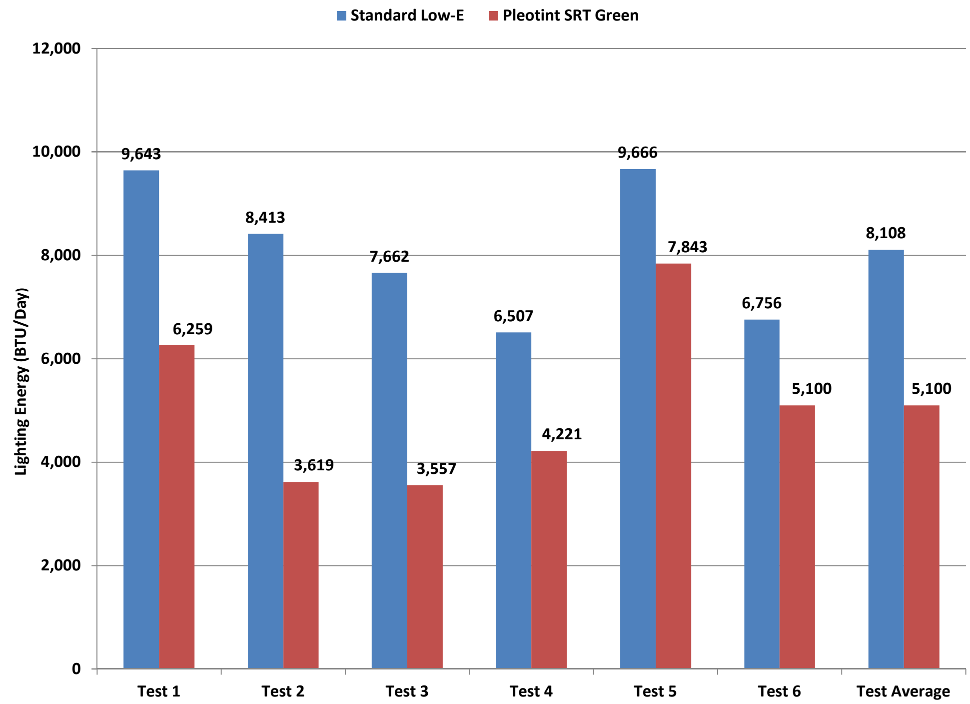

Figure 45. Normalized Lighting Energy (South): Pleotint SRT Green vs. Standard Low-E

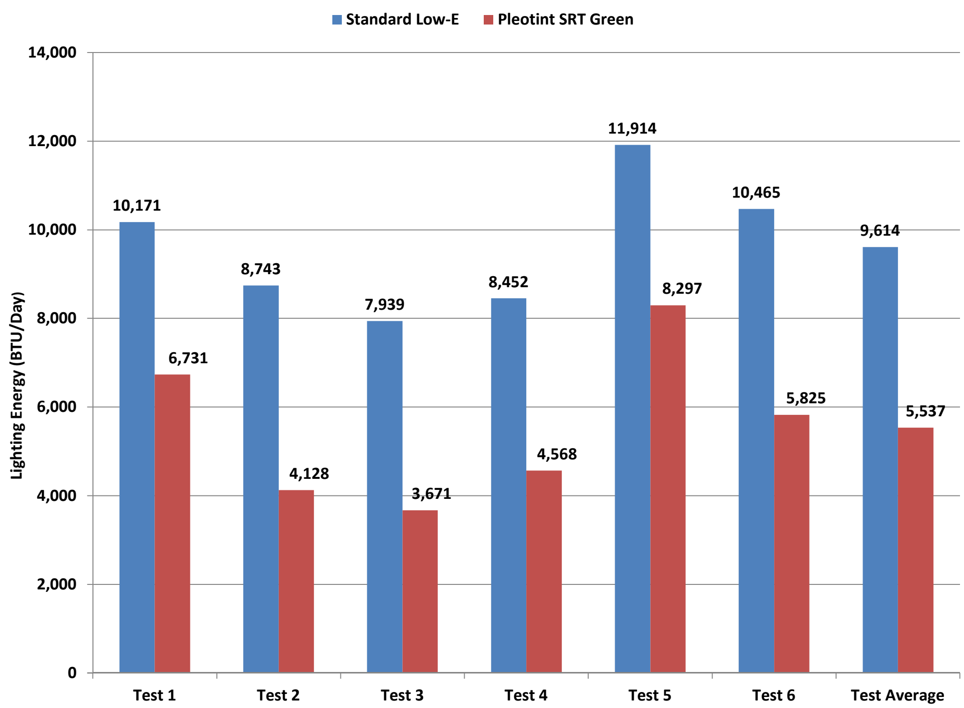

Figure 46. Normalized Lighting Energy (West): Pleotint SRT Green vs. Standard Low-E

From the above charts, several conclusions can be made about lighting energy savings for Pleotint SRT windows when using automatic linear dimming/off lighting control:

- On average, lighting energy savings for Pleotint SRT Azuria windows are about **21.5% (East)**, **15.0% (South)** and **26.7% (West)**.
- On average, lighting energy savings for Pleotint SRT Green windows are about **40.8% (East)**, **37.1% (South)** and **42.4% (West)**.
- Pleotint SRT Green model saved more lighting energy than the Azuria model.
- During the hottest days of summer, the south facing rooms used more energy than standard low-e windows for both Pleotint SRT window models.
- **Overall, lighting energy savings contributed to most of the net building energy savings for Pleotint windows.**

4.3.2. Intraday Light Level and Lighting Energy Comparison

Several examples are given below to show how light levels were maintained at 45 foot-candle minimum and lighting energy saved in a pair of testrooms with different windows installed.

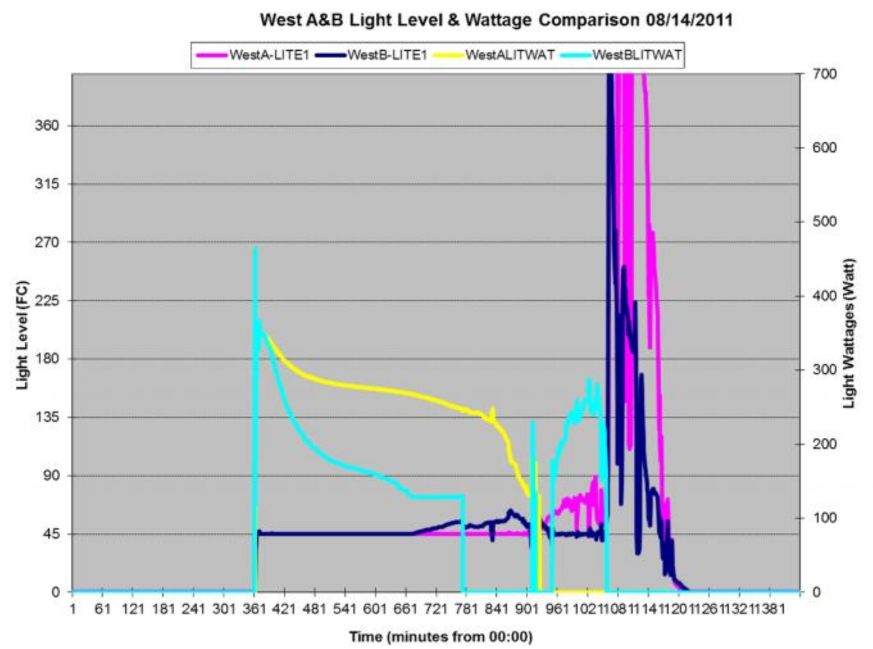

Figure 47. Intraday Light Level and Light Wattages (West)

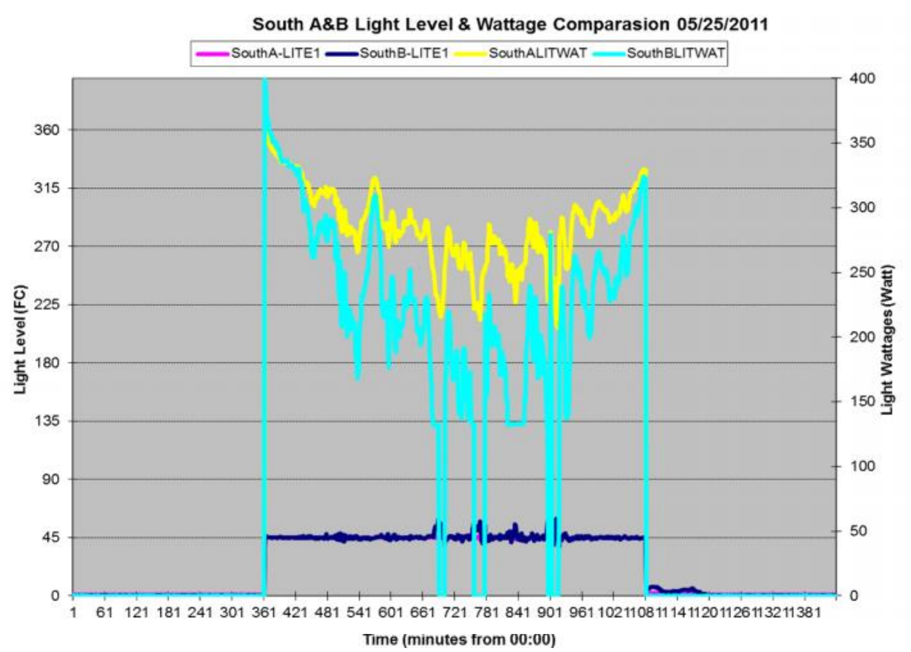

Figure 48. Intraday Light Level and Light Wattages (South, Cloudy)

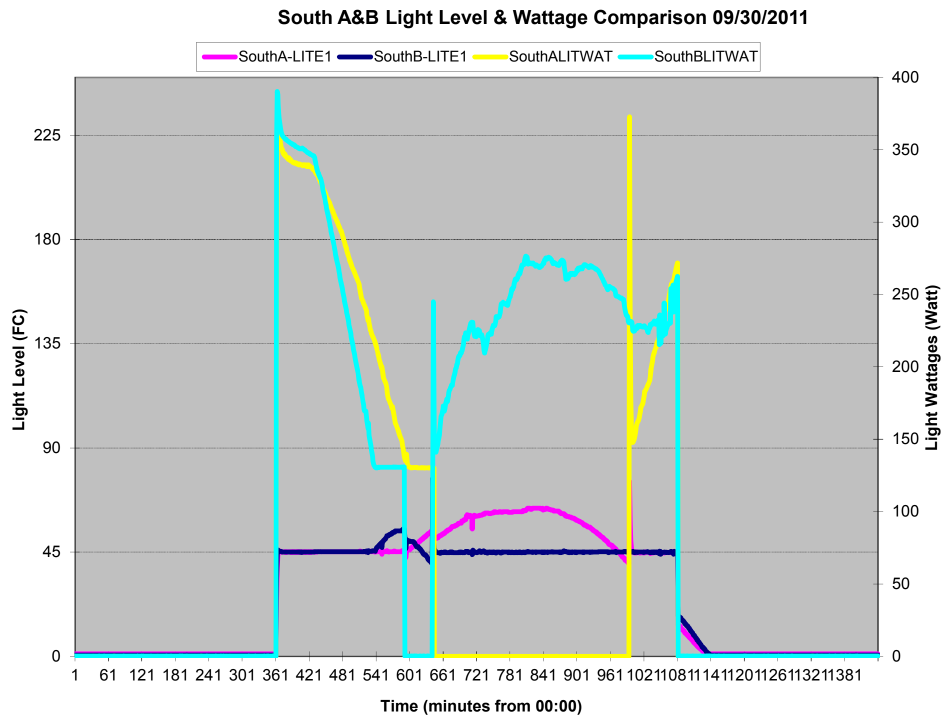

Figure 49. Intraday Light Level and Light Wattages (South – Sunny)

Figure 47 and Figure 48 show how Pleotint SRT windows saved lighting energy in normal lighting conditions. Because Pleotint SRT windows allow more visible light into the room, dimming control in the B rooms used less lighting energy to maintain the same light level (45 foot-candles). If the light level reached 50 foot-candles while the lights had been dimmed to minimum power output, the lights would automatically turn off until the light level dropped below 40 foot-candles.

Figure 49 shows how Pleotint SRT windows may use more lighting energy during a clear sunny day. In the South-B room with Pleotint SRT windows installed, the lights were not turned off in the afternoon, because the outside air temperature and strong direct solar radiation made the Pleotint windows darken too much, blocking too much visible sunlight into the room. In the meantime, in the South-A room, the linear dimming/off lighting control turned off the lights (yellow line) during most of the afternoon.

4.3.3. Pleotint Windows Temperature

The Pleotint windows temperatures in East-B, South-B and West-B testrooms were recorded during the testing period. Figure 50 and 51 give two examples of SRT window temperature patterns.

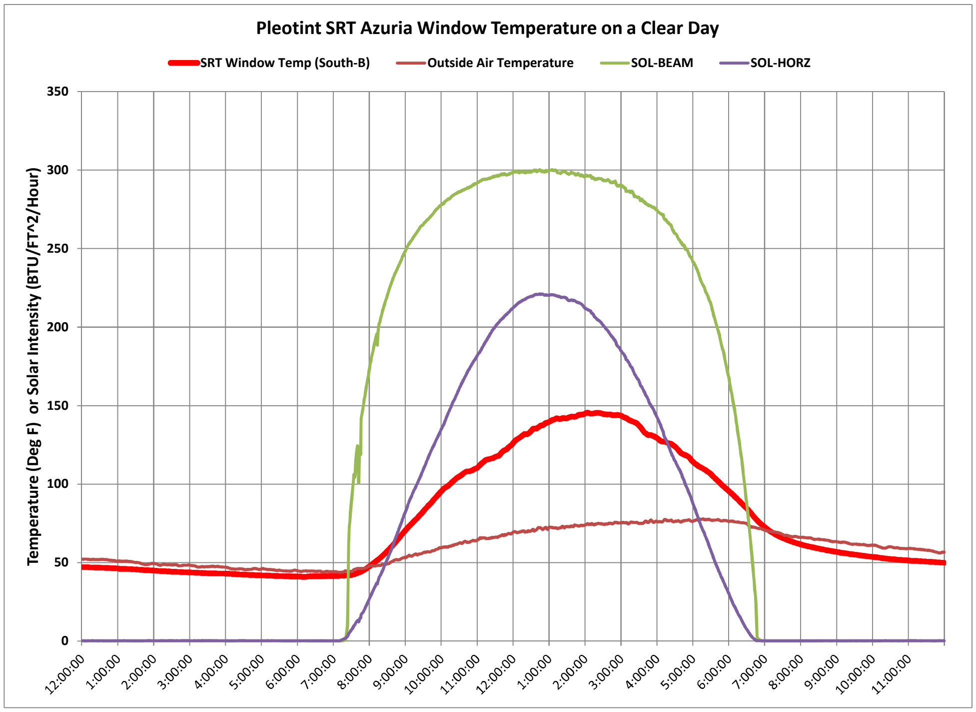

Figure 50. Pleotint SRT Window Temperature on a Clear Sunny Day

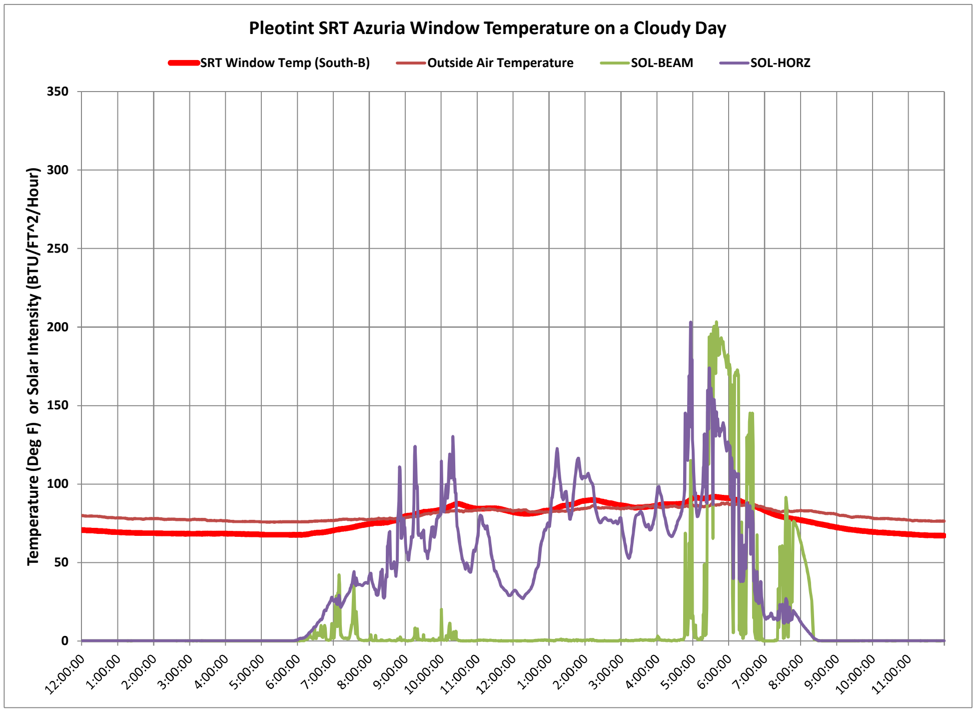

Figure 51. Pleotint SRT Window Temperature on a Cloudy Day

It can be seen that the SRT window temperature is affected by solar radiation (especially direct solar radiation) the most, and can reach as high as 150 Deg F on a clear sunny day as in Figure 50 (recorded on October 2, 2011). Outside air temperature does not significantly affect the window temperature: outside air temperature in Figure 51 (taken on July 29, 2011) is higher than that in Figure 50, yet the window temperature on that cloudy day is lower (during the day).

4.4. Thermal Energy Assessment

4.4.1. Cooling Energy

The cooling energy of the HVAC system is evaluated by the sensible cooling load at air handling unit cooling coils. Since only a fixed small amount of outside air (120 CFM) was injected into each of the air handling units under all test cycles, there was little condensation during the testing periods (designed air flow is 3200 CFM). The cooling coil sensible heat was calculated based on air temperatures measured before and after the cooling coil, and supply air flow rate. Figure 52 and Figure 53 illustrate normalized air handling unit sensible cooling load comparison for two Pleotint SRT windows vs. standard low-e windows.

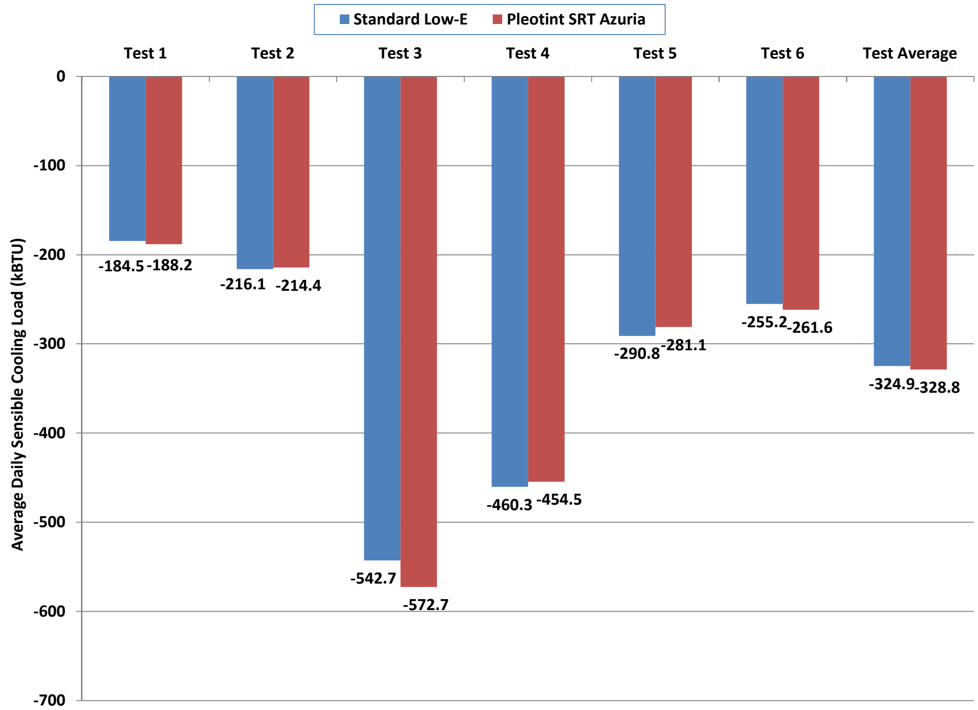

Figure 52. Normalized Sensible Cooling Load: Pleotint SRT Azuria vs. Standard Low-E

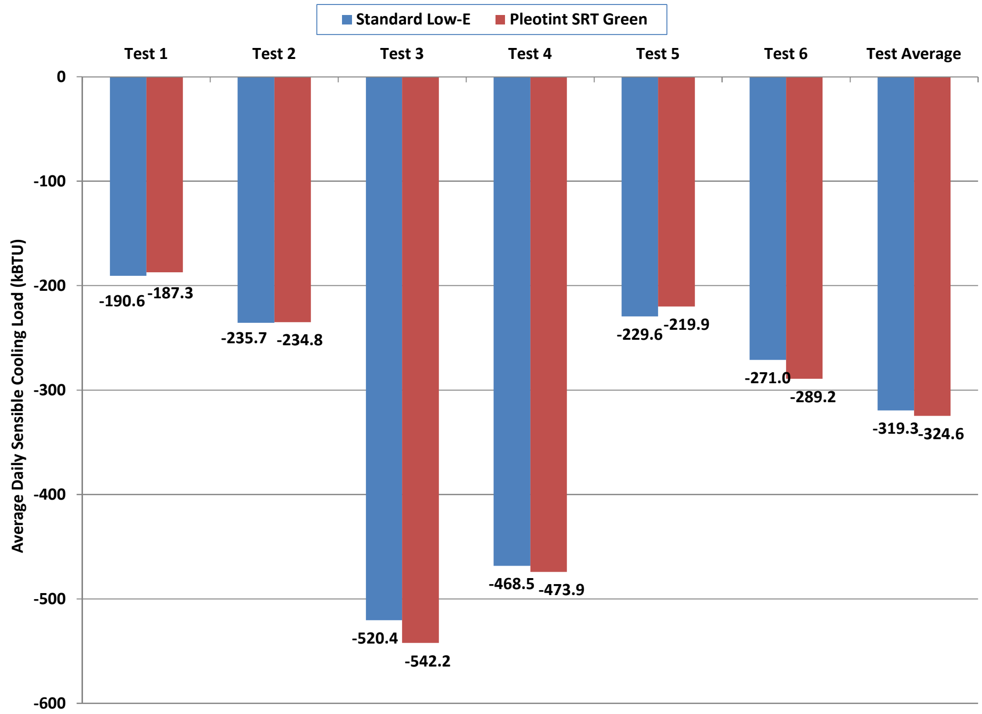

Figure 53. Normalized Sensible Cooling Load: Pleotint SRT Green vs. Standard Low-E

There was little difference in sensible cooling loads for the two HVAC systems with different windows (< 2%) after applying the normalization factors for each test cycle.

4.4.2. Heating Energy

The heating energy of the HVAC system in this project is mainly the re-heat energy by the Variable-Air-Volume (VAV) terminal units in the testrooms during the occupied period (6:00 ~ 18:00). The heating water loop pumps (HWP-LA and HWP-LB in Figure 17) pumped heating water from boiler to hydronic reheat coils in each of the VAV boxes. For each heating water loop, the heating energy can be measured at the loop level using heating water loop flow rate and supply and return water temperatures. The calculated heating energy includes all four test rooms' heat transfer from hydronic coils plus the heat loss through heating water loop pipes. It can be seen from Figure 54 and 55 that heating energy was overall much less than cooling energy, mainly because the test rooms have good insulation, and heat energy only counts for the occupied period during the day, and there were additional false-baseboard heat for test cycles 3 (August/September) to cycle 6 (January/February). The heating energy savings were about 2.5% for Pleotint SRT Azuria model, and about 15% for the Pleotint SRT Green model.

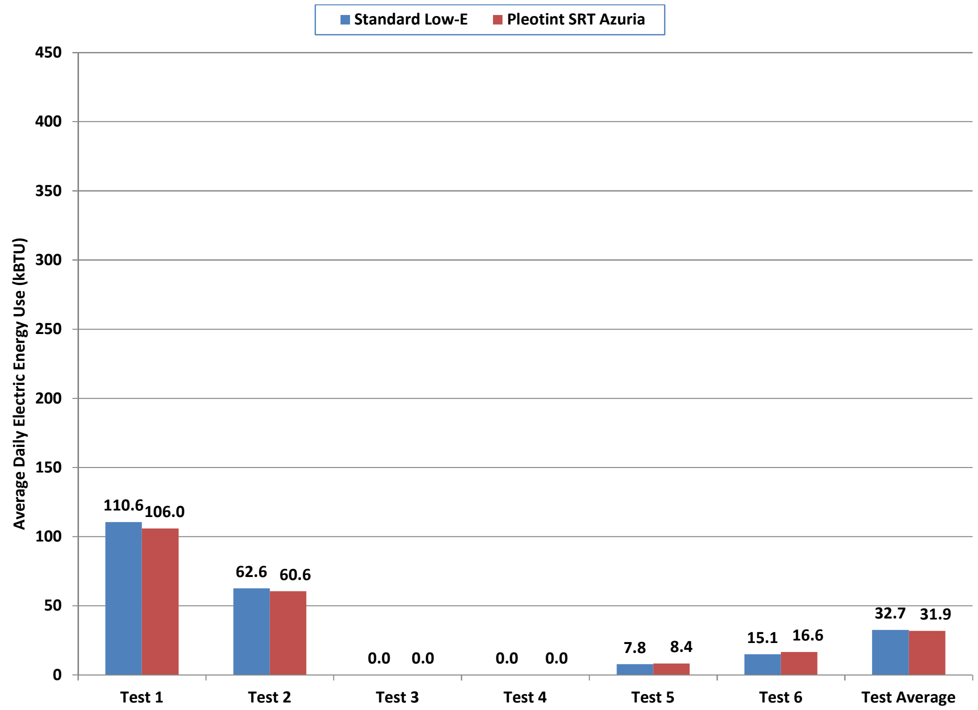

Figure 54. Normalized Heating Load: Pleotint SRT Azuria vs. Standard Low-E

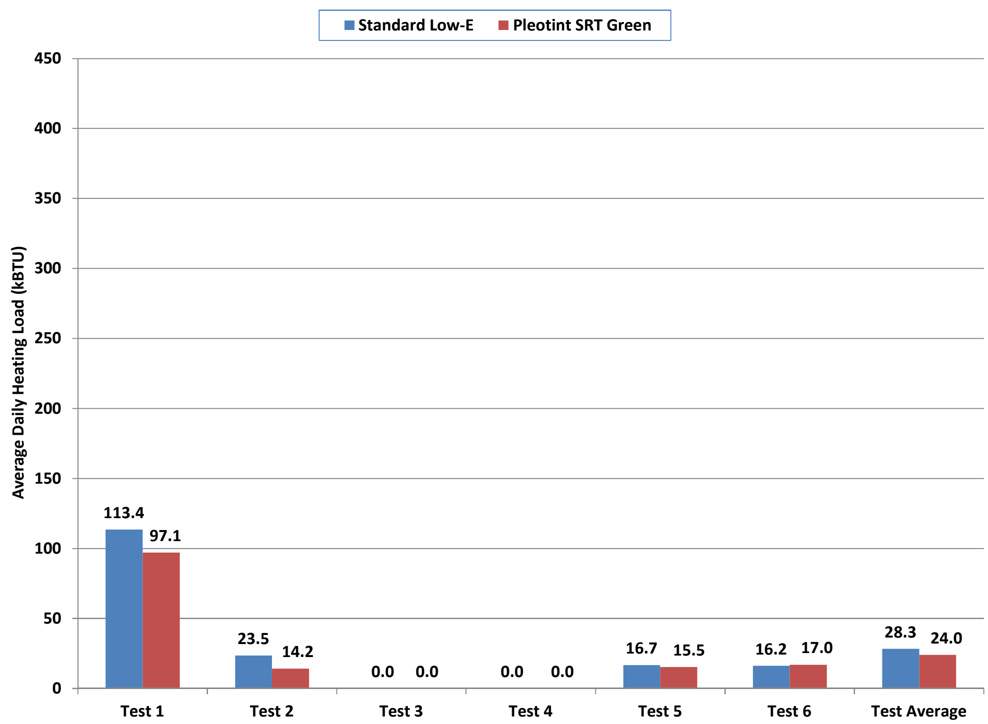

Figure 55. Normalized Heating Load: Pleotint SRT Green vs. Standard Low-E

5. BUILDING ENERGY SIMULATION MODEL AND ENERGY PERFORMANCE

5.1. Approach to Energy Performance Evaluation using Building Energy Simulation

One of the objectives of this project was to build and validate/calibrate a building energy simulation model for the Energy Resource Station facility with the Pleotint widows test setup, so the simulation model results could later be used to extrapolate energy performance at other locations or weather conditions based on standard weather data files. EnergyPlus was selected as the simulation engine for this project. EnergyPlus is a whole building energy simulation program developed by the U.S Department of Energy to help engineers, architects, and researchers model energy and water use in buildings.

The approach to this objective was implemented in five steps:

a. Build a baseline building energy simulation model including building envelope, lighting control, HVAC systems, and standard clear windows using commercial software DesignBuilder by DesignBuilder Software Ltd.
b. Calibrate and validate the baseline model using data from six normalization testing periods.
c. Build an actual testing model for the comparison test. Export the DesignBuilder model to an EnergyPlus model input file, and modify it to replace the window portion of the model from CLEAR window to standard low-e windows in three exterior A testrooms, and Pleotint SRT windows in three exterior B testrooms.
d. Compare simulation results with the actual measured testing data. Run the actual testing model under EnergyPlus environment for 6 test cycles (6 sub-tests for each of the two Pleotint SRT windows).
e. Do an annual energy performance comparison by simulation. Run the actual testing model under EnergyPlus environment using full-year typical weather data from Des Moines, Iowa and analyze the results.

5.2. Building a Baseline Model Using DesignBuilder

DesignBuilder is developed by DesignBuilder Software Ltd. (headquarters in the United Kingdom). It is a software package that provides a comprehensive user interface to the EnergyPlus dynamic thermal simulation engine. The software package combines rapid building modeling and ease of use with state of the art dynamic energy simulation. The latest version 3 enables detailed EnergyPlus HVAC modeling and simulation capability. DesignBuilder usually embeds the up-to-date version of EnergyPlus as its simulation engine, and the simulation results can be displayed in graphical and table format for easy visualization and analysis.

While all features of an EnergyPlus model may not be available using the DesignBuilder software, the simulation model built using DesignBuilder can be exported to an

EnergyPlus compatible input format so that further modifications/additions under EnergyPlus environment possible. Because there is no thermochromic window template yet available in DesignBuilder, the Pleotint SRT windows cannot be modeled directly within DesignBuilder. However, all other features of the simulation model (building envelope, scheduled activities, detailed HVAC, lighting control, etc.) can be modeled and results analyzed using DesignBuilder.

5.2.1. Modeling of Building Envelope

A building envelope model was first built using DesignBuilder software version 3.0.015. The building envelope parameters (dimensions, material properties, etc.) were referred to one of the previous research project technical report [3] as well as the Energy Resource Station internal technical document and drawings [4][5]. Some discrepancies were found between the two documents and solved by making actual field measurements/validations. Customized building layer templates (internal and external walls, ceilings, floors, and roofs, etc.) were created first and then applied to each zone partitions, ceilings, and floors.

The Energy Resource Station building envelope model created included eight test rooms (four A testrooms and four B testrooms), eight testroom plenum zones, and the general service area (media center, offices, mechanical room space, and two class rooms). Since the zones under test only included test rooms and the general service area temperatures were mostly maintained between 70 Deg F ~ 74 Deg F (the test room heating and cooling setpoint), the testroom interior walls (between room and media center, and between a pair of testrooms in the same orientation) were all modeled adiabatic. When doing simulation analysis, only eight test room zones and eight plenum zones were analyzed for thermal energy performance. Figure 56 shows an overall 3-D facility building model created using DesignBuilder, and Figure 57 marks the 8 test rooms used for this project.

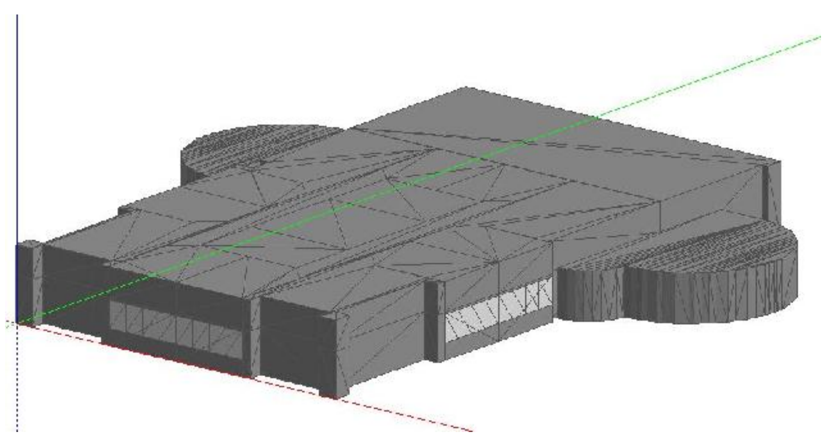

Figure 56. A General Building Envelope Model

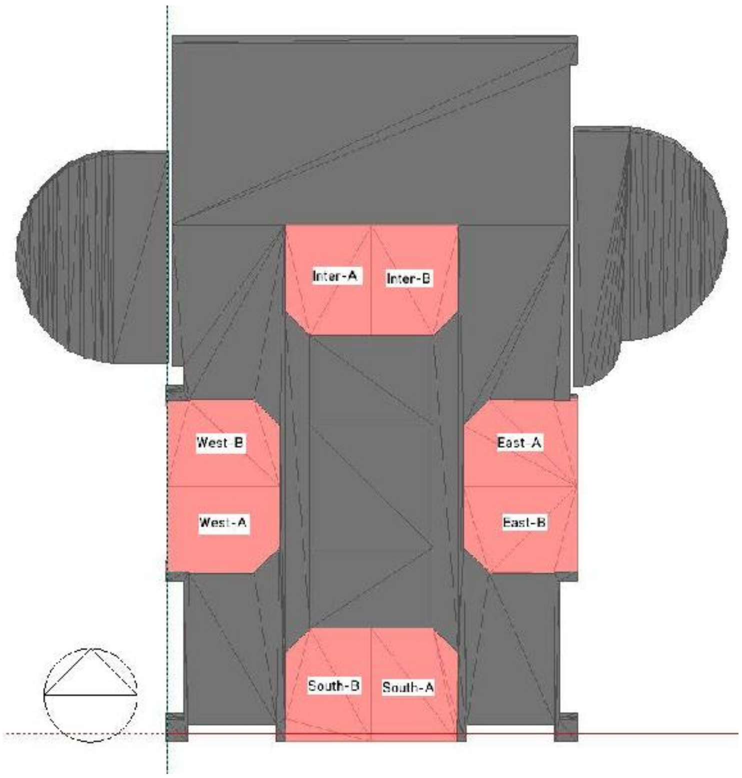

Figure 57. Testrooms in Building Simulation Model

5.2.2. Modeling of Activities

Activities in DesignBuilder were modeled fairly easily through software interface. All schedules (occupancy, computer, equipment, and lighting, etc.) were modeled based on the test protocols described in Chapter 3. A sample zone activity was modeled as shown in Figure 58.

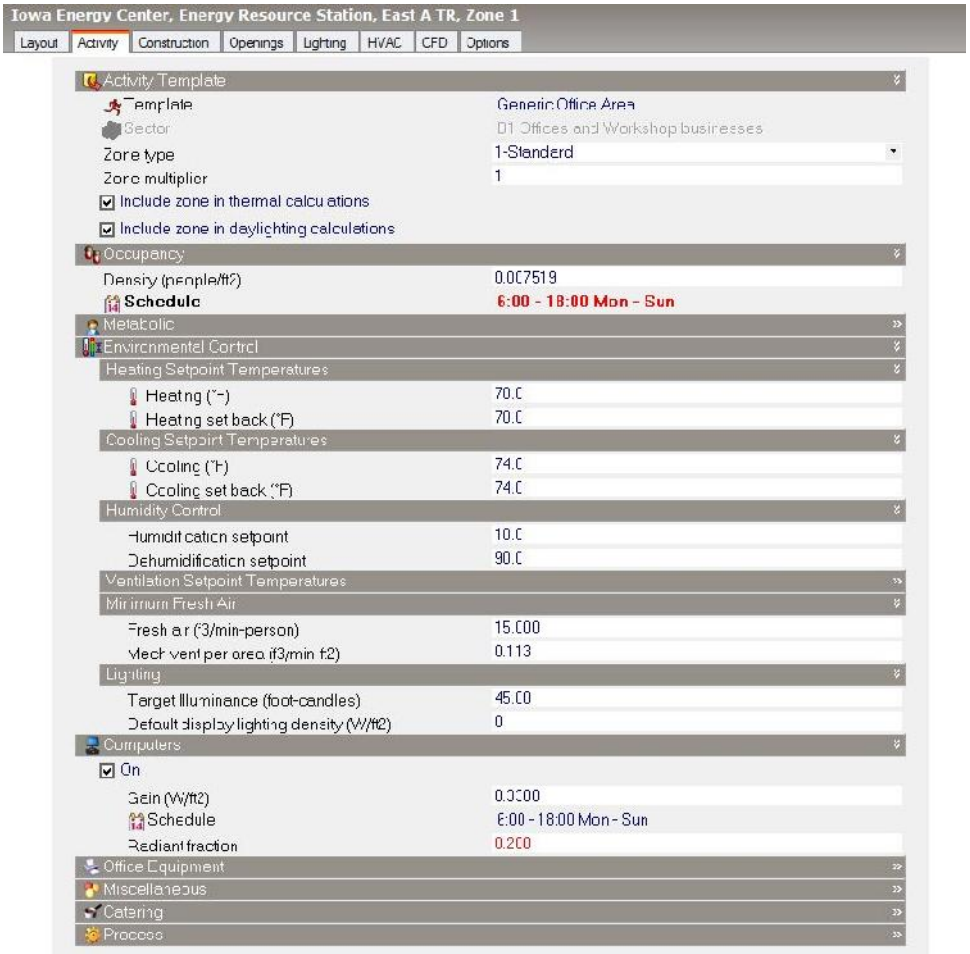

Figure 58. Screenshot of Sample Zone Activities

5.2.3. Modeling of Clear Windows

The DesignBuilder has internal libraries of common window construction types including both clear and low-e tinted windows. A building model can be quickly changed to simulate different window construction types. The windows in the baseline model included the base clear windows described in Section 3.1 & Table 13. The dimensions of windows and frames used the actual filed measurement values. The baseline model was used to compare energy simulation results for test cycles 1~6 normalization days. Screenshots of modeling of base clear windows are shown in Figure 59 and Figure 60.

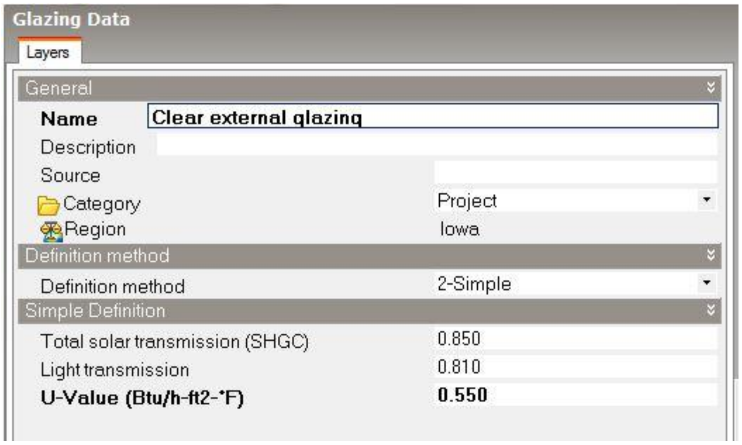

Figure 59. Screenshot of Modeling Base Clear Window Properties

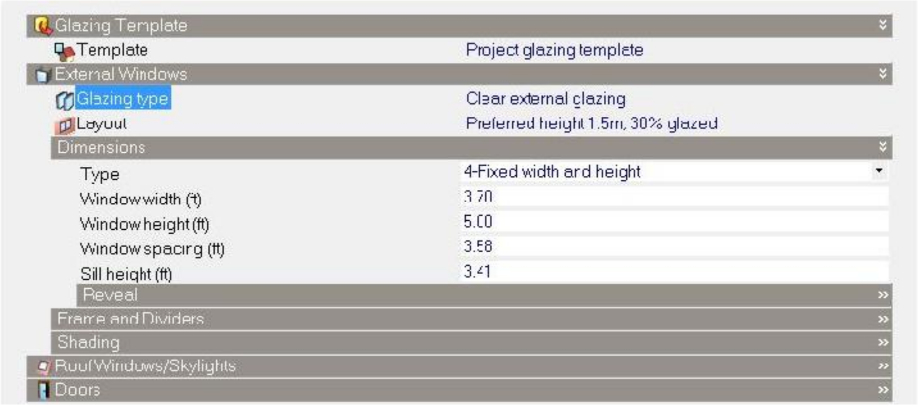

Figure 60. Screenshot of Modeling Base Clear Window Dimensions

5.2.4. Modeling of Lighting Control

For both A testrooms and B testrooms, linear dimming/off control was used to maintain 45 foot-candle light levels on a table surface (table height 2 feet and 4.5 inches) in the middle of each exterior testroom. The lighting control in the ERS building automation system turns off lights in the testroom if lighting power reaches minimum output but light level is above 50 foot-candles. Lights turn back on if the light level is below 40 foot-candles. Parameters for linear/off controls (minimum output fraction and minimum input power fraction) were determined based on actual field testing.

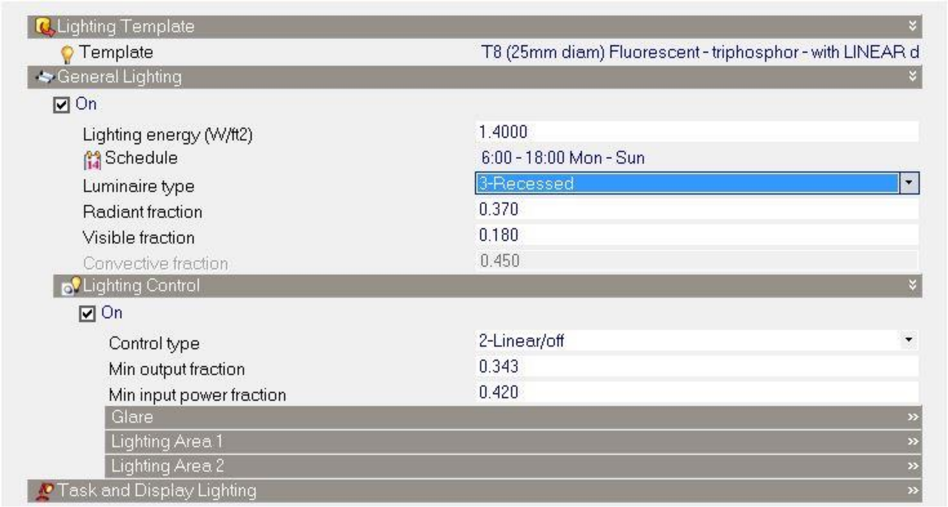

Figure 61. Screenshot of Modeling Lighting Control

5.2.5. Modeling of HVAC Systems

The DesignBuilder software version 3 features detailed HVAC modeling capability and was used in modeling the HVAC system in this project.

The HVAC model in this project includes two identical independent HVAC systems – one for system A and one for system B. For each system, the HVAC model included a chiller, boiler, air handling unit, and a zone group with four variable air volume terminal units, each in one test room zone. The air-cooled chiller was modeled based on parameters from a past project conducted at Energy Resource Station [6]. The air handling unit model consisted of a supply fan, return fan, and cooling coil with parameters derived from actual testing data or manufacturer specifications. The VAV box models had hydronic reheat coils that connected to the heating water supply loop. It is worth mentioning that in reality there is only one boiler in the facility. However, it was found that DesignBuilder cannot model two separate heating water loops connecting to a single boiler as shown in Figure 17, thus two separate boilers were modeled to provide heating water to the two heating water loops, with each boiler modeled only half the actual specified capacity of the real boiler. Figure 62 illustrates the HVAC detailed model graphics in DesignBuilder interface. The outside air injection fans were not modeled in this model. However, fan energy use was small compared to total building energy use and was very consistent, around 5.5 kBTU per day per fan. In simulation results, the fan energy was simply added as a constant.

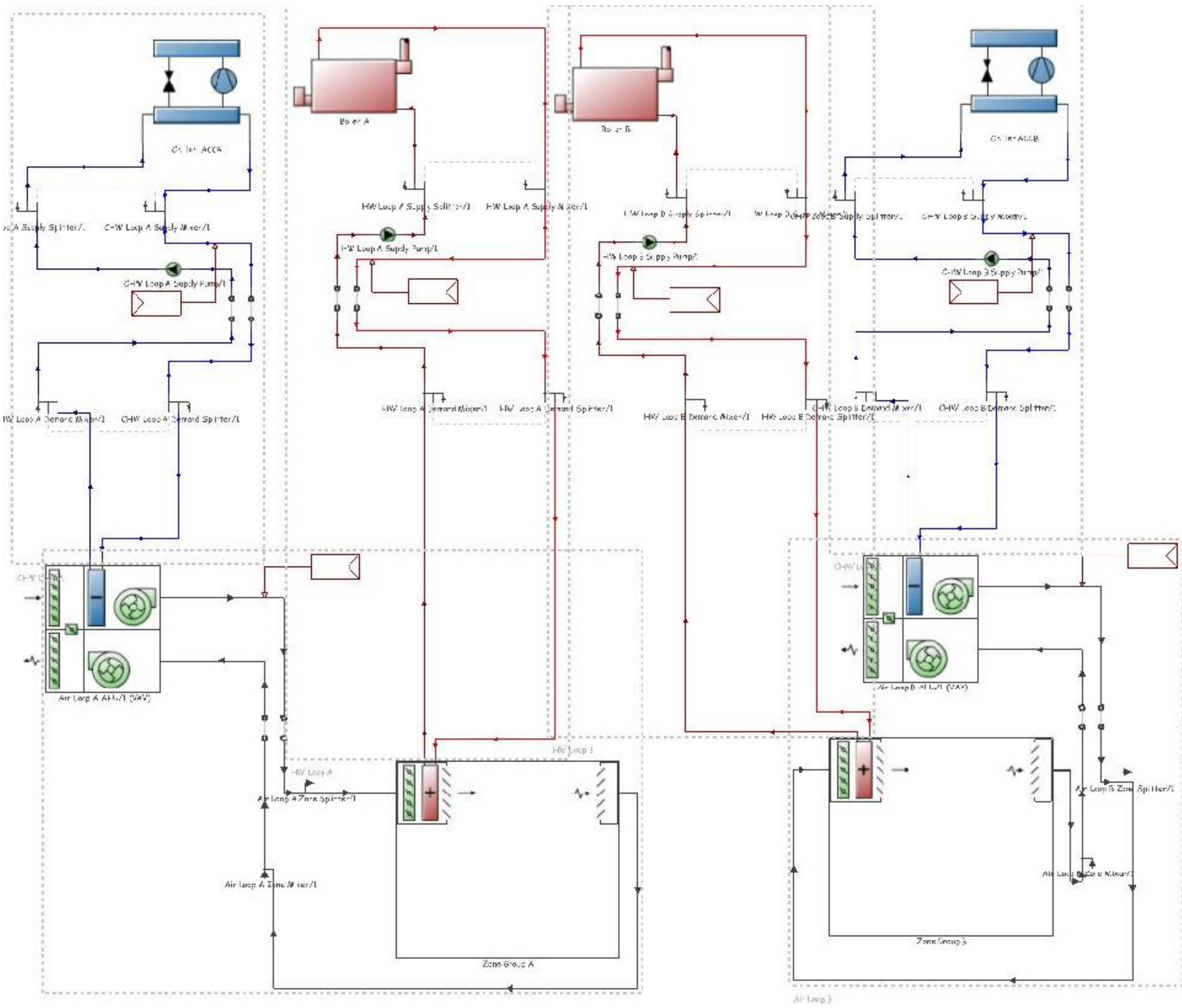

Figure 62. Screenshot of Modeling HVAC Systems

5.3. Calibration and Validation of the Baseline Building Simulation Model

Calibration and validation of the baseline building simulation model was done by manually adjusting relevant model components' parameters after comparing the simulation results to actual measured energy performance results for the six normalization tests. The overall goal was to make average daily simulation results close to actual average daily results for all six testing periods. The calibrated baseline model then could be later modified to become the "actual" testing model used for simulated energy performance comparisons and analysis.

The simulation results for the calibrated baseline model comparison with actual measured data are shown in Figure 63~65. The simulation models' percentage of errors (test averages of total electricity) are **-2.2%** for system A and **+4.5%** for system B.

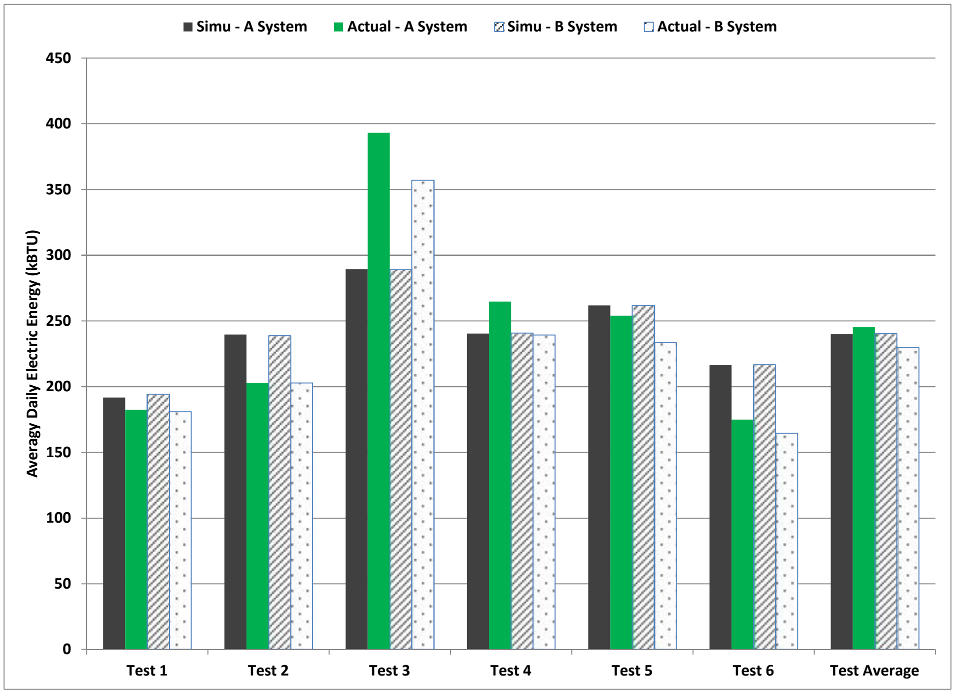

Figure 63. Simulated vs. Measured Electric Energy for Normalization Tests

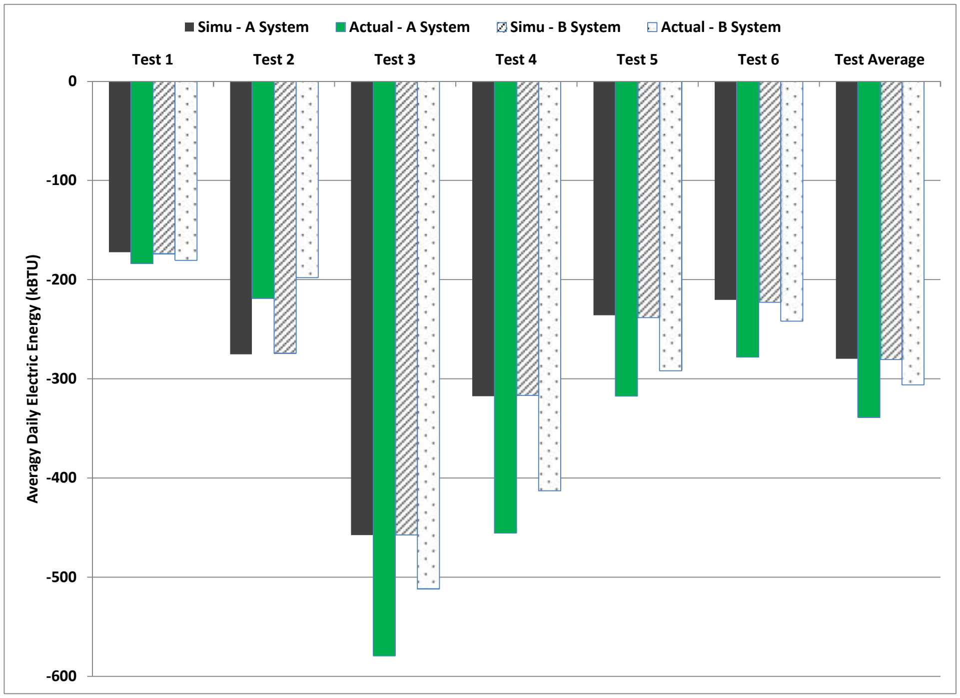

Figure 64. Simulated vs. Measured Cooling Loads for Normalization Tests

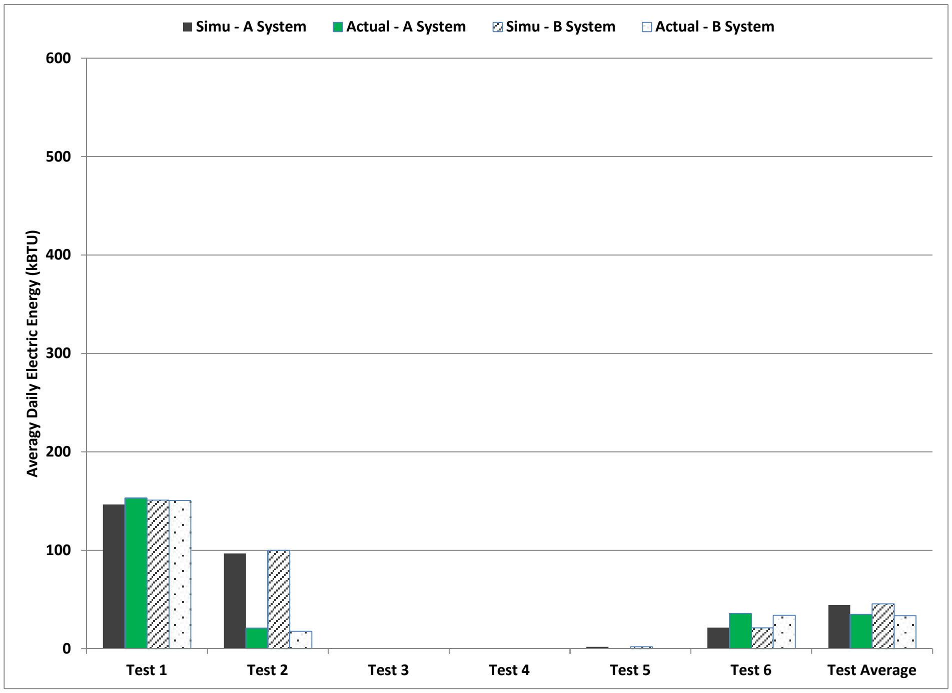

Figure 65. Simulated vs. Measured Heating Loads for Normalization Tests

It was noticed that the simulation model energy performance between A and B systems was very close in every sub-test. This is because the simulation model is a simplified version of reality and did not account for some system design and construction differences and instrumentation errors.

5.4. Building the Actual Testing Model Using EnergyPlus

5.4.1. Modeling of Standard Low-E and Pleotint SRT Windows

The modeling of standard low-e windows (in three exterior testrooms) was done within DesignBuilder. This was accomplished by creating a window glazing template for the low-e windows containing the specific window properties and selecting it for East-A, South-A and West-A test rooms for the baseline simulation model that have clear windows in both A and B exterior test rooms.

Due to the limitations of DesignBuilder, the only way to model a thermochromic window is to obtain the specific window properties from the manufacturer in the form of an EnergyPlus input file and modified within EnergyPlus environment. The "modified baseline" model was exported from DesignBuilder as EnergyPlus input files in order to add the thermochromic windows to the B testrooms. The two EnergyPlus model files of the Pleotint SRT Azuria and Green windows (both in .idf format) were obtained from the manufacturer. By utilizing the EnergyPlus IDF Editor, the Pleotint model files then replaced the three B exterior testrooms' clear window sections. The resulting model was the EnergyPlus model for the actual comparison testing for Tests 1.1 ~ 6.2.

5.5. Simulated Energy Performance and Comparison with Measured Testing Data

The actual testing model ran under EnergyPlus environment (version 7.0.0.036) using real ERS weather data for testing days of Tests 1.1 ~ 6.2. The simulation results were compared with the actual measured data during those testing periods. Figure 66 shows the performance comparisons of building electric energy for Pleotint SRT Azuria windows vs. standard low-e dark tinted windows. Similarly, Figure 67 compares the performance for Pleotint SRT Green windows vs. standard low-e dark tinted windows. Figure 68 ~ 70 show the difference of lighting energy for Pleotint SRT Azuria windows vs. standard low-e windows in each of the three pairs of exterior testrooms. Figure 71 ~ 73 illustrate the difference for Pleotint SRT Green windows vs. standard low-e windows.

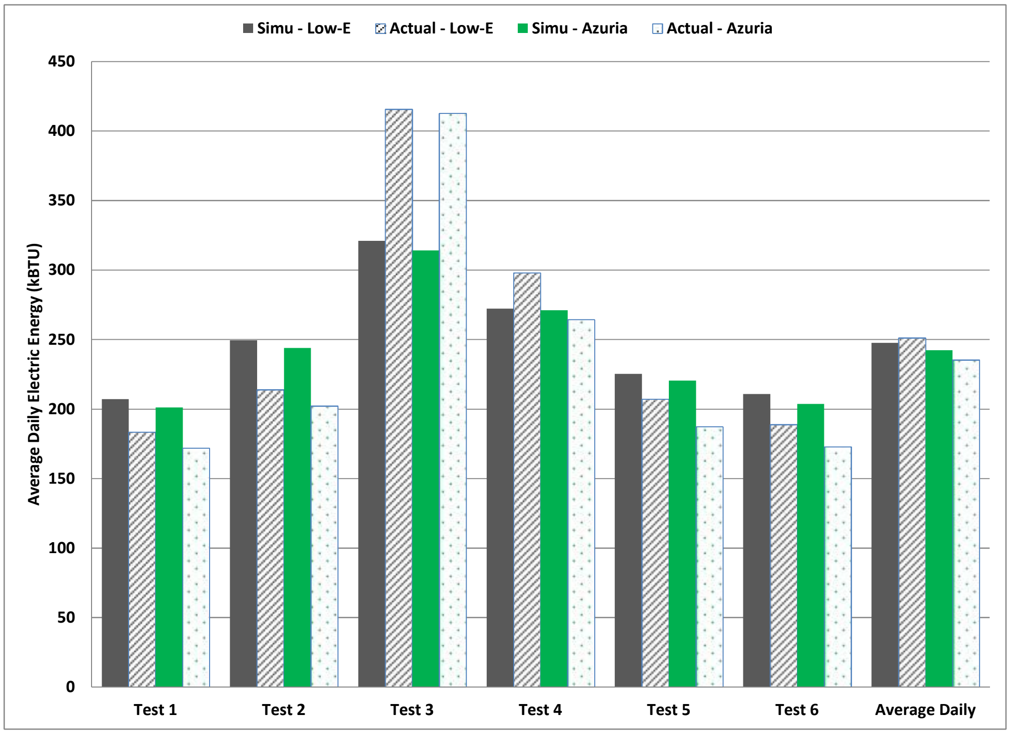

Figure 66. Simulated vs. Measured Building Energy for Low-E vs. Azuria Windows

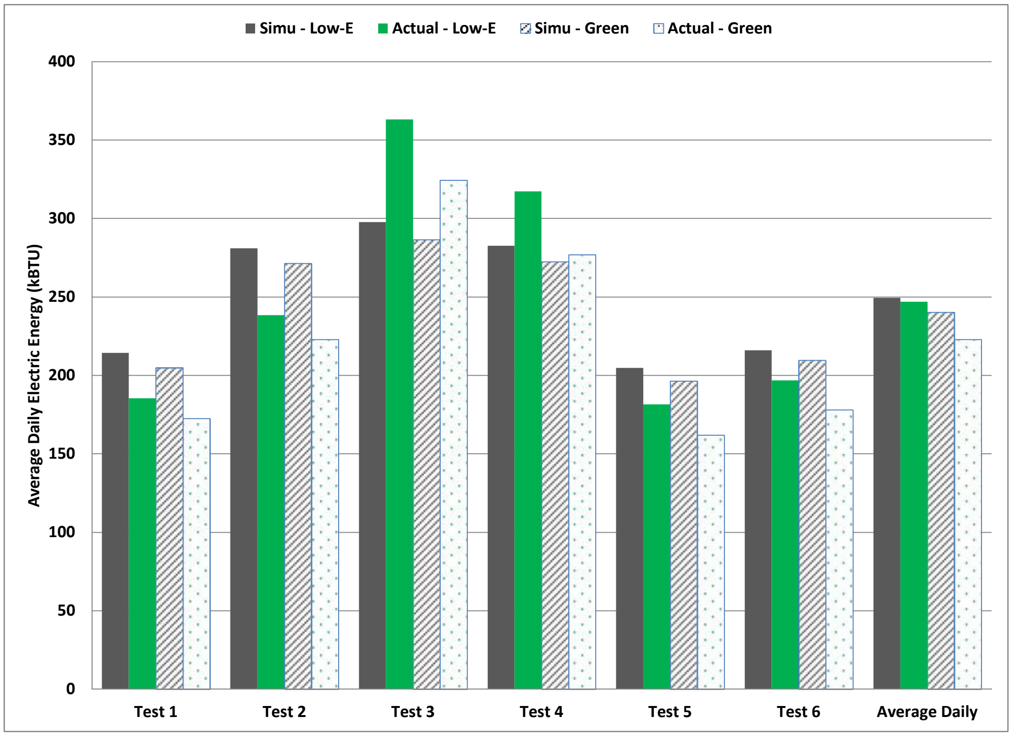

Figure 67. Simulated vs. Measured Building Energy for Low-E vs. Green Windows

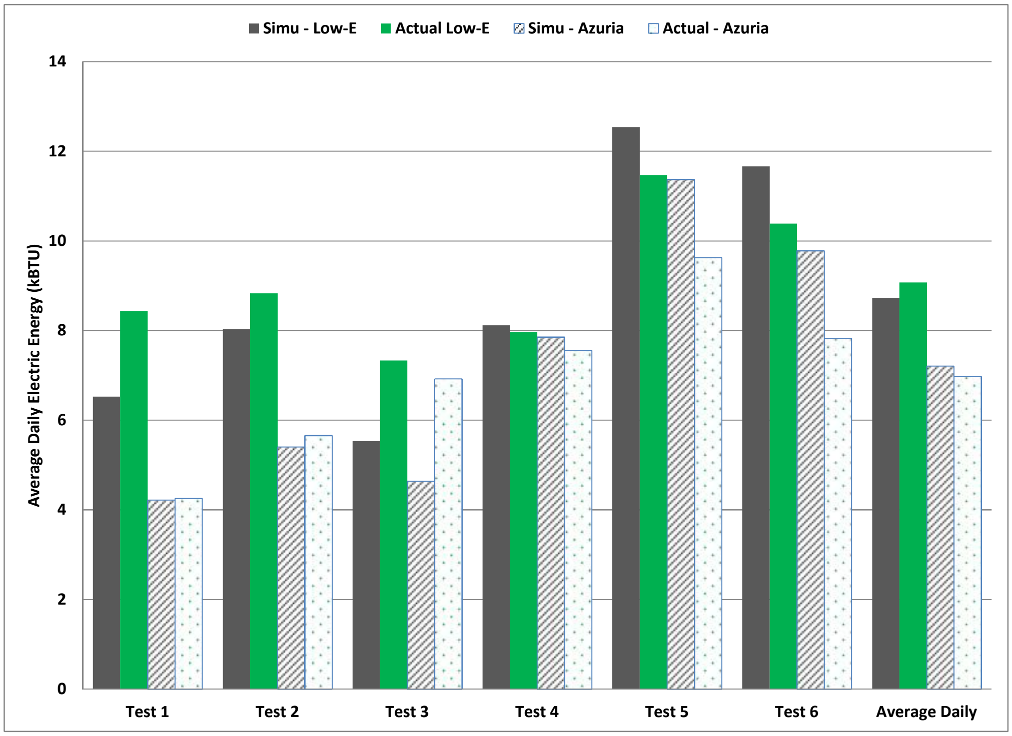

Figure 68. Simulated vs. Measured Lighting Energy (Azuria, East) Comparison

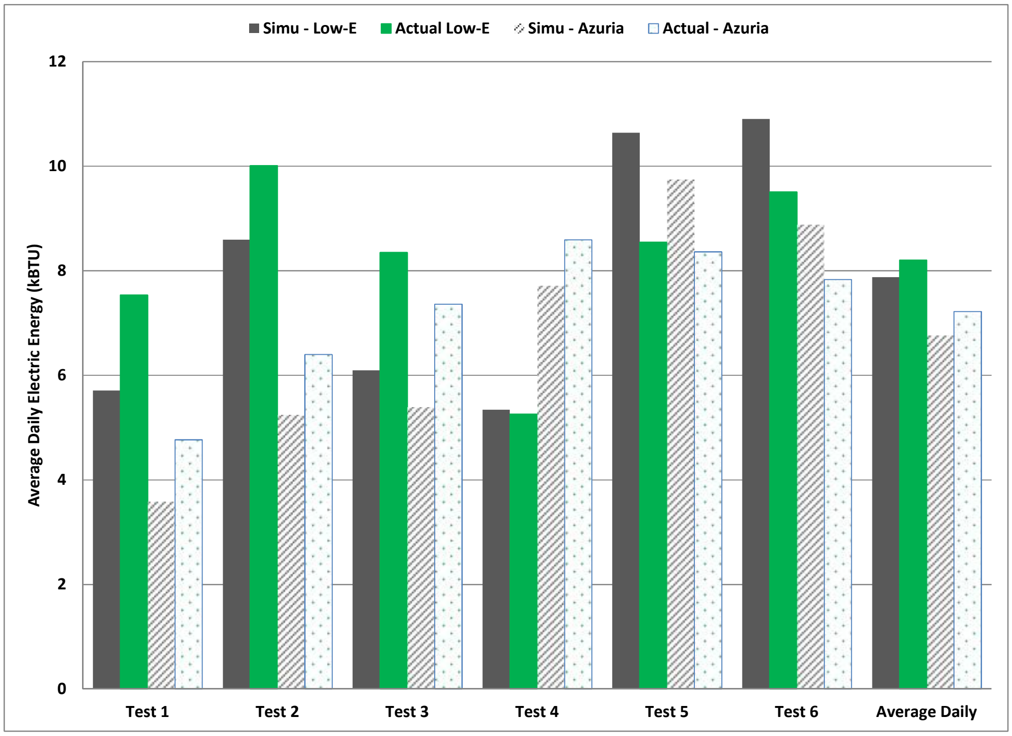

Figure 69. Simulated vs. Measured Lighting Energy (Azuria, South) Comparison

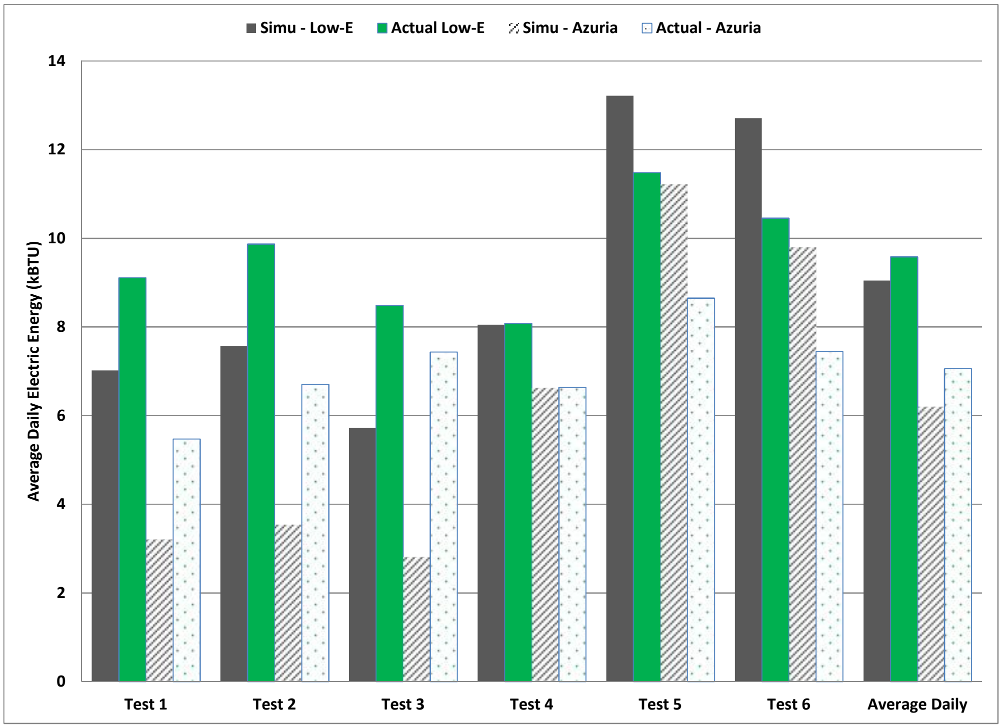

Figure 70. Simulated vs. Measured Lighting Energy (Azuria, West) Comparison

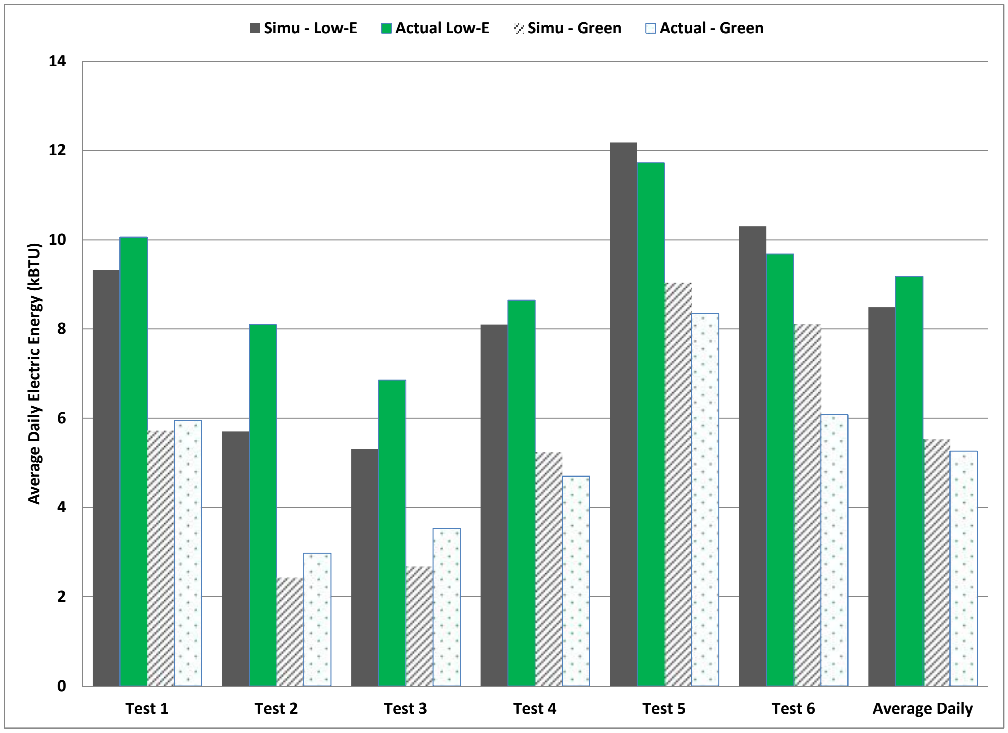

Figure 71. Simulated vs. Measured Lighting Energy (Green, East) Comparison

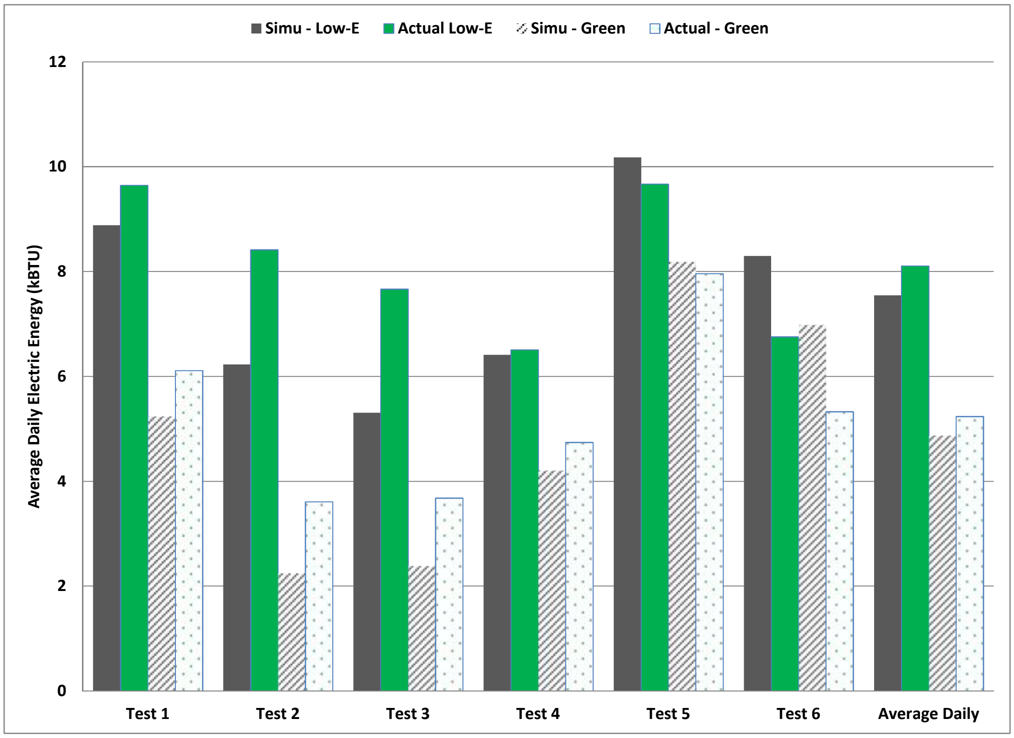

Figure 72. Simulated vs. Measured Lighting Energy (Green, South) Comparison

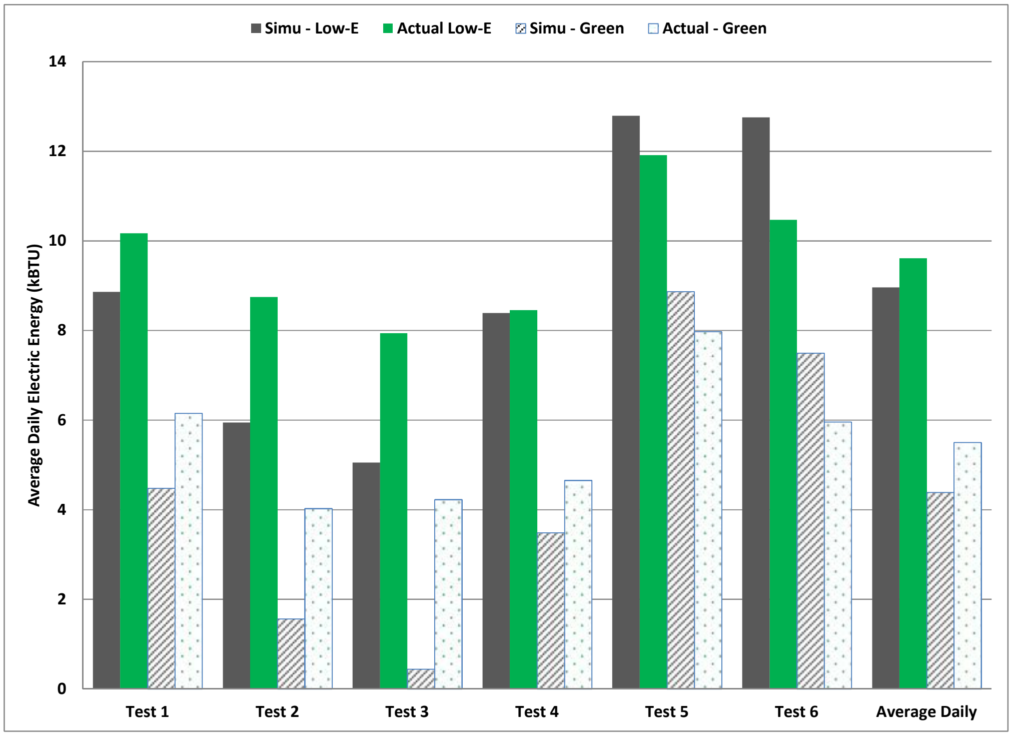

Figure 73. Simulated vs. Measured Lighting Energy (Green, West) Comparison

From daily averages of all sub-tests, the Pleotint SRT Green windows can save approximately **3.7%** total building energy while SRT Azuria can save **2.1%**. This is close to the results from the normalized actual testing comparison (save 4.0% and +0.1% respectively for Green and Azuria models).

By comparing simulation results with measured results for all the testing periods, it can be seen from Table 19 that the daily average of the total building electric energy was reasonably simulated for standard low-e windows – the percentages of differences were within **~1.5%**. SRT Azuria and Green windows' simulation accuracies were not as good (**3.1%** and **7.8%** respectively). One possible reason is that the thermochromic window simulation property and algorithm in EnergyPlus may need to be improved.

Table 19. Differences of Simulation vs. Actual for Total Electric Energy

	Simu. vs Actual (Actual as reference)
SRT Azuria in Azuria Testing	3.05%
Standard Low-E in Azuria Testing	-1.37%
SRT Green in Green Testing	7.81%
Standard Low-E in Green Testing	0.94%

For the daily average of all testing periods, the lighting energy simulation for each of the three orientations experienced a bigger percentage of errors compared to actual data, especially for west-oriented windows (Table 20). This is likely due to the fact that the linear diming/off control simulation algorithm in EnergyPlus did not take into account the deadband of light levels used to trigger ON/OFF control of lights to minimize frequent cycling of lights during partially cloudy days (50 foot-candles to trigger turning off the lights and 40 foot-candles to trigger turning on the lights, even though the setpoint was set at 45 foot-candles). Another possible reason is that the building's surrounding environmental conditions were not as idealistic as assumptions made in the simulation model. For standard low-e dark tinted windows, the simulation consistently underestimated the actual lighting energy used (percentage errors ranged from -3.70% to -7.52%). For Pleotint SRT Azuria and Green models, the simulation error was still reasonable for east and south-facing windows (3.38% to -6.89%), but the west-facing windows had a percentage of error up to 20%. The modeling of thermochromic windows needs improvement.

Table 20. Differences of Simulation vs. Actual for Lighting Energy

	Simu. vs Actual (East) (Actual as reference)	**Simu. vs Actual (South)** (Actual as reference)	**Simu. vs Actual (West)** (Actual as reference)
SRT Azuria in Test x.1	3.38%	-6.35%	-12.10%
Standard Low-E in Test x.1	-3.70%	-3.91%	-5.55%
SRT Green in Test x.2	5.26%	-6.89%	-20.19%
Standard Low-E in Test x.2	-7.52%	-6.88%	-6.75%

5.6. Simulated Annual Energy Performance Comparison Results

The testing simulation model ran using a full-year typical weather data from Des Moines, Iowa to estimate the energy savings for Pleotint windows. Two scenarios were simulated: 1 – without baseboard heat for the entire year, and 2 – with baseboard heat for the entire year. The annual simulation results are shown below in Figure 74 ~ 77 and Table 21. In all cases, Pleotint SRT windows saved building electric energy by 2% ~ 4%, with SRT Green model performing better. Most of the savings were from lighting energy. This is consistent with previous results. Detailed data are listed in Appendix D.

Table 21. Simulated Annual Building Electric Energy Comparison Results

	SRT Azuria vs. Low-E	SRT Green vs. Low-E
Scenario 1	-2.11%	-3.68%
Scenario 2	-3.88%	-4.25%

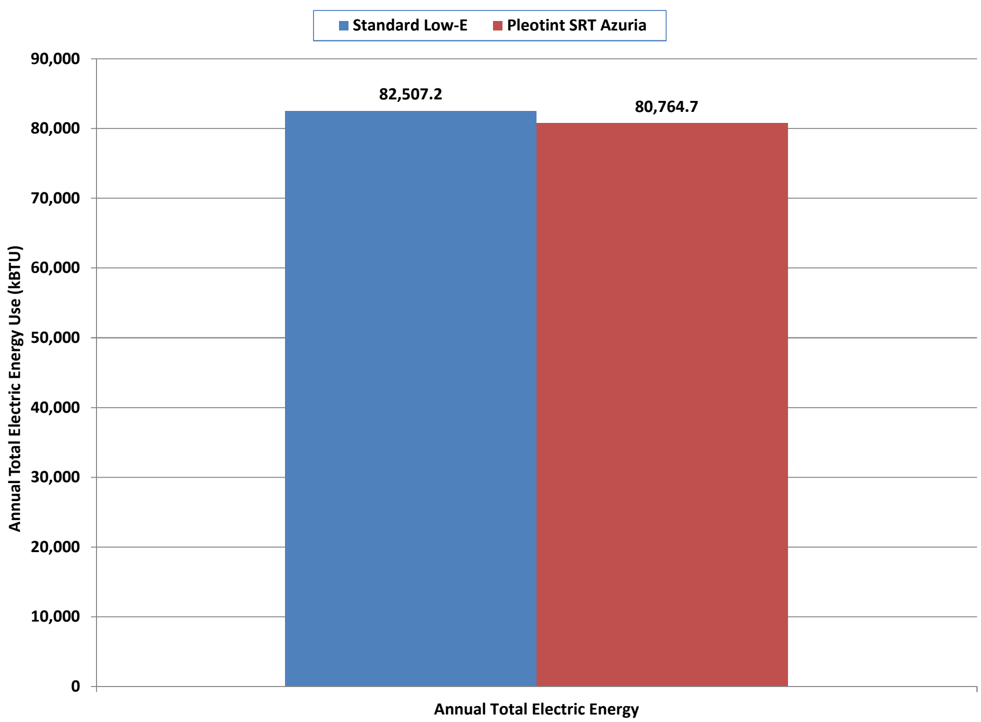

Figure 74. Simulated Annual Building Electric Energy Comparison 1 - Azuria

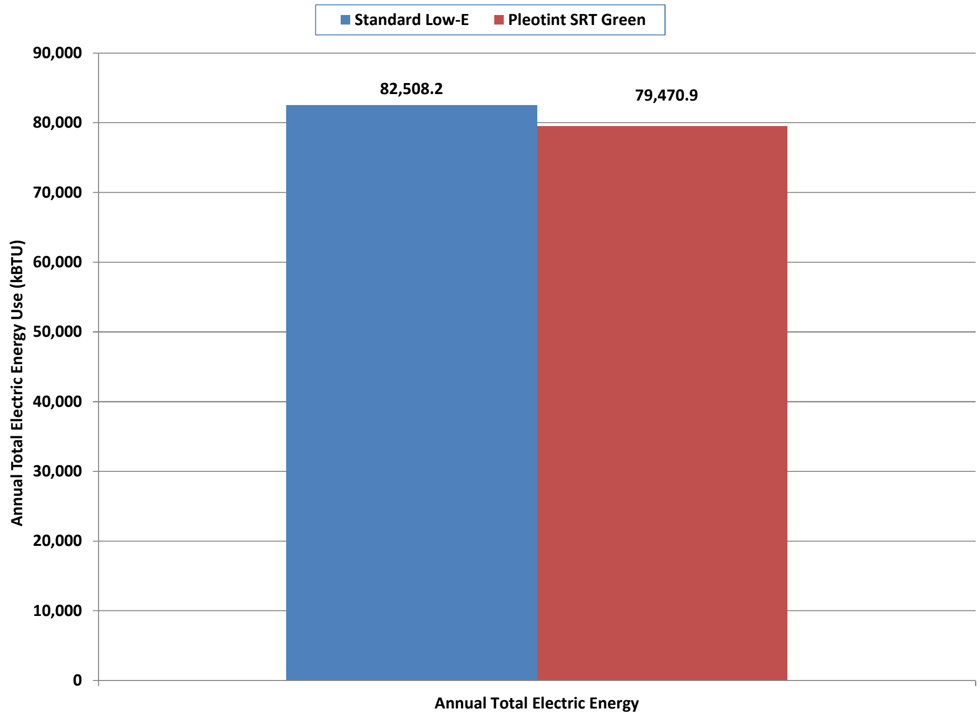

Figure 75. Simulated Annual Building Electric Energy Comparison 1 – Green

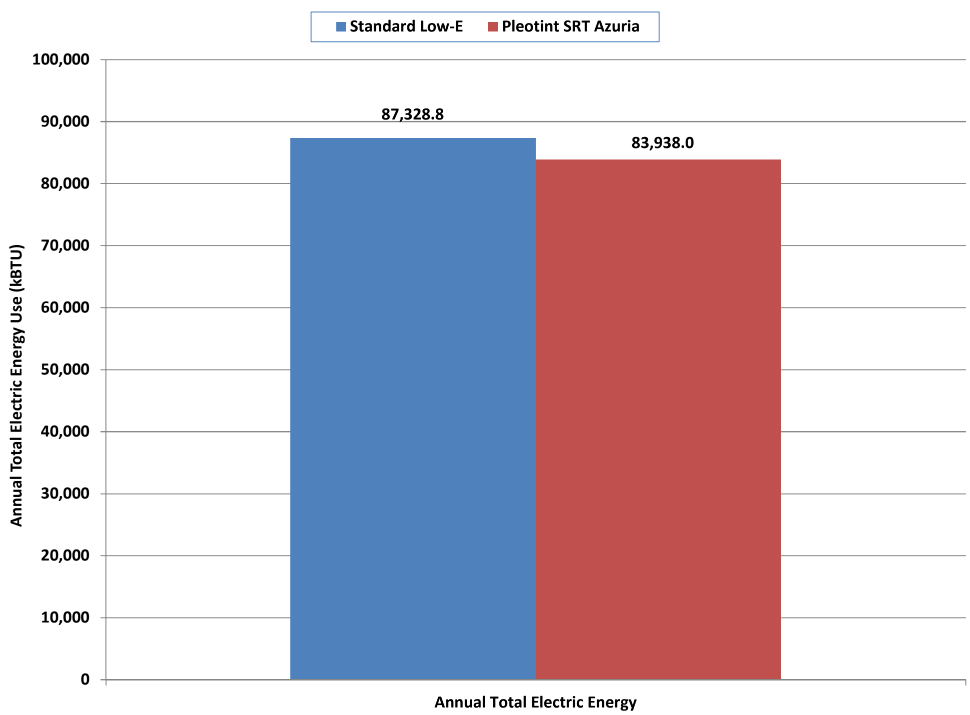

Figure 76. Simulated Annual Building Electric Energy Comparison 2 - Azuria

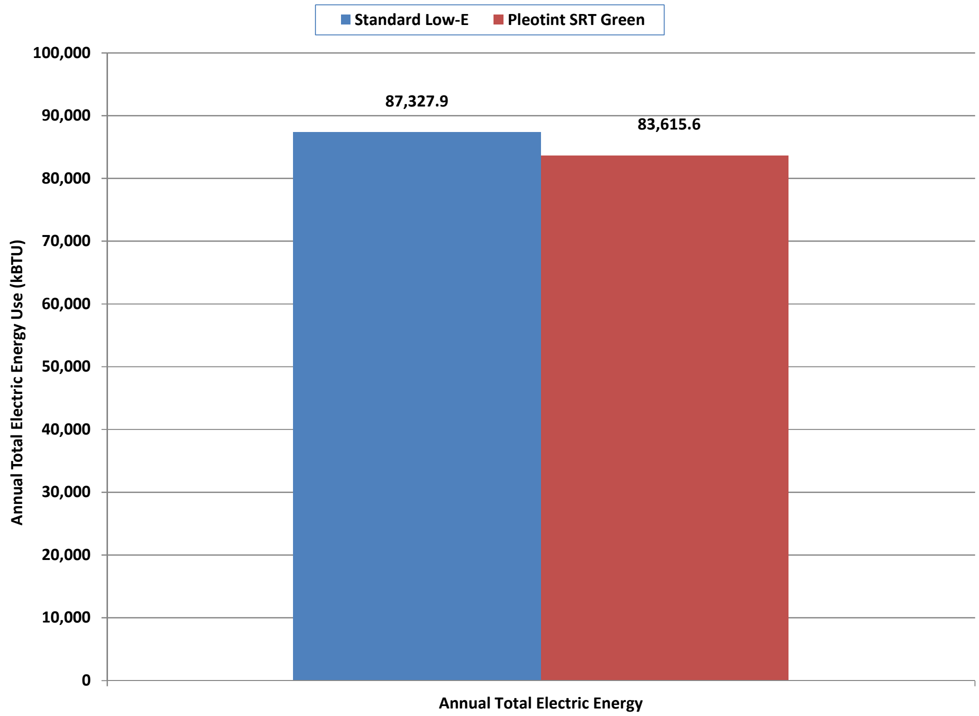

Figure 77. Simulated Annual Building Electric Energy Comparison 2 – Green

6. CONCLUSIONS

In this project, two models of the Pleotint LLC's Sunlight Responsive Thermochromic (SRT) windows were compared with standard low-e dark tinted windows for energy performance evaluation and daylighting assessment under typical central Iowa weather conditions. Several major conclusions can be made from empirical testing results and simulation results: Pleotint SRT windows under test (Azuria model and Green model) saved approximately **0~4%** of building total electric energy in a light commercial office building environment under typical central Iowa weather conditions. Most of the energy savings were due to lighting energy saved by the Pleotint SRT windows. The lighting energy savings on perimeter rooms with windows could range from **15%** (south-facing) to **40%** (west-facing). The savings were from tests under linear dimming/off lighting control, and would be larger if only commonly used ON/OFF lighting control were used. The overall energy savings will vary depending on the type of building, the ratio of perimeter rooms with windows and interior rooms, the ratio of overall lighting energy in total building energy used, and many other factors. The SRT Green model saved more energy than the SRT Azuria model because the Azuria model became too dark on clear, sunny days and lights needed to be unnecessarily turned on more often. The current thermochromic window properties and/or modeling algorithm for the thermochromic windows in EnergyPlus need some improvement as simulation results showed a relatively larger percentage of errors compared to a standard low-e dark tinted window type.

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APPENDICES

Appendix A. Actual Daily Average Building Energy Comparison Results

Table A.1.1 Test 1.1 Building Energy Performance Results

Pleotint Windows Testing March Test 1.1 Energy Performance Daily Average Results				
		System A Energy (BTU)	*System B Energy (BTU)*	% Difference
Fan Energy	AHU Supply Fan	20,048.80	20,587.57	2.69
	AHU Return Fan	8,337.07	7,981.59	-4.26
	AHU Outside Air Injection Fan	5,934.38	5,280.63	-11.02
	Total Fan Energy	34,320.25	33,849.79	-1.37
Pump Energy	Chiller-CH Pump	18,007.02	18,012.26	0.03
	AHU Chilled Water Pump	0.00	0.00	
	Heating Water Loop Pump	18,636.74	18,015.65	-3.33
	Total Pump Energy	36,643.77	36,027.92	-1.68
Chiller Energy	Chiller-CH	72,735.50	72,786.04	0.07
	ACCA / ACCB	0.00	0.00	
	Total Chiller Energy	72,735.50	72,786.04	0.07
Lighting Energy	East Test Room	8,436.37	4,254.51	-49.57
	South Test Room	7,534.64	4,768.29	-36.72
	West Test Room	9,109.90	5,475.91	-39.89
	Interior Test Room	14,659.48	14,754.76	0.65
	Total Lighting Energy	39,740.38	29,253.48	-26.39
System Cooling Energy	AHU Cooling Coil Sensible Heat	-184,538.85	-184,580.10	0.02
	AHU Cooling Coil Total Heat	-179,284.29	-172,819.05	-3.61
System Heating Energy	Heating Loop Energy	110,584.46	104,322.53	-5.66
	Total Heating Energy	110,584.46	104,322.53	-5.66
Total HVAC Electricity Used	Fan+Pump+Chiller	143,699.51	142,663.75	-0.72
Total Building Electricity Used	Fan+Pump+Chiller+Lighting	183,439.89	171,917.22	-6.28

Table A.1.2 Test 1.2 Building Energy Performance Results

Pleotint Windows Testing April Test 1.2 Energy Performance Average Daily Results

		System A Energy (BTU)	System B Energy (BTU)	% Difference
Fan Energy	AHU Supply Fan	20,120.18	20,311.26	0.95
	AHU Return Fan	8,500.58	8,003.51	-5.85
	AHU Outside Air Injection Fan	5,941.87	5,330.73	-10.29
	Total Fan Energy	34,562.63	33,645.50	-2.65
Pump Energy	Chiller-CH Pump	0.00	0.00	#DIV/0!
	AHU Chilled Water Pump	18,570.14	18,678.94	0.59
	Heating Water Loop Pump	10,246.41	10,146.09	-0.98
	Total Pump Energy	28,816.55	28,825.03	0.03
Chiller Energy	Chiller-CH	0.00	0.00	#DIV/0!
	ACCA / ACCB	77,476.28	76,999.09	-0.62
	Total Chiller Energy	77,476.28	76,999.09	-0.62
Lighting Energy	East Test Room	10,057.17	5,948.97	-40.85
	South Test Room	9,643.13	6,111.04	-36.63
	West Test Room	10,170.99	6,152.46	-39.51
	Interior Test Room	14,727.19	14,829.38	0.69
	Total Lighting Energy	44,598.48	33,041.86	-25.91
System Cooling Energy	AHU Cooling Coil Sensible Heat	-190,573.96	-183,672.99	-3.62
System Heating Energy	Heating Loop Energy	113,444.21	95,574.82	-15.75
Total HVAC Electricity Used	Fan+Pump+Chiller	140,855.46	139,469.63	-0.98
Total Building Electricity Used	Fan+Pump+Chiller+Lighting	185,453.94	172,511.48	-6.98

Table A.2.1 Test 2.1 Building Energy Performance Results

Pleotint Windows Testing May Test 2.1 Energy Performance Average Daily Results

		System A Energy (BTU)	System B Energy (BTU)	% Difference
Fan Energy	AHU Supply Fan	20,132.28	20,659.68	2.62
	AHU Return Fan	8,299.69	8,041.07	-3.12
	AHU Outside Air Injection Fan	5,814.90	5,254.20	-9.64
	Total Fan Energy	34,246.87	33,954.95	-0.85
Pump Energy	Chiller-CH Pump	0.00	0.00	#DIV/0!
	AHU Chilled Water Pump	18,532.24	18,566.61	0.19
	Heating Water Loop Pump	9,888.47	9,648.19	-2.43
	Total Pump Energy	28,420.71	28,214.80	-0.72
Chiller Energy	Chiller-CH	0.00	0.00	#DIV/0!
	ACCA / ACCB	107,765.97	106,446.19	-1.22
	Total Chiller Energy	107,765.97	106,446.19	-1.22
Lighting Energy	East Test Room	8,826.09	5,658.27	-35.89
	South Test Room	10,010.88	6,399.75	-36.07
	West Test Room	9,866.41	6,707.73	-32.01
	Interior Test Room	14,743.71	14,847.48	0.70
	Total Lighting Energy	43,447.09	33,613.23	-22.63
System Cooling Energy	AHU Cooling Coil Sensible Heat	-216,095.47	-193,588.50	-10.42
System Heating Energy	Heating Loop Energy	62,551.79	51,130.10	-18.26
Total HVAC Electricity Used	Fan+Pump+Chiller	170,433.55	168,615.94	-1.07
Total Building Electricity Used	Fan+Pump+Chiller+Lighting	213,880.64	202,229.17	-5.45

Table A.2.2 Test 2.2 Building Energy Performance Results

Pleotint Windows Testing June Test 2.2 Energy Performance Average Daily Results				
		System A Energy (BTU)	***System B Energy (BTU)***	% Difference
Fan Energy	AHU Supply Fan	20,000.78	21,040.06	5.20
	AHU Return Fan	8,184.26	8,167.84	-0.20
	AHU Outside Air Injection Fan	5,783.89	5,251.00	-9.21
	Total Fan Energy	33,968.93	34,458.90	1.44
Pump Energy	Chiller-CH Pump	0.00	0.00	#DIV/0!
	AHU Chilled Water Pump	18,560.40	18,444.64	-0.62
	Heating Water Loop Pump	10,021.92	9,428.87	-5.92
	Total Pump Energy	28,582.32	27,873.51	-2.48
Chiller Energy	Chiller-CH	0.00	0.00	#DIV/0!
	ACCA / ACCB	135,824.17	135,098.50	-5.74
	Total Chiller Energy	135,824.17	169,423.09	-5.74
Lighting Energy	East Test Room	8,094.58	2,981.07	-63.17
	South Test Room	8,413.43	3,608.55	-57.11
	West Test Room	8,743.15	4,025.50	-53.96
	Interior Test Room	14,735.85	14,859.30	0.84
	Total Lighting Energy	39,987.02	25,474.42	-36.29
System Cooling Energy	AHU Cooling Coil Sensible Heat	-235,661.22	-212,018.89	-10.03
System Heating Energy	Heating Loop Energy	23,489.00	12,002.93	-48.90
Total HVAC Electricity Used	Fan+Pump+Chiller	198,375.42	197,430.91	-0.48
Total Building Electricity Used	Fan+Pump+Chiller+Lighting	238,362.44	222,905.32	-6.48

Table A.3.1 Test 3.1 Building Energy Performance Results

Pleotint Windows Testing July Test 3.1 Energy Performance Average Daily Results

		System A Energy (BTU)	System B Energy (BTU)	% Difference
Fan Energy	AHU Supply Fan	43,761.10	41,929.71	-4.18
	AHU Return Fan	13,469.81	13,587.12	0.87
	AHU Outside Air Injection Fan	5,738.81	5,312.89	-7.42
	Total Fan Energy	62,969.73	60,829.72	-3.40
Pump Energy	Chiller-CH Pump	0.00	0.00	
	AHU Chilled Water Pump	18,478.04	18,544.28	0.36
	Heating Water Loop Pump	1,402.87	1,475.86	5.20
	Total Pump Energy	19,880.91	20,020.13	0.70
Chiller Energy	Chiller-CH	0.00	0.00	#DIV/0!
	ACCA / ACCB	293,841.24	295,354.48	0.51
	Total Chiller Energy	293,841.24	295,354.48	0.51
Lighting Energy	East Test Room	7,331.30	6,923.08	-5.57
	South Test Room	8,351.86	7,362.53	-11.85
	West Test Room	8,488.53	7,437.59	-12.38
	Interior Test Room	14,781.19	14,841.14	0.41
	Total Lighting Energy	38,952.88	36,564.34	-6.13
System Cooling Energy	AHU Cooling Coil Sensible Heat	-542,667.34	-505,806.41	-6.79
System Heating Energy	Heating Loop Energy	0.00	0.00	
Total HVAC Electricity Used	Fan+Pump+Chiller	376,691.88	376,204.32	-0.13
Total Building Electricity Used	Fan+Pump+Chiller+Lighting	415,644.75	412,768.66	-0.69

Table A.3.2 Test 3.2 Building Energy Performance Results

Pleotint Windows Testing August Test 3.2 Energy Performance Average Daily Results

		System A Energy (BTU)	System B Energy (BTU)	% Difference
Fan Energy	AHU Supply Fan	41,015.60	38,930.90	-5.08
	AHU Return Fan	12,911.93	12,843.78	-0.53
	AHU Outside Air Injection Fan	5,809.61	5,360.75	-7.73
	Total Fan Energy	59,737.14	57,135.43	-4.36
Pump Energy	Chiller-CH Pump	0.00	0.00	#DIV/0!
	AHU Chilled Water Pump	18,469.50	18,613.19	0.78
	Heating Water Loop Pump	1,410.60	1,483.64	5.18
	Total Pump Energy	19,880.09	20,096.83	1.09
Chiller Energy	Chiller-CH	0.00	0.00	#DIV/0!
	ACCA / ACCB	246,275.64	220,905.04	-10.30
	Total Chiller Energy	246,275.64	220,905.04	-10.30
Lighting Energy	East Test Room	6,858.11	3,533.75	-48.47
	South Test Room	7,662.32	3,678.86	-51.99
	West Test Room	7,938.67	4,226.95	-46.75
	Interior Test Room	14,805.53	14,878.36	0.49
	Total Lighting Energy	37,264.63	26,317.91	-29.38
System Cooling Energy	AHU Cooling Coil Sensible Heat	-520,438.81	-478,912.61	-7.98
System Heating Energy	Heating Loop Energy	0.00	0.00	
Total HVAC Electricity Used	Fan+Pump+Chiller	325,892.87	298,137.30	-8.52
Total Building Electricity Used	Fan+Pump+Chiller+Lighting	363,157.50	324,455.21	-10.66

Table A.4.1 Test 4.1 Building Energy Performance Results

Pleotint Windows Testing September Test 4.1 Energy Performance Average Daily Results

		System A Energy (BTU)	System B Energy (BTU)	% Difference
Fan Energy	AHU Supply Fan	37,583.47	33,602.99	-10.59
	AHU Return Fan	11,990.58	11,344.10	-5.39
	AHU Outside Air Injection Fan	5,877.23	5,410.76	-7.94
	Total Fan Energy	55,451.28	50,357.85	-9.19
Pump Energy	Chiller-CH Pump	0.00	0.00	#DIV/0!
	AHU Chilled Water Pump	18,684.67	18,719.72	0.19
	Heating Water Loop Pump	1,379.21	1,471.49	6.69
	Total Pump Energy	20,063.88	20,191.21	0.63
Chiller Energy	Chiller-CH	0.00	0.00	#DIV/0!
	ACCA / ACCB	186,552.08	156,226.67	-16.26
	Total Chiller Energy	186,552.08	156,226.67	-16.26
Lighting Energy	East Test Room	7,966.83	7,556.95	-5.14
	South Test Room	5,260.28	8,592.15	63.34
	West Test Room	8,080.21	6,640.51	-17.82
	Interior Test Room	14,711.95	14,779.87	0.46
	Total Lighting Energy	36,019.27	37,569.48	4.30
System Cooling Energy	AHU Cooling Coil Sensible Heat	-460,314.46	-411,908.25	-10.52
System Heating Energy	Heating Loop Energy	0.00	0.00	
Total HVAC Electricity Used	Fan+Pump+Chiller	262,067.24	226,775.72	-13.47
Total Building Electricity Used	Fan+Pump+Chiller+Lighting	298,086.50	264,345.20	-11.32

Table A.4.2 Test 4.2 Building Energy Performance Results

Pleotint October Test 4.2 Energy Performance Average Daily Results

		System A Energy (BTU)	System B Energy (BTU)	% Difference
Fan Energy	AHU Supply Fan	37,261.48	35,125.38	-5.73
	AHU Return Fan	11,853.89	11,732.87	-1.02
	AHU Outside Air Injection Fan	5,817.75	5,357.36	-7.91
	Total Fan Energy	54,933.12	52,215.61	-4.95
Pump Energy	Chiller-CH Pump	0.00	0.00	#DIV/0!
	AHU Chilled Water Pump	18,693.30	18,803.77	0.59
	Heating Water Loop Pump	1,377.81	1,469.34	6.64
	Total Pump Energy	20,071.11	20,273.11	1.01
Chiller Energy	Chiller-CH	0.00	0.00	#DIV/0!
	ACCA / ACCB	203,860.74	175,426.12	-13.95
	Total Chiller Energy	203,860.74	175,426.12	-13.95
Lighting Energy	East Test Room	8,647.78	4,703.40	-45.61
	South Test Room	6,507.50	4,741.08	-27.14
	West Test Room	8,451.96	4,655.42	-44.92
	Interior Test Room	14,702.93	14,775.12	0.49
	Total Lighting Energy	38,310.16	28,875.02	-24.63
System Cooling Energy	AHU Cooling Coil Sensible Heat	-468,465.65	-429,512.18	-8.32
System Heating Energy	Heating Loop Energy	0.00	0.00	
Total HVAC Electricity Used	Fan+Pump+Chiller	278,864.97	247,914.84	-11.10
Total Building Electricity Used	Fan+Pump+Chiller+Lighting	317,175.14	276,789.86	-12.73

Table A.5.1 Test 5.1 Building Energy Performance Results

Pleotint Windows Testing November Test 5.1 Energy Performance Average Daily Results

		System A Energy (BTU)	System B Energy (BTU)	% Difference
Fan Energy	AHU Supply Fan	26,313.97	25,022.26	-4.91
	AHU Return Fan	9,321.53	9,270.23	-0.55
	AHU Outside Air Injection Fan	6,190.64	5,600.32	-9.54
	Total Fan Energy	41,826.14	39,892.81	-4.62
Pump Energy	Chiller-CH Pump	0.00	0.00	
	AHU Chilled Water Pump	18,499.32	18,516.56	0.09
	Heating Water Loop Pump	1,795.72	1,824.22	1.59
	Total Pump Energy	20,295.04	20,340.78	0.23
Chiller Energy	Chiller-CH	0.00	0.00	
	ACCA / ACCB	98,747.40	85,611.19	-13.30
	Total Chiller Energy	98,747.40	85,611.19	-13.30
Lighting Energy	East Test Room	11,470.00	9,625.71	-16.08
	South Test Room	8,546.85	8,363.01	-2.15
	West Test Room	11,484.07	8,650.10	-24.68
	Interior Test Room	14,752.91	14,798.99	0.31
	Total Lighting Energy	46,253.83	41,437.81	-10.41
System Cooling Energy	AHU Cooling Coil Sensible Heat	-290,769.46	-258,433.93	-11.12
System Heating Energy	Heating Loop Energy	7,792.01	8,370.11	7.42
Total HVAC Electricity Used	Fan+Pump+Chiller	160,868.58	145,844.78	-9.34
Total Building Electricity Used	Fan+Pump+Chiller+Lighting	207,122.41	187,282.59	-9.58

Table A.5.2 Test 5.2 Building Energy Performance Results

Pleotint Windows Testing December Test 5.2 Energy Performance Average Daily Results

		System A Energy (BTU)	System B Energy (BTU)	% Difference
Fan Energy	AHU Supply Fan	23,872.21	22,609.12	-5.29
	AHU Return Fan	8,729.18	8,591.61	-1.58
	AHU Outside Air Injection Fan	6,349.05	5,698.92	-10.24
	Total Fan Energy	38,950.44	36,899.66	-5.27
Pump Energy	Chiller-CH Pump	0.00	0.00	#DIV/0!
	AHU Chilled Water Pump	18,200.66	18,460.37	1.43
	Heating Water Loop Pump	2,711.60	2,458.53	-9.33
	Total Pump Energy	20,912.26	20,918.90	0.03
Chiller Energy	Chiller-CH	0.00	0.00	#DIV/0!
	ACCA / ACCB	73,662.90	65,086.08	-11.64
	Total Chiller Energy	73,662.90	65,086.08	-11.64
Lighting Energy	East Test Room	11,723.87	8,350.38	-28.77
	South Test Room	9,666.32	7,961.44	-17.64
	West Test Room	11,913.94	7,973.86	-33.07
	Interior Test Room	14,745.53	14,797.20	0.35
	Total Lighting Energy	48,049.66	39,082.89	-18.66
System Cooling Energy	AHU Cooling Coil Sensible Heat	-229,625.07	-202,162.42	-11.96
System Heating Energy	Heating Loop Energy	16,712.92	15,472.08	-7.42
Total HVAC Electricity Used	Fan+Pump+Chiller	133,525.59	122,904.64	-7.95
Total Building Electricity Used	Fan+Pump+Chiller+Lighting	181,575.25	161,987.52	-10.79

Table A.6.1 Test 6.1 Building Energy Performance Results

Pleotint Windows Testing February Test 6.1 Energy Performance Average Daily Results

		System A Energy (BTU)	System B Energy (BTU)	% Difference
Fan Energy	AHU Supply Fan	24,438.03	23,763.74	-2.76
	AHU Return Fan	8,871.34	8,863.45	-0.09
	AHU Outside Air Injection Fan	6,268.24	5,668.81	-9.56
	Total Fan Energy	39,577.61	38,295.99	-3.24
Pump Energy	Chiller-CH Pump	0.00	0.00	#DIV/0!
	AHU Chilled Water Pump	18,456.14	18,553.90	0.53
	Heating Water Loop Pump	2,415.74	2,524.03	4.48
	Total Pump Energy	20,871.88	21,077.93	0.99
Chiller Energy	Chiller-CH	0.00	0.00	#DIV/0!
	ACCA / ACCB	83,263.63	75,623.06	-9.18
	Total Chiller Energy	83,263.63	38,295.99	-54.01
Lighting Energy	East Test Room	10,385.67	7,831.24	-24.60
	South Test Room	9,504.82	7,832.07	-17.60
	West Test Room	10,455.09	7,448.31	-28.76
	Interior Test Room	14,720.89	14,770.85	0.34
	Total Lighting Energy	45,066.47	37,882.48	-15.94
System Cooling Energy	AHU Cooling Coil Sensible Heat	-255,155.92	-227,458.06	-10.86
System Heating Energy	Heating Loop Energy	15,083.08	15,727.48	4.27
Total HVAC Electricity Used	Fan+Pump+Chiller	143,713.11	134,996.98	-6.06
Total Building Electricity Used	Fan+Pump+Chiller+Lighting	188,779.58	172,879.45	-8.42

Table A.6.2 Test 6.2 Building Energy Performance Results

Pleotint Windows Testing February Test 6.2 Energy Performance Average Daily Results

		System A Energy (BTU)	System B Energy (BTU)	% Difference
Fan Energy	AHU Supply Fan	25,928.86	25,701.29	-0.88
	AHU Return Fan	9,138.53	9,265.70	1.39
	AHU Outside Air Injection Fan	6,175.58	5,610.68	-9.15
	Total Fan Energy	41,242.98	40,577.68	-1.61
Pump Energy	Chiller-CH Pump	0.00	0.00	#DIV/0!
	AHU Chilled Water Pump	18,441.45	18,579.63	0.75
	Heating Water Loop Pump	2,911.24	3,160.17	8.55
	Total Pump Energy	21,352.69	21,739.80	1.81
Chiller Energy	Chiller-CH	0.00	0.00	#DIV/0!
	ACCA / ACCB	92,636.42	83,615.24	-9.74
	Total Chiller Energy	92,636.42	83,615.24	-9.74
Lighting Energy	East Test Room	9,682.68	6,081.50	-37.19
	South Test Room	6,755.54	5,326.91	-21.15
	West Test Room	10,464.86	5,960.02	-43.05
	Interior Test Room	14,689.04	14,741.10	0.35
	Total Lighting Energy	41,592.13	32,109.54	-22.80
System Cooling Energy	AHU Cooling Coil Sensible Heat	-270,985.58	-251,403.23	-7.23
System Heating Energy	Heating Loop Energy	16,210.90	16,146.55	-0.40
Total HVAC Electricity Used	Fan+Pump+Chiller	155,232.08	145,932.71	-5.99
Total Building Electricity Used	Fan+Pump+Chiller+Lighting	196,824.22	178,042.25	-9.54

Appendix B. Actual Daily Average Building Energy Normalization Results

Table B.1 Test 1 Building Energy Normalization Results

Pleotint Normalization Test 1 Daily Energy Performance Results (4/21 & 4/22 6:00 - 18:00)

		System A Energy (BTU)	System B Energy (BTU)	% Difference
Fan Energy	AHU Supply Fan	19,793.84	20,260.00	2.36
	AHU Return Fan	8,409.27	7,963.90	-5.30
	AHU Outside Air Injection Fan	5,960.47	5,332.08	-10.54
	Total Fan Energy	34,163.57	33,555.97	-1.78
Pump Energy	Chiller-CH Pump	0.00	0.00	
	AHU Chilled Water Pump	18,990.31	19,116.59	0.66
	Heating Water Loop Pump	10,642.65	10,759.33	1.10
	Total Pump Energy	29,632.95	29,875.92	0.82
Chiller Energy	Chiller-CH	0.00	0.00	
	ACCA / ACCB	82,453.63	83,160.67	0.86
	Total Chiller Energy	82,453.63	83,160.67	0.86
Lighting Energy	East Test Room	7,417.39	6,345.34	-14.45
	South Test Room	6,901.39	6,738.12	-2.37
	West Test Room	7,108.76	6,497.57	-8.60
	Interior Test Room	14,730.58	14,831.09	0.68
	Total Lighting Energy	36,158.11	34,412.10	-4.83
System Cooling Energy	AHU Cooling Coil Sensible Heat	-183,829.02	-180,298.86	-1.92
System Heating Energy	Heating Loop Energy	153,182.47	150,770.19	-1.57
Total HVAC Electricity Used	Fan+Pump+Chiller	146,250.15	146,592.55	0.23
Total Building Electricity Used	Fan+Pump+Chiller+Lighting	182,408.26	181,004.65	-0.77

Table B.2 Test 2 Building Energy Normalization Results

Pleotint Normalization Test 2 Energy Performance Result (Daily Average 6/14 & 6/15 6:00 - 18:00)				
		System A Energy (BTU)	***System B Energy (BTU)***	% Difference
Fan Energy	AHU Supply Fan	20,049.98	20,869.46	4.09
	AHU Return Fan	8,251.77	8,169.68	-0.99
	AHU Outside Air Injection Fan	5,807.61	5,248.09	-9.63
	Total Fan Energy	34,109.36	34,287.23	0.52
Pump Energy	Chiller-CH Pump	0.00	0.00	
	AHU Chilled Water Pump	18,542.16	18,353.82	-1.02
	Heating Water Loop Pump	9,805.28	9,943.99	1.41
	Total Pump Energy	28,347.44	28,297.80	-0.18
Chiller Energy	Chiller-CH	0.00	0.00	
	ACCA / ACCB	116,458.20	116,594.44	0.12
	Total Chiller Energy	116,458.20	116,594.44	0.12
Lighting Energy	East Test Room	3,092.12	2,793.31	-9.66
	South Test Room	3,077.96	3,068.79	-0.30
	West Test Room	3,123.24	3,045.47	-2.49
	Interior Test Room	14,757.67	14,881.62	0.84
	Total Lighting Energy	24,050.98	23,789.18	-1.09
System Cooling Energy	AHU Cooling Coil Sensible Heat	-219,047.06	-197,775.68	-9.71
System Heating Energy	Heating Loop Energy	21,011.67	17,739.31	-15.57
Total HVAC Electricity Used	Fan+Pump+Chiller	178,914.99	179,179.46	0.15
Total Building Electricity Used	Fan+Pump+Chiller+Lighting	202,965.97	202,968.64	0.00

Table B.3 Test 3 Building Energy Normalization Results

Pleotint Windows Test 3 Normalization Energy Performance (Average Daily 8/20 - 23 6:00 - 18:00)

		System A Energy (BTU)	System B Energy (BTU)	% Difference
Fan Energy	AHU Supply Fan	52,609.64	44,634.38	-15.16
	AHU Return Fan	15,358.88	14,254.57	-7.19
	AHU Outside Air Injection Fan	5,787.07	5,306.84	-8.30
	Total Fan Energy	73,755.59	64,195.79	-12.96
Pump Energy	Chiller-CH Pump	0.00	0.00	
	AHU Chilled Water Pump	18,519.18	18,524.65	0.03
	Heating Water Loop Pump	1,410.33	1,490.45	5.68
	Total Pump Energy	19,929.51	20,015.09	0.43
Chiller Energy	Chiller-CH	0.00	0.00	
	ACCA / ACCB	279,585.64	252,660.53	-9.63
	Total Chiller Energy	279,585.64	252,660.53	-9.63
Lighting Energy	East Test Room	1,257.20	1,281.35	1.92
	South Test Room	1,710.84	1,769.65	3.44
	West Test Room	2,135.69	2,459.09	15.14
	Interior Test Room	14,758.62	14,842.04	0.57
	Total Lighting Energy	19,862.34	20,352.13	2.47
System Cooling Energy	AHU Cooling Coil Sensible Heat	-579,200.82	-511,569.81	-11.68
System Heating Energy	Heating Loop Energy	0.00	0.00	
Total HVAC Electricity Used	Fan+Pump+Chiller	373,270.74	336,871.41	-9.75
Total Building Electricity Used	Fan+Pump+Chiller+Lighting	393,133.08	357,223.54	-9.13

Table B.4 Test 4 Building Energy Normalization Results

Pleotint Windows Test 4 Normalization Energy Performance (Average Daily 10/15~16 6:00 - 18:00)				
		System A Energy (BTU)	System B Energy (BTU)	% Difference
Fan Energy	AHU Supply Fan	42,373.24	36,430.07	-14.03
	AHU Return Fan	13,021.51	12,103.20	-7.05
	AHU Outside Air Injection Fan	5,888.84	5,378.55	-8.67
	Total Fan Energy	61,283.59	53,911.81	-12.03
Pump Energy	Chiller-CH Pump	0.00	0.00	
	AHU Chilled Water Pump	18,613.17	18,757.10	0.77
	Heating Water Loop Pump	1,376.00	1,447.76	5.21
	Total Pump Energy	19,989.17	20,204.85	1.08
Chiller Energy	Chiller-CH	0.00	0.00	
	ACCA / ACCB	160,030.15	141,623.58	-11.50
	Total Chiller Energy	160,030.15	141,623.58	-11.50
Lighting Energy	East Test Room	2,967.89	2,930.19	-1.27
	South Test Room	2,595.11	2,914.67	12.31
	West Test Room	3,070.43	3,129.37	1.92
	Interior Test Room	14,673.23	14,735.13	0.42
	Total Lighting Energy	23,306.65	23,709.36	1.73
System Cooling Energy	AHU Cooling Coil Sensible Heat	-455,506.63	-412,811.55	-9.37
System Heating Energy	Heating Loop Energy	0.00	0.00	
Total HVAC Electricity Used	Fan+Pump+Chiller	241,302.90	215,740.24	-10.59
Total Building Electricity Used	Fan+Pump+Chiller+Lighting	264,609.55	239,449.59	-9.51

Table B.5 Test 5 Building Energy Normalization Results

Pleotint Windows Testing Test 5 Normalization Energy Performance (Daily Average 12/14 6:00 - 18:00)

		System A Energy (BTU)	System B Energy (BTU)	% Difference
Fan Energy	AHU Supply Fan	24,920.06	22,002.39	-11.71
	AHU Return Fan	15,127.67	13,020.96	-13.93
	AHU Outside Air Injection Fan	5,975.22	5,462.99	-8.57
	Total Fan Energy	46,022.95	40,486.34	-12.03
Pump Energy	Chiller-CH Pump	0.00	0.00	
	AHU Chilled Water Pump	18,428.61	18,586.87	0.86
	Heating Water Loop Pump	1,488.48	1,856.15	24.70
	Total Pump Energy	19,917.09	20,443.02	2.64
Chiller Energy	Chiller-CH	0.00	0.00	
	ACCA / ACCB	108,144.78	93,382.01	-13.65
	Total Chiller Energy	108,144.78	93,382.01	-13.65
Lighting Energy	East Test Room	21,723.90	21,636.40	-0.40
	South Test Room	21,582.01	21,908.22	1.51
	West Test Room	21,747.72	20,899.47	-3.90
	Interior Test Room	14,780.41	14,851.49	0.48
	Total Lighting Energy	79,834.04	79,295.58	-0.67
System Cooling Energy	AHU Cooling Coil Sensible Heat	-317,305.53	-291,729.54	-8.06
System Heating Energy	Heating Loop Energy	0.00	0.00	
Total HVAC Electricity Used	Fan+Pump+Chiller	174,084.82	154,311.37	-11.36
Total Building Electricity Used	Fan+Pump+Chiller+Lighting	253,918.86	233,606.95	-8.00

Table B.6 Test 6 Building Energy Normalization Results

Pleotint Windows Testing February Test 6.1 Energy Performance (Average Daily 2/12 & 2/13 6:00 -18:00)

		System A Energy (BTU)	System B Energy (BTU)	% Difference
Fan Energy	AHU Supply Fan	29,428.72	28,457.43	-3.30
	AHU Return Fan	10,042.52	9,771.54	-2.70
	AHU Outside Air Injection Fan	6,322.40	5,666.82	-10.37
	Total Fan Energy	45,793.64	43,895.79	-4.14
Pump Energy	Chiller-CH Pump	0.00	0.00	
	AHU Chilled Water Pump	17,913.21	17,742.46	-0.95
	Heating Water Loop Pump	6,798.01	6,981.40	2.70
	Total Pump Energy	24,711.22	24,723.86	0.05
Chiller Energy	Chiller-CH	0.00	0.00	
	ACCA / ACCB	81,582.87	72,723.09	-10.86
	Total Chiller Energy	81,582.87	72,723.09	-10.86
Lighting Energy	East Test Room	2,767.55	2,943.27	6.35
	South Test Room	2,581.36	2,695.95	4.44
	West Test Room	2,901.49	2,968.93	2.32
	Interior Test Room	14,638.75	14,721.74	0.57
	Total Lighting Energy	22,889.14	23,329.89	1.93
System Cooling Energy	AHU Cooling Coil Sensible Heat	-277,896.97	-241,604.24	-13.06
System Heating Energy	Heating Loop Energy	35,881.50	34,039.09	-5.13
Total HVAC Electricity Used	Fan+Pump+Chiller	152,087.72	141,342.74	-7.06
Total Building Electricity Used	Fan+Pump+Chiller+Lighting	174,976.86	164,672.63	-5.89

Appendix C. Simulated Daily Average Building Energy Comparison Results

Table C.1.1 Test 1.1 Simulated Building Energy Performance Results

Pleotint Azuria Window Test 1.1 Energy Performance Result Daily Average (03/23/2011 - 4/10/2011)

		System A Energy (kBTU)	System B Energy (kBTU)	% Difference
Fan Energy	AHU Supply Fan	32.68	32.81	0.38
	AHU Return Fan	6.20	5.01	-19.16
	AHU Outside Air Injection Fan	5.50	5.50	0.00
	Total Fan Energy	44.38	43.32	-2.39
Pump Energy	Chiller-CH Pump	0.00	0.00	
	AHU Chilled Water Pump	19.12	19.04	-0.43
	Heating Water Loop Pump	15.37	18.86	22.71
	Total Pump Energy	34.49	37.90	9.88
Chiller Energy	Chiller-CH	0.00	0.00	
	ACCA / ACCB	93.23	93.12	-0.12
	Total Chiller Energy	93.23	93.12	-0.12
Lighting Energy	East Test Room	6.52	4.22	-35.34
	South Test Room	5.71	3.59	-37.16
	West Test Room	7.02	3.22	-54.18
	Interior Test Room	15.78	15.78	0.00
	Total Lighting Energy	35.03	26.80	-23.50
System Cooling Energy	AHU Cooling Coil Sensible Heat	-185.90	-185.75	-0.08
System Heating Energy	Heating Loop Energy	143.84	149.78	4.13
Total HVAC Electricity Used	Fan+Pump+Chiller	172.10	174.33	1.30
Total Building Electricity Used	Fan+Pump+Chiller+Lighting	207.13	201.14	-2.90

Table C.1.2 Test 1.2 Simulated Building Energy Performance Results

Pleotint Green Window Test 1.2 Energy Performance Result Daily Average (04/12/2011 - 4/19/2011)

		System A Energy (kBTU)	System B Energy (kBTU)	% Difference
Fan Energy	AHU Supply Fan	32.52	32.47	-0.13
	AHU Return Fan	6.18	4.98	-19.45
	AHU Outside Air Injection Fan	5.50	5.50	0.00
	Total Fan Energy	44.20	42.96	-2.82
Pump Energy	Chiller-CH Pump	0.00	0.00	
	AHU Chilled Water Pump	19.12	19.04	-0.42
	Heating Water Loop Pump	13.60	16.69	22.73
	Total Pump Energy	32.72	35.73	9.20
Chiller Energy	Chiller-CH	0.00	0.00	
	ACCA / ACCB	94.67	95.02	0.37
	Total Chiller Energy	94.67	95.02	0.37
Lighting Energy	East Test Room	9.32	5.73	-38.54
	South Test Room	8.88	5.24	-41.02
	West Test Room	8.86	4.48	-49.49
	Interior Test Room	15.78	15.78	0.00
	Total Lighting Energy	42.85	31.22	-27.13
System Cooling Energy	AHU Cooling Coil Sensible Heat	-193.77	-194.69	0.47
System Heating Energy	Heating Loop Energy	137.32	142.66	3.89
Total HVAC Electricity Used	Fan+Pump+Chiller	171.59	173.70	1.23
Total Building Electricity Used	Fan+Pump+Chiller+Lighting	214.43	204.93	-4.43

Table C.2.1 Test 2.1 Simulated Building Energy Performance Results

Pleotint Azuria Window Test 2.1 Energy Performance Result Daily Average (5/24/2011 - 5/31/2011)

		System A Energy (kBTU)	System B Energy (kBTU)	% Difference
Fan Energy	AHU Supply Fan	31.85	32.07	0.70
	AHU Return Fan	6.14	4.95	-19.38
	AHU Outside Air Injection Fan	5.50	5.50	0.00
	Total Fan Energy	43.49	42.52	-2.23
Pump Energy	Chiller-CH Pump	0.00	0.00	
	AHU Chilled Water Pump	19.12	19.04	-0.42
	Heating Water Loop Pump	10.38	15.38	48.21
	Total Pump Energy	29.50	34.42	16.69
Chiller Energy	Chiller-CH	0.00	0.00	
	ACCA / ACCB	136.57	137.06	0.36
	Total Chiller Energy	136.57	137.06	0.36
Lighting Energy	East Test Room	8.03	5.41	-32.71
	South Test Room	8.60	5.25	-38.98
	West Test Room	7.58	3.55	-53.22
	Interior Test Room	15.78	15.78	0.00
	Total Lighting Energy	39.98	29.97	-25.04
System Cooling Energy	AHU Cooling Coil Sensible Heat	-253.50	-254.76	0.50
System Heating Energy	Heating Loop Energy	124.40	138.56	11.38
Total HVAC Electricity Used	Fan+Pump+Chiller	209.55	214.00	2.12
Total Building Electricity Used	Fan+Pump+Chiller+Lighting	249.54	243.97	-2.23

Table C.2.2 Test 2.2 Simulated Building Energy Performance Results

Pleotint Green Window Test 2.2 Energy Performance Result Daily Average (6/2/2011 - 6/12/2011)				
		System A Energy (kBTU)	*System B Energy (kBTU)*	% Difference
Fan Energy	AHU Supply Fan	31.81	31.83	0.07
	AHU Return Fan	6.14	4.93	-19.66
	AHU Outside Air Injection Fan	5.50	5.50	0.00
	Total Fan Energy	43.45	42.27	-2.73
Pump Energy	Chiller-CH Pump	0.00	0.00	
	AHU Chilled Water Pump	19.12	19.04	-0.42
	Heating Water Loop Pump	6.22	8.79	41.28
	Total Pump Energy	25.34	27.83	9.82
Chiller Energy	Chiller-CH	0.00	0.00	
	ACCA / ACCB	178.49	179.21	0.40
	Total Chiller Energy	178.49	179.21	0.40
Lighting Energy	East Test Room	5.70	2.43	-57.33
	South Test Room	6.23	2.25	-63.90
	West Test Room	5.95	1.56	-73.70
	Interior Test Room	15.78	15.78	0.00
	Total Lighting Energy	33.65	22.02	-34.57
System Cooling Energy	AHU Cooling Coil Sensible Heat	-295.78	-297.20	0.48
System Heating Energy	Heating Loop Energy	103.68	114.63	10.56
Total HVAC Electricity Used	Fan+Pump+Chiller	247.28	249.30	0.82
Total Building Electricity Used	Fan+Pump+Chiller+Lighting	280.94	271.32	-3.42

Table C.3.1 Test 3.1 Simulated Building Energy Performance Results

Pleotint Azuria Window Test 3.1 Energy Performance Result Daily Average (7/29/2011 - 8/7/2011)

		System A Energy (kBTU)	System B Energy (kBTU)	% Difference
Fan Energy	AHU Supply Fan	40.61	39.41	-2.96
	AHU Return Fan	6.66	5.54	-16.81
	AHU Outside Air Injection Fan	5.50	5.50	0.00
	Total Fan Energy	52.76	50.44	-4.40
Pump Energy	Chiller-CH Pump	0.00	0.00	
	AHU Chilled Water Pump	19.12	19.04	-0.43
	Heating Water Loop Pump	0.00	0.00	
	Total Pump Energy	19.12	19.04	-0.43
Chiller Energy	Chiller-CH	0.00	0.00	
	ACCA / ACCB	216.03	215.92	-0.05
	Total Chiller Energy	216.03	215.92	-0.05
Lighting Energy	East Test Room	5.53	4.64	-16.18
	South Test Room	6.10	5.39	-11.55
	West Test Room	5.72	2.82	-50.70
	Interior Test Room	15.78	15.78	0.00
	Total Lighting Energy	33.12	28.63	-13.58
System Cooling Energy	AHU Cooling Coil Sensible Heat	-473.95	-461.32	-2.67
System Heating Energy	Heating Loop Energy	0.00	0.00	
Total HVAC Electricity Used	Fan+Pump+Chiller	287.92	285.40	-0.87
Total Building Electricity Used	Fan+Pump+Chiller+Lighting	321.04	314.03	-2.19

Table C.3.2 Test 3.2 Simulated Building Energy Performance Results

Pleotint Green Window Test 3.2 Energy Performance Result Daily Average (8/9/2011 - 8/15/2011)				
		System A Energy (kBTU)	*System B Energy (kBTU)*	% Difference
Fan Energy	AHU Supply Fan	39.87	39.44	-1.08
	AHU Return Fan	6.61	5.54	-16.29
	AHU Outside Air Injection Fan	5.50	5.50	0.00
	Total Fan Energy	51.99	50.48	-2.90
Pump Energy	Chiller-CH Pump	0.00	0.00	
	AHU Chilled Water Pump	19.12	19.04	-0.43
	Heating Water Loop Pump	0.00	0.00	#DIV/0!
	Total Pump Energy	19.12	19.04	-0.43
Chiller Energy	Chiller-CH	0.00	0.00	
	ACCA / ACCB	195.14	195.65	0.26
	Total Chiller Energy	195.14	195.65	0.26
Lighting Energy	East Test Room	5.31	2.69	-49.30
	South Test Room	5.31	2.39	-54.95
	West Test Room	5.06	0.44	-91.27
	Interior Test Room	15.78	15.78	0.00
	Total Lighting Energy	31.45	21.30	-32.27
System Cooling Energy	AHU Cooling Coil Sensible Heat	-406.95	-401.74	-1.28
System Heating Energy	Heating Loop Energy	0.00	0.00	-100.00
Total HVAC Electricity Used	Fan+Pump+Chiller	266.25	265.17	-0.40
Total Building Electricity Used	Fan+Pump+Chiller+Lighting	297.69	286.47	-3.77

Table C.4.1 Test 4.1 Simulated Building Energy Performance Results

Pleotint Azuria Window Test 4.1 Energy Performance Result Daily Average (9/28/2011 - 10/4/2011)

		System A Energy (kBTU)	System B Energy (kBTU)	% Difference
Fan Energy	AHU Supply Fan	37.12	36.59	-1.43
	AHU Return Fan	6.45	5.31	-17.75
	AHU Outside Air Injection Fan	5.50	5.50	0.00
	Total Fan Energy	49.07	47.39	-3.42
Pump Energy	Chiller-CH Pump	0.00	0.00	
	AHU Chilled Water Pump	19.12	19.04	-0.43
	Heating Water Loop Pump	0.00	0.00	
	Total Pump Energy	19.12	19.04	-0.43
Chiller Energy	Chiller-CH	0.00	0.00	
	ACCA / ACCB	166.79	166.68	-0.07
	Total Chiller Energy	166.79	166.68	-0.07
Lighting Energy	East Test Room	8.12	7.85	-3.22
	South Test Room	5.34	7.71	44.45
	West Test Room	8.05	6.64	-17.55
	Interior Test Room	15.78	15.78	0.00
	Total Lighting Energy	37.28	37.98	1.87
System Cooling Energy	AHU Cooling Coil Sensible Heat	-330.60	-324.03	-1.99
System Heating Energy	Heating Loop Energy	0.00	0.00	
Total HVAC Electricity Used	Fan+Pump+Chiller	234.99	233.11	-0.80
Total Building Electricity Used	Fan+Pump+Chiller+Lighting	272.26	271.09	-0.43

Table C.4.2 Test 4.2 Simulated Building Energy Performance Results

Pleotint Green Window Test 4.2 Energy Performance Result Daily Average (10/6/2011 - 10/12/2011)

		System A Energy (kBTU)	System B Energy (kBTU)	% Difference
Fan Energy	AHU Supply Fan	36.43	36.46	0.08
	AHU Return Fan	6.42	5.30	-17.39
	AHU Outside Air Injection Fan	5.50	5.50	0.00
	Total Fan Energy	48.35	47.26	-2.25
Pump Energy	Chiller-CH Pump	0.00	0.00	
	AHU Chilled Water Pump	19.12	19.04	-0.43
	Heating Water Loop Pump	0.00	0.00	
	Total Pump Energy	19.12	19.04	-0.43
Chiller Energy	Chiller-CH	0.00	0.00	
	ACCA / ACCB	176.59	177.28	0.39
	Total Chiller Energy	176.59	177.28	0.39
Lighting Energy	East Test Room	8.10	5.25	-35.23
	South Test Room	6.41	4.21	-34.34
	West Test Room	8.39	3.48	-58.46
	Interior Test Room	15.78	15.78	0.00
	Total Lighting Energy	38.67	28.71	-25.75
System Cooling Energy	AHU Cooling Coil Sensible Heat	-349.46	-348.19	-0.36
System Heating Energy	Heating Loop Energy	0.00	0.00	
Total HVAC Electricity Used	Fan+Pump+Chiller	244.06	243.58	-0.20
Total Building Electricity Used	Fan+Pump+Chiller+Lighting	282.74	272.29	-3.69

Table C.5.1 Test 5.1 Simulated Building Energy Performance Results

Pleotint Azuria Window Test 5.1 Energy Performance Result Daily Average (11/23/2011 - 11/30/2011)

		System A Energy (kBTU)	System B Energy (kBTU)	% Difference
Fan Energy	AHU Supply Fan	32.42	32.62	0.62
	AHU Return Fan	6.18	4.99	-19.19
	AHU Outside Air Injection Fan	5.50	5.50	0.00
	Total Fan Energy	44.10	43.11	-2.23
Pump Energy	Chiller-CH Pump	0.00	0.00	
	AHU Chilled Water Pump	19.12	19.04	-0.42
	Heating Water Loop Pump	0.06	0.04	-30.77
	Total Pump Energy	19.18	19.08	-0.51
Chiller Energy	Chiller-CH	0.00	0.00	
	ACCA / ACCB	109.92	110.29	0.33
	Total Chiller Energy	109.92	110.29	0.33
Lighting Energy	East Test Room	12.54	11.37	-9.29
	South Test Room	10.64	9.75	-8.41
	West Test Room	13.21	11.22	-15.11
	Interior Test Room	15.78	15.78	0.00
	Total Lighting Energy	52.17	48.11	-7.78
System Cooling Energy	AHU Cooling Coil Sensible Heat	-224.27	-225.30	0.46
System Heating Energy	Heating Loop Energy	3.43	2.82	-17.84
Total HVAC Electricity Used	Fan+Pump+Chiller	173.20	172.48	-0.41
Total Building Electricity Used	Fan+Pump+Chiller+Lighting	225.36	220.59	-2.12

Table C.5.2 Test 5.2 Simulated Building Energy Performance Results

Pleotint Green Window Test 5.2 Energy Performance Result Daily Average (12/2/2011 - 12/9/2011)

		System A Energy (kBTU)	System B Energy (kBTU)	% Difference
Fan Energy	AHU Supply Fan	31.89	32.26	1.15
	AHU Return Fan	6.15	4.96	-19.22
	AHU Outside Air Injection Fan	5.50	5.50	0.00
	Total Fan Energy	43.54	42.72	-1.87
Pump Energy	Chiller-CH Pump	0.00	0.00	
	AHU Chilled Water Pump	19.12	19.04	-0.42
	Heating Water Loop Pump	0.60	0.46	-23.57
	Total Pump Energy	19.72	19.50	-1.12
Chiller Energy	Chiller-CH	0.00	0.00	
	ACCA / ACCB	90.57	92.35	1.97
	Total Chiller Energy	90.57	92.35	1.97
Lighting Energy	East Test Room	12.18	9.04	-25.77
	South Test Room	10.18	8.19	-19.53
	West Test Room	12.79	8.87	-30.65
	Interior Test Room	15.78	15.78	0.00
	Total Lighting Energy	50.92	41.87	-17.76
System Cooling Energy	AHU Cooling Coil Sensible Heat	-182.66	-186.75	2.24
System Heating Energy	Heating Loop Energy	22.87	20.44	-10.65
Total HVAC Electricity Used	Fan+Pump+Chiller	153.82	154.57	0.49
Total Building Electricity Used	Fan+Pump+Chiller+Lighting	204.74	196.44	-4.05

Table C.6.1 Test 6.1 Simulated Building Energy Performance Results

Pleotint Azuria Window Test 6.1 Energy Performance Result Daily Average (2/2/2012 - 2/8/2012)

		System A Energy (kBTU)	System B Energy (kBTU)	% Difference
Fan Energy	AHU Supply Fan	32.03	32.31	0.87
	AHU Return Fan	6.16	4.97	-19.32
	AHU Outside Air Injection Fan	5.50	5.50	0.00
	Total Fan Energy	43.69	42.78	-2.09
Pump Energy	Chiller-CH Pump	0.00	0.00	
	AHU Chilled Water Pump	19.12	19.04	-0.43
	Heating Water Loop Pump	0.26	0.22	-15.09
	Total Pump Energy	19.38	19.26	-0.63
Chiller Energy	Chiller-CH	0.00	0.00	
	ACCA / ACCB	96.78	97.39	0.63
	Total Chiller Energy	96.78	97.39	0.63
Lighting Energy	East Test Room	11.66	9.78	-16.13
	South Test Room	10.90	8.88	-18.50
	West Test Room	12.71	9.80	-22.92
	Interior Test Room	15.78	15.78	0.00
	Total Lighting Energy	51.05	44.24	-13.34
System Cooling Energy	AHU Cooling Coil Sensible Heat	-196.32	-197.85	0.78
System Heating Energy	Heating Loop Energy	12.14	12.48	2.83
Total HVAC Electricity Used	Fan+Pump+Chiller	159.85	159.43	-0.26
Total Building Electricity Used	Fan+Pump+Chiller+Lighting	210.90	203.67	-3.43

Table C.6.2 Test 6.2 Simulated Building Energy Performance Results

Pleotint Green Window Test 6.2 Energy Performance Result Daily Average (1/25/2012 - 1/31/2012)

		System A Energy (kBTU)	System B Energy (kBTU)	% Difference
Fan Energy	AHU Supply Fan	32.45	33.02	1.74
	AHU Return Fan	6.18	5.03	-18.69
	AHU Outside Air Injection Fan	5.50	5.50	0.00
	Total Fan Energy	44.13	43.54	-1.34
Pump Energy	Chiller-CH Pump	0.00	0.00	
	AHU Chilled Water Pump	19.12	19.04	-0.43
	Heating Water Loop Pump	0.18	0.12	-35.14
	Total Pump Energy	19.30	19.16	-0.76
Chiller Energy	Chiller-CH	0.00	0.00	
	ACCA / ACCB	105.38	108.56	3.01
	Total Chiller Energy	105.38	108.56	3.01
Lighting Energy	East Test Room	10.31	8.12	-21.22
	South Test Room	8.30	6.99	-15.77
	West Test Room	12.75	7.50	-41.21
	Interior Test Room	15.78	15.78	0.00
	Total Lighting Energy	47.13	38.38	-18.57
System Cooling Energy	AHU Cooling Coil Sensible Heat	-214.90	-222.09	3.34
System Heating Energy	Heating Loop Energy	8.95	8.31	-7.15
Total HVAC Electricity Used	Fan+Pump+Chiller	168.82	171.25	1.44
Total Building Electricity Used	Fan+Pump+Chiller+Lighting	215.95	209.63	-2.92

Appendix D. Simulated Annual Building Energy Comparison Results

Table D.1 Annual Simulation Results without Baseboard Heat – Azuria

Pleotint Azuria Window Test Full Year without Baseboard Heat Energy Performance Result (01/01/2011-12/31/2011)

		System A Energy (kBTU)	System B Energy (kBTU)	% Difference
Fan Energy	AHU Supply Fan	11,829.06	11,854.58	0.22
	AHU Return Fan	2,255.02	1,818.63	-19.35
	AHU Outside Air Injection Fan	2,007.50	2,007.50	0.00
	Total Fan Energy	16,091.59	15,680.71	-2.55
Pump Energy	Chiller-CH Pump	0.00	0.00	
	AHU Chilled Water Pump	6,979.11	6,949.22	-0.43
	Heating Water Loop Pump	4,473.23	5,856.60	30.93
	Total Pump Energy	11,452.34	12,805.82	11.82
Chiller Energy	Chiller-CH	0.00	0.00	
	ACCA / ACCB	41,696.72	41,860.70	0.39
	Total Chiller Energy	41,696.72	41,860.70	0.39
Lighting Energy	East Test Room	2,572.73	1,692.18	-34.23
	South Test Room	2,145.17	1,429.84	-33.35
	West Test Room	2,790.54	1,537.29	-44.91
	Interior Test Room	5,758.11	5,758.11	0.00
	Total Lighting Energy	13,266.55	10,417.42	-21.48
System Cooling Energy	AHU Cooling Coil Sensible Heat	-76,047.12	-76,402.68	0.47
System Heating Energy	Heating Loop Energy	48,112.37	51,764.53	7.59
Total HVAC Electricity Used	Fan+Pump+Chiller	69,240.65	70,347.23	1.60
Total Building Electricity Used	Fan+Pump+Chiller+Lighting	82,507.20	80,764.65	-2.11

Table D.2 Annual Simulation Results without Baseboard Heat – Green

Pleotint Clear Window Test Full Year without Baseboard Heat Energy Performance Result (01/01/2011-12/31/2011)

		System A Energy (kBTU)	System B Energy (kBTU)	% Difference
Fan Energy	AHU Supply Fan	11,829.03	11,822.75	-0.05
	AHU Return Fan	2,255.02	1,816.07	-19.47
	AHU Outside Air Injection Fan	2,007.50	2,007.50	0.00
	Total Fan Energy	16,091.55	15,646.32	-2.77
Pump Energy	Chiller-CH Pump	0.00	0.00	
	AHU Chilled Water Pump	6,979.11	6,949.22	-0.43
	Heating Water Loop Pump	4,473.13	5,444.60	21.72
	Total Pump Energy	11,452.24	12,393.82	8.22
Chiller Energy	Chiller-CH	0.00	0.00	
	ACCA / ACCB	41,697.81	42,225.82	1.27
	Total Chiller Energy	41,697.81	42,225.82	1.27
Lighting Energy	East Test Room	2,572.73	1,213.67	-52.83
	South Test Room	2,145.17	1,067.83	-50.22
	West Test Room	2,790.54	1,165.35	-58.24
	Interior Test Room	5,758.11	5,758.11	0.00
	Total Lighting Energy	13,266.55	9,204.96	-30.62
System Cooling Energy	AHU Cooling Coil Sensible Heat	-76,049.40	-77,172.36	1.48
System Heating Energy	Heating Loop Energy	48,111.70	50,180.62	4.30
Total HVAC Electricity Used	Fan+Pump+Chiller	69,241.61	70,265.96	1.48
Total Building Electricity Used	Fan+Pump+Chiller+Lighting	82,508.16	79,470.92	-3.68

Table D.3 Annual Simulation Results with Baseboard Heat – Azuria

Pleotint Azuria Window Test Full Year with Baseboard Heat Energy Performance Result (01/01/2011-12/31/2011)

		System A Energy (kBTU)	System B Energy (kBTU)	% Difference
Fan Energy	AHU Supply Fan	12,504.67	12,403.47	-0.81
	AHU Return Fan	2,294.77	1,862.58	-18.83
	AHU Outside Air Injection Fan	2,007.50	2,007.50	0.00
	Total Fan Energy	16,806.95	16,273.55	-3.17
Pump Energy	Chiller-CH Pump	0.00	0.00	
	AHU Chilled Water Pump	6,979.11	6,949.22	-0.43
	Heating Water Loop Pump	102.80	87.69	-14.70
	Total Pump Energy	7,081.91	7,036.91	-0.64
Chiller Energy	Chiller-CH	0.00	0.00	
	ACCA / ACCB	50,173.39	50,155.17	-0.04
	Total Chiller Energy	50,173.39	50,155.17	-0.04
Lighting Energy	East Test Room	2,572.73	1,714.02	-33.38
	South Test Room	2,145.17	1,452.86	-32.27
	West Test Room	2,790.54	1,547.33	-44.55
	Interior Test Room	5,758.11	5,758.11	0.00
	Total Lighting Energy	13,266.55	10,472.32	-21.06
System Cooling Energy	AHU Cooling Coil Sensible Heat	-102,000.72	-100,444.80	-1.53
System Heating Energy	Heating Loop Energy	3,271.06	3,076.05	-5.96
Total HVAC Electricity Used	Fan+Pump+Chiller	74,062.25	73,465.63	-0.81
Total Building Electricity Used	Fan+Pump+Chiller+Lighting	87,328.80	83,937.95	-3.88

Table D.4 Annual Simulation Results with Baseboard Heat – Green

Pleotint Green Window Test Full Year with Baseboard Heat Energy Performance Result (01/01/2011-12/31/2011)

		System A Energy (kBTU)	System B Energy (kBTU)	% Difference
Fan Energy	AHU Supply Fan	12,504.33	12,612.70	0.87
	AHU Return Fan	2,294.77	1,879.16	-18.11
	AHU Outside Air Injection Fan	2,007.50	2,007.50	0.00
	Total Fan Energy	16,806.61	16,499.36	-1.83
Pump Energy	Chiller-CH Pump	0.00	0.00	
	AHU Chilled Water Pump	6,979.11	6,949.22	-0.43
	Heating Water Loop Pump	102.80	69.81	-32.09
	Total Pump Energy	7,081.91	7,019.03	-0.89
Chiller Energy	Chiller-CH	0.00	0.00	
	ACCA / ACCB	50,172.85	50,879.44	1.41
	Total Chiller Energy	50,172.85	50,879.44	1.41
Lighting Energy	East Test Room	2,572.73	1,221.31	-52.53
	South Test Room	2,145.17	1,072.09	-50.02
	West Test Room	2,790.54	1,166.29	-58.21
	Interior Test Room	5,758.11	5,758.11	0.00
	Total Lighting Energy	13,266.55	9,217.80	-30.52
System Cooling Energy	AHU Cooling Coil Sensible Heat	-101,995.44	-103,082.16	1.07
System Heating Energy	Heating Loop Energy	3,270.76	2,569.30	-21.45
Total HVAC Electricity Used	Fan+Pump+Chiller	74,061.37	74,397.82	0.45
Total Building Electricity Used	Fan+Pump+Chiller+Lighting	87,327.92	83,615.62	-4.25

Appendix E. Linear Dimming/Off Lighting Control Sequence

Objective

The objective of this document is to describe Energy Resource Station testroom lighting control "Dimming-Off" algorithm that is used in certain research projects.

Test Room Lighting Fixtures

The lighting fixture type installed in the exterior test rooms (East-A, East-B, South-A, South-B, West-A, West-B) is a recessed grid troffer measuring 2' x 2'. Each fixture is equipped with three U-shaped T8 fluorescent tube lamps sized at 31 watts each. All the test room fixtures have dimmable ballasts. There are a total of six lights in each exterior test room, set up for 2-stage lighting. With the six fixtures and both stages "ON" with 100% output, there is a total light level of 85 foot candles at the work surface in each test room (in no sunlight condition), and the total nominal lighting power in each room is 558 watts.

The lighting fixture type installed in the interior test rooms (Interior-A and Interior-B) is a 2' x 4' recessed grid troffers. Each fixture is equipped with three U-shaped T8 fluorescent tube lamps sized at 31 watts each. There are a total of four lights in each interior test room, set up for 2-stage lighting. With the four fixtures and both stages "ON", the total nominal lighting power in each room is 372 watts.

Test Room Lighting Control Modes

Day lighting controls are available in the exterior test rooms. There are various light sensors within the room that can control the light output through the dimmable electronic ballasts.

The test room lighting system has three modes of control:

- Local control – through the wall mounted switches located in each exterior test room to turn lights on or off, the light output is automatically controlled (dimmed) by a stand-alone local dimming photosensor.
- DDC control – use of the building automation system to control test room lighting schedule, sequence and light output based on feedback from any of the light sensors.
- On/Off control – turn on/off test room lights on full power through building automation system

When using DDC control mode, the lighting control can be configured as either "Continuous Dimming" or "Dimming-Off". The "Continuous Dimming" option allows lights to dim when sunlight is bright but it will never turn off automatically during the schedule "ON" time period. The "Dimming-Off" option allows lights to turn off when sunlight alone can provide enough light levels on the work surface.

Test Room Lighting Dimming-Off Control

When using DDC control mode and the “Dimming-Off” option, following ERS Test System lighting points are involved.

Point Name	Description		Unit
LITECTRL	Lighting Control Mode	0 = On / 1 = Off / 2 = Local / 3 = DDC	
RM-LITE1	Light Level Sensor on Table w/View toward Ceiling		FtC
DIMCTRSP	Dim Control Setpoint		FtC
DIM-CTRL	Light Level Control Output		%

After a desired dimming control setpoint (DIMCTRSP) is set (usually between 45~55 foot candles) and lighting control mode set to “DDC” mode, a PID control loop will be in effect with light level on the work surface (LITECTRL) as the monitored input variable and light level control output (DIM-CTRL) as the PID loop output.

Under normal or low outside lighting conditions, the dimming control output will be in the range of 0%~100% output (equivalent to apply 0~10VDC to the dimming ballast) to control the RM-LITE1 light level around the specified setpoint. The actual lighting wattage will be between the minimum of approximately 128 watts to the maximum of 558 watt.

In high outside lighting conditions, the dimming control output will be kept at the minimum first (while the lighting power is also at the minimum of ~128 watts, until the RM-LITE1 value exceeds the setpoint (DIMCTRSP) plus 10 FtC. Then the lights in that test room will be automatically turned off by the ERS Test Building Control System to save lighting energy.

When outside lighting conditions become darker, the RM-LITE1 level will drop (with the testroom lights already turned off). When the RM-LITE1 level drops below the setpoint (DIMCTRSP) minus 5 FtC, the ERS Test Building Control System will automatically turn on all the lights and the dimming control PID loop starts to take effect again.

For a DIMCTRSP setpoint of 45 FtC, the lights will be turned off when RM-LITE1 > 55 FtC, and will be turned on again if the RM-LITE1 < 40 FtC.

Appendix B. Lawrence Berkeley National Laboratory Final Technical Report

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Empirical results for polymer thermochromic windows for commercial building applications and some observations on material science development objectives

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Abstract

Large-area polymer thermochromic (TC) windows were evaluated in a full-scale testbed office. The TC film exhibited thermochromism through a ligand exchange process, producing a change in solar absorption primarily in the visible range while maintaining transparent, undistorted views through the material. The device had a broad switching temperature range and when combined to make an insulating window unit had center-of-glass properties of Tsol=0.12-0.03, Tvis= 0.028-0.03 for a glass temperature range of 24-75°C. Field test measurements enabled characterization of switching as a function of incident solar irradiance and outdoor air temperature, illustrating how radiation influences glass temperature and thus effectively lowers the critical switching temperature of TC devices. This was further supported by EnergyPlus building energy simulations. Both empirical and simulation data were used to illustrate how the ideal critical switching temperature for TC devices should be based on zone heat balance, not ambient air temperature. Annual energy use data are given to illustrate the energy savings potential of this type of thermochromic. Based on observations in the field, a broad switching temperature range was found to be useful in ensuring a uniform appearance when incident irradiance is non-uniform across the facade. As previously indicated in prior research, a high visible transmittance in the unswitched state is also desirable both to enable reduction of lighting energy use and to enhance indoor environmental quality.

Keywords: Thermochromic; Windows, Solar control; Building energy efficiency

1. Introduction

Thermochromic (TC) materials transition from a clear cold state to tinted hot state at a critical temperature or range of temperatures that is inherent to the fundamental chemistry and makeup of the material. Unlike thermotropic materials which are translucent when switched, the thermochromic maintains a transparent view irrespective of its switched state. These materials have been and continue to be developed for window and skylight applications as a means of passively controlling solar heat gains in buildings. The concept is to transmit solar radiation through the cold, untinted window in the winter to reduce heating energy use requirements and absorb then reject radiation with the hot, tinted window in the summer to reduce cooling energy use requirements. Windows are responsible for about 30% of US building heating and heating loads and have an annual impact of 4.1 Quads (Quad = $1x10^{15}$ Btu) of primary energy use in the US [1]. Control of solar heat gains in this manner has the potential to reduce building energy use and peak electric demand, assuming that the switching pattern matches the typical heating and cooling demand profiles of residential and commercial buildings.

Thermochromic windows are starting to emerge on the market but very little is known about how these devices affect the energy performance and indoor environmental quality in buildings. As with any innovative technology, consumers require information in order to determine how the technology works and whether the technology provides sufficient benefits that would justify the incremental cost of the thermochromic above a conventional window. The thermochromic window has been argued to be competitive to electrochromic (EC) windows because it can provide dynamic control without the added cost and complexity of thin film electrochromic coatings: electrochromic windows require dc power and an automatic control system to capture energy efficiency benefits. Thermochromic glazings and films (for laminate applications) require neither power or controls and would be applicable to the new and replacement windows market.

Proving energy efficiency claims at the proof-of-concept stage is hindered by a number of technical barriers. The full spectral properties of TC prototypes must be fully characterized under a range of thermal conditions, so the prototype must be sufficiently stable and durable. Simulation tools must be modified to accept these data in order to model building energy performance. Field verification by way of calorimetry, mockups in outdoor testbed facilities, or installations in occupied buildings require large-area prototypes, so the prototype must be at minimum in the fabrication stage of maturity. As such, material scientists have been and are continuing to formulate new TC devices based on limited guidance as to what the optimal solar-optical properties and critical switching temperatures should be for building energy-efficiency applications.

There are two classes of thermochromic materials: inorganic and polymer based thermochromics, both of which have seen significant developments occur on the material science front recently as a result of exploiting nanoparticle composites for spectrally selective absorption. Both types have been extensively reviewed in the literature [2-4], providing information on the current status of material science developments, switching characteristics of the various material formulations, and an assessment of market maturity. Near-term polymer thermochromics exhibit absorption but remain transparent in the tinted phase, where absorption is primarily in the visible (VIS) range (wavelengths between 380-780 nm). Recently, significant R&D effort is being expended to achieve modulation in the near-infrared (NIR) portion of the spectrum (750-2500 nm) while maintaining sufficient transmittance in the VIS range. Li et al. [3] summarizes the material science development objectives for inorganic VO_2-based thermochromic materials, which applies in general to organic TC materials as well even though the mechanisms for thermochromism may differ:

1) lower the critical temperature, τ_c, at which the TC transitions between semiconducting (untinted) to metallic (tinted) states from ~68°C for bulk VO_2 to a comfort temperature of ~25°C,
2) broaden the modulation of solar transmission (ΔT_{sol}) and,
3) achieve a high visible transmittance in the unswitched state.

Simulation studies and prior field measurements have been used to evaluate the energy savings potential of this technology and to provide guidance to the material science community as to which properties increase energy efficiency [5-7]. Saeli et al. [6] used the EnergyPlus building energy simulation program to evaluate the energy savings potential of actual and ideal thermochromic films in a daylit office zone, showing that coatings with broad NIR switching and a low critical switching temperature (20°C) produced significant energy savings in warmer climates compared to conventional glass.

This study provides a detailed investigation of the field performance of polymer based, ligand exchange thermochromic windows for internal load dominated commercial building applications. The film transitions from an untinted clear to dark tinted phase over a range of critical temperatures between approximately 24-75°C. The film can be produced using roll-to-roll processing techniques in large areas and is designed to be used as an interlayer in a laminate configuration within a low-e insulating glass unit (IGU). The thermochromic switches primarily within the visible portion of the solar spectrum.

A large-area thermochromic window was installed in a full-scale office testbed. Detailed measurements were made to characterize switching performance under variable outdoor conditions. Measured and simulated data were related to the perimeter zone heat balance and energy use for an internal load dominated office zone to illustrate how TC properties affect heating, ventilation, and air-conditioning (HVAC) energy use. Observations were made in the field concerning the appearance of the TC window when the incident irradiation was non-uniform and of its ability to control discomfort glare. Some additional observations were made relating the properties of this specific thermochromic to the three material science development objectives delineated above.

2. Outdoor field measurements

2.1. Field test set-up

A polymer thermochromic window was evaluated in this study. The chemistry of the ligand exchange thermochromic film that was tested is described in [4] and in the patent literature [8]. The developers describe the chemical process as “the rearrangement of ligands around metal ions which cause the formation of metal complexes that increase visible light absorbance with increased temperature.” Spectral normal transmittance and spectral reflectance of a 3 mm, clear, thermochromic laminate sample were measured using a spectrophotometer (Perkin Elmer Lambda 950) [9]. No hysteresis was noted upon heating and cooling the sample. As shown in Figure 1, the TC exhibited switching in primarily the VIS portion of the spectrum.

A dual-pane clear TC window and tinted TC window were constructed for the field test, where the former was used in the upper portion of the window wall and the latter was used in the lower portion of the window wall. The clear TC window consisted of two glazing layers: an outboard TC polymer film laminated between two layers of clear glass and an inboard advanced spectrally-selective, low-emittance (e=0.035) glass. The tinted TC window also consisted of two layers, but the outboard TC film was laminated between two panes of spectrally selective tinted glass with the inboard layer unchanged. The general makeup of the window unit (substrate materials, low-e coating, gas fill, frame details) affects energy performance but this aspect was not explored in this study.

The thermochromic windows were installed in a full-scale, south-facing, conditioned testbed office and instrumented so as to measure the normal hemispherical visible and solar transmittance of the insulating glass unit and the temperature of the TC glazing layer. A conventional spectrally selective, low-e dual pane window was installed in an adjacent test room and used as reference. Center-of-glass window properties for all windows are given in Table 1. Outdoor weather conditions were also monitored: direct beam and global horizontal irradiance, vertical irradiance, outdoor air temperature, and wind speed and direction. The testbed was located in a mild climate: Berkeley, California at a latitude of 37.9°N. Analysis of field results focused on the clear TC window, but both the clear and tinted TC window were evaluated using EnergyPlus simulations (Section 3).

2.2. Switching profile

To characterize how the TC switches, the visible transmittance of the window was measured at normal incidence by projecting light from a white light-emitting diode (LED) through the window from one side and mounting a photodetector on the other side to measure this light. The sensor provides a nominal or approximate value with an estimated error of ±0.05 and so is denoted as Tvis'. Sensors were located 38 cm from the edge of the framing.

Pyranometers (LICOR LI-200) were also installed on the outdoor and indoor vertical face of the IGU, surfaces 1 and 4, respectively, and used to measure the amount of transmitted solar radiation through the window, Qtrans. The spectral response of the cosine corrected silicon photovoltaic detector is limited to wavelengths within the range of 400-1100 nm with an error of less than 5% if measuring unobstructed daylight. As the TC switches from a clear to dark tinted state, the spectral distribution of the transmitted radiation changes, affecting the accuracy of the measurement. The pyranometer readings were correlated to a reference radiometer (Huseflux SR03) with a broadband spectral response (305-3000 nm) and a correction factor was applied to the pyranometer data. The TC switches however almost entirely within the 400-1100 nm VIS range with minimal change in transmission occurring beyond about 1100 nm, so the readings are expected to be accurate to within about 5%. Indoor measurements were scaled to a range of 0-436.8 W/m^2 to a resolution of 0.11 W/m^2; actual monitored levels were below 130 W/m^2.

Example data are given in Figure 2 for test days between April 1 through May 19. Switching patterns were logical. With increased solar radiation and outdoor temperature in the morning and then the reverse occurring in the afternoon, the TC tint level (Tvis') darkened then lightened in proportion. Peak tinting occurred a little over an hour after peak solar conditions at noon when the combined influence of both incident solar irradiance and outdoor air temperature produced the highest glass surface temperature. The TC window (Tsol=0.122-0.021) significantly reduced transmitted solar radiation by 33-42% compared to the reference window (Tsol=0.376) with non-coincident peak levels that ranged from 51-88 W/m^2 (TC) compared to 122-260 W/m^2 (reference) over the monitored period. Outdoor air temperatures and levels of incident radiation were moderate: 7-25°C and up to 766 W/m^2, respectively.

Note that instead of exhibiting a pattern of solar transmission that mirrors the pattern of incident radiation over the course of the day, as is the case with the reference window, the TC admits more radiation in the morning and less in the afternoon with peak levels occurring a few hours before noon. With conventional glass, HVAC engineers size cooling systems based on peak loads that occur in the mid-afternoon so the TC window provides demand responsive benefits to the utility grid in addition to energy use reductions and could result in downsizing of chiller capacity.

Glass surface temperature measurements were made on surfaces 1 and 2 of the window using epoxy-encapsulated copper thermistors (YSI 44016, ±0.1°C) mounted with a clear RTV sealant. When irradiated, both sensor readings were greater than the actual surface temperature by approximately 1-3°C, so data are indicative of the actual temperature of the TC laminate. The outdoor glass surface #1 temperature was slightly lower than that of surface #2 during the day. Daytime glass temperatures (surface #2) ranged from 6-55°C over the monitored period.

Note in Figure 2 that the visible transmittance is inversely proportional to the glass surface temperature, mirroring its pattern with no perceptible hysteresis: the degree of switching was the same upon heating and then cooling of the TC window. Differences in Qtrans in the morning and evening can be explained by the warmer outdoor air temperatures in the afternoon.

2.3. Relationship between environmental conditions, degree of switching, and Qtrans

The empirical data presented in Section 2.2 provides an opportunity to characterize how outdoor environmental conditions dictate the glass surface temperature, the switching phase of this particular laminated TC window system, and the associated transmitted solar heat gains.

The measured nominal visible transmittance, Tvis', glass temperature of surface #2, Tg, and transmitted solar radiation, Qtrans, were correlated to outdoor environmental conditions using least squares fits, resulting in coefficients that were statistically significant (z-test>2, t- test<5%) for the independent variables, incident vertical irradiation (Iv, W/m^2-glass) and outdoor dry-bulb air temperature (To, °C):

$$Tvis' = -0.0000359\ Iv - 0.003653\ To - 0.00000898\ Iv * To + 0.314,\ r^2=0.68 \quad (1)$$

$$Tg = 0.0117\ Iv + 0.5697\ To + 0.0017\ Iv*To + 13.3,\ r^2=0.67 \quad (2)$$

$$Qtrans = 0.21\ Iv + 0.38\ To - 0.007\ Iv*To + 8.51,\ r^2=0.85 \quad (3)$$

Summary statistics for the least squares fits are given in Table 2. All terms were defined by 10-min running averages since prior environmental conditions influence the window heat balance and therefore the temperature and switching status of the window. Data were filtered to eliminate times of day when shadows may have produced non-uniform irradiance across the façade. These fits were produced for a specific range of environmental conditions for this two month period as summarized in Table 3. Indoor air temperatures were maintained at 24.2±0.11°C. Wind had a minimal influence on the fit, possibly because wind speeds were low: on average 1.3±0.7 m/s over the monitored period.

A temporal plot of measured and predicted Qtrans data over several of the test days is shown in Figure 3. The combined Iv*To term revealed the dependency between the two environmental variables: i.e., when it is cold outdoors but there are high levels of radiation, the TC will switch. On some days, the fit failed to capture the peaks and low ends of the monitored data. To better capture the peaks, we attempted fits to 10-min and 20-min running average or sums to determine if average or cumulative effects of outdoor air temperature and/or incident radiation had an effect on glazing temperature, TC tint level, and therefore levels of transmitted solar radiation. Incident solar radiation levels could be highly variable under dynamic sky conditions. These data were sampled once per minute in order to get an accurate depiction of sky conditions. Outdoor temperature data were also variable: there was a maximum variation of 0.2-0.4°C between 1-min time steps due to the noisy signal. Potential errors were also introduced with non-instantaneous sampling of indoor and outdoor data (sampling of all data occurred within a 10 s sweep). The fits involving cumulative irradiation data were found to be poorer than the 10-min running averaged data. The fits between 10-min and 20-min data were found to produce almost the same degree of error.

2.4. Thermochromic properties as related to passive solar heating and solar rejection

In Figure 4, predicted values are presented at defined intervals and measured values are provided as well, enabling the reader to visualize where extrapolation for the fits occurs. All predicted parameters resulting from the fits are plotted in Figure 5. The predicted values are shown as a function of incident solar radiation, Iv (x-axis) and outdoor air temperature, To (8-24°C, 2°C increments). Glass temperature, Tg, and visible transmittance, Tvis', are also given in Figure 5 to illustrate the sensitivity of each parameter to outdoor conditions.

We use the fits to evaluate how the TC controls transmitted solar heat gains during the summer when it is temperate and sunny. Referring to the group of predicted values for Qtrans in Figure 5, we see that with outdoors conditions of 500 W/m^2 and 24°C, Tg=50°C, Tvis'=0.10, and Qtrans is 40 W/m^2-glass. This is a meaningful level of solar control: for use of low-energy cooling strategies such as radiant cooling in commercial buildings, mechanical engineers strive to maintain peak perimeter zone loads below about 32 W/m^2-floor, so if this was a 4.6 m deep office zone with a large-area window (1.8 m high, window-to-wall ratio (WWR=0.50), Qtrans would contribute 16 W/m^2-floor to this load. Window heat gains from the absorbed and reradiated solar radiation and conductive heat gains would need to be added to Qtrans to obtain the total heat gains due to the window.

For summer conditions when outdoor air temperature, not solar radiation, is the main driver for switching (100-200 W/m^2, 24°C) as might occur with a north-facing window in a hot climate, the TC switches less: Tg=31-36°C, Tvis'=0.18-0.20, Qtrans=22-27 W/m^2 or 9-11 W/m^2-floor.

For winter conditions when To is low and incident solar irradiance can be high for south-facing facades (e.g., 1000-1500 W/m^2), we would need to extrapolate beyond the measured data to understand HVAC impacts in cold climates, so no example is given. However, we can deduce that switching will occur even when outdoor temperatures are moderately cold. For outdoor conditions of 500 W/m^2 and To=8°C, for example, Figure 5 shows that the TC is partially switched as indicated by Tvis'=0.23, where 0.276 is the maximum value.

Note that the near maximum switching level (Tvis'=0.03, Tg=67°C) was attained when To=24°C and Iv=800 W/m^2. For this window assembly, solar irradiance effectively reduces the critical switching temperature to the target "comfort" temperature defined by [3].

The switching temperature of the TC window *assembly* could be effectively lowered by combining the TC layer with an absorptive tinted glazing substrate which raises glass temperature when irradiated but this has the disadvantage of lowering the overall visible transmittance of the window.

Note that this discussion of TC window heat gains are decoupled from any particular perimeter zone load profile and HVAC system: they simply reflect independently what the TC window will do when exposed to a limited range of outdoor conditions and a stable indoor air temperature. Because the response characteristics of TC windows are inherent with the material design (and its combination with substrate layers, low-emittance coatings, etc.), the TC window may or may not be a good fit with the actual load profile of the building's perimeter zone. We examine this issue in the next section using the EnergyPlus building energy simulation software.

3. EnergyPlus simulations

EnergyPlus [10] simulations were conducted on a prototypical large office building that complied with the ASHRAE 90.1-2004 code [11], where the building characteristics such as construction, schedules, and HVAC system were derived from statistical data compiled for the existing building stock in the US then amended to meet the energy-efficiency code. At full power, the equipment power load was 8.1 W/m^2, lighting power density was 10.8 W/m^2, and occupant density was 18.6 m^2 of floor area per person. Fresh air requirements were met with a ventilation rate of 0.00051 $m^3/s\text{-}m^2$. The building was conditioned with a variable air volume system with an airside economizer (for the Chicago climate only). Further details on the model can be found in [12].

EnergyPlus models thermochromic windows using spectral data that have been input at regular temperature intervals over the switching range. Since EnergyPlus does not interpolate between switching temperatures, the smaller the interval between input temperatures, the more accurate the simulated values. To generate spectral data without having to resort to measurements at increments of 1°C, for example, quadratic fits were made to enable interpolation of the measured spectral data [9]. These fits were used to generate full spectral data at 2°C intervals, which were then used in Optics and Window [13] to produce input data for the EnergyPlus simulations. For temperatures below 24°C, the spectral data for 24°C was used; TC properties likely continued to change below this temperature with indications from one measurement at 15°C (where condensation affected results) that the change was small. Window 7 will incorporate this interpolation capability within the software, enabling the end user to generate spectral data for any arbitrary window configuration and at user-specified temperature intervals.

Figure 6 shows the range of outdoor environmental conditions over the year when the perimeter zone cooling load is significant (greater than 50% of the maximum annual cooling load) due to heat gains from internal loads from equipment, people and lights, and heat flow through the building envelope (including the window). For this south-facing zone with a moderate-area window (window to exterior wall area ratio, WWR=0.45) in Chicago, there are many periods when it is both cold outside (< 0°C) and incident radiation levels are moderate to high (400-900 W/m^2) when control of window heat gains would lead to less cooling energy use. Superimposed on this data are the cases when the TC glass temperature is greater than 48°C and the TC glazing is switched about halfway, providing cooling load control. The TC window is able to curtail summer cooling loads but not the winter cooling loads when incident solar radiation levels are significant due to the low altitude angles of the sun. If the critical switching temperature range was lowered, annual cooling energy use could be decreased.

Site annual energy use and savings were determined for the 4.57 m deep south-facing perimeter zone for the hot/cold climate of Chicago and hot climate of Houston. Results are given for the 90.1-2004 code-compliant window (A or C), an advanced spectrally-selective low-e window (E), a triple pane insulating window (F), and the two types of thermochromic windows (TC2 and TC3). The TC2 thermochromic window was modeled without the thermochromic interlayer (TC2') so that the benefit of the thermochromic film could be determined. Whole window properties for the windows are given in Table 4. Energy use data are given in Table 5 and shown in Figure 7. The thermochromic interlayer was found to produce significant HVAC energy use reductions compared to the same window without the thermochromic (TC') – for the moderate to large-area south, east, and west-facing windows (WWR=0.30-0.60), the incremental benefit was 15-25% in both Chicago and Houston. Savings for south, east, and west facing windows compared to the 90.1-2004 code window (C) in Chicago were 20-43%, increasing with window area, and 4-22% in Houston. Data for reference windows E and F are given to benchmark performance. The thermochromic filter could be added to these reference windows to provide greater HVAC energy reductions, however the advantage of the static reference windows is the high visible transmittance, particularly window E, which is likely to reduce lighting energy use.

4. Other field observations

4.1. Breadth of switching temperature range

Non-uniform incident irradiance can produce differences in tint level if the switching range of the thermochromic device is narrow. Shadows from framing members, exterior attachments such as overhangs, or adjacent building wings can then make the tinted appearance of the façade non-uniform when the TC is in transition, which is undesirable from an aesthetic point of view.

Infrared (IR) thermography was used to characterize the surface temperature gradient across the plane of the thermochromic window at 15-min intervals on two sunny summer days, June 16-17, 2011. Measurements were made using a FLIR SC660 infrared camera using a microbolometer focal plane array sensor with 640x480 pixels. The sensitivity of the sensor is less than 0.03°C. The infrared camera was fitted with a 45° opening angle lens allowing it to measure a relatively wide subject area from a limited distance. IR images were taken at a position with a slightly upward view toward the sky to avoid seeing any local obstructions reflected by the window.

An example photographic image and IR image are given in Figure 8, where only the very top edge of the window was shaded by a beam above the window and the depth of the window frame. The upper window had the clear thermochromic window and so was cooler than the lower window with the tinted thermochromic. The upper edge of both the upper and lower windows was significantly cooler than the center and lower regions of the window by about 10-13°C (Figure 9). One can also see significant temperature differences at the junction between the glass and the frame, compounded by the shadowing effect of the frame. For this thermochromic, which has a broad switching range, the change in tint level (ΔTvis=0.04) over the upper window height of 80 cm was imperceptible. Views out the window were clear and undistorted.

4.2. Visible transmittance level as related to daylight and discomfort glare

We know from prior work that specular glazing cannot reduce the brightness of the sun orb to comfortable levels for critical visual tasks (e.g., computer-based tasks) unless the visible transmittance is very low (< 0.001) and in doing so, useful daylight is effectively eliminated. On April 6th for example, the orb of the sun is blocked partially by the vertical mullion at the top of the window: its luminance (23,000 cd/m^2) is well over the maximum range depicted on the falsecolor scale. Note how in Figure 10 sunlit patches can be seen in the photographic images of the room with thermochromic windows while the room with the interior blind has no sunlit patches. Contrast between sunlit and shadowed areas can also be a source of visual discomfort.

Given the low Tvis range of the clear TC window in this study (Tvis=0.28-0.03), the window can however moderate discomfort glare from the bright sky. This is illustrated in Figure 10 where the visible transmittance of the windows increases between April 6 and May 21, but is still sufficient to control luminance levels to within near acceptable levels. On April 6th, for example, the upper TC window is switched adequately to control window luminance at noon below 2000 cd/m^2. On May 21st at noon, window luminance was slightly greater than 3000 cd/m^2. The 2000 cd/m^2 threshold is an approximate threshold where a) the luminance contrast between a computer-based task (with an average monitor luminance of 200 cd/m^2) and the window is less than or equal to 10:1, a limit defined for tasks where the glare source is within ones remote field of view, and b) where it was found in an field test that there was a 50% probability that people would lower the shades when the window luminance exceeded this level [14]. Time-lapsed high dynamic range imaging was used to measure the luminance of various regions of the window within the field of view of a seated person facing the window.

The low transmittance levels are less likely to satisfy daylight illuminance requirements unless the window area is large. At the lower end of Tvis, the quality of the indoor environment is also likely to be gloomy. Indoor daylight illuminance levels at desk or work plane height were 683-1047 lux during this brightest time of the day in the room with the thermochromic windows, where 300-500 lux is needed for typical reading and writing tasks. Summary data are given in Table 6.

Further study of these effects is needed, however the argument for a higher range of Tvis is well founded: architects, occupants, and the real estate market value daylight, there have been studies that link daylight to improved health (e.g., combatting seasonal affective disorder, regulating melatonin, etc.), and daylight serves to reduce lighting energy use as well.

5. Conclusions

A field test was conducted where the performance of large-area polymer thermochromic windows were evaluated in a south-facing conditioned office testbed in a moderate climate. The TC film that was studied switched from a metallic to rutile state through a ligand exchange process and exhibited a tinted, transparent, absorptive state when switched. The TC device modulated solar radiation primarily within the visible range and had a broad switching temperature range.

The thermochromic window that was field tested consisted of two glazing layers in an insulating glass unit configuration where the outdoor layer consisted of the TC film interlayer placed between two layers of 6 mm clear glass and the indoor layer consisted of 6 mm spectrally selective glazing with a low-emittance coating (e=0.035). Center-of-glass properties of this window were Tsol=0.12-0.03 and Tvis=0.28-0.03 for glass temperature range of 24-75°C. No hysteresis was exhibited by the TC upon heating and cooling of the device. The window maintained a transparent, undistorted view across its switching range.

The field measured data were used to illustrate how the TC window controlled transmitted solar radiation as a function of outdoor temperature and incident solar irradiance. The TC switching response was then related to the heating and cooling demands of a typical commercial office building using EnergyPlus simulations.

Specific to the polymer thermochromic evaluated in this study:

1. Annual energy savings in the south, east, and west perimeter zones were 20-43% in the hot/cold climate of Chicago compared to the ASHRAE 90.1-2004 Standard prescriptive window. The greater the window area, the greater the energy savings. The TC window was able to produce energy savings that were greater than an advanced low-e dual pane window but less than a triple pane low-e window. Savings were due to reductions in HVAC energy use and did not include lighting energy use savings due to daylight dimming. Lighting energy savings due to daylight dimming was not quantified and should be investigated separately since it requires consideration of discomfort glare and use of interior shading. Savings in hot climates were lower: 4-22% in Houston.

2. The TC windows had a broad switching temperature range and so exhibited a uniform tinted appearance even though there were times when the distribution of radiation across the window was non-uniform. An example sunny day was used to illustrate this finding: infrared thermography indicated that a temperature gradient of 10-13°C occurred over a 80-cm wide area due to local shading by the window frame but no discernible difference in tinting was visible when viewed from the indoors and outdoors. Other TC formulations result in devices with very narrow switching ranges (e.g., 1-2°C): these will exhibit a mottled, non-uniform appearance when switching if the windows are shaded by overhangs, adjacent building wings, and other exterior near field projections.

Several observations were made that are relevant to material scientists who are continuing to develop new thermochromic materials:

1. Thermochromic windows switch as a function of both outdoor air temperature and solar irradiance. This is generally known but has not been clearly relayed to material scientists who are developing new TC materials based on a "comfort" temperature of ~24°C, which is likely based on a desirable indoor air temperature.

2. The critical switching temperature of a TC device is effectively lowered by incident solar radiation. For example, the TC2 glass temperature of 60°C was attained when the outdoor temperature was 24°C and incident vertical irradiance was 720 W/m^2. For this window assembly, solar irradiance effectively reduces the critical switching temperature to the target "comfort" temperature.

3. The ideal critical switching temperature that material scientists should design to is dependent on the characteristics of the building. Commercial buildings are typically internal load dominated due to the high density of people, equipment, and lights. A south-facing perimeter office zone is often in cooling mode on a sunny winter day even in a cold climate like Chicago. The combined influence of outdoor air temperature and solar irradiance should be used to define the critical switching temperature per building type, window area, window orientation, climate zone, etc. These considerations complicate the rule set needed to develop energy-efficient TC materials. Further work is needed to develop a simple general set of criteria.

4. The primary benefit of TC windows is control of window solar heat gains and minimization of HVAC energy use. TC switching is not correlated to daylight availability and therefore may or may not contribute to lighting energy savings. The requirement for a high visible transmittance (Tvis=0.50-0.70) in the unswitched state is well founded from the view point of enabling interior spaces to be well daylit and to avoid interior gloom. The manufacturer involved in this study has developed an alternate TC window system that admits more daylight [16] but the energy performance has been unverified. It is the belief of the authors that thermochromics should not be used to control glare and cannot be effective at controlling glare from direct views of the orb of the sun. Interior shading should be used in combination with TC windows.

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Tables

Table 1.
Center-of-glass solar-optical properties of the reference and thermochromic windows used in the field test

Type	Layer 1 (outside)	Gap	Layer 2 (inside)
Reference	6 mm Viracon VRE15-67 Ultrawhite, e=0.051 on #2	6 mm, air	6 mm Ultrawhite
TC2	6 mm clear + TC interlayer + 6 mm clear	10 mm, 95% argon	6 mm Solarban 60, e=0.035 on surface #3 (Tsol=0.40)
TC3	6 mm Azuria + TC interlayer + 6 mm clear	10 mm gap, 95% argon	6 mm Solarban 60, e=0.035 on surface #3 (Tsol=0.23)

Type	Tg (°C)	Tsol	Tvis	SHGC	U-value (W/m^2-K)
Reference		0.376	0.620	0.402	1.70
TC2	24	0.122	0.276	0.326	1.75
	34	0.108	0.234	0.306	1.75
	48	0.079	0.157	0.266	1.75
	62	0.046	0.074	0.218	1.75
	75	0.027	0.032	0.190	1.75
TC3	24	0.076	0.214	0.223	1.75
	34	0.066	0.182	0.209	1.75
	48	0.046	0.122	0.183	1.75
	62	0.024	0.058	0.153	1.75
	75	0.012	0.025	0.136	1.75

Note: Thermochromic properties were calculated using Window version 6.3.9.0 and measured spectral data.

Table 2.
Statistics for least squares fit to thermochromic parameters (N=5426)

		m1 Iv (W/m^2)	m2 To (°C)	m3 Iv*To ($W\text{-}°C/m^2$)	b	r^2	SE	% error
Tvis	coefficient	-3.589E-05	-3.653E-03	-8.977E-06	0.31	0.68	0.02	10.3%
	z-test	2.65	9.28	11.14	46.95			
	t-test	0.799%	0.000%	0.000%	0.000%			
Tglass	coefficient	0.0117	0.5697	0.0017	13.3	0.67	3.8	7.8%
(°C)	z-test	4.55	7.62	10.87	10.52			
	t-test	0.001%	0.000%	0.000%	0.000%			
Qtrans	coefficient	0.210	0.383	-0.007	8.51	0.85	6.0	8.4%
(W/m^2)	z-test	64.82	4.03	34.27	5.48			
	t-test	0.000%	0.006%	0.000%	0.000%			

% error defined as the average percent difference between measured and predicted values.

Table 3.
Summary of outdoor environmental and thermochromic conditions for fitted field test data

		avg	stdev	min	max
Iv	W/m^2	462.3	114.6	47.8	766.0
To	°C	16.7	3.2	6.9	24.7
Ti	°C	24.2	0.1	23.7	24.7
Wind speed	m/s	1.3	0.7	0.0	4.6
Tg (upper east pane)	°C	41.2	6.7	23.5	57.7
Tg (upper west pane)	°C	42.2	6.1	26.4	57.4
Qtrans (upper west pane)	W/m^2	59.3	17.1	10.5	136.2

Glass temperature, Tg, measured on surface #2 (surface #1 is the outside glass surface).
Iv: incident vertical irradiance; Qtrans: transmitted vertical solar irradiance; To: outdoor air temperature;
Ti: indoor air temperature.

Table 4.
Whole window properties of the reference and thermochromic windows used in EnergyPlus simulations

	Layer 1 (outside)	Gap	Layer 2 (inside)	Gap	Layer 3 (inside)
A	6 mm Viracon VS1-14				
C	6 mm Fitrasol Grey	6 mm Air	6 mm PPG Sungate 500 on clear		
E	6 mm PPG Solarban 70 on Starphire	12 mm, 95% argon	6 mm clear		
F	6 mm PPG Solarban 70 on Starphire	12 mm, 95% argon	Serious Materials suspended film	12 mm, 95% argon	6 mm PPG Solarban 70 on Starphire
TC2'	6 mm clear + Dupont interlayer Butacite clear (30 mil)+ 6 mm clear	10 mm, 95% argon	6 mm Solarban 60, e=0.035 on surface #3		
TC2	6 mm clear + TC interlayer + 6 mm clear	10 mm, 95% argon	6 mm Solarban 60, e=0.035 on surface #3		
TC3	6 mm Azuria + TC interlayer + 6 mm clear	10 mm gap, 95% argon	6 mm Solarban 60, e=0.035 on surface #3		

	Description	Tg (°C)	Tvis	SHGC	U-value (W/m^2-K)
A	ASHRAE 90.1-2004 Houston		0.11	0.25	4.55
C	ASHRAE 90.1-2004 Chicago		0.31	0.4	3.12
E	Spectrally selective low-e		0.52	0.26	2.17
F	Triple pane window		0.39	0.2	1.20
TC2'	Thermochromic2 static		0.264	0.363	2.558
TC2	Thermochromic 2	24	0.216	0.311	2.556
		34	0.183	0.289	2.556
		48	0.123	0.244	2.556
		62	0.058	0.192	2.556

		75	0.025	0.163	2.556
TC3	Thermochromic 3	24	0.181	0.234	2.191
		34	0.154	0.217	2.191
		48	0.104	0.184	2.191
		62	0.049	0.146	2.191
		75	0.021	0.125	2.191

Note: Thermochromic properties were calculated using Window version 6.3.9.0 and measured spectral data.

Table 5. Annual site heating, cooling, and fan energy use (kWh/m^2-yr) for Chicago

WWR	C	TC 2'	TC 2	E	TC 3	F	d(C,TC2)	d(C,E)	d(C,TC3)
North									
0	55.7	55.7	55.7	55.7	55.7	55.7	0%	0%	0%
15	82.0	67.4	68.0	64.5	67.7	56.8	17%	21%	17%
30	112.3	81.3	82.7	74.8	82.6	58.7	26%	33%	26%
45	143.7	95.2	99.1	85.0	97.8	60.9	31%	41%	32%
60	143.7	108.2	114.0	96.5	112.9	62.9	21%	33%	21%
South									
0	49.1	49.1	49.1	49.1	49.1	49.1	0%	0%	0%
15	70.5	60.6	55.3	56.1	55.9	50.1	22%	20%	21%
30	101.3	80.9	67.2	67.5	66.4	53.5	34%	33%	34%
45	137.6	105.5	82.7	82.5	78.3	57.7	40%	40%	43%
60	137.6	132.4	99.5	98.2	91.8	64.6	28%	29%	33%
East									
0	25.4	25.4	25.4	25.4	25.4	25.4	0%	0%	0%
15	42.3	35.8	32.7	32.2	32.1	27.7	23%	24%	24%
30	62.0	48.0	40.9	40.2	39.6	30.4	34%	35%	36%
45	83.1	61.6	49.9	48.7	47.5	33.3	40%	41%	43%
60	83.1	74.0	59.1	57.5	55.8	36.7	29%	31%	33%
West									
0	25.2	25.2	25.2	25.2	25.2	25.2	0%	0%	0%
15	41.7	35.0	31.7	31.9	31.2	27.7	24%	24%	25%
30	58.8	46.5	39.0	39.3	37.4	30.3	34%	33%	37%
45	77.7	59.0	47.1	46.7	44.5	33.0	39%	40%	43%
60	77.7	72.1	55.2	54.5	51.8	36.5	29%	30%	33%

Note: d(C,TC2), as an example, is the percentage difference in energy use between window C and TC2.

Table 5. Annual site heating, cooling, and fan energy use (kWh/m^2-yr) for Houston

WWR	A	TC 2'	TC 2	E	TC 3	F	d(A,TC2)	d(A,E)	d(A,TC3)
North									
0	71.3	71.3	71.3	71.3	71.3	71.3	0%	0%	0%
15	76.7	74.2	72.7	71.0	71.6	68.9	5%	7%	7%
30	81.8	77.8	74.5	70.6	72.2	66.9	9%	14%	12%
45	87.4	81.7	77.3	71.7	73.4	65.6	12%	18%	16%
60	87.4	86.0	79.8	72.4	74.2	64.7	9%	17%	15%
South									
0	76.4	76.4	76.4	76.4	76.4	76.4	0%	0%	0%
15	85.2	89.3	82.3	82.3	80.2	78.5	4%	4%	6%
30	95.5	104.4	89.0	89.0	84.4	81.7	7%	7%	12%
45	107.3	120.6	96.8	97.5	89.5	85.4	10%	9%	17%
60	107.3	137.6	103.8	105.0	93.9	88.5	3%	2%	12%
East									
0	38.9	38.9	38.9	38.9	38.9	38.9	0%	0%	0%
15	43.9	44.6	40.7	40.9	39.8	38.9	7%	7%	9%
30	49.6	51.3	43.5	43.6	41.6	39.9	12%	12%	16%
45	56.1	58.3	46.7	47.1	43.6	41.0	17%	16%	22%
60	56.1	65.8	49.6	50.2	45.4	42.0	12%	11%	19%
West									
0	39.0	39.0	39.0	39.0	39.0	39.0	0%	0%	0%
15	43.1	44.3	40.9	40.7	39.9	39.0	5%	6%	7%
30	48.5	51.2	43.5	43.6	41.3	39.8	10%	10%	15%
45	54.5	58.3	47.1	47.3	43.5	41.1	14%	13%	20%
60	54.5	65.3	50.6	50.4	45.3	42.3	7%	8%	17%

Note: d(A,TC2), as an example, is the percentage difference in energy use between window A and TC2.

Table 6.
Indoor illuminance and luminance in the thermochromic and reference test rooms at noon

Day	Iv (W/m^2)	To (°C)	Tg (°C)	Tvis' upper TC
April 6	638	16.6	51	0.115
May 10	442	14.9	43	0.16
May 21	401	17.8	37	0.19
Day	**Iworkplane TC (lux)**	**Iworkplane Ref (lux)**	**Lwindow TC (cd/m^2)**	**Lwindow Ref (cd/m^2)**
April 6	683	2596	1765	4241
May 10	813	1622	1922	2638
May 21	1047	1492	3049	2015

Note:
Reference room has an interior Venetian blind set to a fixed blocking angle to prevent admission of direct sun.
Iworkplane is given as the average workplane illuminance in the area 3.3-4.6 m from the window.
Lwindow is given for upper right hand pane of the TC2 window, facing the window from indoors.

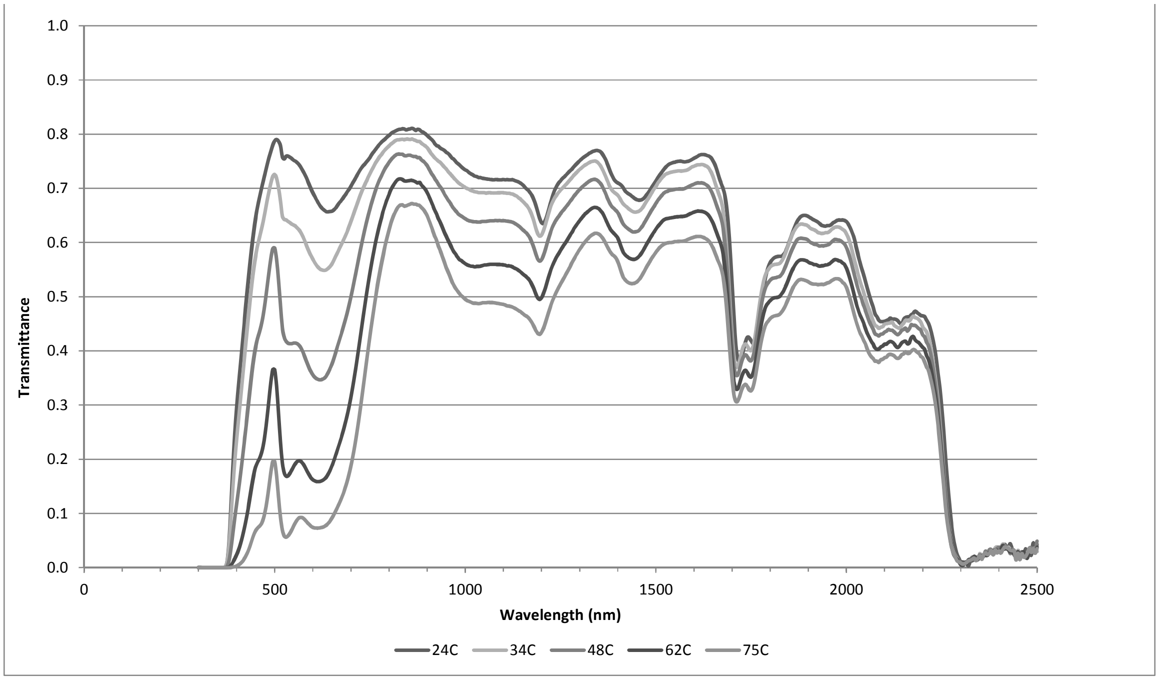

Fig. 1. Transmittance spectra for the polymer thermochromic on a clear glass substrate.

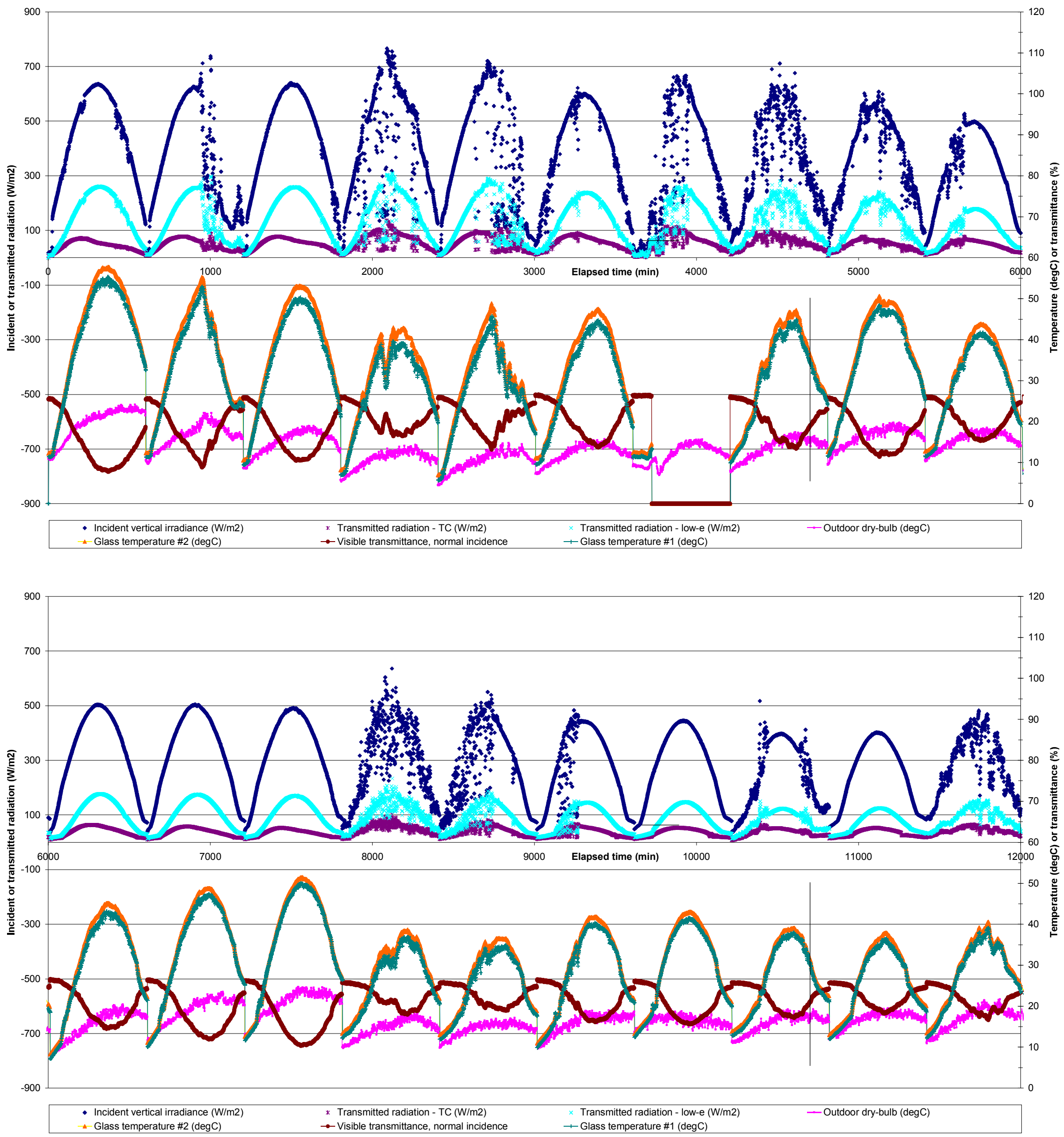

Fig. 2. Switching pattern of the clear thermochromic window for test days between April 1 through May 19. On the x-axis is elapsed time denoting 1-min data for each day between the hours of 7:00-17:00 Local Standard Time (ST) and on the y-axis are data pertaining to the status of the TC window (glass temperature for surfaces #1 and #2, nominal Tvis, transmitted vertical irradiance) and the outdoor environmental conditions (incident vertical irradiance, outdoor dry-bulb air temperature). Transmitted vertical irradiance is also given for the low-e reference window. The indoor air temperature was maintained at an average of 24±1°C over the monitored period.

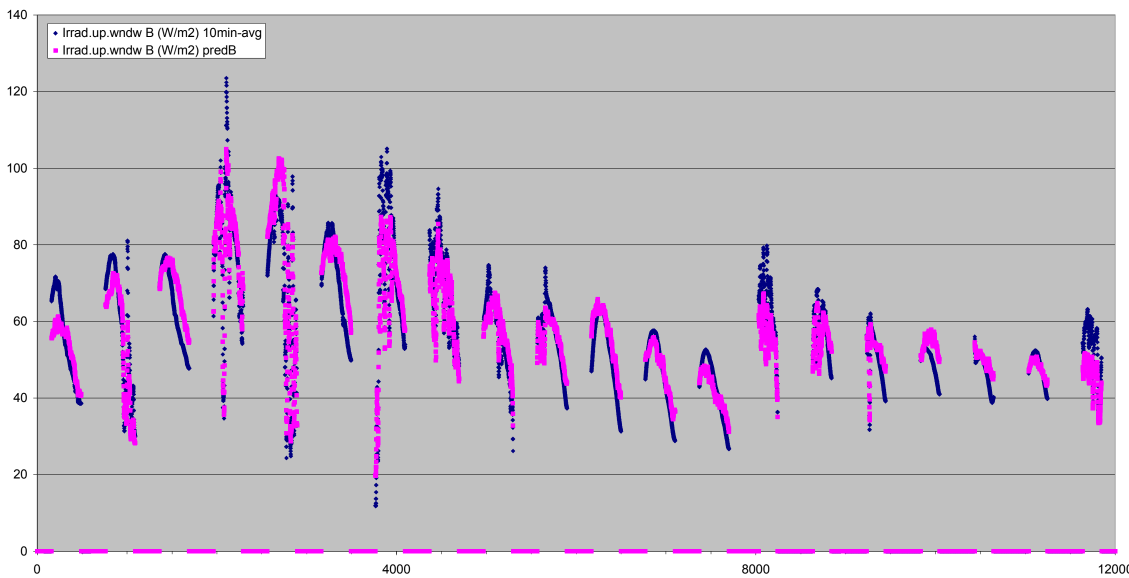

Fig. 3. Predicted versus measured transmitted solar radiation, Qtrans

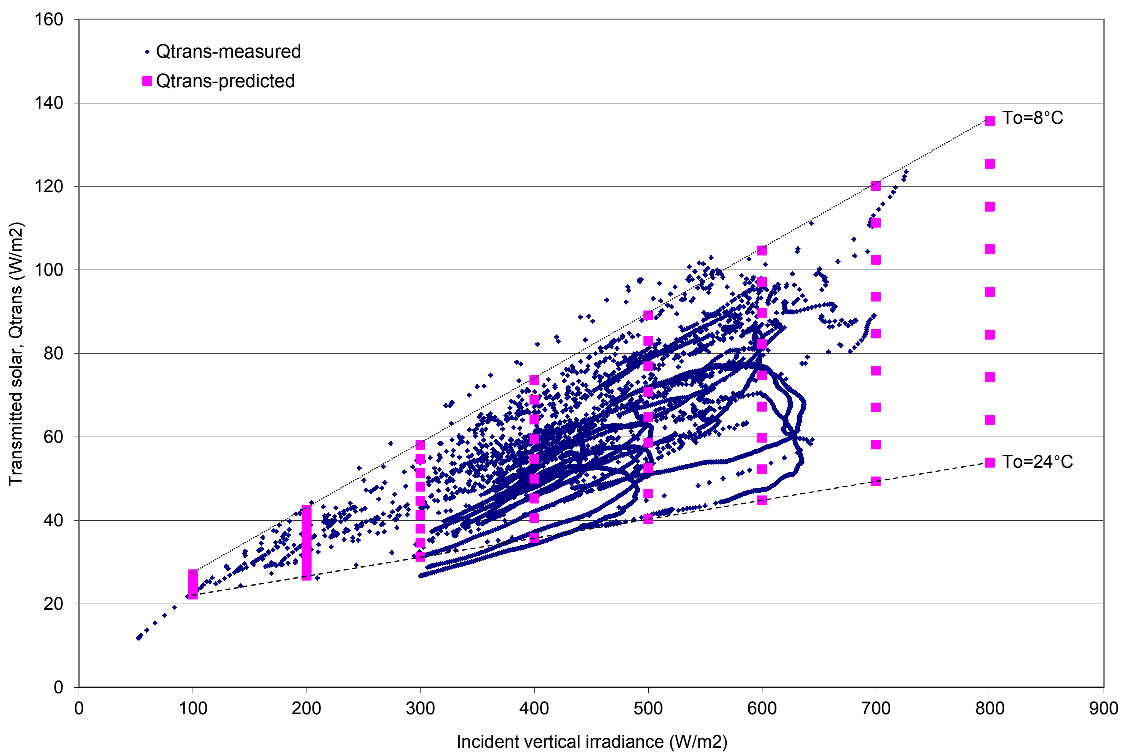

Figure 4. Predicted and measured values for transmitted solar irradiance (W/m^2) from the full scale testbed.

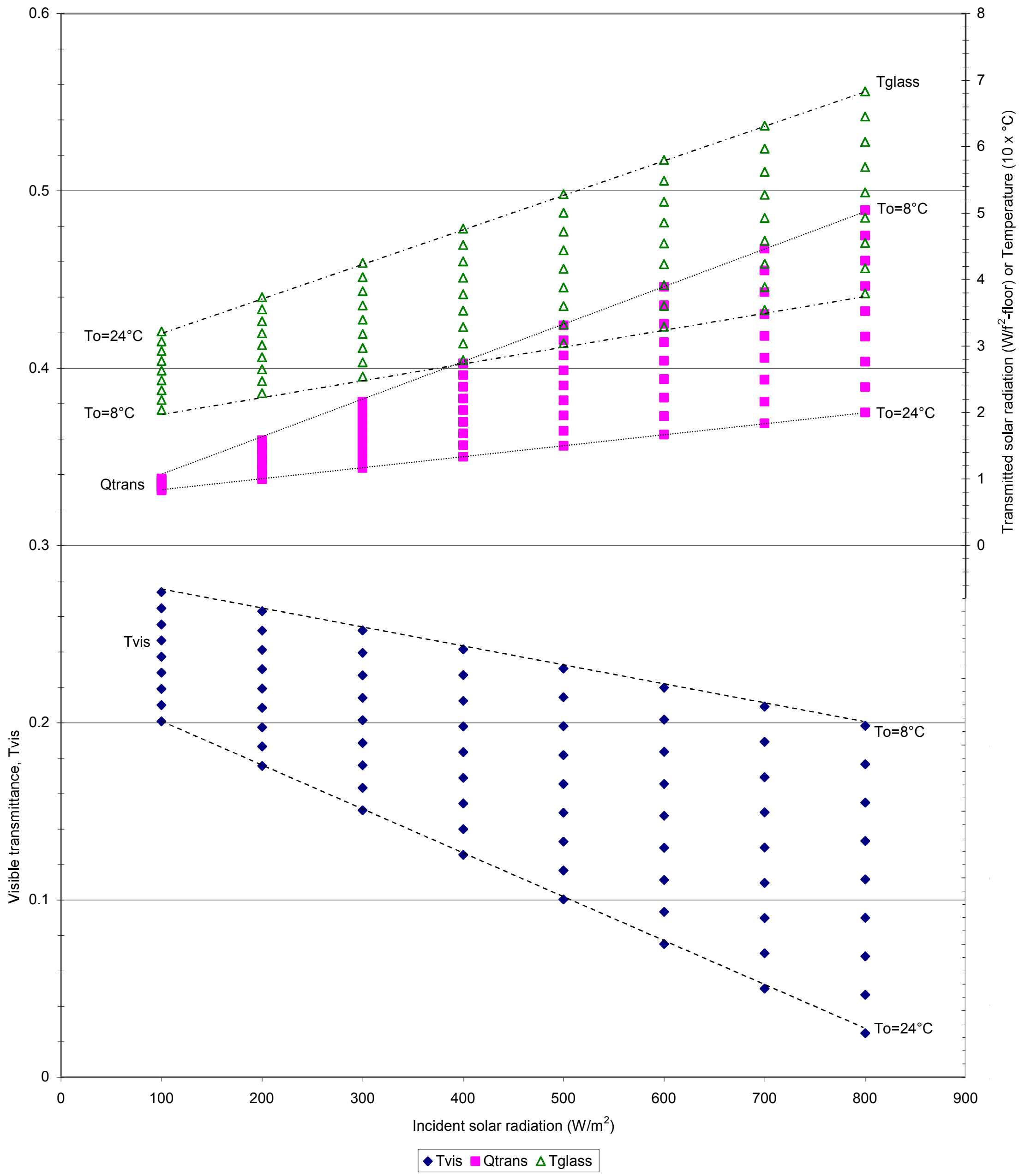

Fig. 5. Predicted values for visible transmittance at normal incidence, transmitted solar radiation (W/ft^2-floor), and glass surface #2 temperature (°C, multiply values by 10) based on least squares fits to incident vertical irradiation and outdoor dry-bulb air temperature. The dotted lines show lines of equal outdoor air temperature for each group of predicted values. [change back to W/m2 for Qtrans]

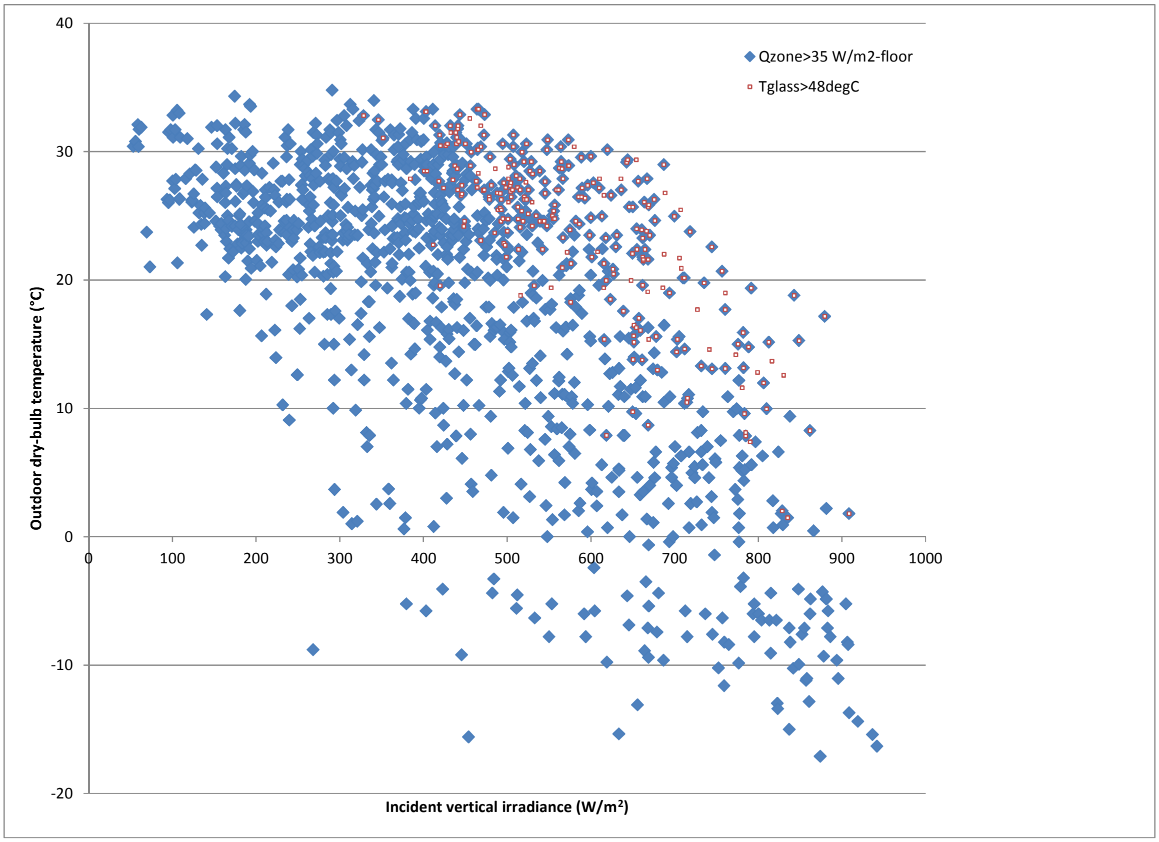

Fig. 6. Incident vertical irradiance and outdoor air temperatures that correspond to hours of the year when perimeter zone cooling loads are significant due to both internal loads and heat flow through the building envelope, including the window. The open symbols correspond to outdoor conditions when the thermochromic is switched to about 50% of its maximum tint level. South-facing perimeter zone, WWR=0.45, Chicago.

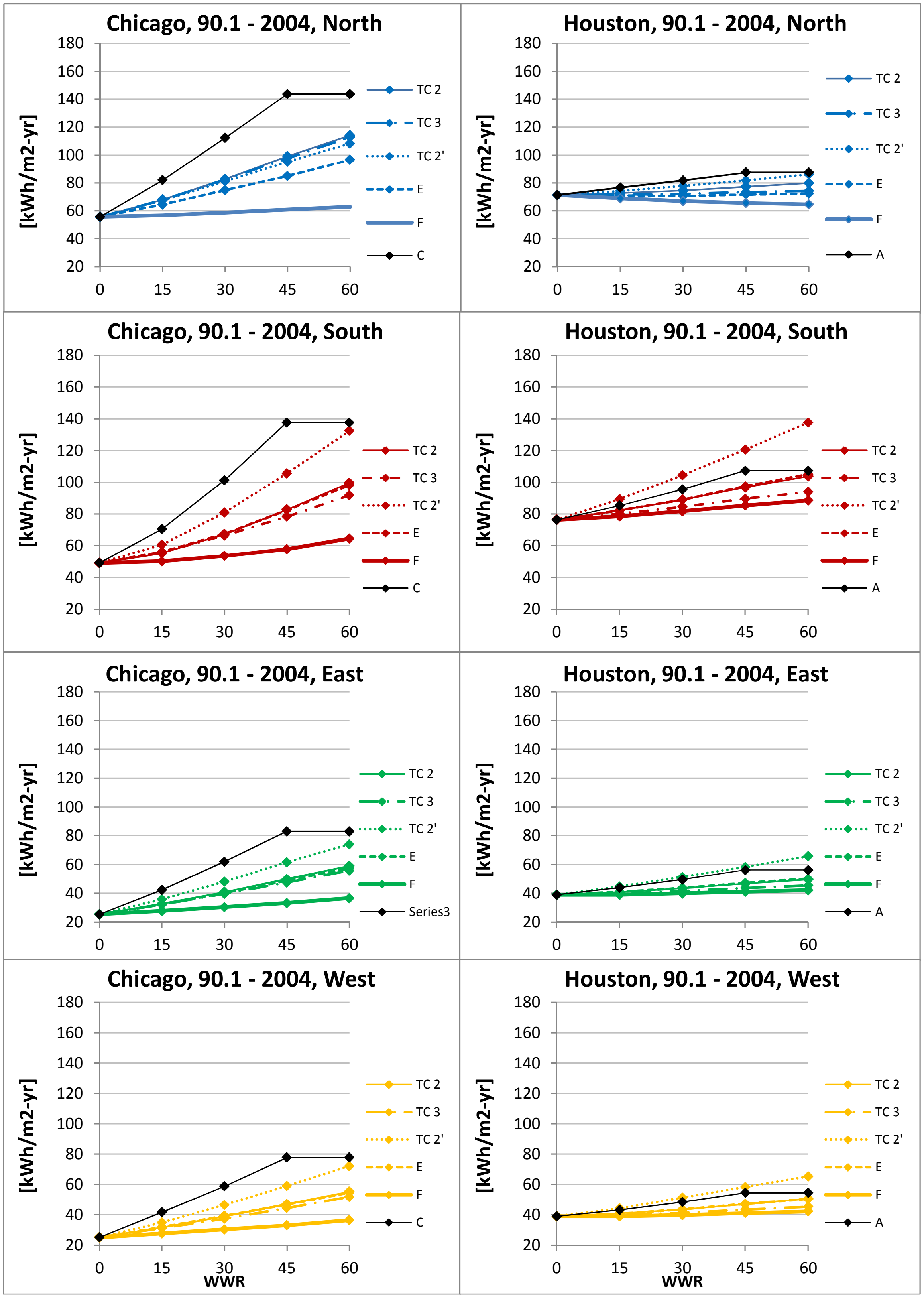

Fig. 7. Annual energy use as determined by EnergyPlus. [expand caption]

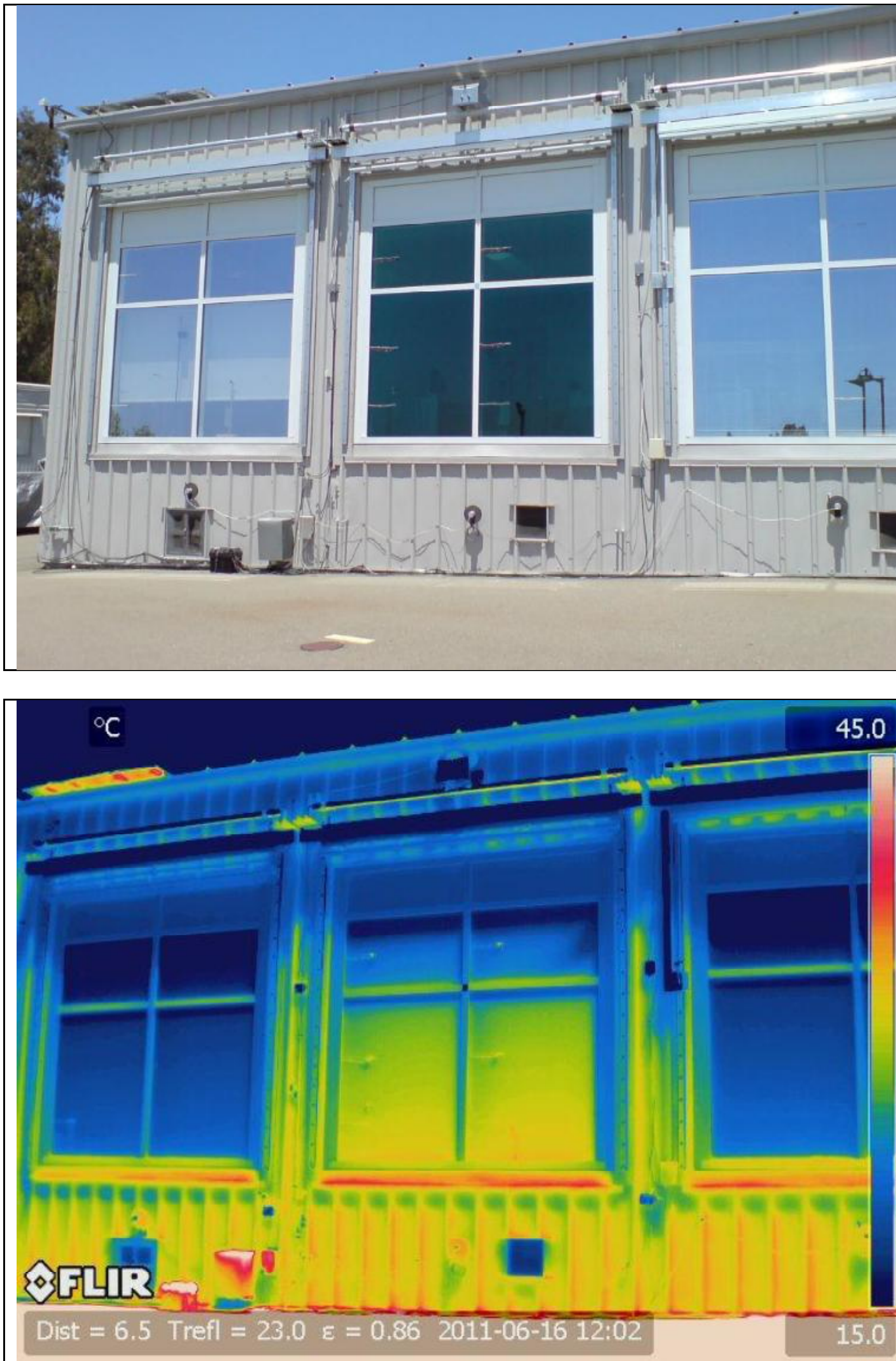

Fig. 8. Outdoor view of the thermochromic window (middle room) and corresponding infrared image showing the surface temperature of the window on June 16, 12:02 PM.

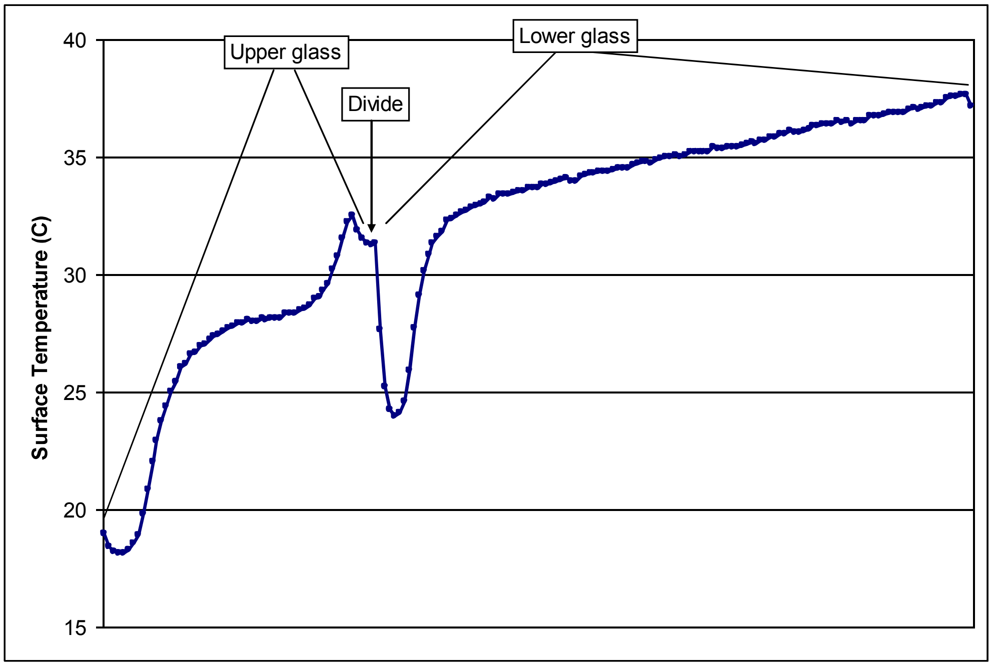

Fig. 9. Surface temperature profile over the height of the thermochromic window on June 16, 12:02 PM.

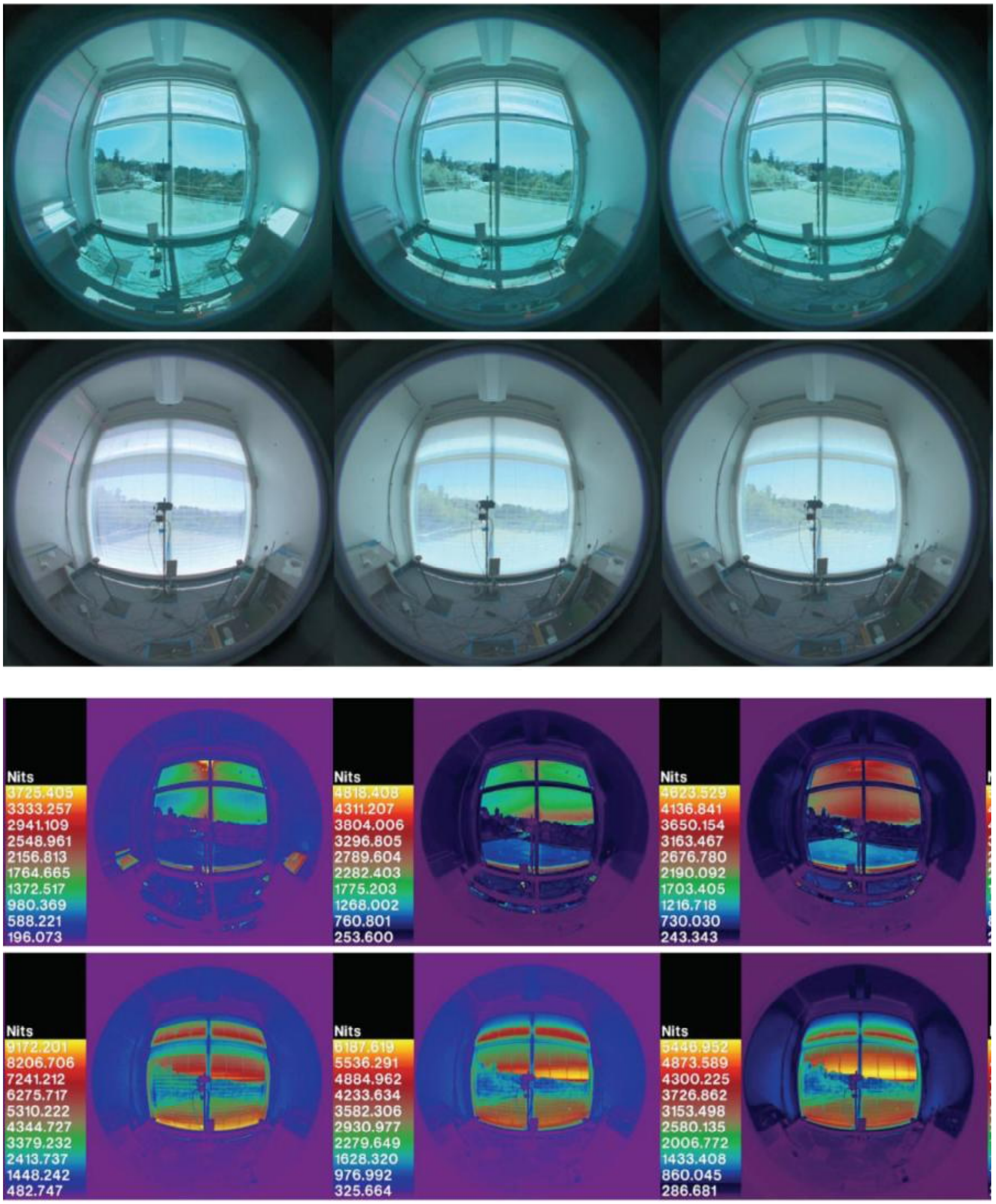

Fig. 10. Upper images: Fisheye photographs of the interior of the test room at noon on three clear, sunny days: April 6 (left), May 10 (middle), and May 21 (right). The upper row of images are given for the thermochromic test room. The lower row of images is given for the reference low-e window with an interior Venetian blind. The blind slat angle was positioned to just occlude direct sun.
Lower images: Falsecolor luminance (cd/m^2 or nits) images of the same views as the upper photographs.

Appendix C. GARD Analytics Final Technical Report

Final Report for

EnergyPlus Modeling for Thermochromic Window Tests

Pleotint Subcontract under DOE/NETL Contract No. **DE-**EE0004011
GARD Project Number PL390

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1. Objective

GARD Analytics provided technical services to Pleotint, LLC for EnergyPlus modeling of thermochromic windows being tested at the Iowa Energy Center Energy Resource Station (ERS) in Ankeny, Iowa. A feature of EnergyPlus added in April 2009 allows the modeling of thermochromic windows using the object called WindowMaterial:GlazingGroup:Thermochromic which allows a window glazing layer to be defined with variable properties as a function of temperature. EnergyPlus was used to model the test rooms at the ERS with the thermochromic windows installed and compare EnergyPlus predicted results to actual measured data recorded onsite in the ERS test rooms.

2. Thermochromic Model in EnergyPlus

Thermochromic (TC) materials have active, reversible optical properties that vary with temperature. Thermochromic windows are adaptive window systems for incorporation into building envelopes. Thermochromic windows respond by absorbing sunlight and turning the sunlight energy into heat. As the thermochromic film warms it changes its light transmission level from less absorbing to more absorbing. The more sunlight it absorbs the lower the light level going through it. Figure 1 shows the variations of window properties with the temperature of the thermochromic glazing layer. By using the sun's own energy the window adapts based solely on the directness and amount of sunlight. Thermochromic materials will normally reduce optical transparency by absorption and/or reflection, and are specular (maintaining vision).

On cloudy days the window is at full transmission and letting in diffuse daylighting. On sunny days the window maximizes diffuse daylighting and tints based on the angle of the sun relative to the window. For a south facing window (northern hemisphere) the daylight early and late in the day is maximized and the direct sun at mid day is minimized. The active thermochromic material can be embodied within a laminate layer or a surface film. The overall optical state of the window at a given time is a function primarily of

- thermochromic material properties
- solar energy incident on the window
- construction of the window system that incorporates the thermochromic layer
- environmental conditions (interior, exterior, air temperature, wind, etc).

The tinted film, in combination with a heat reflecting, low-e layer allows the window to reject most of the absorbed radiation thus reducing undesirable heat load in a building. In the absence of direct sunlight the window cools and clears and again allows lower intensity diffuse radiation into a building. TC windows can be designed in several ways (Figure 2), with the most common being a triple pane window with the TC glass layer in the middle or double pane windows with the TC layer on the inner surface of the outer pane or for sloped glazing a double pane with the laminate layer on the inner pane with a low-e layer toward the interior. The TC glass layer has variable optical properties depending on its temperature, with a lower temperature at which the optical change is initiated, and an upper temperature at which a minimum transmittance is reached. TC windows act as passive solar shading

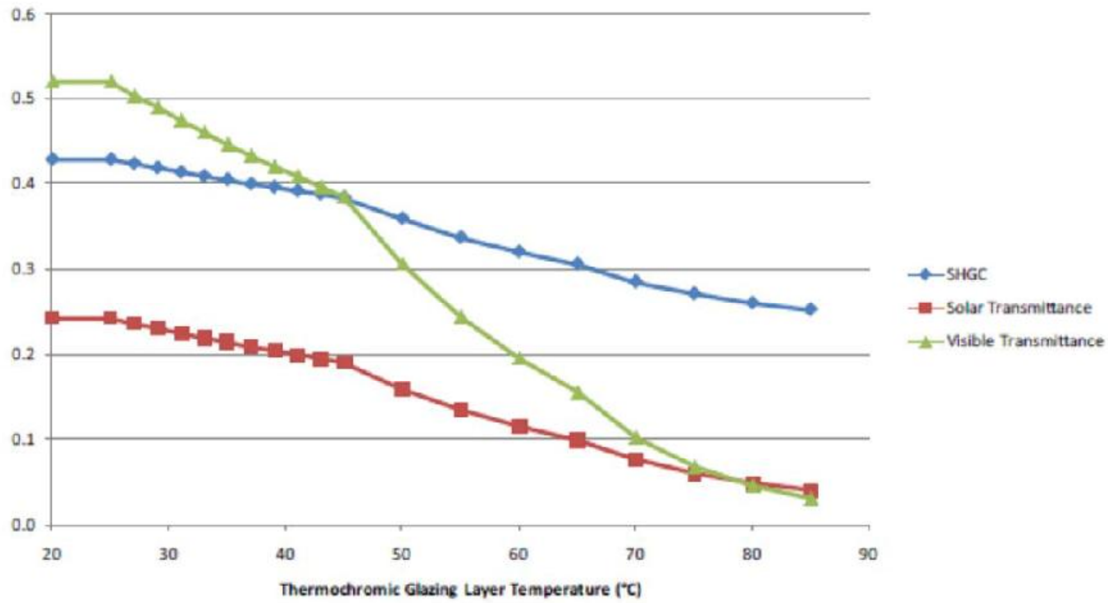


Figure 1 Variations of Window Properties with the Temperature of the Thermochromic Glazing layer (Excerpted from EnergyPlus Version 7.1 Engineering Reference Manual, Figure 75)

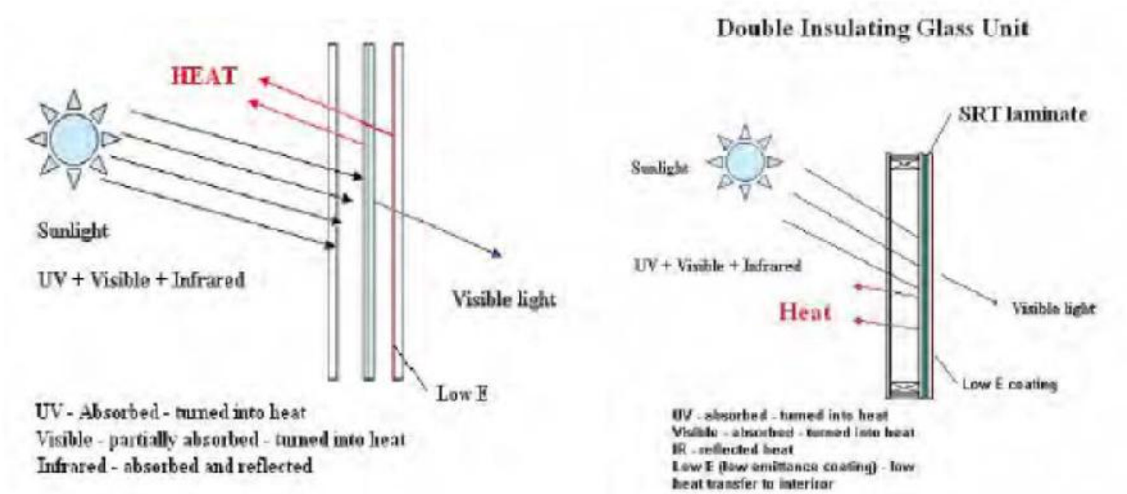


Figure 2 Configurations of Thermochromic Windows
(Excerpted from EnergyPlus Version 7.1 Engineering Reference Manual, Figure 76)

devices without the need for sensors, controls and power supplies but their optical performance is dependent on varying solar and other environmental conditions at the location of the window.

EnergyPlus describes a thermochromic window with a Construction object which references a special layer defined with a WindowMaterial:GlazingGroup:Thermochromic object. The WindowMaterial:GlazingGroup:Thermochromic object further references a series of WindowMaterial:Glazing objects corresponding to each specification temperature of the TC layer. During EnergyPlus run time, a series of TC windows corresponding to each specification temperature is created once. At the beginning of a particular time step, the temperature of the TC glass layer from the previous time step is used to look up the closest specification temperature whose corresponding TC window construction will be used for the current time step calculations. The current time step calculated temperature of the TC glass layer can be different from the previous time step, but no iterations are done in the current time step for the new TC glass layer temperature. This is an approximation that considers the reaction time of the TC glass layer can be close to the EnergyPlus simulation time step of say 10 to 15 minutes.

3. ERS Test facility

As described in the report titled *Iowa Energy Center Energy Resource Station – Technical Description* dated June 2010, the ERS test facility is a demonstration, training and test facility built to compare different energy-efficiency measures, to record energy consumption, and to disseminate information concerning energy efficient design and operation of buildings.

To achieve the unique ability to simultaneously test side-by-side, the building is equipped with two identical air handling units, each with its own dedicated and identical chiller. One air handling unit supplies the four test rooms designated as the A rooms and the other unit serves the four test rooms designated as the B rooms. There is one A test room and one B test rooms arranged as pairs in a side-by-side design with each pair having a different exposure (Figure 3). There is a pair of test rooms that face the south, east and west facing pairs, and an interior pair of test rooms with no exterior exposure. Each of the test rooms is a mirror image of its match with identical construction. The rooms are unoccupied; however, the capability to impose false loads on the rooms exists. The false loads and room lighting can be scheduled to simulate various usage patterns. The test rooms are designated as:

East A	East B
South A	South B
West A	West B
Interior A	Interior B

Each test room has a floor area of 266 Sq. ft., ceiling height of 8.4 ft., exterior wall area of 137 sq. ft. and window area of 74 sq. ft. The interior test rooms do not have any exterior windows. For more complete details of the ERS test facility including description of building envelope, mechanical systems, lighting systems, and data acquisition and control systems see the *ERS – Technical Description* report.

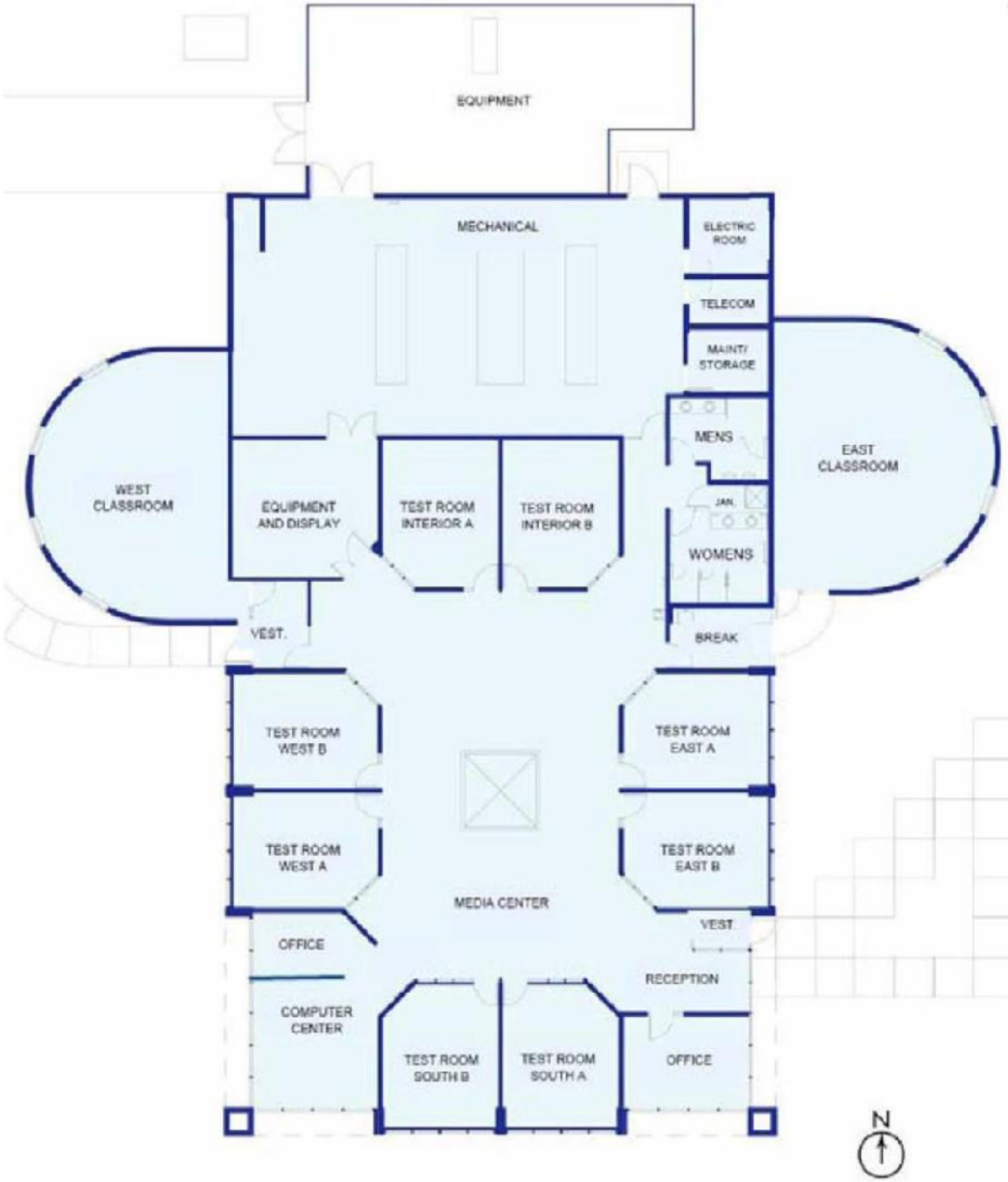


Figure 3 Floor Plan of Energy Resource Station Showing Test Rooms (Excerpted from ERS – Technical Description document dated June 2010)

4. Tests Conducted at ERS Test Facility

A series of tests with different window systems installed in the test rooms were conducted at the ERS test facility beginning in early 2011 and continuing through early 2012 as described below:

Test	Period	Test Rooms A	Test Rooms B
2.1	May 24 - 31, 2011	Standard Low-E Window	Pleotint SRT Azuria
2.2	June 2 -12, 2011	Standard Low-E Window	Pleotint SRT Clear
3.1	July 29 - August 7, 2011	Standard Low-E Window	Pleotint SRT Azuria
3.2	August 9 - 15, 2011	Standard Low-E Window	Pleotint SRT Clear
4.1	September 28 - October 4, 2011	Standard Low-E Window	Pleotint SRT Azuria
4.2	October 6 - 12, 2011	Standard Low-E Window	Pleotint SRT Clear
5.1	November 23 - 31, 2011	Standard Low-E Window	Pleotint SRT Azuria
5.2	December 2 - 9, 2011	Standard Low-E Window	Pleotint SRT Clear
6.1	February 2 - 8, 2012	Standard Low-E Window	Pleotint SRT Azuria
6.2	January 25 - 31, 2012	Standard Low-E Window	Pleotint SRT Clear

The Standard Low-E window installed in Test Rooms A was a high performance dark-tinted window provided by Viracon of Qwatonna, MN and consisted of ¼" (6mm) VE3-55 #2 outer pane, ½" (13.2mm) airspace and ¼" (6mm) clear glass inner pane with the following characteristics:

a. Transmittance

Visible light	23%
Solar energy	14%
Ultra-violet	5%
Reflectance	
Visible light-exterior	6%
Visible light-interior	15%
Solar energy	10%
ASHRAE U-Value	
Winter nighttime	0.31 Btu/hr-sqft-F
Summer Daytime	0.33 Btu/hr-sqft-F
Shade Coefficient	0.26
Solar Heat Gain Factor (SHGF)	0.22

A compatible EnergyPlus dual-pane window construction was defined which had a resultant Solar Heat Gain factor of 0.222. See Appendix A for the EnergyPlus IDF. Pleotint provided GARD Analytics with EnergyPlus IDF inputs for the Pleotint SRT Azuria and Pleotint SRT Clear windows.

The Azuria had the following construction

> 6 mm Azuria laminated to 6 mm clear with the Pleotint film. The laminate was made into an insulated glass unit with a ½ inch argon space (90% argon, 10% air) and a 6 mm Solarban 60, low E coating facing the argon space. The Azuria laminate faces the sun.

The Clear had the following construction:

> 6 mm clear laminated to 6 mm clear with the Pleotint film. The laminate was made into an insulated glass unit with a ½ inch argon space (90% argon, 10% air) and a 6 mm Solarban 60, low E coating facing the argon space. The clear laminate faces the sun.

5. Documents and Files Provided by the Iowa Energy Center

Numerous documents and files were provided by the Iowa ERS and Pleotint to GARD Analytics to aid in preparing an EnergyPlus model of the ERS test facility. Some of the more pertinent ones are listed below:

> 2010 Technical Report.pdf
> Bldg Tech Binder Set-11x17.pdf
> Controls Tech Binder Set-11x17.pdf
> Elec Tech Binder Set-11x17.pdf
> ERS Building Description.pdf
> ERS Technical Description III.pdf
> ERS Test Room Standard SHGC Window Specs.pdf
> Mech Tech Binder Set-11x17.pdf
> SRT Window Test 2011 - PLEOTINT LLC - Floor & Rfltd Clg Plan-Sheet No 1.pdf
> SRT Window Test 2011 - PLEOTINT LLC - Floor & Rfltd Clg Plan-Sheet No 2.pdf
> SRT Window Test 2011 - PLEOTINT LLC - HVAC Partial Plan-Sheet No 4.pdf
> SRT Window Test 2011 - PLEOTINT LLC - Section View-Sheet No 3.pdf
> Tech Dwg List-Cover Page-11x17.pdf
> TOC Architectural .doc
> TOC Controls.doc
> TOC Electrical.doc
> TOC Instrumentation.doc
> TOC Mechanical.doc
> 2008 Record Drawings-CAD Format.zip
> ERS Control Modes Graphic Schedule X.X.xls (X.X specifies particular test, e.g. 2.1, 2.2, etc)
> ERS Test Setup Sheet X.X.doc (X.X specifies particular test, e.g. 2.1, 2.2, etc)
> Lighting and Wattage Comparison.xls
> Lighting Watts A-B.xls
> EnergyPlus Window Data files: Clear.idf and Azuria.idf
> Test X.X Energy Consumption.xls (X.X specifies particular test, e.g. 2.1, 2.2, etc)

In addition, GARD was given access to the ERS FTP site where test data files are available for all tests performed by the Iowa Energy Center at the ERS test facility.

6. EnergyPlus Model of ERS Test Facility

GARD Analytics obtained an EnergyPlus model of the test rooms at the ERS facility that had been developed for an International Energy Agency (IEA) project titled *Empirical Validations of Shading/Daylighting/Load Interactions in Building Energy Simulation Tools* (August 2007) (www.iea-shc.org/task34/publications/index.htm). Beginning with that EnergyPlus model, GARD updated the model to reflect changes that had been made to the ERS test rooms as described in the following:

1. *Iowa Energy Center Energy Resource Station, Technical Description* dated June 2010
2. *Description of the Iowa Energy Center Energy Resource Station: Facility Update III* dated March 2000, Technical Report ME-TFS-00-001
3. Various emails between Xiaohui Zhou of Iowa ERS, Fred Millett and Michael Broekhuis of Pleotint, and Bob Henninger and Mike Witte of GARD.

Some of the changes made to the IEA EnergyPlus model to reflect current conditions at the ERS included:

1. Separated test room external walls into 3 opaque bottom sections and 1 opaque top section due to different construction materials in each section
2. Removed all shade fins and overhangs on west windows
3. Removed all internal and external shading and controls
4. Changed material properties and constructions to match March 2000 Facility Update III document
5. Took out insulation layer below concrete floor since that insulation was for perimeter
6. Changed all Test Room A plenum "ceilings" from LAY-CEILING construction to LAY-ROOF construction like Test Room B
7. Each test zone had a baseboard heater for adding internal loads when needed. These were scheduled OFF for tests where they were not used
8. Turned off the daylighting controls and instead used ERS measured lighting power from test data files for each test to create EnergyPlus Schedule:File objects to simulate actual measured hourly lighting loads in each room
9. Simulated the test room VAV reheat coils as electric reheat coils
10. Since no floor slab temperature measurements were available, the EnergyPlus Slab program was used along with the slab construction details and Des Moines TMY weather to estimate a monthly temperature at the soil-slab interface as follows:

January	62.9 F
February	62.9 F
March	64.1 F
April	65.0 F
May	65.9 F

June	66.9 F
July	67.7 F
August	67.9 F
September	67.2 F
October	65.8 F
November	64.9 F
December	63.6 F

11. Set outside air quantity to a constant 120 CFM during the occupied hours from 6AM to 6PM
12. Set the supply fans for Systems A and B to flow rate of 3200 CFM and static pressure of 3.2 in. water
13. For tests that used baseboard heaters (Tests 3.1 through 6.2), set the baseboard heat output during occupied hours of 6AM through 6PM to be those provided by ERS based on measured data as follows:

West A	1,660 watts
West B	1,650 watts
South A	1,690 watts
South B	1,710 watts
East A	1,710 watts
East B	1,690 watts
Interior A	1,740 watts
Interior B	1,720 watts

14. The EnergyPlus simulation timestep was set to 6 timesteps per hour.

Test room operational parameters for each test including room internal loads (lights, computers, people, baseboard heat), thermostat setpoint schedules, supply air flows, supply air temperatures to reheat coils, etc were described in ERS System Test Setup sheets and Schedule Profiles.

Each test room was equipped with automatic daylighting equipment which when operating using DDC control mode and the “dimming-off” option allowed the lights within the room to be dimmed when sunlight is available in order to maintain a 45 footcandle level at the light level sensor. In actual operation with a 45 footcandle setpoint, the lights will turn off when the light level sensor measurement is >55 FtC and will come back on when the light level falls to <40 FtC. ERS recorded the total light energy usage in each test room on a minute-by-minute basis during the test period and made these data files available to GARD Analytics for this project work. The minute-by-minute data were converted by GARD to average hourly lighting energy consumption and then these hourly values were read by EnergyPlus for each hour of the simulation so that simulated hourly lighting energy exactly matched actual measured lighting energy for each test room.

Weather data was recorded onsite at the ERS test facility during each test period and the weather data was then processed into a TMY format and made available as part of the data files for each test. These

TMY weather files were used along with the EnergyPlus weather processing program to convert them into EnergyPlus compatible weather files and then used for each EnergyPlus simulation.

7. EnergyPlus Test Results

Following EnergyPlus simulations of the 10 test periods, several approaches were taken to compare the EnergyPlus results for each test simulation with the data recorded onsite at the ERS test facility.

7.1 Window Performance

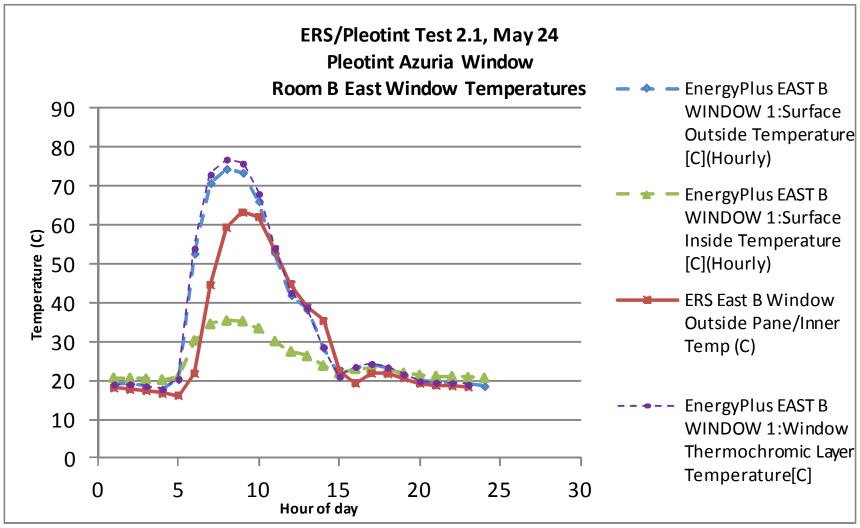
One of the goals of this project was to determine how well the EnergyPlus thermochromic window model tracks the actual performance of Pleotint thermochromic windows. Various EnergyPlus output parameters are available to indicate window performance including transmitted beam and diffuse solar, window heat gain/loss, surface temperatures, transmittance, absorptance, reflectance, and also thermochromic layer temperature.

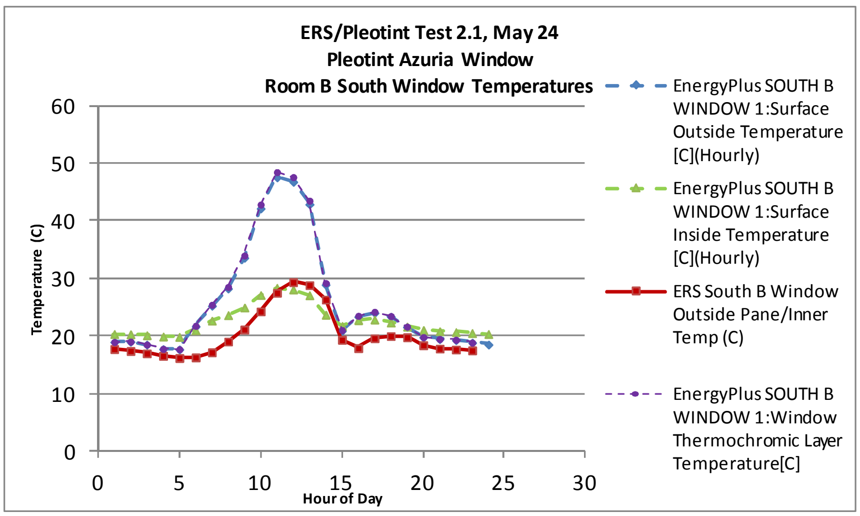
A thermocouple embedded between the two panes of Pleotint windows (Room B) measured the temperature of the inside of the outer pane. The measured temperature from the thermocouple embedded between the two panes was compared to the EnergyPlus outer surface temperature of the outer pane and inside surface temperature of the inner pane. The results for Test 2.1 with the Pleotint Azuria window in Room B are shown in Figure 4 for May 24 for the east, south and west rooms. Similar charts are shown in Figure 5 for June 2 for the Pleotint Clear window tested in Test 2.2. Figure 6 shows the results for Test 5.1 with Pleotint Azuria windows where especially for the East window the comparison is particularly poor. Charts showing similar results for other tests can be found in Appendix B.

It is interesting to note the following regarding the results shown in Figure 4 for Test 2.1 with the Pleotint Azuria window.

1. The shapes of the ERS and EnergyPlus curves are similar although there is a time shift between the two.
2. The dip in the curves between the hours of 14 and 17 is due to cloudiness that occurred on May 24 which caused a drop off in the direct and diffuse solar.
3. The ERS temperature of the window gap generally falls between the window inner and outer surface temperatures which is what would be expected.

Similar comments apply to the results shown in Figure 5 for Test 2.2 with the Pleotint Clear window where cloudiness occurred on June 2 between the hours of 10 and 14.





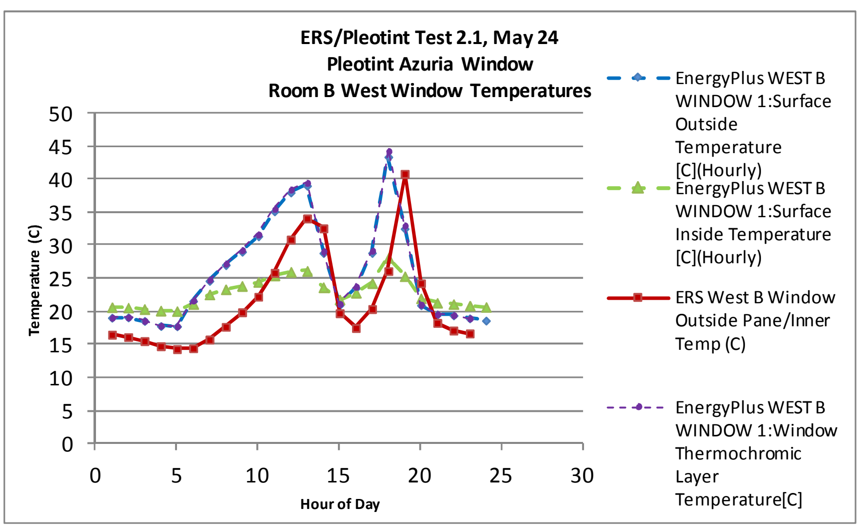
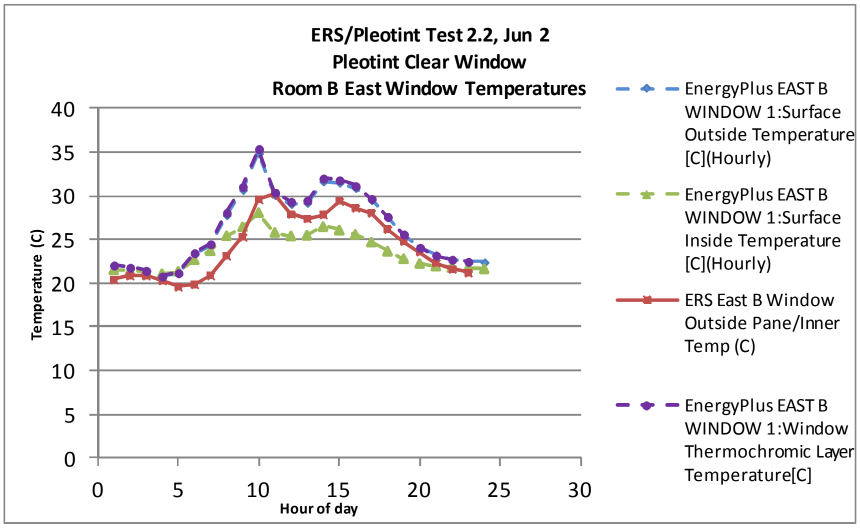
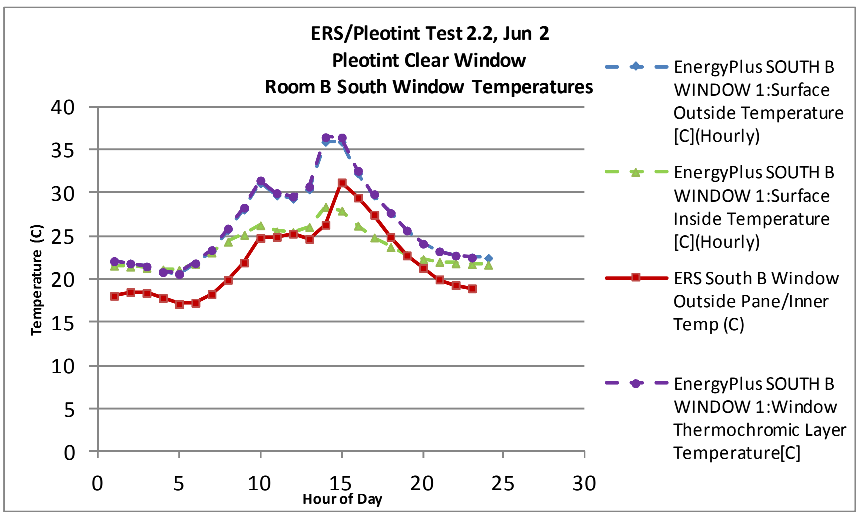


Figure 4 EnergyPlus Versus ERS Window Temperatures for Test 2.1, Pleotint Azuria Window for East, South, and West Exposures





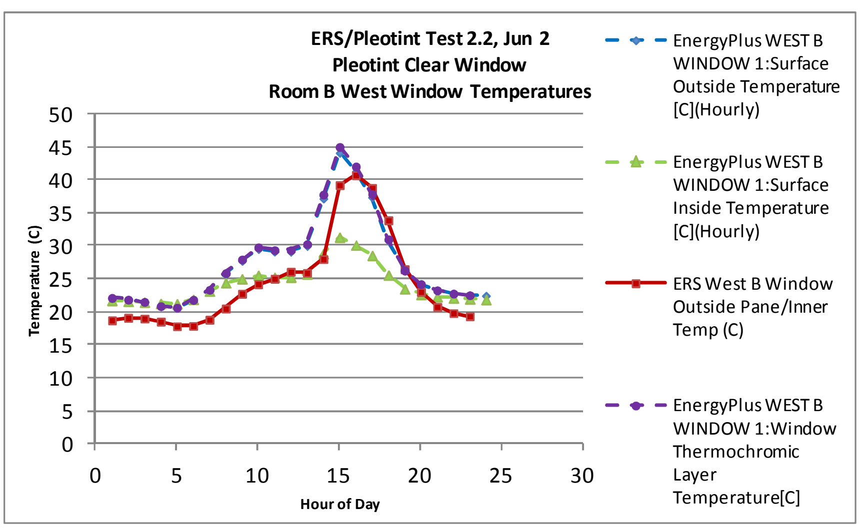
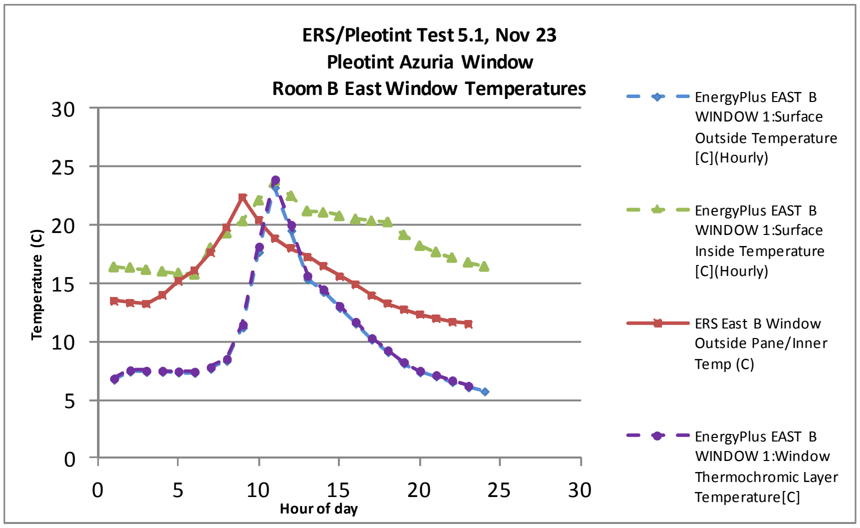
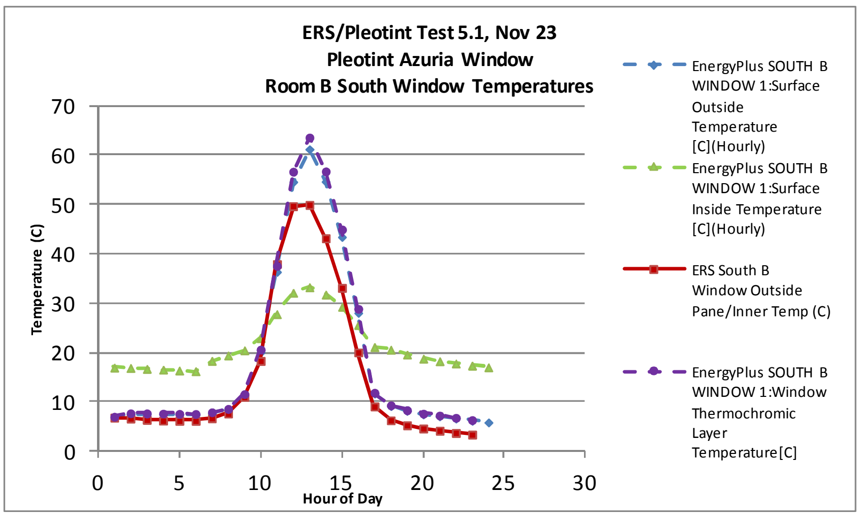


Figure 5 EnergyPlus Versus ERS Window Temperatures for Test 2.2, Pleotint Clear Window for East, South and West Exposures





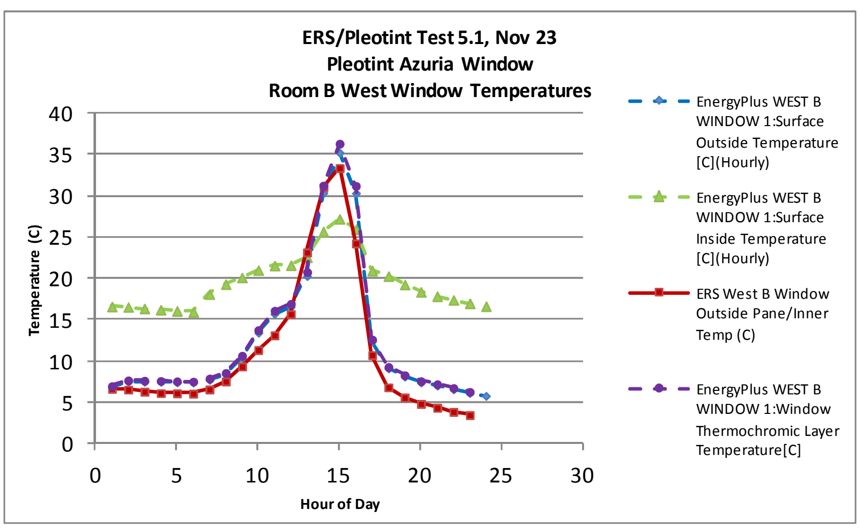


Figure 6 EnergyPlus Versus ERS Window Temperatures for Test 5.1, Pleotint Azuria Window for East, South and West Exposures

Figures 7 and 8 show charts of the transmittance, reflectance and absorptance determined by EnergyPlus for the Room A and Room B windows for Test 2.1 on May 24 and Test 2.2 on June 2. A complete set of these charts for all tests are included in Appendix C. Additional charts showing the Beam Solar and Diffuse Solar entering each test room along with Window Heat Gain determined by EnergyPlus for each test room during each test are included in Appendix D.

7.2 Comparing System Cooling Loads

The ERS test facility has two separate air handling units (AHU), one to serve the four A test rooms and one to serve the four B test rooms. Each test room receives supply air through a variable air volume (VAV) mixing box which has a reheat coil. Each AHU has a central cooling coil and VAV fan. The AHUs were operated in a similar manner for each test to provide the following:

1. The AHUs operated only during the occupied hours from 6 AM till 6 PM and during the nighttime hours in night setback mode.
2. 55 F supply air was supplied to each VAV mixing box where the reheat coil heated the supply air to satisfy the room thermostat setpoints which were: heating 70 F, cooling 74 F during occupied hours; heating 63 F and cooling 78 F during unoccupied hours.
3. Outdoor air was provided by an injection fan at the central AHU at a rate of 120 CFM during occupied hours only
4. Chilled water from two separate air-cooled water chillers supplied chilled water to cooling coils in each main AHU
5. One hot water boiler supplied hot water to all reheat coils in VAV boxes
6. For certain tests where internal loads created by baseboard heaters were required, the baseboards were operated at constant output during occupied hours only.

An attempt was made to compare the AHU sensible cooling coil loads for Systems A and B. ERS provided summary spreadsheets for each test that presented for Systems A and B the following energy used over the duration of each test:

- Fan energy (supply fan, return fan, outdoor air injection fan)
- Pump energy (chilled water pump, heating water pump)
- Chiller energy
- Lighting energy (east room, south room, west room, interior room)
- System cooling coil energy (sensible and latent)
- System heating energy (provided to 4 room reheat coils)
- Total electricity used (fan + pump + chiller)
- Total building electricity used (fan + pump + chiller + lighting)

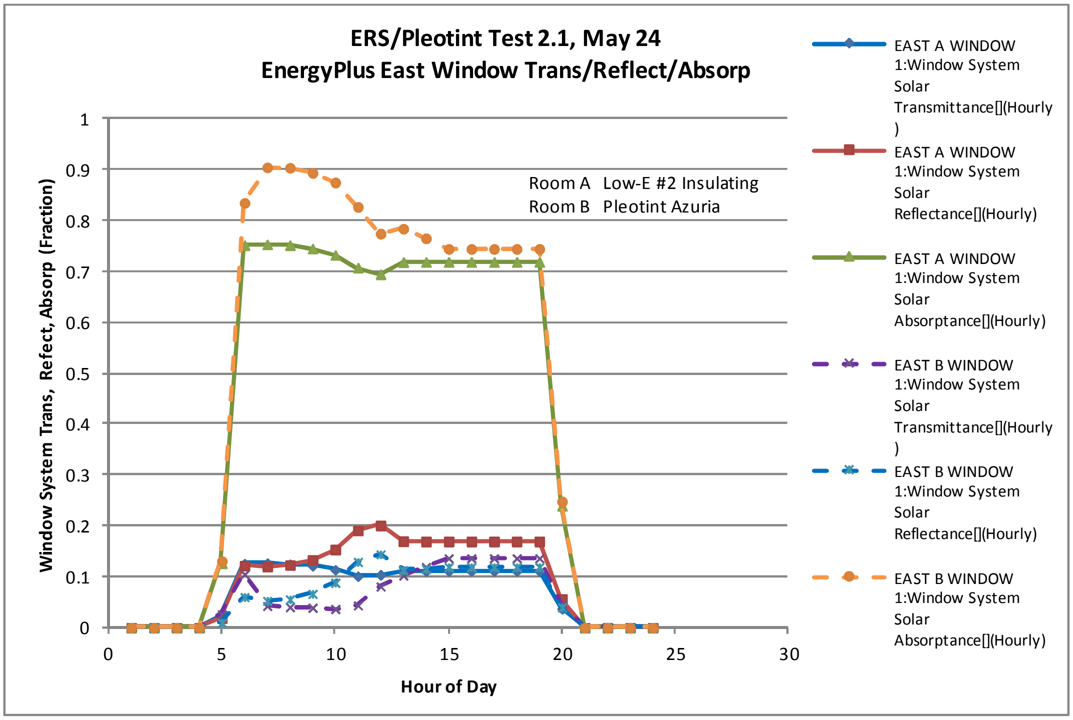


Figure 7 EnergyPlus Window Properties for Test 2.1, Rooms A and B Windows for East Exposure

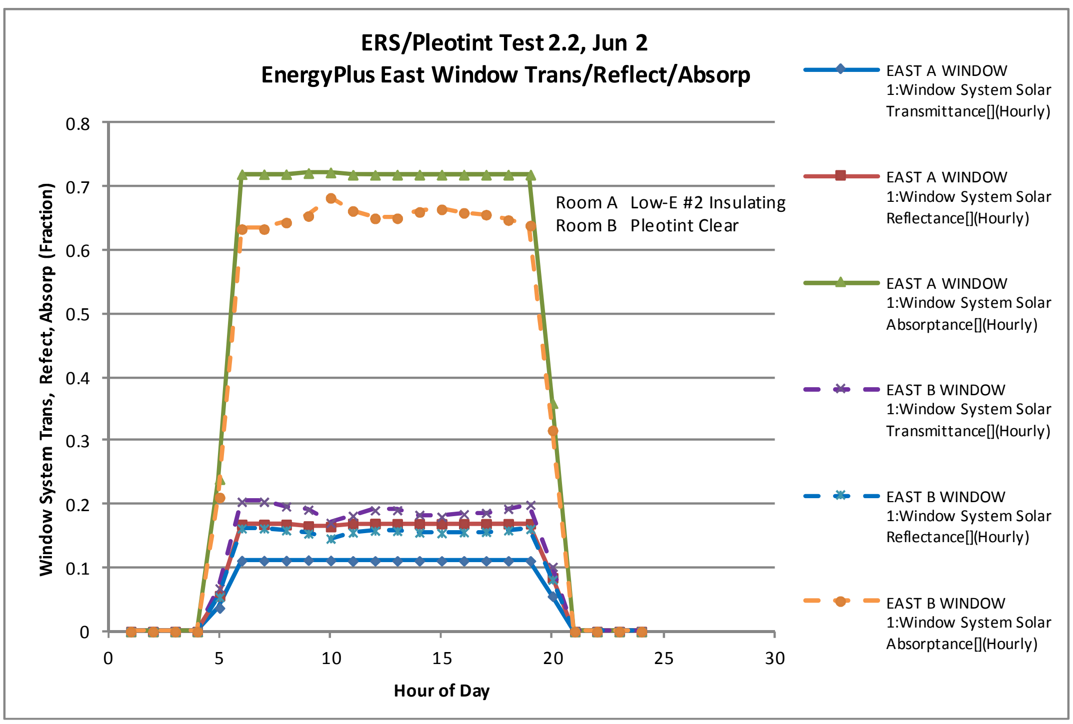


Figure 8 EnergyPlus Window Properties for Test 2.2, Rooms A and B Windows for East Exposure

An estimate of the total sensible cooling provided by each system to the four test rooms that it served was calculated as follows:

Total Room Sensible Cooling = Cooling Coil Sensible Energy – Fan Energy – Heating Energy

The resultant Total Room Sensible Cooling Energy calculated in this manner also includes the 120 CFM outdoor air load for which there was no estimate provided by ERS but which is small compared to the total room loads.

An example of the results of this analysis procedure using the data provided by ERS is shown in Table 1 for Systems A and B where results are expressed in total room sensible cooling including outdoor air load in BTU of energy provided over the duration of the test. A similar analysis procedure was used for EnergyPlus simulations and is shown in Table 2. A comparison of results, i.e. ERS versus EnergyPlus is provided in Table 3. The differences in sensible cooling coil energy loads between ERS and EnergyPlus for System A and System B are considerable with generally larger differences for System A tests where the standard dark-tinted windows are used.

The last section of Table 3 compares the differences in sensible cooling load for (System B – System A) for both ERS and EnergyPlus which gives an indication of the change in room sensible cooling load that results when using Pleotint windows versus standard dark-tinted low-E windows. Here the results for EnergyPlus versus ERS are much closer with ERS indicating greater savings than EnergyPlus. In 3 of the tests, EnergyPlus actually indicates that there is a very small increase in energy usage of 0.4% or less.

Table 1 System Room Sensible Cooling Load Using ERS Test Results

ERS Tests
Calculation of Room System Sensible Cooling Load (includes outdoor air load)
Data taken from ERS Energy Performance Results Spreadsheets

System A (Serves Rooms East-A, West-A, South-A and Interior-A)

Test	Test Period	Window Type	Sensible Cooling Coil Energy (Btu)	Total Fan Energy (Btu)	Reheat Coil Energy (Btu)	Total Room Sensible Cooling (Incl Outdoor Air) (Btu)
Test 2.1	May 24-31, 2011	Standard Dark-Tinted	1,728,763.7	273,975.0	500,414.3	954,374.5
Test 2.2	Jun 2-12, 2011	Standard Dark-Tinted	2,120,951.0	305,720.4	211,401.0	1,603,829.6
Test 3.1	Jul 29-Aug7, 2011	Standard Dark-Tinted	5,426,673.4	629,697.3	-	4,796,976.1
Test 3.2	Aug 9-15, 2011	Standard Dark-Tinted	3,643,071.7	418,160.0	-	3,224,911.7
Test 4.1	Sep 28-Oct 4, 2011	Standard Dark-Tinted	3,222,201.2	388,159.0	-	2,834,042.2
Test 4.2	Oct 6-12, 2011	Standard Dark-Tinted	3,279,259.5	384,531.9	-	2,894,727.7
Test 5.1	Nov 23-30, 2011	Standard Dark-Tinted	2,326,155.7	334,609.1	62,336.1	1,929,210.5
Test 5.2	Dec 2-9, 2011	Standard Dark-Tinted	1,837,000.6	311,603.5	133,703.3	1,391,693.7
Test 6.1	Feb 2-8, 2012	Standard Dark-Tinted	1,530,935.5	237,465.6	90,498.5	1,202,971.4
Test 6.2	Jan 25-31, 2012	Standard Dark-Tinted	1,896,899.0	288,700.9	113,476.3	1,494,721.9

System B (Serves Rooms East-B, West-B, South-B and Interior-B)

Test	Test Period	Window Type	Sensible Cooling Coil Energy (Btu)	Total Fan Energy (Btu)	Reheat Coil Energy (Btu)	Total Room Sensible Cooling (Incl Outdoor Air) (Btu)
Test 2.1	May 24-31, 2011	Pleotint Azuria	1,548,708.0	271,639.6	409,040.8	868,027.7
Test 2.2	Jun 2-12, 2011	Pleotint Clear	1,908,170.0	310,130.1	108,026.4	1,490,013.5
Test 3.1	Jul 29-Aug7, 2011	Pleotint Azuria	5,058,064.1	608,297.2	-	4,449,767.0
Test 3.2	Aug 9-15, 2011	Pleotint Clear	3,352,388.3	399,948.0	-	2,952,440.2
Test 4.1	Sep 28-Oct 4, 2011	Pleotint Azuria	2,883,357.8	352,504.9	-	2,530,852.8
Test 4.2	Oct 6-12, 2011	Pleotint Clear	3,006,585.3	365,509.3	-	2,641,076.0
Test 5.1	Nov 23-30, 2011	Pleotint Azuria	2,067,471.4	319,142.5	66,960.9	1,681,368.1
Test 5.2	Dec 2-9, 2011	Pleotint Clear	1,617,299.4	295,197.3	123,776.7	1,198,325.4
Test 6.1	Feb 2-8, 2012	Pleotint Azuria	1,364,748.3	229,776.0	94,364.9	1,040,607.5
Test 6.2	Jan 25-31, 2012	Pleotint Clear	1,759,822.6	284,043.8	113,025.9	1,362,753.0

Table 2 System Room Sensible Cooling Load Using EnergyPlus Simulation Results

ERS Tests
Calculation of System Room Sensible Cooling Load (includes outdoor air load)
Data taken from EnergyPlus Simulations

System A (Serves Rooms East-A, West-A, South-A and Interior-A)

Test	Test Period	Window Type	Sensible Cooling Coil Energy (Btu)	Total Supply Fan Energy (Btu)	Room South-A Reheat Coil Energy (Btu)	Room West-A Reheat Coil Energy (Btu)	Room East-A Reheat Coil Energy (Btu)	Room Interior-A Reheat Coil Energy (Btu)	Total Room Sensible Cooling (Incl Outdoor Air) (Btu)
Test 2.1	May 24-31, 2011	Standard Dark-Tinted	1,362,345	141,394	175,693	191,670	180,041	202,209	471,338.2
Test 2.2	Jun 2-12, 2011	Standard Dark-Tinted	1,723,534	159,079	179,943	169,073	158,914	212,108	844,417.1
Test 3.1	Jul 29-Aug7, 2011	Standard Dark-Tinted	4,124,445	317,613	-	-	-	-	3,806,832.7
Test 3.2	Aug 9-15, 2011	Standard Dark-Tinted	2,783,178	221,741	-	-	-	-	2,561,436.8
Test 4.1	Sep 28-Oct 4, 2011	Standard Dark-Tinted	2,478,008	212,228	319	399	539	-	2,264,522.2
Test 4.2	Oct 6-12, 2011	Standard Dark-Tinted	2,442,876	205,988	50	90	83	-	2,236,664.0
Test 5.1	Nov 23-30, 2011	Standard Dark-Tinted	1,954,127	211,189	3,324	3,534	3,593	746	1,731,740.4
Test 5.2	Dec 2-9, 2011	Standard Dark-Tinted	1,429,904	193,466	6,021	6,289	6,229	1,584	1,216,316.3
Test 6.1	Feb 2-8, 2012	Standard Dark-Tinted	1,187,553	146,523	3,863	4,028	3,954	1,261	1,027,924.3
Test 6.2	Jan 25-31, 2012	Standard Dark-Tinted	1,552,394	179,059	4,150	4,407	4,376	1,485	1,358,917.0

System B (Serves Rooms East-B, West-B, South-B and Interior-B)

Test	Test Period	Window Type	Sensible Cooling Coil Energy (Btu)	Total Supply Fan Energy (Btu)	Room South-B Reheat Coil Energy (Btu)	Room West-B Reheat Coil Energy (Btu)	Room East-B Reheat Coil Energy (Btu)	Room Interior-B Reheat Coil Energy (Btu)	Total Room Sensible Cooling (Incl Outdoor Air) (Btu)
Test 2.1	May 24-31, 2011	Pleotint Azuria	1,360,202	141,394	191,839	204,518	195,702	201,848	424,900.3
Test 2.2	Jun 2-12, 2011	Pleotint Clear	1,740,087	159,095	185,361	174,123	163,282	211,576	846,650.1
Test 3.1	Jul 29-Aug7, 2011	Pleotint Azuria	4,092,881	311,888	-	-	-	-	3,780,993.0
Test 3.2	Aug 9-15, 2011	Pleotint Clear	2,792,312	220,668	-	-	-	-	2,571,643.8
Test 4.1	Sep 28-Oct 4, 2011	Pleotint Azuria	2,445,016	208,989	151	265	422	-	2,235,188.8
Test 4.2	Oct 6-12, 2011	Pleotint Clear	2,448,142	205,780	26	57	70	-	2,242,208.2
Test 5.1	Nov 23-30, 2011	Pleotint Azuria	1,873,152	208,209	3,200	3,504	3,593	757	1,653,889.3
Test 5.2	Dec 2-9, 2011	Pleotint Clear	1,349,407	192,745	5,886	6,379	6,332	1,597	1,136,468.5
Test 6.1	Feb 2-8, 2012	Pleotint Azuria	1,113,033	143,931	3,781	4,029	3,933	1,271	956,089.1
Test 6.2	Jan 25-31, 2012	Pleotint Clear	1,524,500	180,321	4,005	4,410	4,378	1,496	1,329,889.3

Table 3 Comparison of Results Using the System Cooling Load Method – ERS Versus EnergyPlus

ERS Tests

Comparison of System Room Sensible Cooling Loads (includes outdoor air load)

System A (Serves Rooms East-A, West-A, South-A and Interior-A)

Test	Test Period	Room A Window Type	ERS/Pleotint Total Room Sensible Cooling (Incl Outdoor Air) (Btu)	EnergyPlus Total Room Sensible Cooling (Incl Outdoor Air) (Btu)	Difference (EnergyPlus - ERS)	% Difference (EnergyPlus - ERS)
Test 2.1	May 24-31, 2011	Standard Dark-Tinted	954,374.5	471,338.2	(483,036.3)	-50.6%
Test 2.2	Jun 2-12, 2011	Standard Dark-Tinted	1,603,829.6	844,417.1	(759,412.4)	-47.3%
Test 3.1	Jul 29-Aug7, 2011	Standard Dark-Tinted	4,796,976.1	3,806,832.7	(990,143.4)	-20.6%
Test 3.2	Aug 9-15, 2011	Standard Dark-Tinted	3,224,911.7	2,561,436.8	(663,474.9)	-20.6%
Test 4.1	Sep 28-Oct 4, 2011	Standard Dark-Tinted	2,834,042.2	2,264,522.2	(569,520.0)	-20.1%
Test 4.2	Oct 6-12, 2011	Standard Dark-Tinted	2,894,727.7	2,236,664.0	(658,063.7)	-22.7%
Test 5.1	Nov 23-30, 2011	Standard Dark-Tinted	1,929,210.5	1,731,740.4	(197,470.1)	-10.2%
Test 5.2	Dec 2-9, 2011	Standard Dark-Tinted	1,391,693.7	1,216,316.3	(175,377.4)	-12.6%
Test 6.1	Feb 2-8, 2012	Standard Dark-Tinted	1,202,971.4	1,027,924.3	(175,047.1)	-14.6%
Test 6.2	Jan 25-31, 2012	Standard Dark-Tinted	1,494,721.9	1,358,917.0	(135,804.8)	-9.1%

System B (Serves Rooms East-B, West-B, South-B and Interior-B)

Test	Test Period		ERS/Pleotint Total Room Sensible Cooling (Incl Outdoor Air) (Btu)	EnergyPlus Total Room Sensible Cooling (Incl Outdoor Air) (Btu)	Difference (EnergyPlus - ERS)	% Difference (EnergyPlus - ERS)
Test 2.1	May 24-31, 2011	Pleotint Azuria	868,027.7	424,900.3	(443,127.4)	-51.0%
Test 2.2	Jun 2-12, 2011	Pleotint Clear	1,490,013.5	846,650.1	(643,363.4)	-43.2%
Test 3.1	Jul 29-Aug7, 2011	Pleotint Azuria	4,449,767.0	3,780,993.0	(668,773.9)	-15.0%
Test 3.2	Aug 9-15, 2011	Pleotint Clear	2,952,440.2	2,571,643.8	(380,796.4)	-12.9%
Test 4.1	Sep 28-Oct 4, 2011	Pleotint Azuria	2,530,852.8	2,235,188.8	(295,664.0)	-11.7%
Test 4.2	Oct 6-12, 2011	Pleotint Clear	2,641,076.0	2,242,208.2	(398,867.8)	-15.1%
Test 5.1	Nov 23-30, 2011	Pleotint Azuria	1,681,368.1	1,653,889.3	(27,478.7)	-1.6%
Test 5.2	Dec 2-9, 2011	Pleotint Clear	1,198,325.4	1,136,468.5	(61,856.9)	-5.2%
Test 6.1	Feb 2-8, 2012	Pleotint Azuria	1,040,607.5	956,089.1	(84,518.4)	-8.1%
Test 6.2	Jan 25-31, 2012	Pleotint Clear	1,362,753.0	1,329,889.3	(32,863.7)	-2.4%

System B versus System A (System B Cooling Load - System A Cooling Load)

Test	Test Period	ERS/Pleotint Total Room Sensible Cooling (Incl Outdoor Air) (Btu)	EnergyPlus Total Room Sensible Cooling (Incl Outdoor Air) (Btu)	% Difference ERS (Sys B - Sys A)	% Difference EnergyPlus (Sys B - Sys A)
Test 2.1	May 24-31, 2011	(86,346.8)	(46,438.0)	-9.0%	-9.9%
Test 2.2	Jun 2-12, 2011	(113,816.0)	2,233.0	-7.1%	0.3%
Test 3.1	Jul 29-Aug7, 2011	(347,209.1)	(25,839.7)	-7.2%	-0.7%
Test 3.2	Aug 9-15, 2011	(272,471.5)	10,206.9	-8.4%	0.4%
Test 4.1	Sep 28-Oct 4, 2011	(303,189.4)	(29,333.4)	-10.7%	-1.3%
Test 4.2	Oct 6-12, 2011	(253,651.7)	5,544.2	-8.8%	0.2%
Test 5.1	Nov 23-30, 2011	(247,842.4)	(77,851.1)	-12.8%	-4.5%
Test 5.2	Dec 2-9, 2011	(193,368.3)	(79,847.8)	-13.9%	-6.6%
Test 6.1	Feb 2-8, 2012	(162,363.9)	(71,835.2)	-13.5%	-7.0%
Test 6.2	Jan 25-31, 2012	(131,968.9)	(29,027.7)	-8.8%	-2.1%

7.3 Comparing Room Cooling Loads

EnergyPlus results were also compared to ERS results using measured hourly test data to estimate hourly heating and cooling energy provided to each room. The approximate actual heating or cooling energy supplied to each room was calculated using data recorded from various sensors and stored in ERS electronic data files. This was done in the following manner using data available from sensors at each VAV reheat box and within the room:

- Room supply airflow (cfm) designated as point VAVCFMDP in data files
- Room supply air temperature (F) which is the VAV reheat box discharge air temperature designated as point VAV-DAT in data files
- Resulting room temperature (F) designated as RM-TEMP in data files

The heating or cooling energy provided to the room was then calculated as

Q (Btu/hr) = 1.08 * VAVCFMDP * (RM-TEMP – VAV-DAT)

where +Q was cooling and –Q was heating.

Spreadsheets like that shown in Figure 9 comparing these calculated hourly loads to the EnergyPlus results for the Rooms South A & B, West A & B, East A & B and Internal A & B were prepared for each day of each test. Figure 8 shows the analysis results for Room South-B for August 11 of Test 3.2. The left-hand portion of the spreadsheet shows values of the measured data extracted from the ERS data files labeled 0811lite.ers and 0811rmsb.ers including: light power, VAV airflow, VAV reheat coil entering air temperature, VAV Reheat coil discharge air temperature supplied to the room, and the resulting room temperature. The column labeled 'Sensible Heat Delivered" then shows the calculated heating (-) or cooling (+).

The right-hand portion of the spreadsheet shows the values for the same parameters as determined by EnergyPlus. The last two columns then show the difference in net heat delivered to the room for EnergyPlus versus ERS along with the percentage difference. Overall for the day, the amount of sensible cooling determined by EnergyPlus was 6.8% less than that calculated from ERS data. Note that during the occupied hours of the day when the AHU was running the ERS resulting room temperature varied somewhat from the EnergyPlus values which were holding constant at the thermostat setpoint temperature of 70 F.

Test 3.2 South Room B

ERS Recorded Data - 60 minute data averaged over the hour to get hourly result

EnergyPlus Data - Timestep=6, results reported hourly

	EnergyPlus Hour Ending	Light Power (W)	VAVCFM DP VAV Airflow (cfm)	VAV-EAT VAV Entering Air Temp (F)	VAV-DAT VAV Discharge Air Temp (F)	RM-TEMP Room Temp (F)	Sensible Heat Delivered (Calculated) (Btu) Cool (+) Heat (-)	Light Power (W)	Room Supply Airflow (cfm)	VAV Box Entering Air Temp (F)	Room Supply Air Temp (F)	Room Temp (F)	Space Sensible Heating (Btu/hr)	Space Sensible Cooling (Btu/hr)	Net Heat Delivered (Btu/Hr)	Net Delta (Btu/hr)	Percent Diff
8/11/2011	1:00:00	0.086	0.0	73.5	76.4	75.8	0.0	0.086	0.0	78.0	0.0	73.3	0.0	0.0	0.0	0.0	
8/11/2011	2:00:00	0.079	0.0	73.6	76.3	75.4	0.0	0.079	0.0	77.9	0.0	73.0	0.0	0.0	0.0	0.0	
8/11/2011	3:00:00	0.085	0.0	73.6	76.2	75.0	0.0	0.085	0.0	77.6	0.0	72.7	0.0	0.0	0.0	0.0	
8/11/2011	4:00:00	0.080	0.0	73.7	76.2	74.8	0.0	0.080	0.0	77.4	0.0	72.4	0.0	0.0	0.0	0.0	
8/11/2011	5:00:00	0.088	0.0	75.7	75.7	74.4	0.0	0.088	0.0	77.2	0.0	72.2	0.0	0.0	0.0	0.0	
8/11/2011	6:00:00	0.085	0.0	76.2	75.5	74.1	0.0	0.085	0.0	76.9	0.0	72.1	0.0	0.0	0.0	0.0	
8/11/2011	7:00:00	321.330	442.7	59.8	61.4	73.8	5904.6	321.330	309.4	55.0	309.4	74.0	0.0	6552.1	6552.1	647.5	11%
8/11/2011	8:00:00	209.454	391.0	56.0	57.5	74.1	7023.0	209.454	320.8	55.0	320.8	74.0	0.0	6802.5	6802.5	-220.4	-3%
8/11/2011	9:00:00	137.767	410.6	56.0	57.3	74.0	7412.4	137.767	332.1	55.0	332.1	74.0	0.0	7042.8	7042.8	-369.6	-5%
8/11/2011	10:00:00	72.631	423.8	56.0	57.3	74.0	7663.3	72.631	347.0	55.0	347.0	74.0	0.0	7359.5	7359.5	-303.8	-4%
8/11/2011	11:00:00	0.060	435.3	55.8	57.2	74.0	7928.4	0.060	357.9	55.0	357.9	74.0	0.0	7592.2	7592.2	-336.2	-4%
8/11/2011	12:00:00	0.056	448.3	55.9	57.1	74.0	8171.9	0.056	365.1	55.0	365.1	74.0	0.0	7742.5	7742.5	-429.4	-5%
8/11/2011	13:00:00	0.052	459.4	55.9	57.2	74.0	8380.3	0.052	371.2	55.0	371.2	74.0	0.0	7869.1	7869.1	-511.3	-6%
8/11/2011	14:00:00	0.033	464.3	55.9	57.1	74.0	8470.1	0.033	367.8	55.0	367.8	74.0	0.0	7795.1	7795.1	-675.0	-8%
8/11/2011	15:00:00	57.073	467.6	56.0	57.2	74.0	8504.0	57.073	363.4	55.0	363.4	74.0	0.0	7696.9	7696.9	-807.1	-9%
8/11/2011	16:00:00	127.937	464.2	55.7	57.0	74.0	8513.3	127.937	354.6	55.0	354.6	74.0	0.0	7506.9	7506.9	-1006.4	-12%
8/11/2011	17:00:00	131.700	468.5	55.9	57.2	74.0	8513.0	131.700	344.6	55.0	344.6	74.0	0.0	7290.0	7290.0	-1223.0	-14%
8/11/2011	18:00:00	141.592	459.1	55.9	57.1	74.0	8357.5	141.592	338.5	55.0	338.5	74.0	0.0	7158.1	7158.1	-1199.4	-14%
8/11/2011	19:00:00	2.608	10.8	66.0	72.7	77.0	50.2	2.608	0.0	77.4	0.0	75.2	0.0	0.0	0.0	-50.2	
8/11/2011	20:00:00	0.086	0.0	72.2	77.5	77.8	0.0	0.086	0.0	78.5	0.0	75.3	0.0	0.0	0.0	0.0	
8/11/2011	21:00:00	0.096	0.0	73.2	77.3	77.6	0.0	0.096	0.0	78.8	0.0	74.9	0.0	0.0	0.0	0.0	
8/11/2011	22:00:00	0.096	0.0	73.4	77.2	77.2	0.0	0.096	0.0	78.8	0.0	74.6	0.0	0.0	0.0	0.0	
8/11/2011	23:00:00	0.095	0.0	73.5	76.9	76.8	0.0	0.095	0.0	78.8	0.0	74.3	0.0	0.0	0.0	0.0	
8/11/2011	0:00:00	0.092	0.0	73.7	76.8	76.5	0.0	0.093	0.0	78.7	0.0	74.0	0.0	0.0	0.0	0.0	
		1203.262					94891.8	1203.262					0.0	88407.6	88407.6	-6484.3	-6.8%

Figure 9 Spreadsheet Showing the Calculation of ERS Room Load Versus EnergyPlus Predicted Room Load

The table below presents results of such an analysis showing the sum of the sensible cooling provided to each room and percent differences (EnergyPlus versus ERS) during the daytime hours over the 7 day test period for Test 3.2 from August 9 -15 when the HVAC systems were running.

Table 4 Comparison of ERS and EnergyPlus Room Cooling Loads

Sensible Cooling Load Comparison (Btu)
ERS/Pleotint Test 3.2
August 9 - 15, 2011

Test Room	ERS (BTU)	EnergyPlus (BTU)	Difference (%)
East A	781,204	635,635	-18.6%
East B	740,067	630,577	-14.8%
South A	589,960	609,681	3.3%
South B	661,991	613,062	-7.4%
West A	731,954	602,692	-17.7%
West B	627,282	598,211	-4.6%
Internal A	613,675	579,346	-5.6%
Internal B	574,648	573,804	-0.1%

The room total sensible cooling loads predicted by EnergyPlus were usually less than those calculated during ERS testing.

The table below compares the total sensible cooling load for each room over the test period and A versus B differences for measured data and EnergyPlus results.

Table 5 Comparison of Room A Loads Versus Room B Loads

Room Sensible Cooling Load Comparison (Btu) - Room B versus Room A
ERS/Pleotint Test 3.2
August 9 - 15, 2011

	ERS - >				EnergyPlus - >			
Exposure	**Room A**	**Room B**	**Diff**	**% Diff**	**Room A**	**Room B**	**Diff**	**% Diff**
South	589,960	661,991	72,031	12.2%	609,681	613,062	3,381	0.6%
West	731,954	627,282	(104,672)	-14.3%	602,692	598,211	(4,481)	-0.7%
East	781,204	740,067	(41,138)	-5.3%	635,635	630,577	(5,058)	-0.8%
Internal	613,675	574,648	(39,027)	-6.4%	579,346	573,804	(5,542)	-1.0%
Totals	2,716,794	2,603,988	(112,806)	-4.2%	2,427,354	2,415,654	(11,700)	-0.5%

The ERS results indicated reduced cooling loads in the B test rooms compared to the A test rooms for the west, east and internal rooms while an increase in cooling load for the south room. EnergyPlus results showed similar but much smaller changes with an overall reduction of -4.2% for ERS versus an EnergyPlus reduction of -0.5%. Consult Appendix E for similar results for the other tests. Table 6 compares the ERS and EnergyPlus results for each test using the room cooling load method.

Table 6 Comparison of Results Using the Room Cooling Load Method – ERS Versus EnergyPlus

ERS Tests
Comparison of Results for Room Cooling Load Method

Test	Test Period	ERS "A" Rooms	ERS "B" Rooms	Diff	% Diff	EnergyPlus "A" Rooms	EnergyPlus "B" Rooms	Diff	% Diff
Test 2.1	May 24-31, 2011	619,027	634,462	15,435	2.5%	478,432	433,703	(44,729)	-9.3%
Test 2.2	Jun 2-12, 2011	1,174,468	1,163,704	(10,764)	-0.9%	842,854	824,106	(18,747)	-2.2%
Test 3.1	Jul 29-Aug7, 2011	3,916,626	3,751,031	(165,595)	-4.2%	3,454,315	3,414,566	(39,749)	-1.2%
Test 3.2	Aug 9-15, 2011	2,716,794	2,603,988	(112,806)	-4.2%	2,427,354	2,415,654	(11,700)	-0.5%
Test 4.1	Sep 28-Oct 4, 2011	2,587,123	2,321,016	(266,107)	-10.3%	2,313,293	2,278,150	(35,143)	-1.5%
Test 4.2	Oct 6-12, 2011	2,555,721	2,406,289	(149,432)	-5.8%	2,253,164	2,251,011	(2,153)	-0.1%
Test 5.1	Nov 23-30, 2011	1,977,827	1,895,726	(82,101)	-4.2%	2,225,416	2,258,536	33,120	1.5%
Test 5.2	Dec 2-9, 2011	1,695,754	1,591,572	(104,182)	-6.1%	2,097,096	2,078,083	(19,013)	-0.9%
Test 6.1	Feb 2-8, 2012	1,340,040	1,192,937	(147,102)	-11.0%	1,593,804	1,565,486	(28,318)	-1.8%
Test 6.2	Jan 25-31, 2012	1,657,130	1,540,163	(116,967)	-7.1%	1,946,989	1,952,507	5,517	0.3%

When comparing the above results for the Room Cooling Load Method to those for the System Cooling Load Method at the bottom of Table 3, the Room Cooling Load Method is generally showing less percent differences for both the ERS and EnergyPlus results.

7.4 Daylighting Comparison

A set of EnergyPlus simulations were performed letting the EnergyPlus daylighting control operate each room's light in order to maintain a certain light level. As was explained in Section 6, each ERS test room was equipped with automatic daylighting equipment which allowed the lights within the room to be dimmed when sunlight is available in order to maintain a 45 footcandle level at the light level sensor. In actual operation with a 45 footcandle setpoint, the lights would turn off when the light level sensor measurement was >55 FtC and would come back on when the light level fell to <40 FtC. The EnergyPlus daylighting simulation algorithms allow the user to specify only one light level to control to. The EnergyPlus daylighting simulations were set to control to the average between 40 FtC and 55 FtC or 47.5 FtC. The maximum installed lighting capacity for each room which was allowed to be on only during the occupied hours of 6 AM through 6 PM was assumed to be as follows:

Room East A	558 watts	Room East B	558 watts
Room West A	558 watts	Room West B	558 watts
Room South A	558 watts	Room South B	558 watts
Room Interior A	372 watts	Room Interior B	372 watts

The results of the EnergyPlus analysis along with the measured ERS results and projected reduction in lighting energy usage for the "B" rooms which had Pleotint windows versus the "A" rooms which had standard dark-tinted low-E windows is shown in Table 7

Table 7 Comparison of Effectiveness of Daylighting Control – ERS versus EnergyPlus

ERS Tests
Comparison of Results for Room Daylighting Control
Room Lighting Energy (W)

Test	Test Period	ERS "A" Rooms Lights (W)	ERS "B" Rooms Lights (W)	Diff Lights (W)	% Diff	EnergyPlus "A" Rooms Lights (W)	EnergyPlus "B" Rooms Lights (W)	Diff Lights (W)	% Diff
Test 2.1	May 24-31, 2011	101,839	78,789	(23,050)	-22.6%	94,713	64,319	(30,395)	-32.1%
Test 2.2	Jun 2-12, 2011	105,445	67,175	(38,269)	-36.3%	89,471	55,056	(34,415)	-38.5%
Test 3.1	Jul 29-Aug7, 2011	114,131	107,133	(6,998)	-6.1%	91,341	67,799	(23,542)	-25.8%
Test 3.2	Aug 9-15, 2011	76,429	53,978	(22,452)	-29.4%	60,655	38,412	(22,244)	-36.7%
Test 4.1	Sep 28-Oct 4, 2011	73,875	77,054	3,179	4.3%	82,409	67,889	(14,520)	-17.6%
Test 4.2	Oct 6-12, 2011	78,573	59,222	(19,351)	-24.6%	84,867	60,513	(24,354)	-28.7%
Test 5.1	Nov 23-30, 2011	108,418	97,129	(11,289)	-10.4%	148,516	132,680	(15,836)	-10.7%
Test 5.2	Dec 2-9, 2011	112,627	91,609	(21,018)	-18.7%	140,480	115,808	(24,672)	-17.6%
Test 6.1	Feb 2-8, 2012	79,226	66,597	(12,629)	-15.9%	107,247	89,358	(17,889)	-16.7%
Test 6.2	Jan 25-31, 2012	85,305	65,856	(19,449)	-22.8%	114,281	92,085	(22,196)	-19.4%
Totals		935,868	764,542	(171,326)	-18.3%	1,013,980	783,918	(230,062)	-22.7%

Overall results are very similar with EnergyPlus predicting a somewhat larger reduction than the ERS data.

8. Conclusions

An EnergyPlus model of the Iowa Energy Center Energy Resource Station (ERS) in Ankeny, Iowa was created in order to simulate tests that were conducted in monitored test rooms where two types of Pleotint thermochromic windows (Azuria and Clear) performance were compared to the performance of standard dark-tinted low-E windows. The ERS test results of 10 different tests conducted over periods of 7 to 11 days duration provided measured data to compare Pleotint Azuria windows and Pleotint Clear windows versus the baseline standard dark-tinted windows. EnergyPlus simulations were performed for each test using recorded onsite weather data and schedules of internal loads. The ERS measured results for each test were then compared to EnergyPlus results.

Based on several types of comparisons (Window Performance Method, System Cooling Load Method and Room Cooling Load Method) of EnergyPlus results versus ERS measured test data, the analysis of results indicated the following

A) When comparing the ERS measured temperatures of the air gap between the window panes versus the EnergyPlus predicted temperatures of the outer and inner surfaces of the windows, the shapes of the temperatures curves over a 24-hour period were very similar although there was a time shift of 1-2 hours in some instances. As expected, the ERS temperature of the window gap usually fell in between the outer and inner window surface temperatures predicted by EnergyPlus.

B) For the System Cooling Load Method, when comparing the total sensible cooling load on the cooling coil for System A which supplied cooling to 4 test rooms with standard dark-tinted windows versus the total sensible cooling load on the cooling coil of System B which provided cooling to 4 similar test rooms that had **Pleotint Azuria** windows (Tests 2.1, 3.1, 4.1, 5.1 and 6.1), ERS was predicting a reduction in cooling coil sensible load of from 7.2% to 13.5% while EnergyPlus predicted reductions of from 0.7% to 9.9%.

C) For the System Cooling Load Method, when comparing the total sensible cooling load on the cooling coil for System A which supplied cooling to 4 test rooms with standard dark-tinted windows versus the total sensible cooling load on the cooling coil of System B which provided cooling to 4 similar test rooms that had **Pleotint Clear** windows (Tests 2.2, 3.2, 4.2, 5.2 and 6.2), ERS predicted a reduction in cooling coil sensible load of from 7.1% to 13.9% while EnergyPlus predicted a slight increase of 0.2% to a reduction of 6.6%.

D) For the Room Cooling Load Method, the room sensible cooling loads using ERS test data showed reductions in the "B" Rooms compared to the "A" Rooms of from 0.9% to 11.0% except for Test 2.1 which showed an increase in room cooling load of 2.5%. EnergyPlus results showed a reduction in cooling load in the "B" Rooms versus the "A" Rooms at a somewhat lower level of from 0.1% to 9.3% except for Tests 5.1 and 6.2 which showed an increases in room cooling loads up to 1.5%.

E) The EnergyPlus room cooling loads calculated using the System Cooling Load Method were generally 15% to 20% less on average than those calculated using the ERS test data.

F) EnergyPlus simulation of daylighting control with the control point set to 47.5 FtC predicted that the reduction in lighting energy consumption for "B" rooms with Pleotint windows versus "A" rooms with standard dark-tinted low-E windows ranged from 10.7% to 38.5% with an overall average for all tests being 22.7%. ERS test results indicated an overall average reduction for all test of 18.3%.

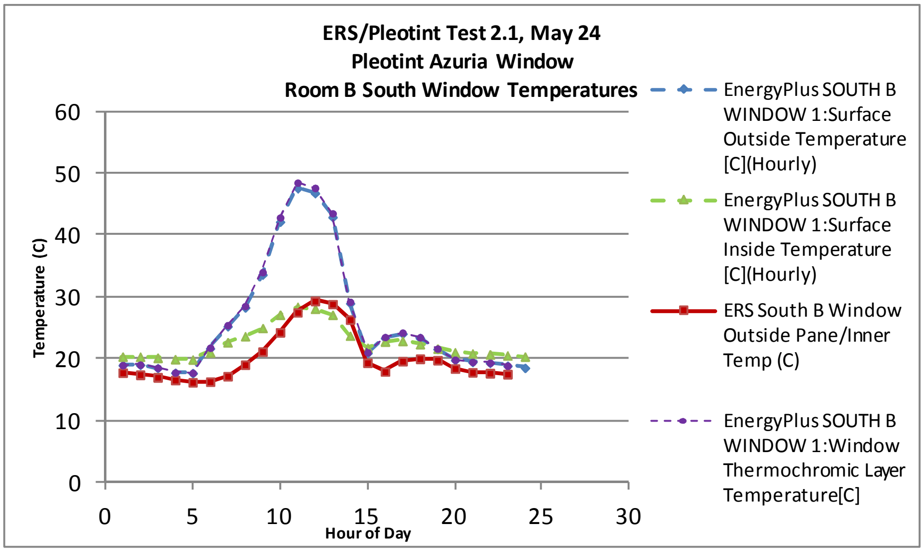
Appendix A

EnergyPlus IDF Description of Standard Low-E High Performance Dark-Tinted Window Used in Room A

```
!----------------------------------------------------
!     Window Glass Layers
!----------------------------------------------------

WindowMaterial:Glazing,
Glass_30005_LayerAvg,           !- Layer name : VE348.VIR-Modified to VE355
SpectralAverage,                !- Optical Data Type
,                               !- Spectral Data name
0.005660,                       !- Thickness
0.171000,                       !- Solar Transmittance
1.100000e-001,                  !- Solar Front Reflectance
2.300000e-001,                  !- Solar Back Reflectance
0.260000,                       !- Visible Transmittance
0.073280,                       !-Visible Front Reflectance
0.030610,                       !-Visible Back reflectance
0.000000,                       !- IR Transmittance
0.840000,                       !-Front Emissivity
0.088879,                       !-Back Emissivity
1.000000;                       !-Conductivity

WindowMaterial:Glazing,
Glass_103_LayerAvg,             !- Layer name : CLEAR_6.DAT
SpectralAverage,                !- Optical Data Type
,                               !- Spectral Data name
0.005715,                       !- Thickness
0.770675,                       !- Solar Transmittance
6.997562e-002,                  !- Solar Front Reflectance
7.023712e-002,                  !- Solar Back Reflectance
0.883647,                       !- Visible Transmittance
0.080395,                       !-Visible Front Reflectance
0.080395,                       !-Visible Back reflectance
0.000000,                       !- IR Transmittance
0.840000,                       !-Front Emissivity
0.840000,                       !-Back Emissivity
1.000000;                       !-Conductivity

!------------------------------------------------------------------
!      Window Gap Layers
!------------------------------------------------------------------

WindowMaterial:Gas,
Gap_1_W_0_0132,                 !- gap name - Air
Air,                            !- type
0.                              !- thickness

!----------------------------------------------------
!     Window Construction
!----------------------------------------------------

CONSTRUCTION,
GlzSys_10,                      !- Glazing System name: MJW Viracon Double Low-e Air VE-55 #2
Glass_30005_LayerAvg,           !- glass name : VE348.VIR-Modified to VE355
Gap_1_W_0_0132,                 !- gap name - Air
Glass_103_LayerAvg;             !- glass name : CLEAR_6.DAT
```

Appendix B

Charts Comparing Window Outer Pane Surface Temperatures - EnergyPlus versus ERS Results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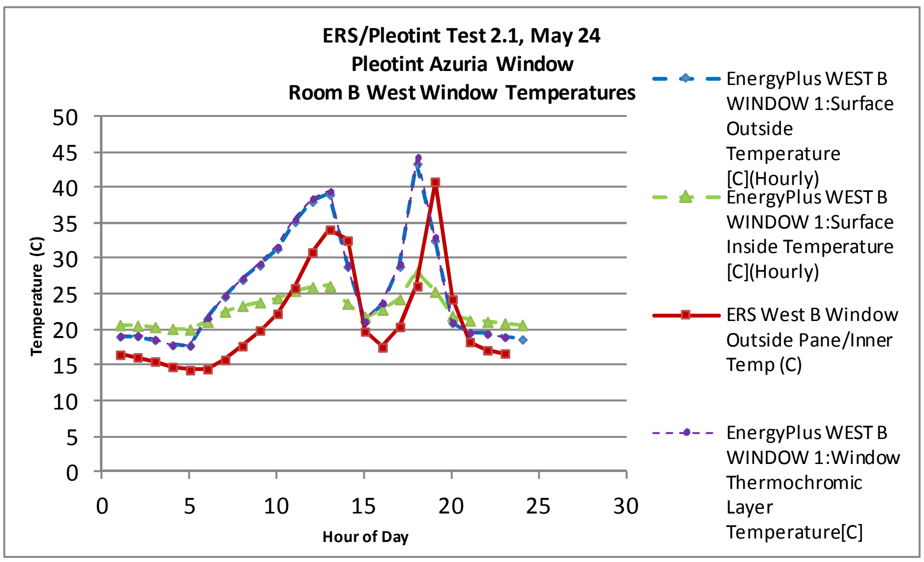
Pleotint Azuria Window
Room B South Window Temperatures
Temperature (C)
Hour of Day
EnergyPlus SOUTH B WINDOW 1:Surface Outside Temperature [C](Hourly)
EnergyPlus SOUTH B WINDOW 1:Surface Inside Temperature [C](Hourly)
ERS South B Window Outside Pane/Inner Temp (C)
EnergyPlus SOUTH B WINDOW 1:Window Thermochromic Layer Temperature[C]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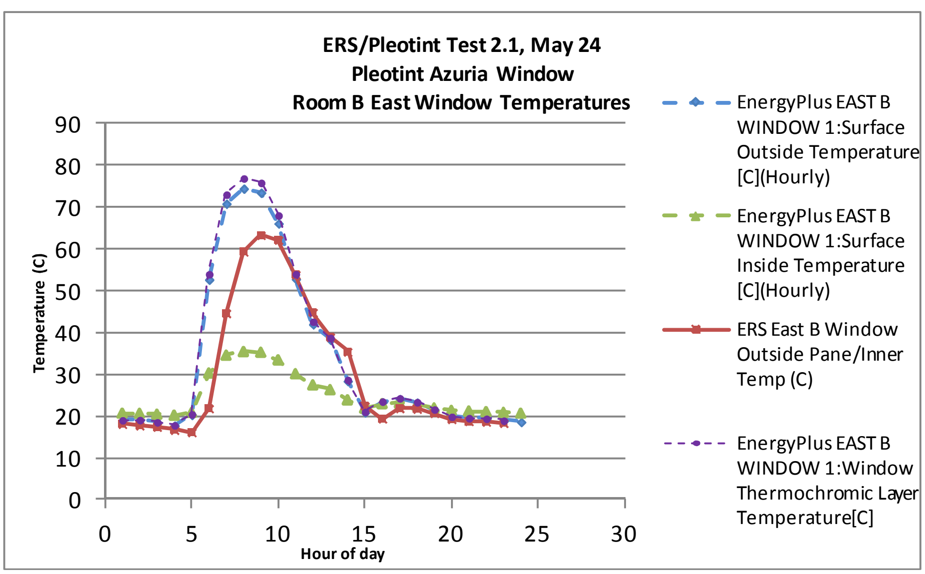
Pleotint Azuria Window
Room B West Window Temperatures
Temperature (C)
Hour of Day
EnergyPlus WEST B WINDOW 1:Surface Outside Temperature [C](Hourly)
EnergyPlus WEST B WINDOW 1:Surface Inside Temperature [C](Hourly)
ERS West B Window Outside Pane/Inner Temp (C)
EnergyPlus WEST B WINDOW 1:Window Thermochromic Layer Temperature[C]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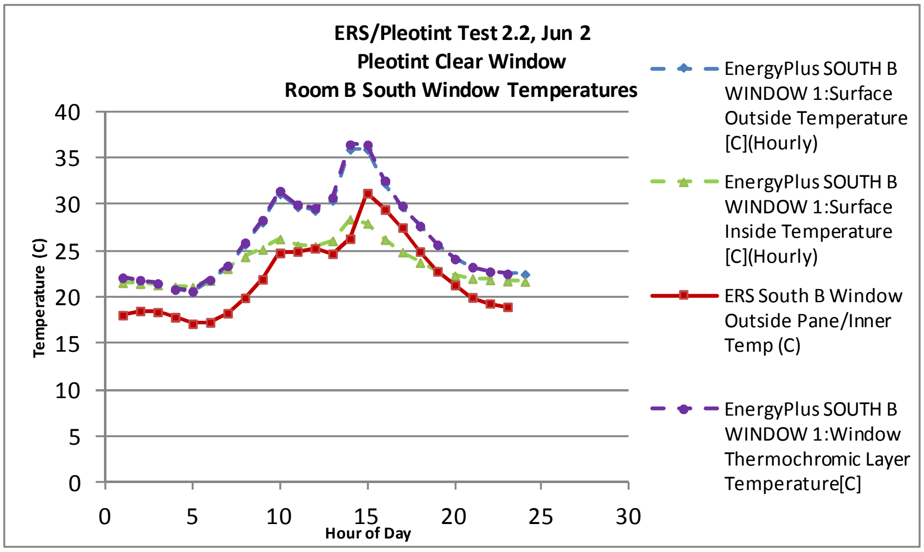
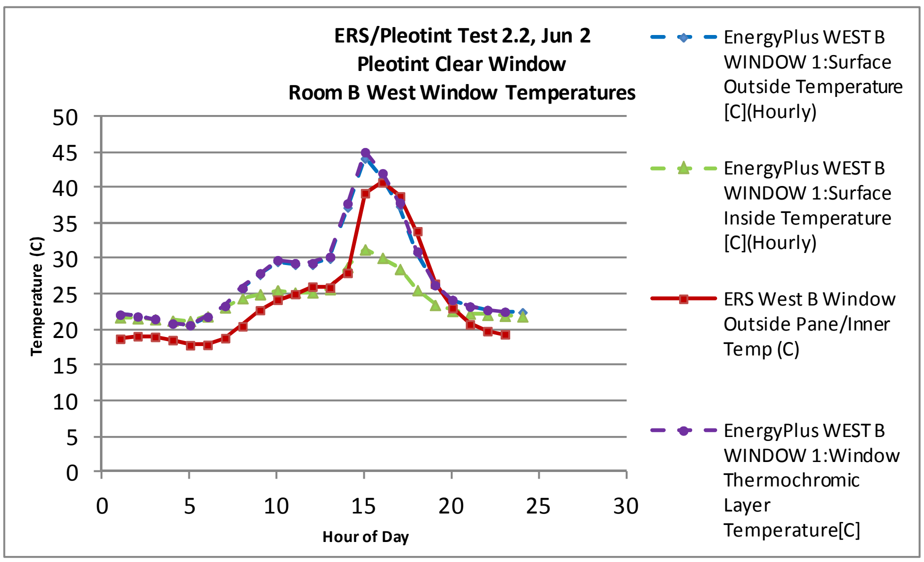
Pleotint Azuria Window
Room B East Window Temperatures
Temperature (C)
Hour of day
EnergyPlus EAST B WINDOW 1:Surface Outside Temperature [C](Hourly)
EnergyPlus EAST B WINDOW 1:Surface Inside Temperature [C](Hourly)
ERS East B Window Outside Pane/Inner Temp (C)
EnergyPlus EAST B WINDOW 1:Window Thermochromic Layer Temperature[C]


ERS/Pleotint Test 2.2, Jun 2
Pleotint Clear Window
Room B South Window Temperatures
Temperature (C)
Hour of Day
EnergyPlus SOUTH B WINDOW 1:Surface Outside Temperature [C](Hourly)
EnergyPlus SOUTH B WINDOW 1:Surface Inside Temperature [C](Hourly)
ERS South B Window Outside Pane/Inner Temp (C)
EnergyPlus SOUTH B WINDOW 1:Window Thermochromic Layer Temperature[C]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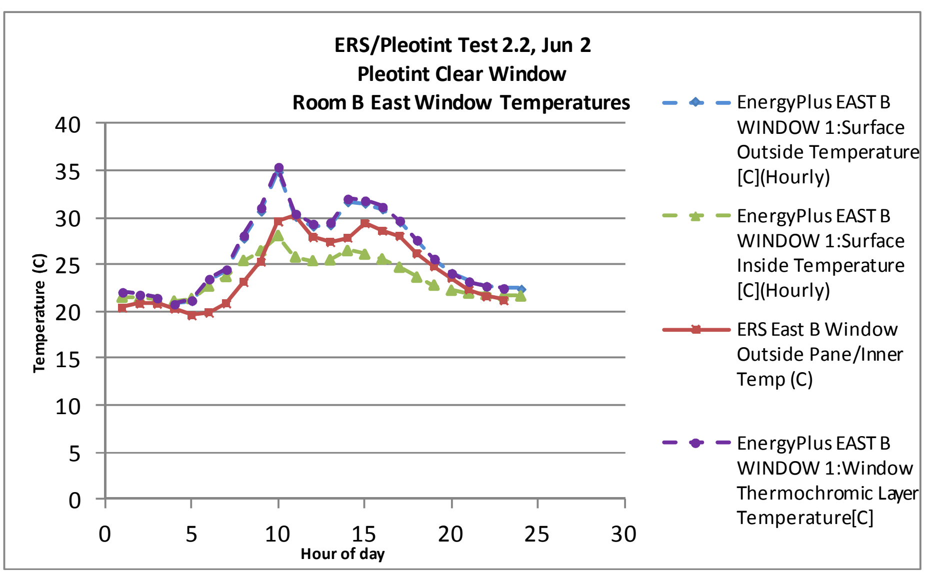
Pleotint Clear Window
Room B West Window Temperatures
Temperature (C)
Hour of Day
EnergyPlus WEST B WINDOW 1:Surface Outside Temperature [C](Hourly)
EnergyPlus WEST B WINDOW 1:Surface Inside Temperature [C](Hourly)
ERS West B Window Outside Pane/Inner Temp (C)
EnergyPlus WEST B WINDOW 1:Window Thermochromic Layer Temperature[C]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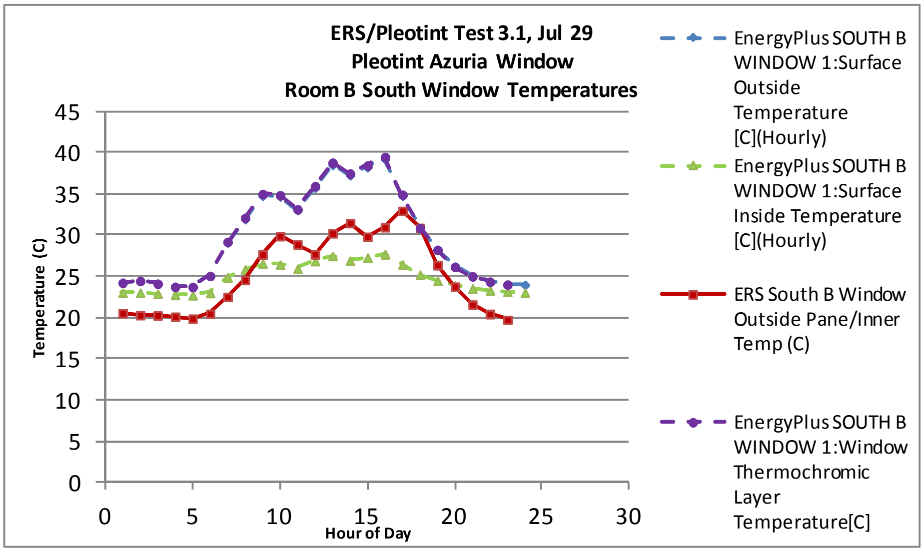
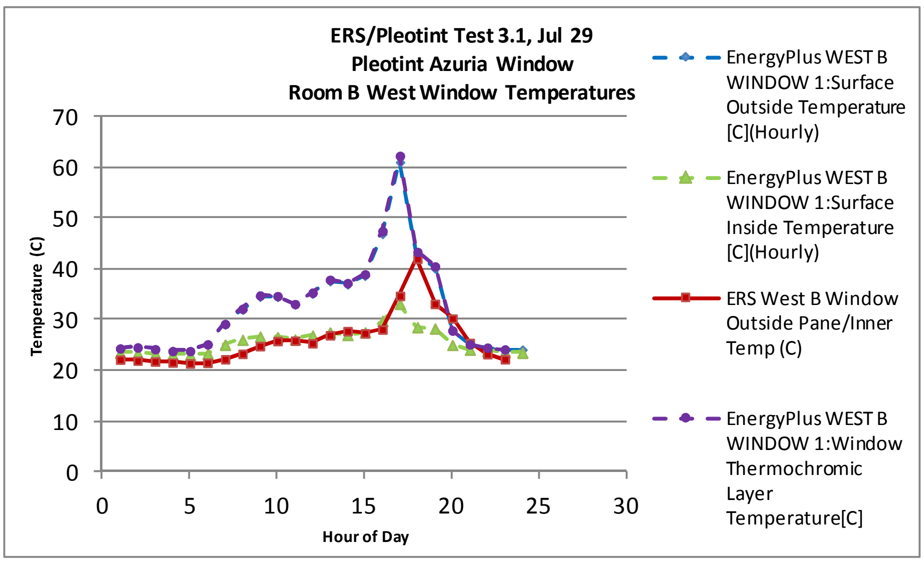
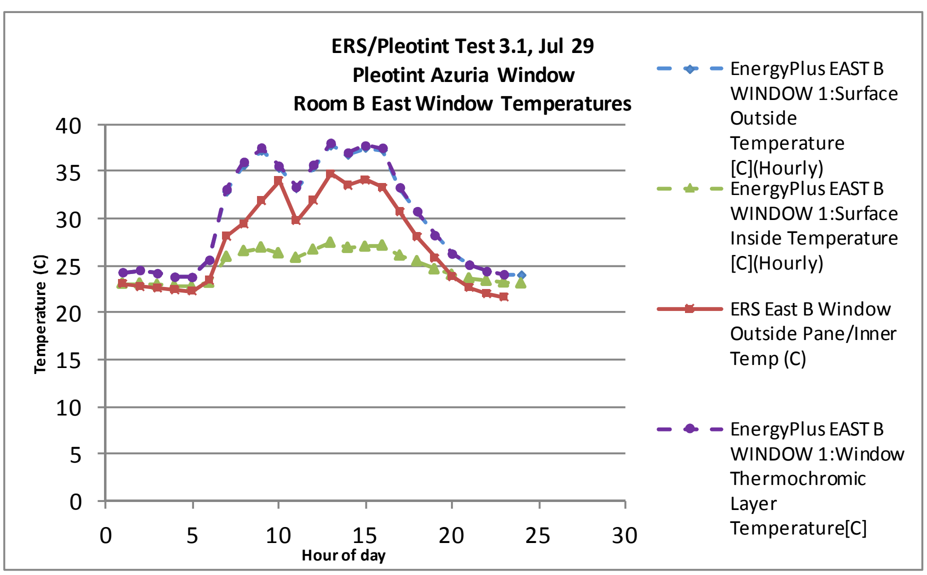
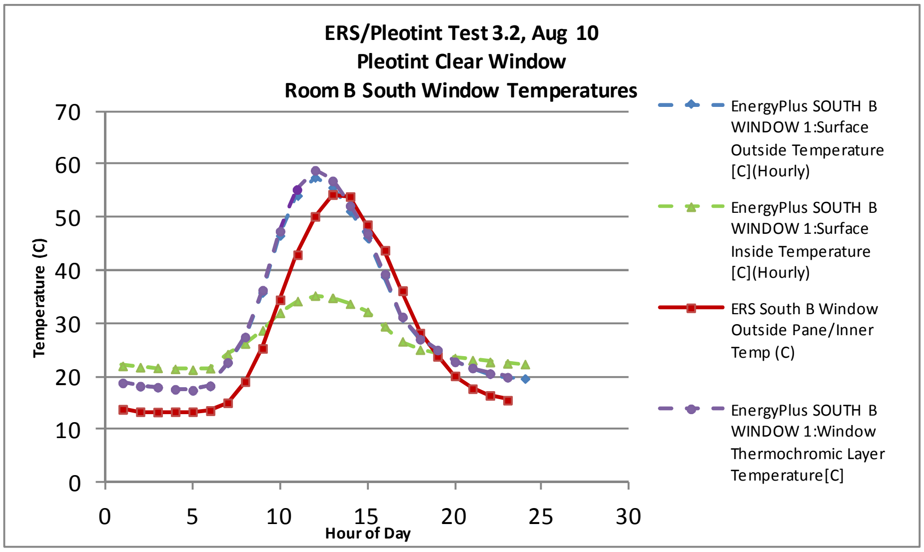
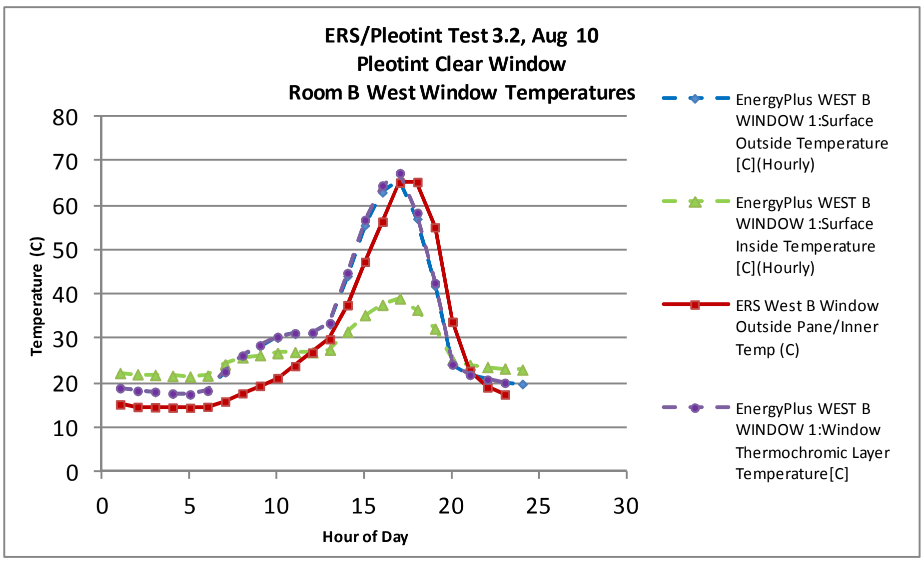
Pleotint Clear Window
Room B East Window Temperatures
Temperature (C)
Hour of day
EnergyPlus EAST B WINDOW 1:Surface Outside Temperature [C](Hourly)
EnergyPlus EAST B WINDOW 1:Surface Inside Temperature [C](Hourly)
ERS East B Window Outside Pane/Inner Temp (C)
EnergyPlus EAST B WINDOW 1:Window Thermochromic Layer Temperature[C]

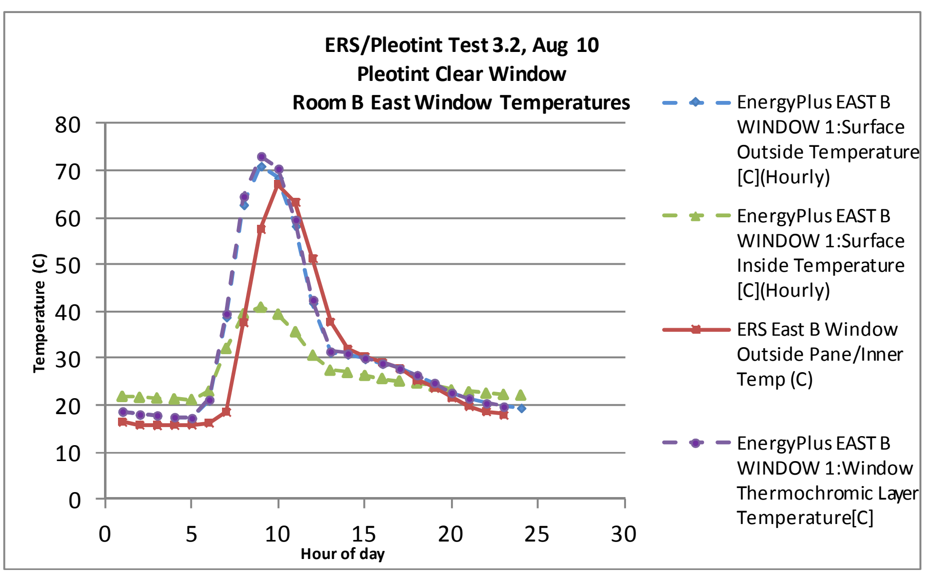

ERS/Pleotint Test 3.1, Jul 29
Pleotint Azuria Window
Room B South Window Temperatures
Temperature (C)
45
40
35
30
25
20
15
10
5
0
0
5
10
15
20
25
30
Hour of Day
EnergyPlus SOUTH B WINDOW 1:Surface Outside Temperature [C](Hourly)
EnergyPlus SOUTH B WINDOW 1:Surface Inside Temperature [C](Hourly)
ERS South B Window Outside Pane/Inner Temp (C)
EnergyPlus SOUTH B WINDOW 1:Window Thermochromic Layer Temperature[C]

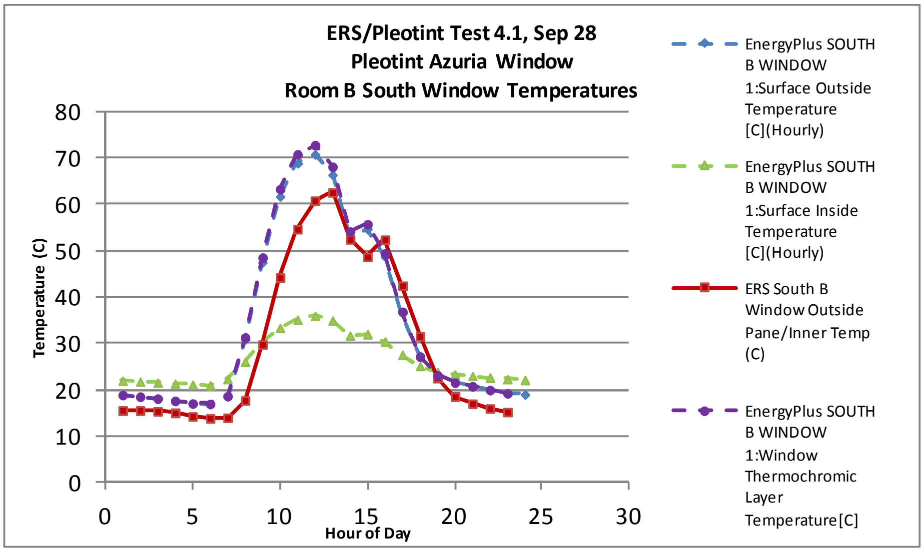

ERS/Pleotint Test 3.1, Jul 29
Pleotint Azuria Window
Room B West Window Temperatures
Temperature (C)
70
60
50
40
30
20
10
0
0
5
10
15
20
25
30
Hour of Day
EnergyPlus WEST B WINDOW 1:Surface Outside Temperature [C](Hourly)
EnergyPlus WEST B WINDOW 1:Surface Inside Temperature [C](Hourly)
ERS West B Window Outside Pane/Inner Temp (C)
EnergyPlus WEST B WINDOW 1:Window Thermochromic Layer Temperature[C]

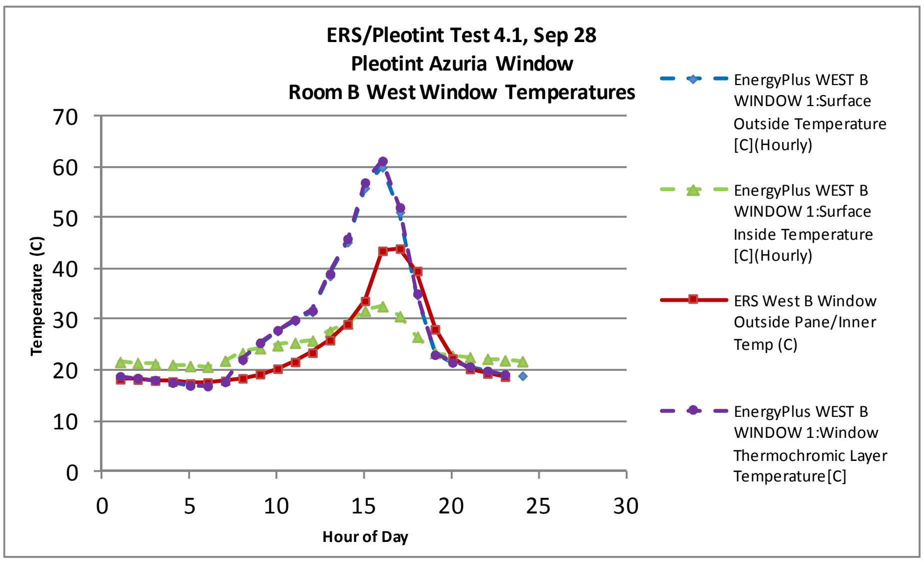

ERS/Pleotint Test 3.1, Jul 29
Pleotint Azuria Window
Room B East Window Temperatures
Temperature (C)
40
35
30
25
20
15
10
5
0
0
5
10
15
20
25
30
Hour of day
EnergyPlus EAST B WINDOW 1:Surface Outside Temperature [C](Hourly)
EnergyPlus EAST B WINDOW 1:Surface Inside Temperature [C](Hourly)
ERS East B Window Outside Pane/Inner Temp (C)
EnergyPlus EAST B WINDOW 1:Window Thermochromic Layer Temperature[C]

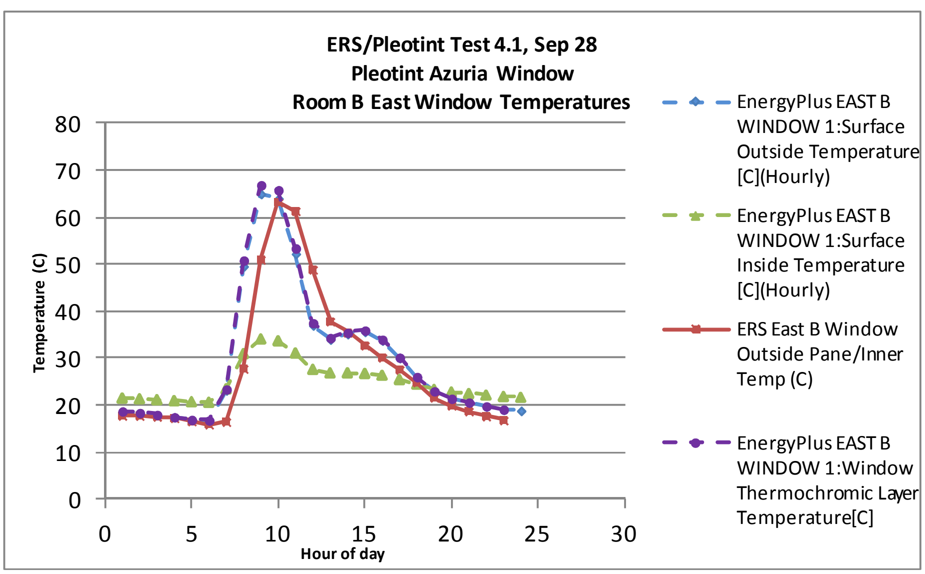

ERS/Pleotint Test 3.2, Aug 10
Pleotint Clear Window
Room B South Window Temperatures
Temperature (C)
Hour of Day
EnergyPlus SOUTH B WINDOW 1:Surface Outside Temperature [C](Hourly)
EnergyPlus SOUTH B WINDOW 1:Surface Inside Temperature [C](Hourly)
ERS South B Window Outside Pane/Inner Temp (C)
EnergyPlus SOUTH B WINDOW 1:Window Thermochromic Layer Temperature[C]

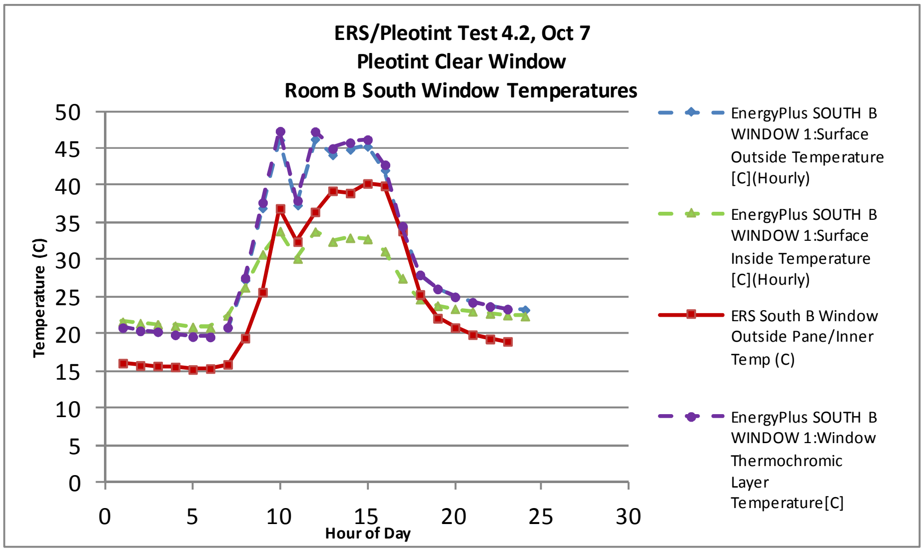

ERS/Pleotint Test 3.2, Aug 10
Pleotint Clear Window
Room B West Window Temperatures
Temperature (C)
Hour of Day
EnergyPlus WEST B WINDOW 1:Surface Outside Temperature [C](Hourly)
EnergyPlus WEST B WINDOW 1:Surface Inside Temperature [C](Hourly)
ERS West B Window Outside Pane/Inner Temp (C)
EnergyPlus WEST B WINDOW 1:Window Thermochromic Layer Temperature[C]

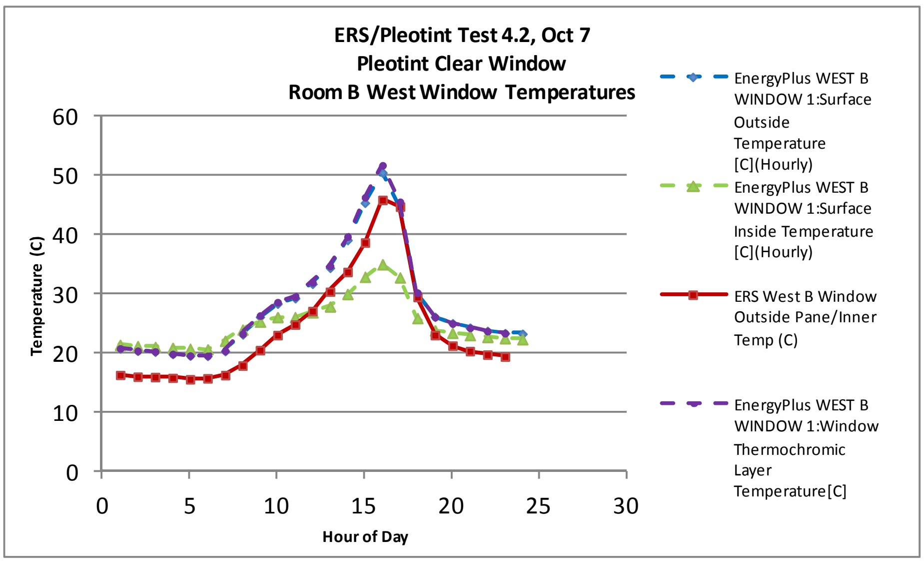

ERS/Pleotint Test 3.2, Aug 10
Pleotint Clear Window
Room B East Window Temperatures
Temperature (C)
Hour of day
EnergyPlus EAST B WINDOW 1:Surface Outside Temperature [C](Hourly)
EnergyPlus EAST B WINDOW 1:Surface Inside Temperature [C](Hourly)
ERS East B Window Outside Pane/Inner Temp (C)
EnergyPlus EAST B WINDOW 1:Window Thermochromic Layer Temperature[C]

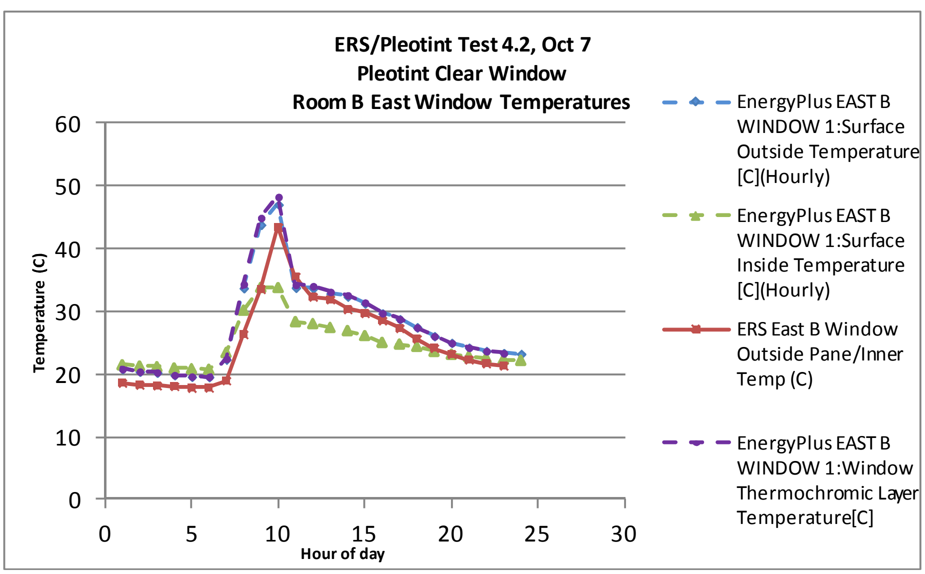

ERS/Pleotint Test 4.1, Sep 28
Pleotint Azuria Window
Room B South Window Temperatures
Temperature (C)
Hour of Day
EnergyPlus SOUTH B WINDOW 1:Surface Outside Temperature [C](Hourly)
EnergyPlus SOUTH B WINDOW 1:Surface Inside Temperature [C](Hourly)
ERS South B Window Outside Pane/Inner Temp (C)
EnergyPlus SOUTH B WINDOW 1:Window Thermochromic Layer Temperature[C]

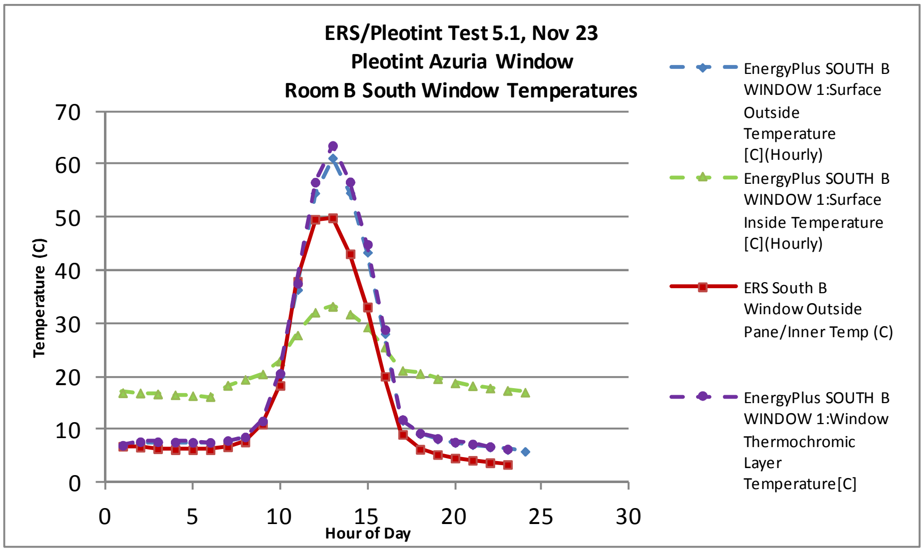

ERS/Pleotint Test 4.1, Sep 28
Pleotint Azuria Window
Room B West Window Temperatures
Temperature (C)
Hour of Day
EnergyPlus WEST B WINDOW 1:Surface Outside Temperature [C](Hourly)
EnergyPlus WEST B WINDOW 1:Surface Inside Temperature [C](Hourly)
ERS West B Window Outside Pane/Inner Temp (C)
EnergyPlus WEST B WINDOW 1:Window Thermochromic Layer Temperature[C]

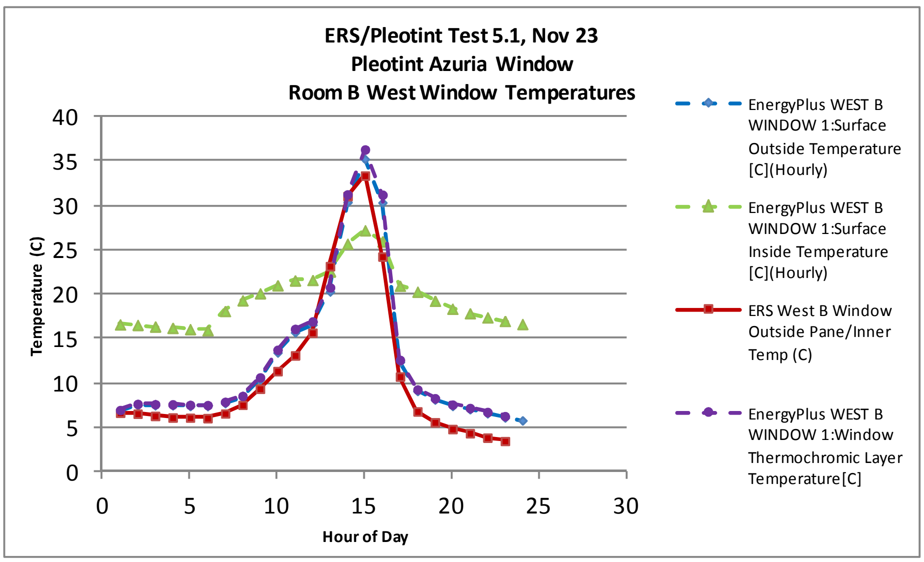

ERS/Pleotint Test 4.1, Sep 28
Pleotint Azuria Window
Room B East Window Temperatures
Temperature (C)
Hour of day
EnergyPlus EAST B WINDOW 1:Surface Outside Temperature [C](Hourly)
EnergyPlus EAST B WINDOW 1:Surface Inside Temperature [C](Hourly)
ERS East B Window Outside Pane/Inner Temp (C)
EnergyPlus EAST B WINDOW 1:Window Thermochromic Layer Temperature[C]


ERS/Pleotint Test 4.2, Oct 7
Pleotint Clear Window
Room B South Window Temperatures
Temperature (C)
Hour of Day
EnergyPlus SOUTH B WINDOW 1:Surface Outside Temperature [C](Hourly)
EnergyPlus SOUTH B WINDOW 1:Surface Inside Temperature [C](Hourly)
ERS South B Window Outside Pane/Inner Temp (C)
EnergyPlus SOUTH B WINDOW 1:Window Thermochromic Layer Temperature[C]


ERS/Pleotint Test 4.2, Oct 7
Pleotint Clear Window
Room B West Window Temperatures
Temperature (C)
Hour of Day
EnergyPlus WEST B WINDOW 1:Surface Outside Temperature [C](Hourly)
EnergyPlus WEST B WINDOW 1:Surface Inside Temperature [C](Hourly)
ERS West B Window Outside Pane/Inner Temp (C)
EnergyPlus WEST B WINDOW 1:Window Thermochromic Layer Temperature[C]


ERS/Pleotint Test 4.2, Oct 7
Pleotint Clear Window
Room B East Window Temperatures
Temperature (C)
Hour of day
EnergyPlus EAST B WINDOW 1:Surface Outside Temperature [C](Hourly)
EnergyPlus EAST B WINDOW 1:Surface Inside Temperature [C](Hourly)
ERS East B Window Outside Pane/Inner Temp (C)
EnergyPlus EAST B WINDOW 1:Window Thermochromic Layer Temperature[C]


ERS/Pleotint Test 5.1, Nov 23
Pleotint Azuria Window
Room B South Window Temperatures
Temperature (C)
Hour of Day
EnergyPlus SOUTH B WINDOW 1:Surface Outside Temperature [C](Hourly)
EnergyPlus SOUTH B WINDOW 1:Surface Inside Temperature [C](Hourly)
ERS South B Window Outside Pane/Inner Temp (C)
EnergyPlus SOUTH B WINDOW 1:Window Thermochromic Layer Temperature[C]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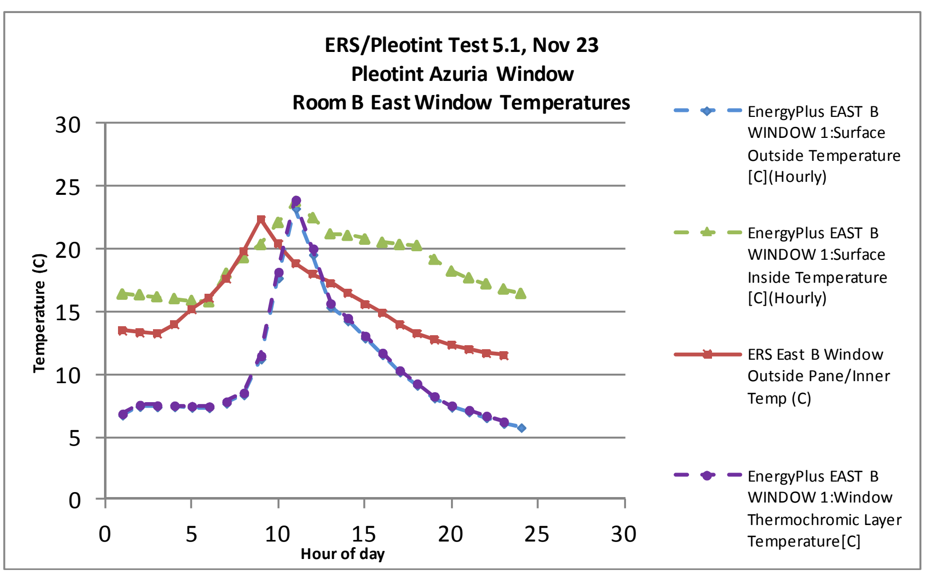
Pleotint Azuria Window
Room B West Window Temperatures
Temperature (C)
Hour of Day
EnergyPlus WEST B WINDOW 1:Surface Outside Temperature [C](Hourly)
EnergyPlus WEST B WINDOW 1:Surface Inside Temperature [C](Hourly)
ERS West B Window Outside Pane/Inner Temp (C)
EnergyPlus WEST B WINDOW 1:Window Thermochromic Layer Temperature[C]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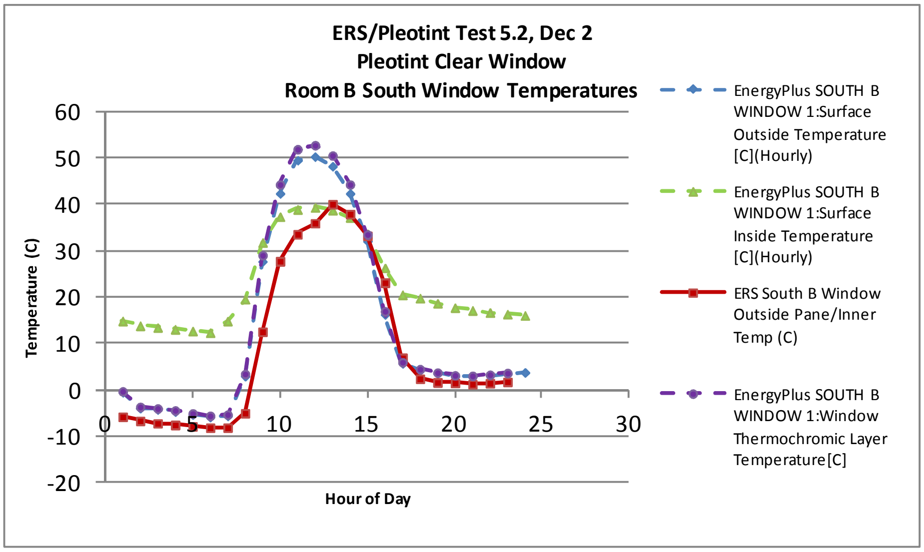
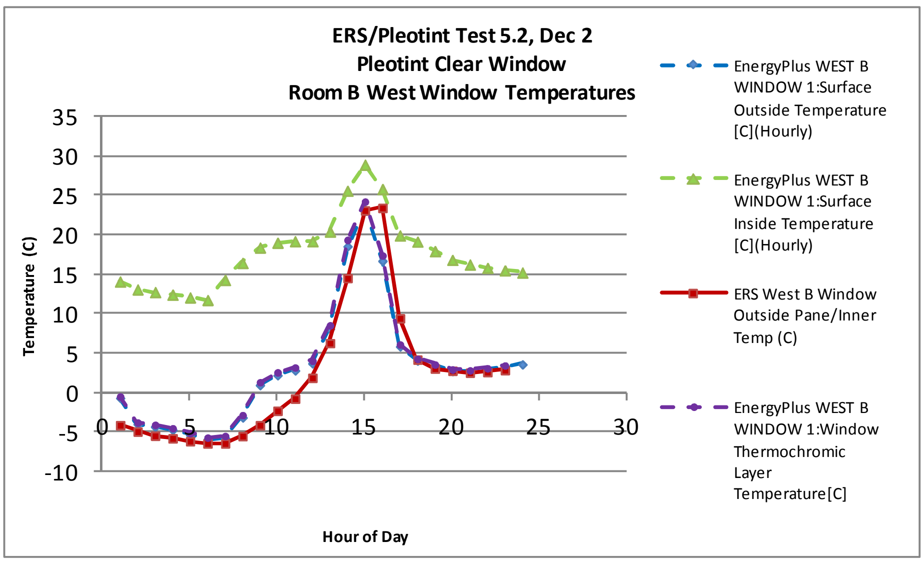
Pleotint Azuria Window
Room B East Window Temperatures
Temperature (C)
Hour of day
EnergyPlus EAST B WINDOW 1:Surface Outside Temperature [C](Hourly)
EnergyPlus EAST B WINDOW 1:Surface Inside Temperature [C](Hourly)
ERS East B Window Outside Pane/Inner Temp (C)
EnergyPlus EAST B WINDOW 1:Window Thermochromic Layer Temperature[C]


ERS/Pleotint Test 5.2, Dec 2
Pleotint Clear Window
Room B South Window Temperatures
Temperature (C)
Hour of Day
60
50
40
30
20
10
0
-10
-20
0
5
10
15
20
25
30
EnergyPlus SOUTH B WINDOW 1:Surface Outside Temperature [C](Hourly)
EnergyPlus SOUTH B WINDOW 1:Surface Inside Temperature [C](Hourly)
ERS South B Window Outside Pane/Inner Temp (C)
EnergyPlus SOUTH B WINDOW 1:Window Thermochromic Layer Temperature[C]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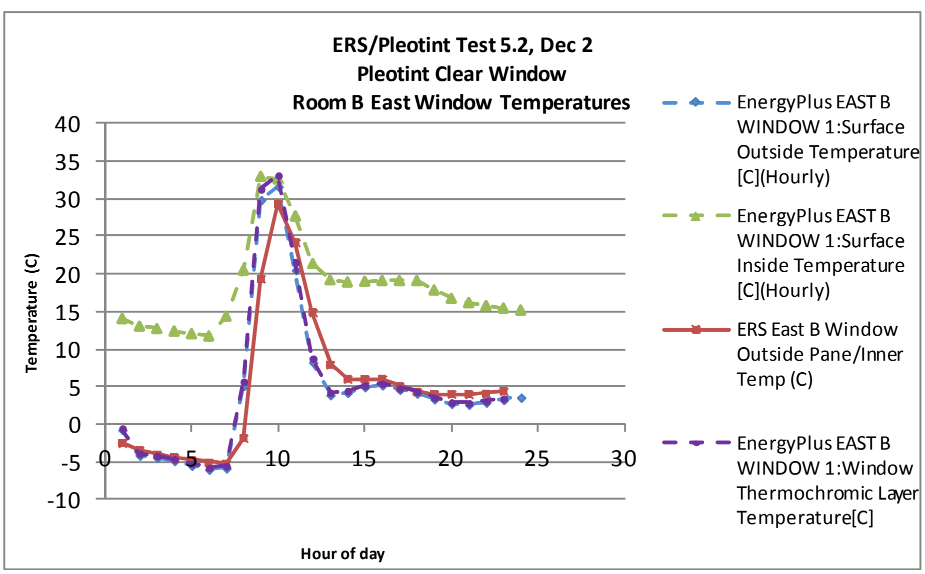
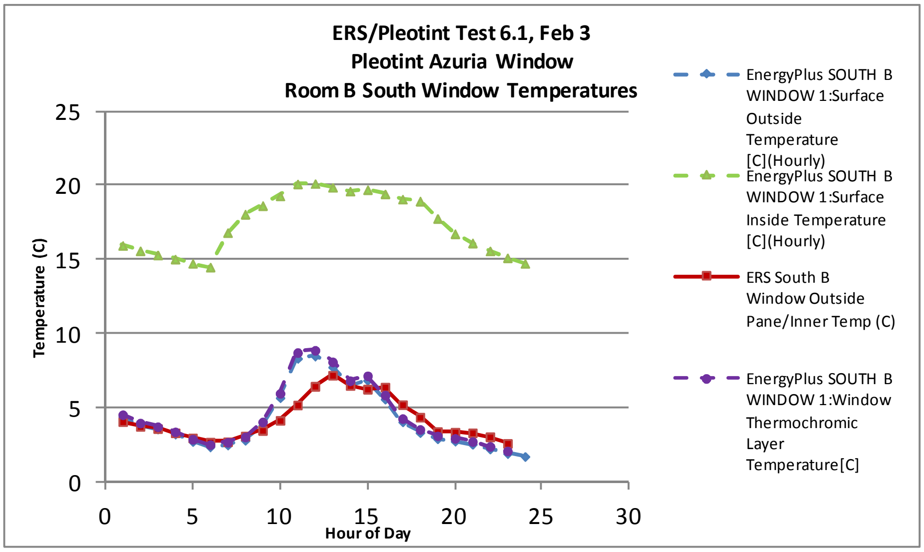
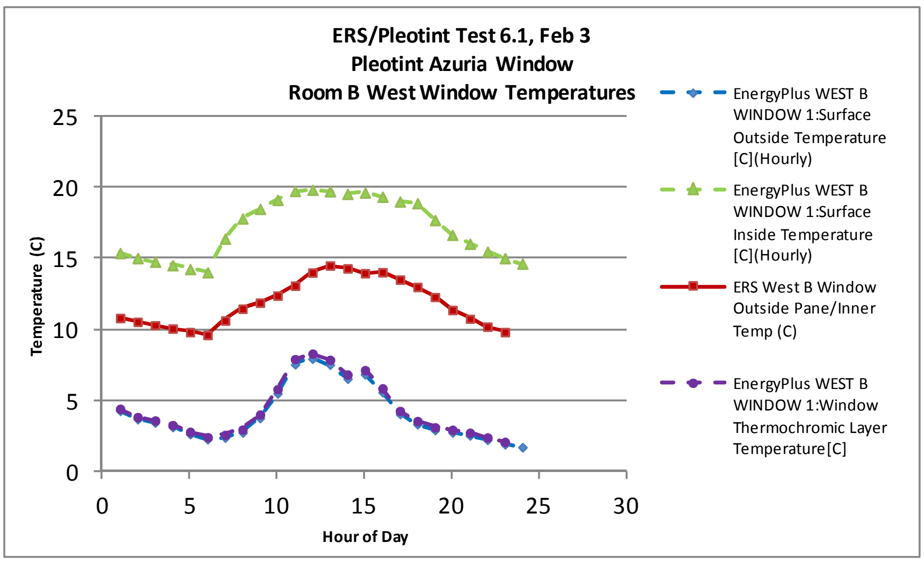
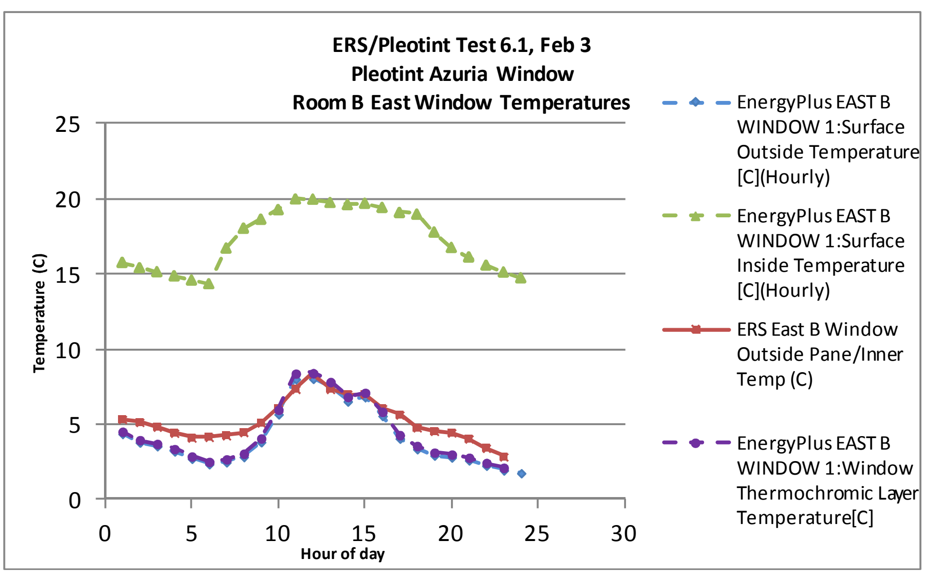
Pleotint Clear Window
Room B West Window Temperatures
Temperature (C)
Hour of Day
35
30
25
20
15
10
5
0
-5
-10
0
5
10
15
20
25
30
EnergyPlus WEST B WINDOW 1:Surface Outside Temperature [C](Hourly)
EnergyPlus WEST B WINDOW 1:Surface Inside Temperature [C](Hourly)
ERS West B Window Outside Pane/Inner Temp (C)
EnergyPlus WEST B WINDOW 1:Window Thermochromic Layer Temperature[C]


ERS/Pleotint Test 5.2, Dec 2
Pleotint Clear Window
Room B East Window Temperatures
Temperature (C)
Hour of day
40
35
30
25
20
15
10
5
0
-5
-10
0
5
10
15
20
25
30
EnergyPlus EAST B WINDOW 1:Surface Outside Temperature [C](Hourly)
EnergyPlus EAST B WINDOW 1:Surface Inside Temperature [C](Hourly)
ERS East B Window Outside Pane/Inner Temp (C)
EnergyPlus EAST B WINDOW 1:Window Thermochromic Layer Temperature[C]


ERS/Pleotint Test 6.1, Feb 3
Pleotint Azuria Window
Room B South Window Temperatures
Temperature (C)
Hour of Day
0
5
10
15
20
25
30
EnergyPlus SOUTH B WINDOW 1:Surface Outside Temperature [C](Hourly)
EnergyPlus SOUTH B WINDOW 1:Surface Inside Temperature [C](Hourly)
ERS South B Window Outside Pane/Inner Temp (C)
EnergyPlus SOUTH B WINDOW 1:Window Thermochromic Layer Temperature[C]


ERS/Pleotint Test 6.1, Feb 3
Pleotint Azuria Window
Room B West Window Temperatures
Temperature (C)
Hour of Day
0
5
10
15
20
25
30
EnergyPlus WEST B WINDOW 1:Surface Outside Temperature [C](Hourly)
EnergyPlus WEST B WINDOW 1:Surface Inside Temperature [C](Hourly)
ERS West B Window Outside Pane/Inner Temp (C)
EnergyPlus WEST B WINDOW 1:Window Thermochromic Layer Temperature[C]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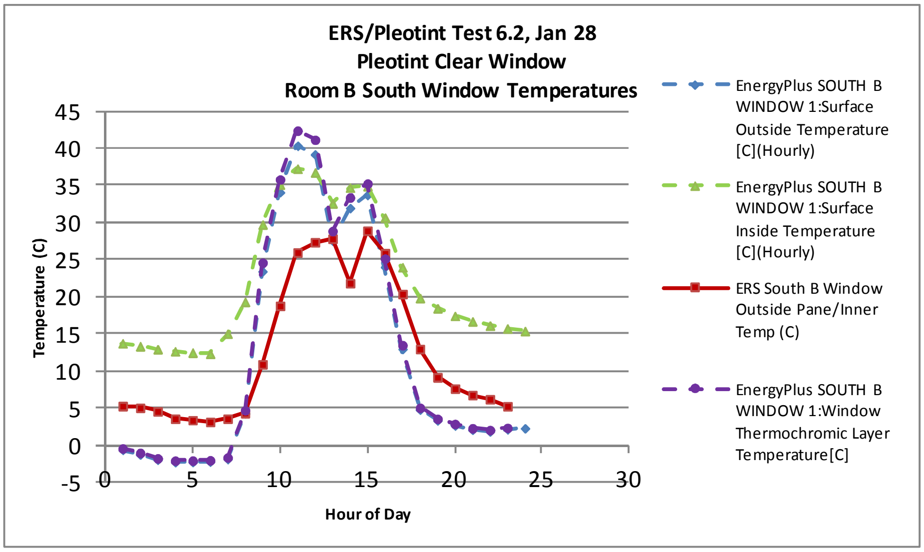
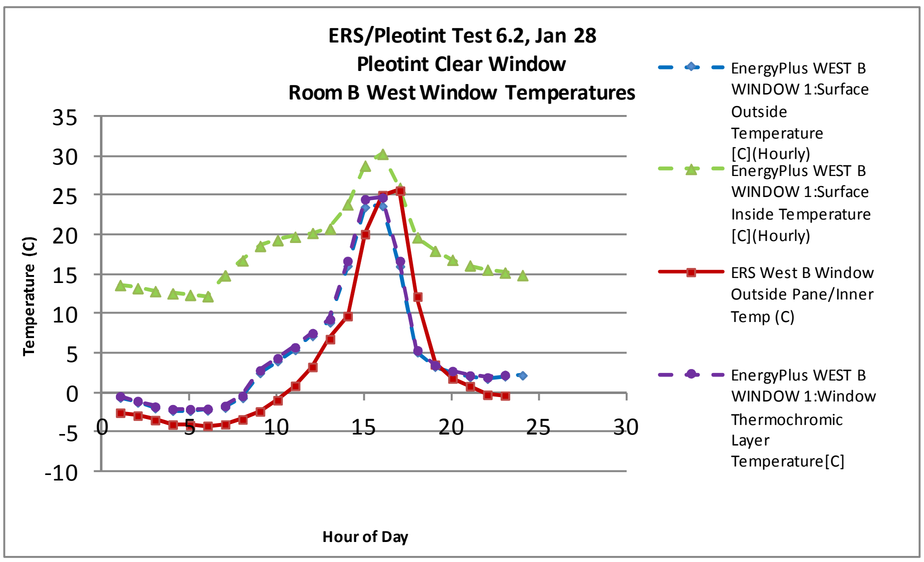
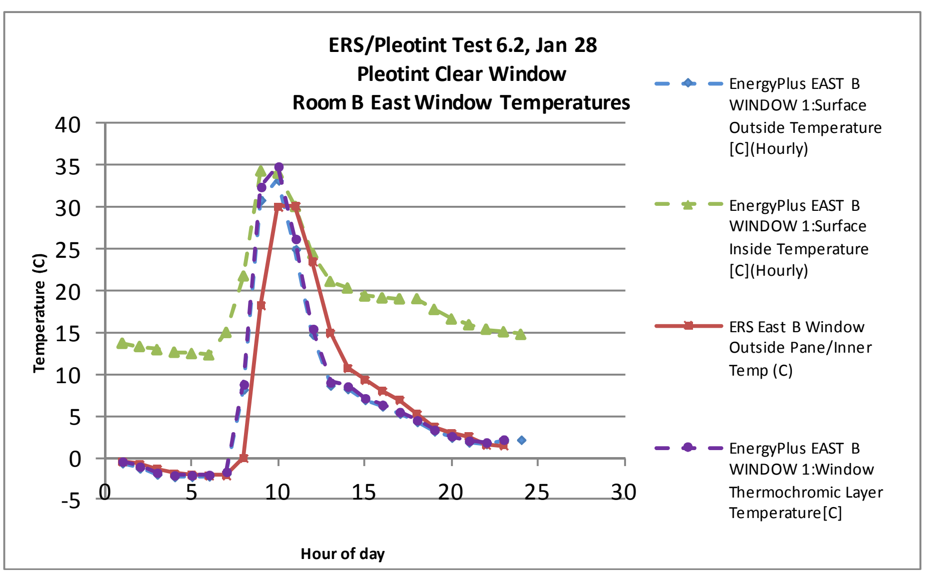
Pleotint Azuria Window
Room B East Window Temperatures
Temperature (C)
Hour of day
0
5
10
15
20
25
30
EnergyPlus EAST B WINDOW 1:Surface Outside Temperature [C](Hourly)
EnergyPlus EAST B WINDOW 1:Surface Inside Temperature [C](Hourly)
ERS East B Window Outside Pane/Inner Temp (C)
EnergyPlus EAST B WINDOW 1:Window Thermochromic Layer Temperature[C]

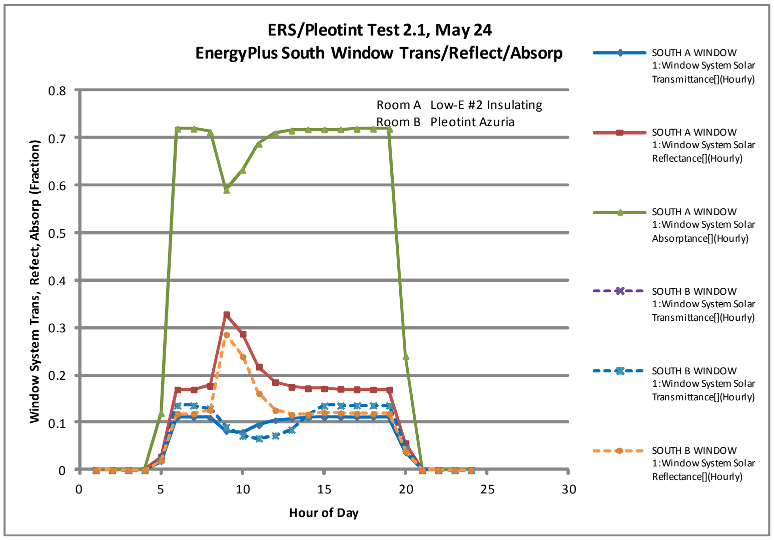

ERS/Pleotint Test 6.2, Jan 28
Pleotint Clear Window
Room B South Window Temperatures
Temperature (C)
Hour of Day
EnergyPlus SOUTH B WINDOW 1:Surface Outside Temperature [C](Hourly)
EnergyPlus SOUTH B WINDOW 1:Surface Inside Temperature [C](Hourly)
ERS South B Window Outside Pane/Inner Temp (C)
EnergyPlus SOUTH B WINDOW 1:Window Thermochromic Layer Temperature[C]


ERS/Pleotint Test 6.2, Jan 28
Pleotint Clear Window
Room B West Window Temperatures
Temperature (C)
Hour of Day
EnergyPlus WEST B WINDOW 1:Surface Outside Temperature [C](Hourly)
EnergyPlus WEST B WINDOW 1:Surface Inside Temperature [C](Hourly)
ERS West B Window Outside Pane/Inner Temp (C)
EnergyPlus WEST B WINDOW 1:Window Thermochromic Layer Temperature[C]

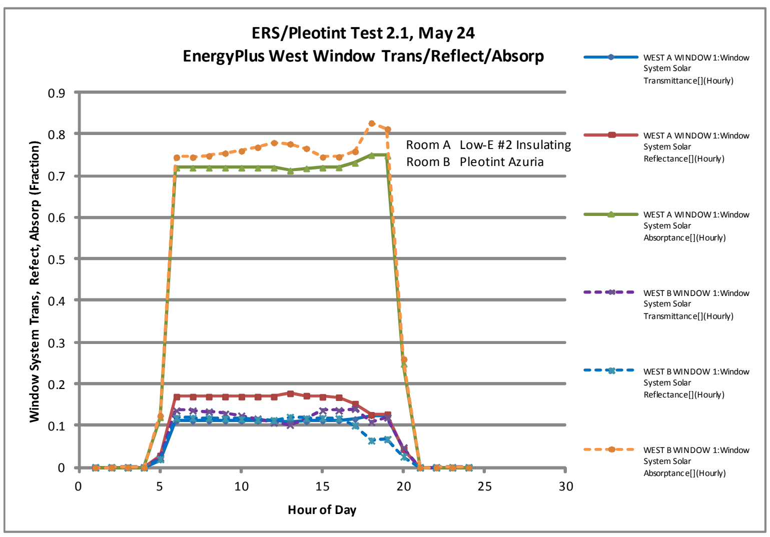

ERS/Pleotint Test 6.2, Jan 28
Pleotint Clear Window
Room B East Window Temperatures
Temperature (C)
Hour of day
EnergyPlus EAST B WINDOW 1:Surface Outside Temperature [C](Hourly)
EnergyPlus EAST B WINDOW 1:Surface Inside Temperature [C](Hourly)
ERS East B Window Outside Pane/Inner Temp (C)
EnergyPlus EAST B WINDOW 1:Window Thermochromic Layer Temperature[C]

Appendix C

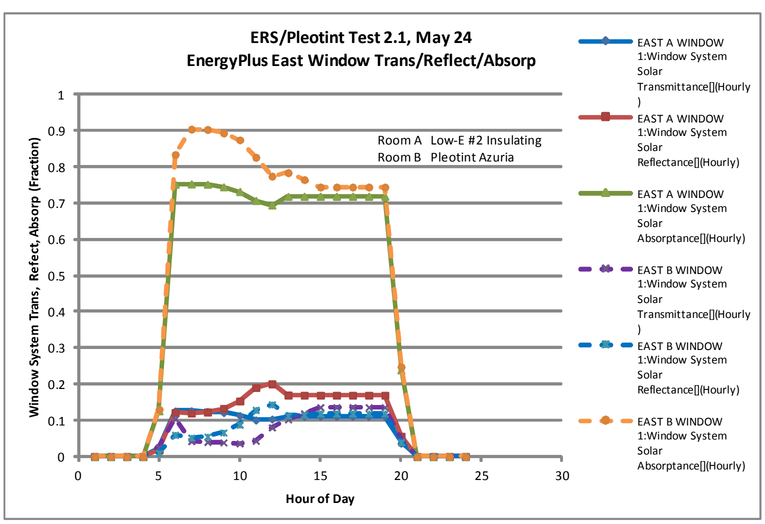
Charts Showing EnergyPlus Window Performance Results - Transmittance, Reflectance and Absorptance



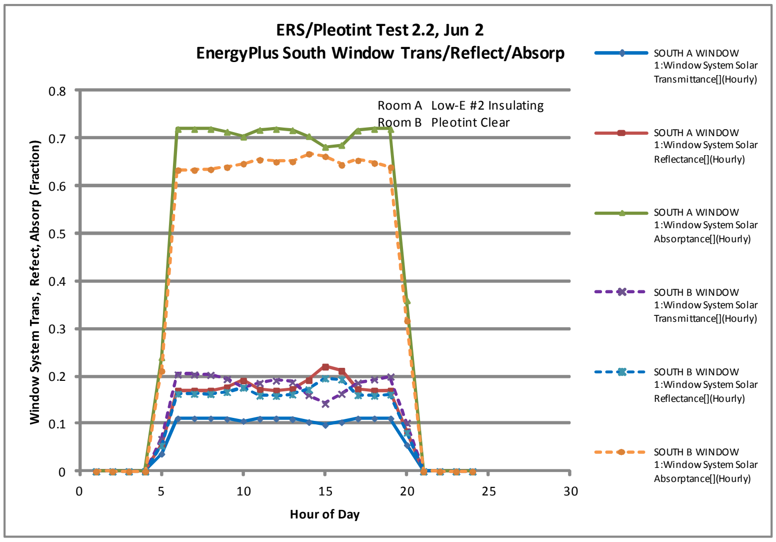
	Daily Average Window System Transmittance	Daily Average Window System Reflectance	Daily Average Window System Absorptance
Room A Low-E #2 Insulating	0.064	0.117	0.423
Room B Pleotint Azuria	0.069	0.086	0.449



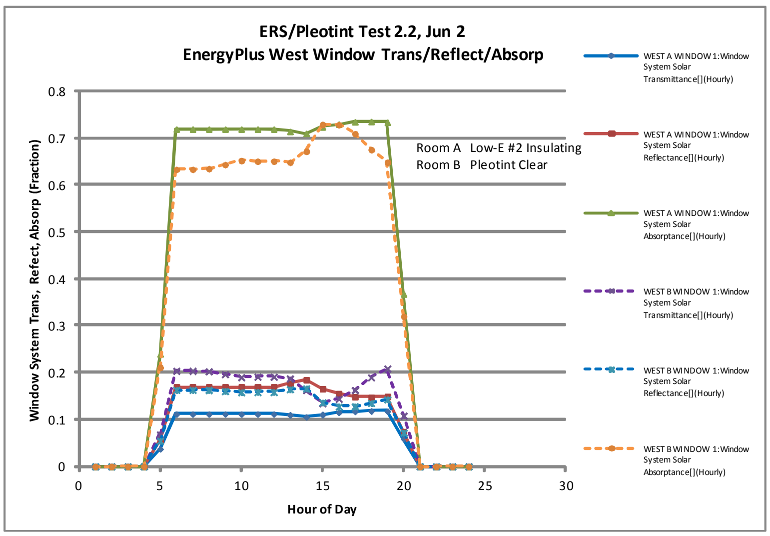
	Daily Average Window System Transmittance	Daily Average Window System Reflectance	Daily Average Window System Absorptance
Room A Low-E #2 Insulating	0.069	0.098	0.437
Room B Pleotint Azuria	0.076	0.065	0.463



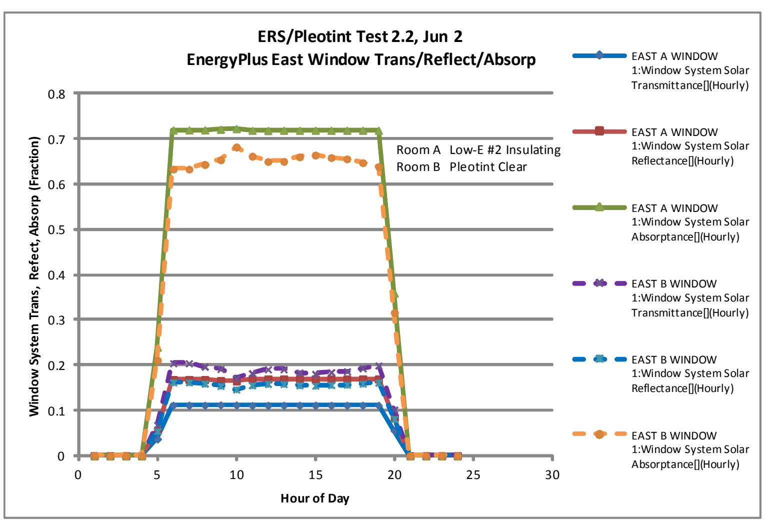
	Daily Average Window System Transmittance	Daily Average Window System Reflectance	Daily Average Window System Absorptance
Room A Low-E #2 Insulating	0.069	0.096	0.439
Room B Pleotint Azuria	0.057	0.061	0.486



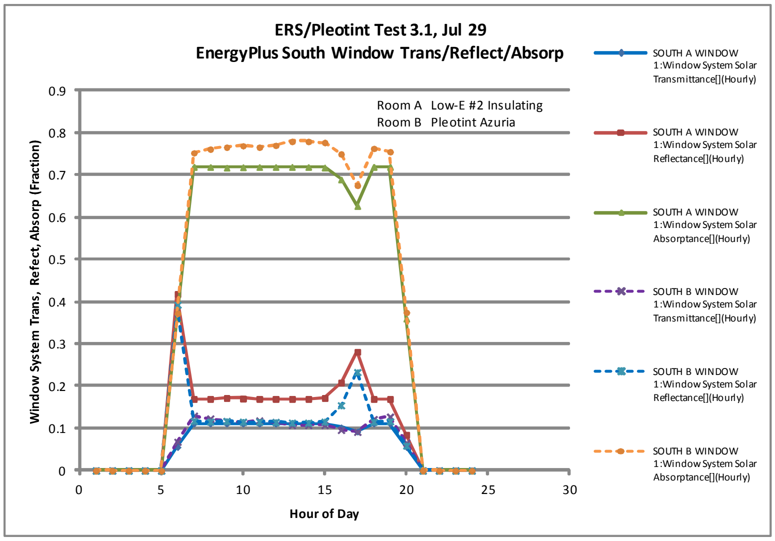
	Daily Average Window System Transmittance	Daily Average Window System Reflectance	Daily Average Window System Absorptance
Room A Low-E #2 Insulating	0.067	0.111	0.440
Room B Pleotint Clear	0.115	0.104	0.399



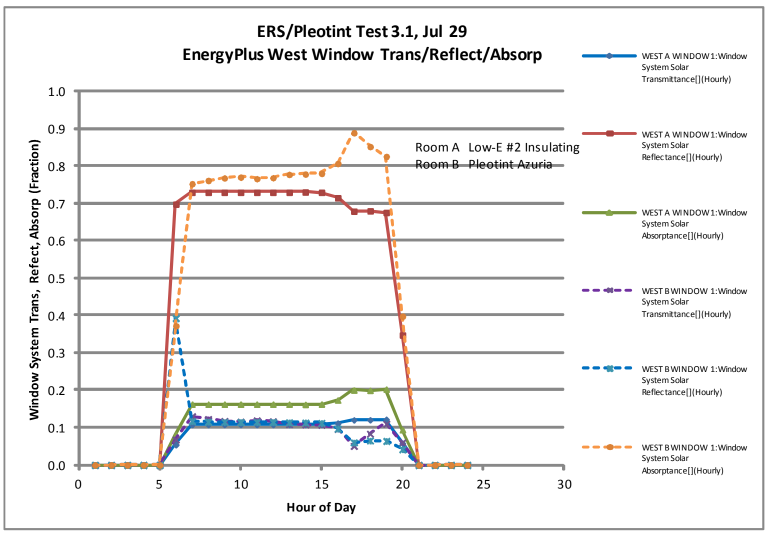
	Daily Average Window System Transmittance	Daily Average Window System Reflectance	Daily Average Window System Absorptance
Room A Low-E #2 Insulating	0.070	0.102	0.447
Room B Pleotint Clear	27.489	0.114	0.410



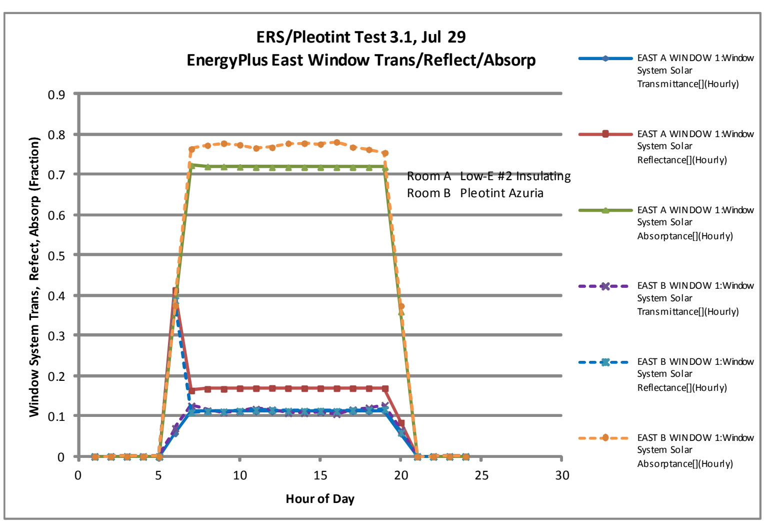
	Daily Average Window System Transmittance	Daily Average Window System Reflectance	Daily Average Window System Absorptance
Room A Low-E #2 Insulating	0.069	0.104	0.445
Room B Pleotint Clear	0.118	0.097	0.403



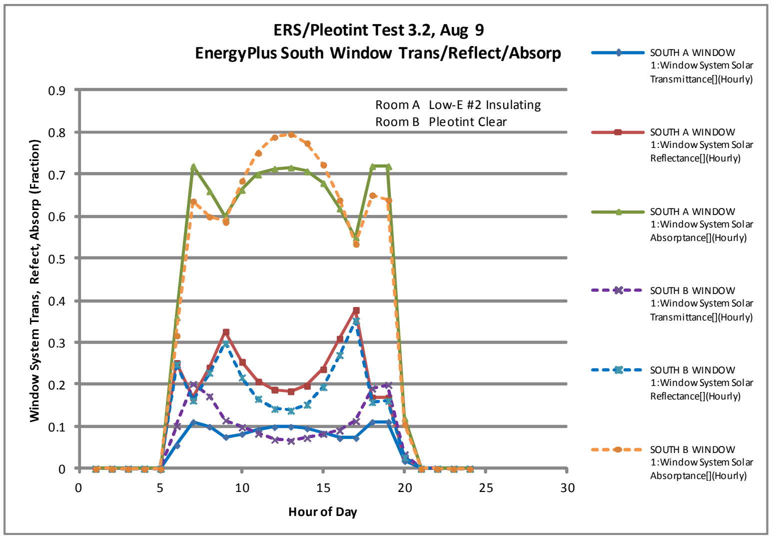
	Daily Average Window System Transmittance	Daily Average Window System Reflectance	Daily Average Window System Absorptance
Room A Low-E #2 Insulating	0.064	0.119	0.414
Room B Pleotint Azuria	0.067	0.088	0.442



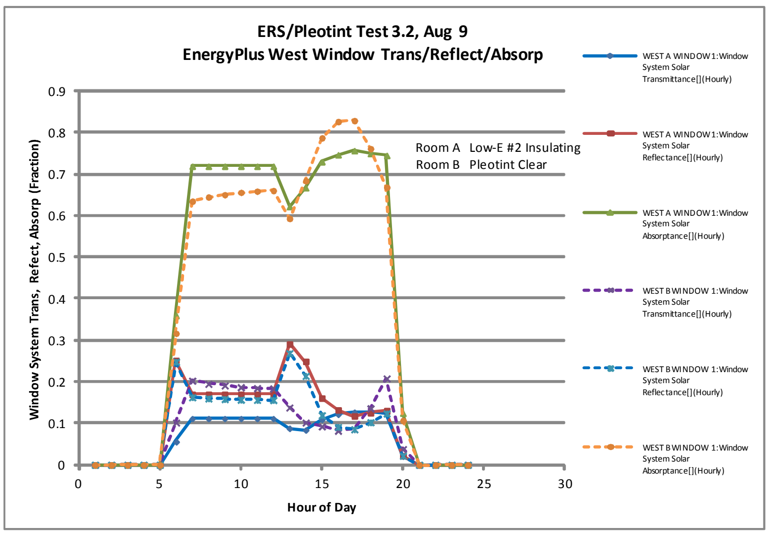
	Daily Average Window System Transmittance	Daily Average Window System Reflectance	Daily Average Window System Absorptance
Room A Low-E #2 Insulating	0.065	0.432	0.101
Room B Pleotint Azuria	0.063	0.073	0.461



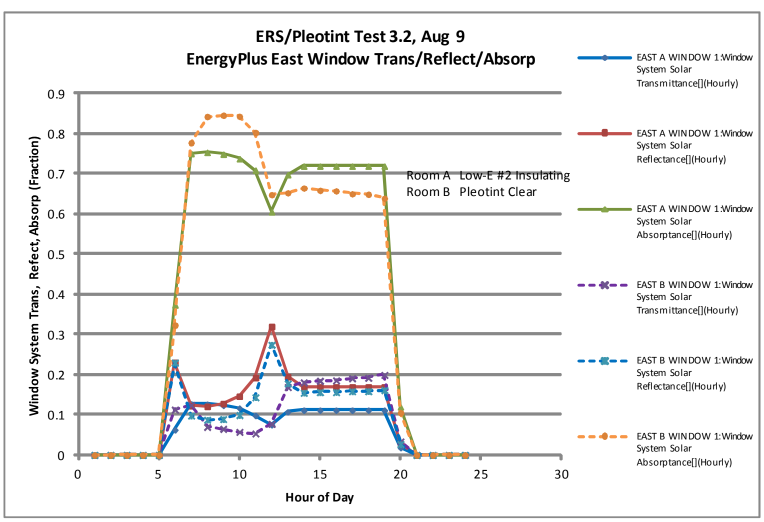
	Daily Average Window System Transmittance	Daily Average Window System Reflectance	Daily Average Window System Absorptance
Room A Low-E #2 Insulating	0.065	0.112	0.420
Room B Pleotint Azuria	0.068	0.080	0.449



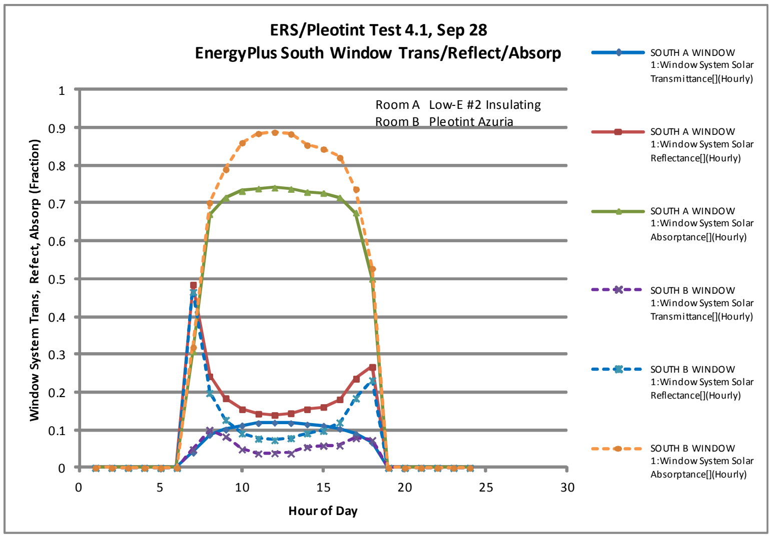
	Daily Average Window System Transmittance	Daily Average Window System Reflectance	Daily Average Window System Absorptance
Room A Low-E #2 Insulating	0.053	0.138	0.385
Room B Pleotint Clear	0.071	0.122	0.384



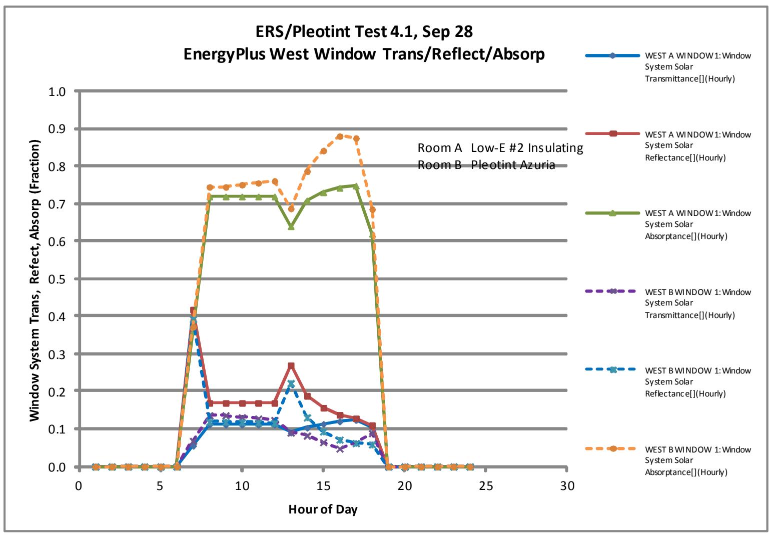
	Daily Average Window System Transmittance	Daily Average Window System Reflectance	Daily Average Window System Absorptance
Room A Low-E #2 Insulating	0.063	0.104	0.409
Room B Pleotint Clear	0.089	0.093	0.395



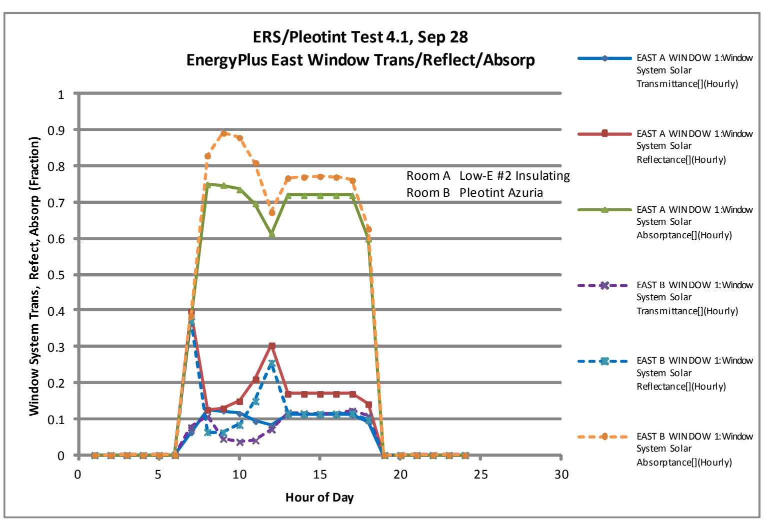
	Daily Average Window System Transmittance	Daily Average Window System Reflectance	Daily Average Window System Absorptance
Room A Low-E #2 Insulating	0.063	0.104	0.409
Room B Pleotint Clear	0.079	0.091	0.407



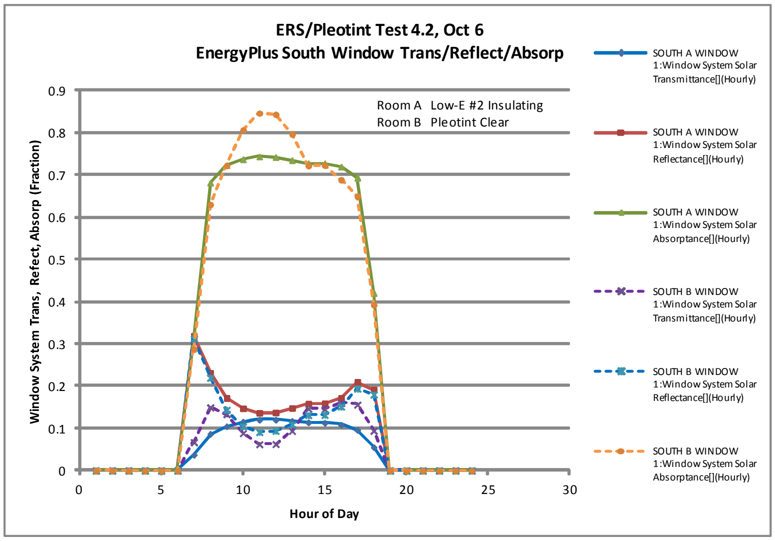
	Daily Average Window System Transmittance	Daily Average Window System Reflectance	Daily Average Window System Absorptance
Room A Low-E #2 Insulating	0.049	0.104	0.333
Room B Pleotint Azuria	0.030	0.076	0.380



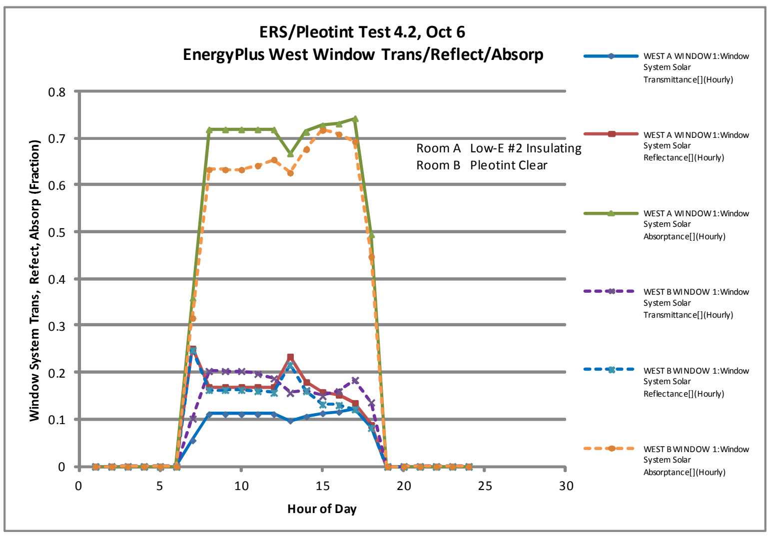
	Daily Average Window System Transmittance	Daily Average Window System Reflectance	Daily Average Window System Absorptance
Room A Low-E #2 Insulating	0.053	0.094	0.339
Room B Pleotint Azuria	0.048	0.068	0.370



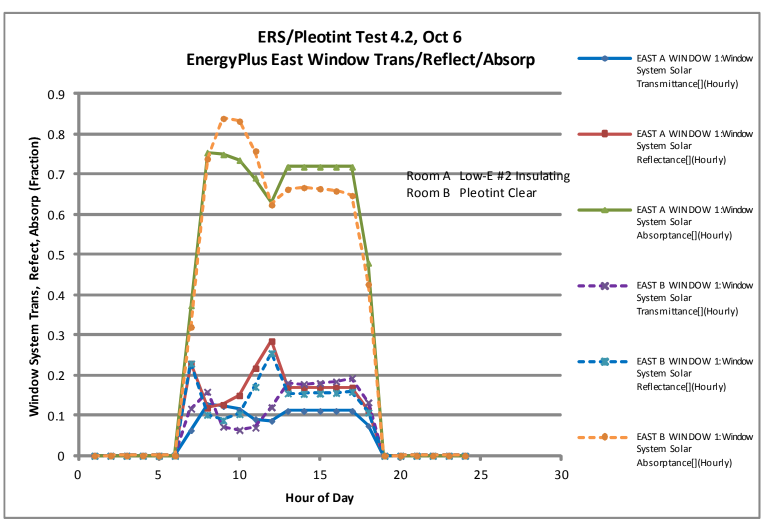
	Daily Average Window System Transmittance	Daily Average Window System Reflectance	Daily Average Window System Absorptance
Room A Low-E #2 Insulating	0.052	0.096	0.338
Room B Pleotint Azuria	0.045	0.069	0.372



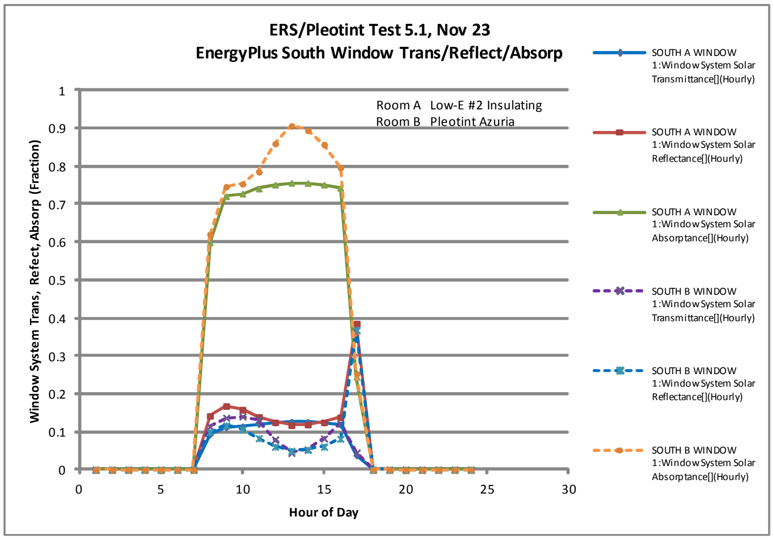
	Daily Average Window System Transmittance	Daily Average Window System Reflectance	Daily Average Window System Absorptance
Room A Low-E #2 Insulating	0.050	0.091	0.332
Room B Pleotint Clear	0.057	0.078	0.338



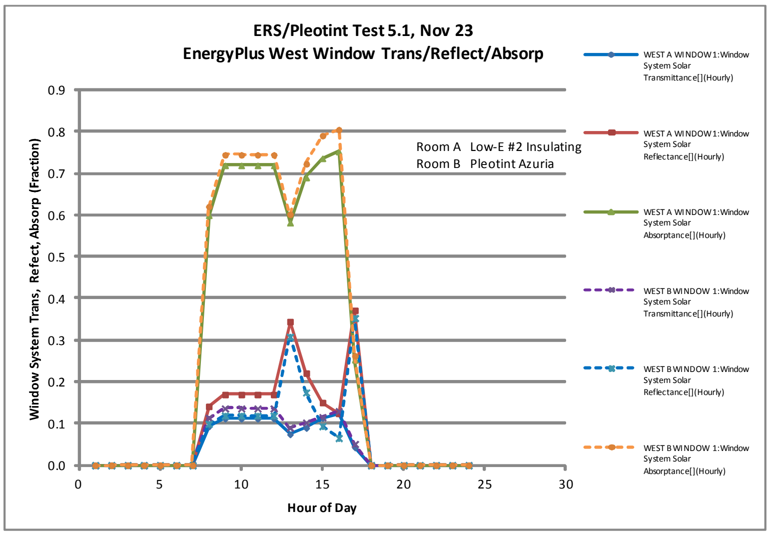
	Daily Average Window System Transmittance	Daily Average Window System Reflectance	Daily Average Window System Absorptance
Room A Low-E #2 Insulating	0.052	0.085	0.335
Room B Pleotint Clear	0.085	0.079	0.308



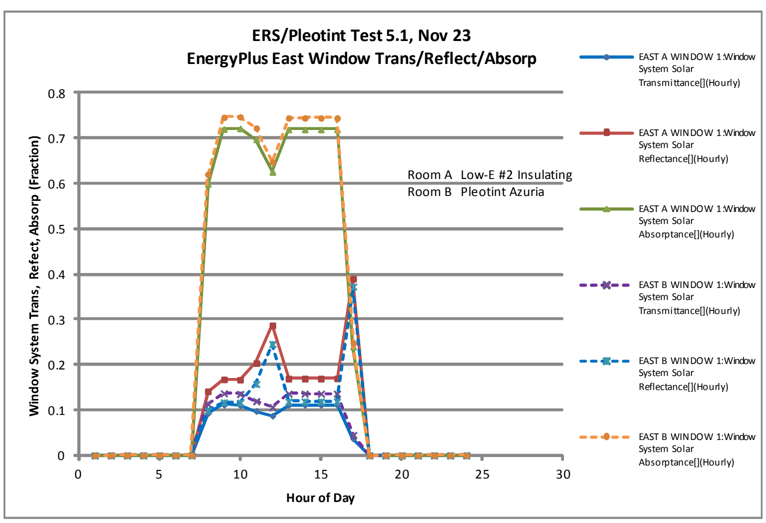
	Daily Average Window System Transmittance	Daily Average Window System Reflectance	Daily Average Window System Absorptance
Room A Low-E #2 Insulating	0.052	0.087	0.334
Room B Pleotint Clear	0.069	0.077	0.327



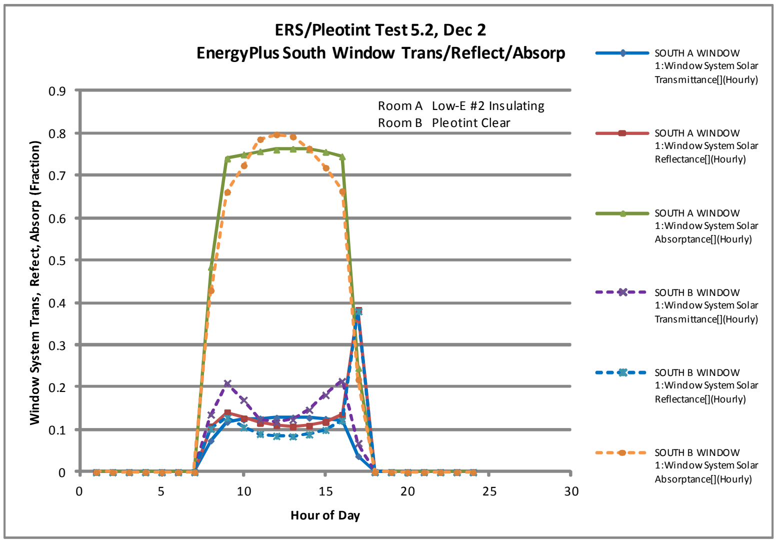
	Daily Average Window System Transmittance	Daily Average Window System Reflectance	Daily Average Window System Absorptance
Room A Low-E #2 Insulating	0.046	0.067	0.283
Room B Pleotint Azuria	0.040	0.045	0.311



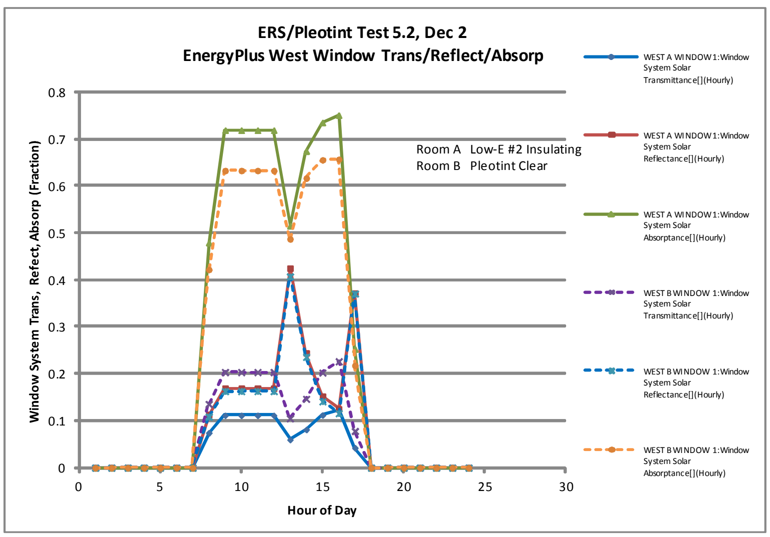
	Daily Average Window System Transmittance	Daily Average Window System Reflectance	Daily Average Window System Absorptance
Room A Low-E #2 Insulating	0.041	0.085	0.270
Room B Pleotint Azuria	0.048	0.065	0.283



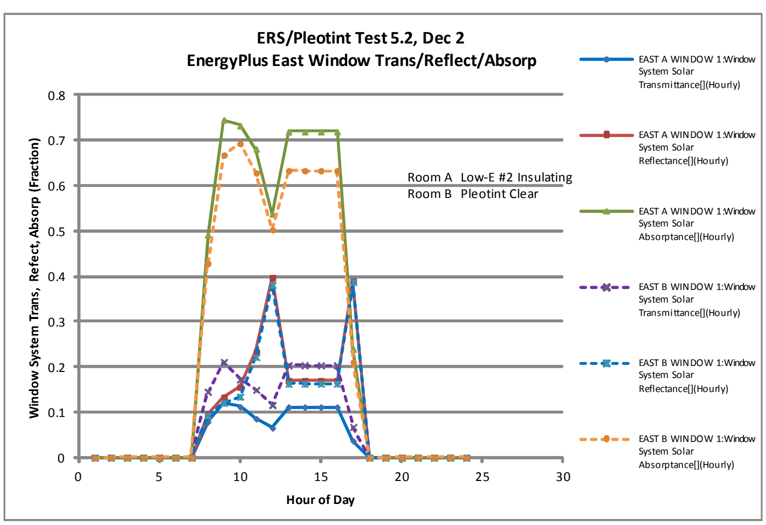
	Daily Average Window System Transmittance	Daily Average Window System Reflectance	Daily Average Window System Absorptance
Room A Low-E #2 Insulating	0.041	0.085	0.270
Room B Pleotint Azuria	0.050	0.066	0.280



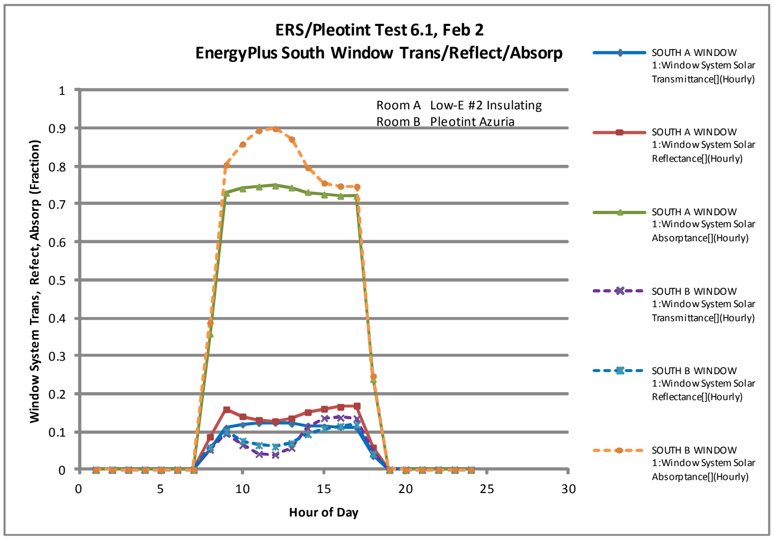
	Daily Average Window System Transmittance	Daily Average Window System Reflectance	Daily Average Window System Absorptance
Room A Low-E #2 Insulating	0.046	0.061	0.282
Room B Pleotint Clear	0.062	0.054	0.273



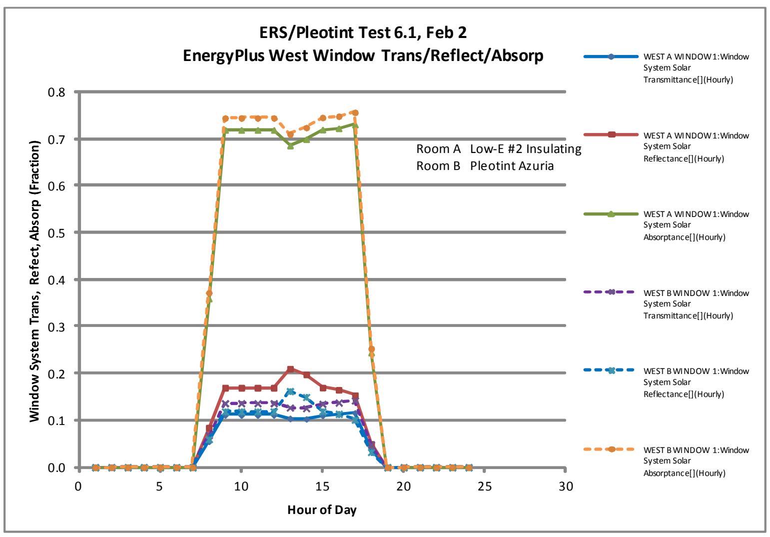
	Daily Average Window System Transmittance	Daily Average Window System Reflectance	Daily Average Window System Absorptance
Room A Low-E #2 Insulating	0.039	0.088	0.262
Room B Pleotint Clear	0.071	0.085	0.233



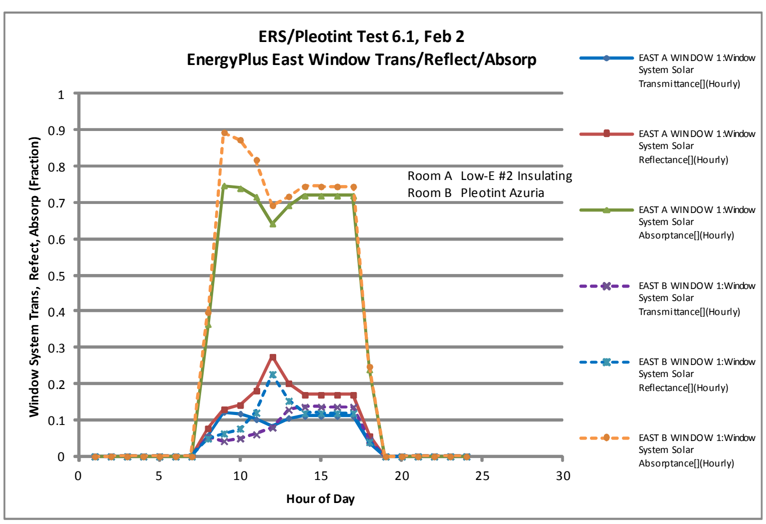
	Daily Average Window System Transmittance	Daily Average Window System Reflectance	Daily Average Window System Absorptance
Room A Low-E #2 Insulating	0.039	0.087	0.263
Room B Pleotint Clear	0.070	0.083	0.236



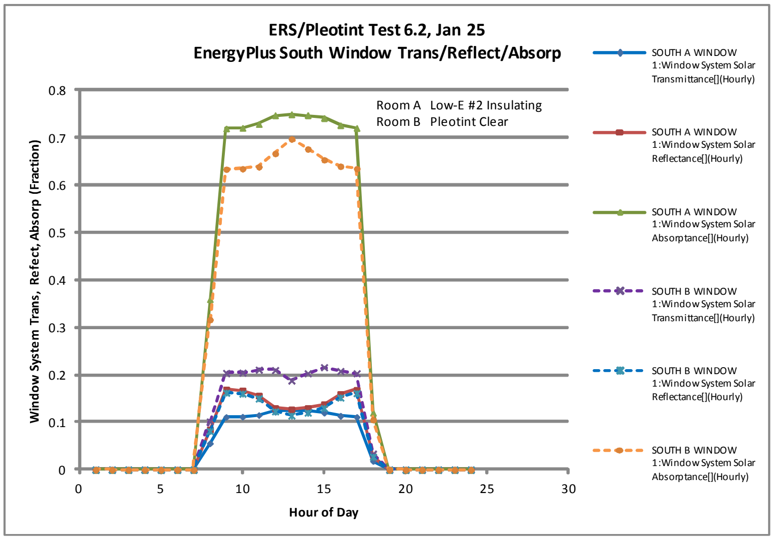
	Daily Average Window System Transmittance	Daily Average Window System Reflectance	Daily Average Window System Absorptance
Room A Low-E #2 Insulating	0.047	0.062	0.300
Room B Pleotint Azuria	0.038	0.038	0.334



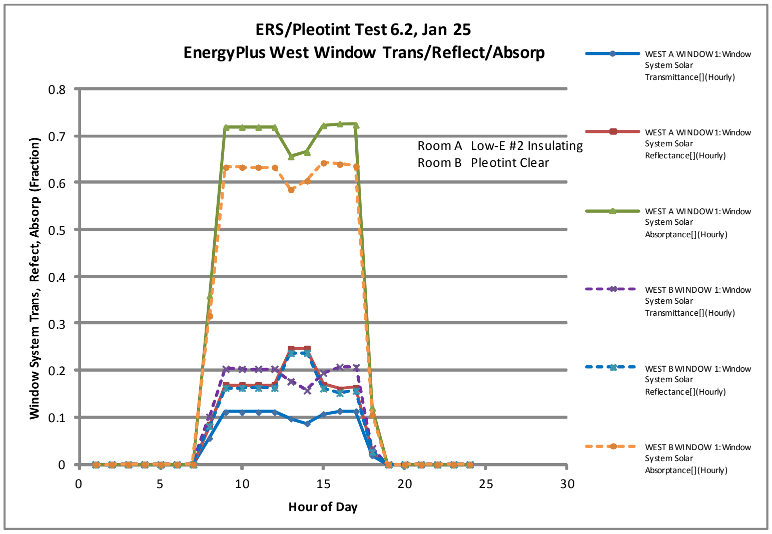
	Daily Average Window System Transmittance	Daily Average Window System Reflectance	Daily Average Window System Absorptance
Room A Low-E #2 Insulating	0.045	0.071	0.293
Room B Pleotint Azuria	0.055	0.051	0.304



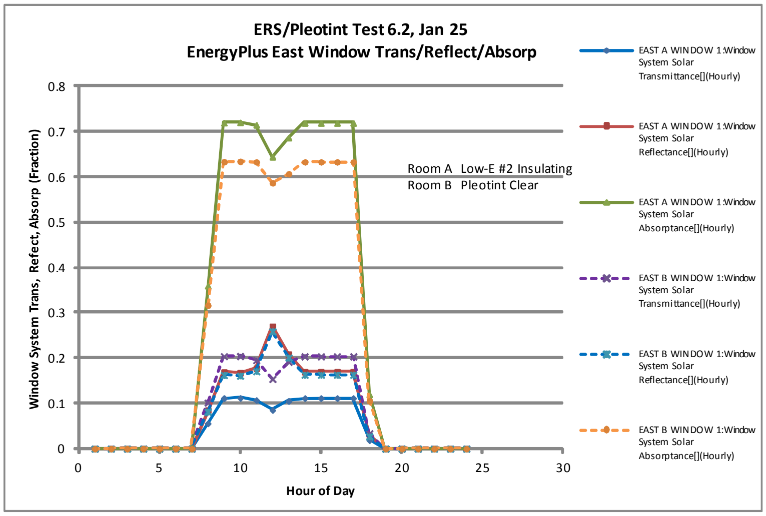
	Daily Average Window System Transmittance	Daily Average Window System Reflectance	Daily Average Window System Absorptance
Room A Low-E #2 Insulating	0.045	0.073	0.292
Room B Pleotint Azuria	0.042	0.050	0.318



	Daily Average Window System Transmittance	Daily Average Window System Reflectance	Daily Average Window System Absorptance
Room A Low-E #2 Insulating	0.047	0.061	0.295
Room B Pleotint Clear	0.083	0.058	0.262



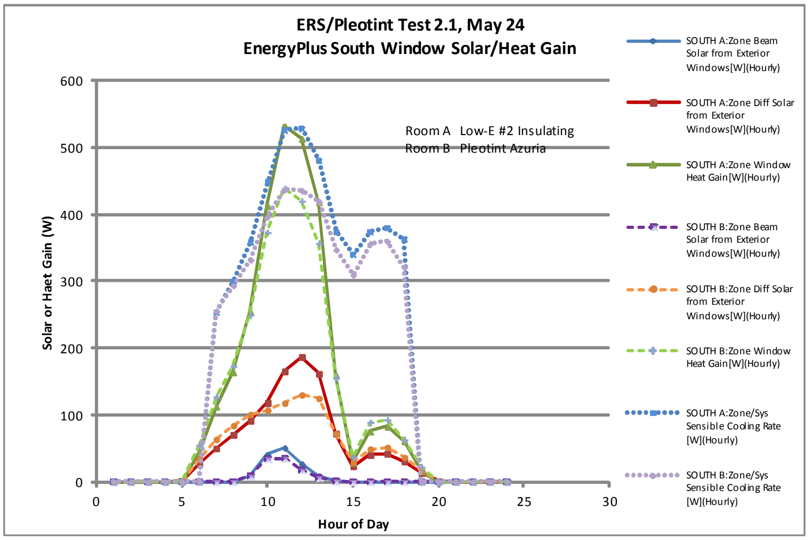
	Daily Average Window System Transmittance	Daily Average Window System Reflectance	Daily Average Window System Absorptance
Room A Low-E #2 Insulating	0.043	0.074	0.285
Room B Pleotint Clear	0.079	0.071	0.253



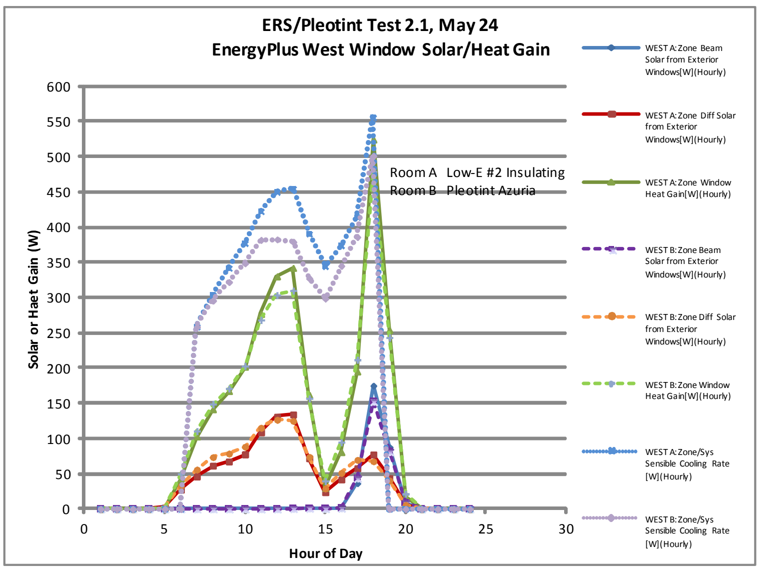
	Daily Average Window System Transmittance	Daily Average Window System Reflectance	Daily Average Window System Absorptance
Room A Low-E #2 Insulating	0.043	0.074	0.285
Room B Pleotint Clear	0.079	0.071	0.252

Appendix D

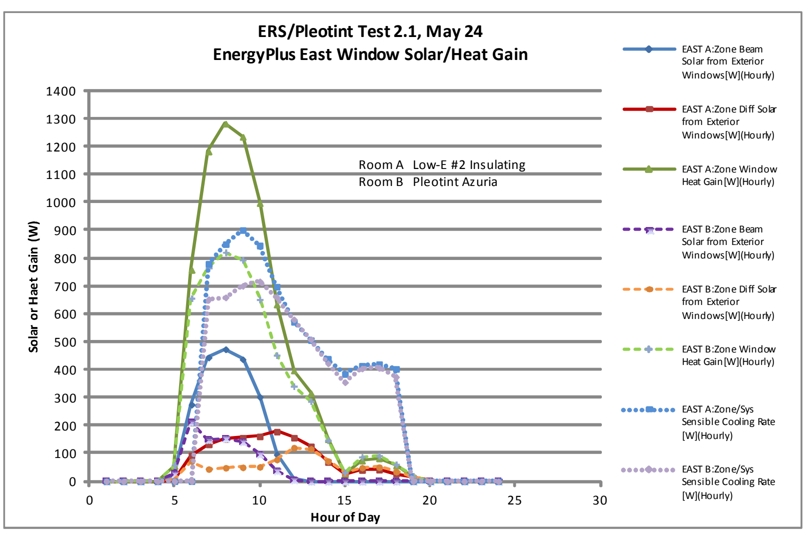
Charts Showing EnergyPlus Window Performance Results - Beam Solar, Diffuse Solar and Window Heat gain



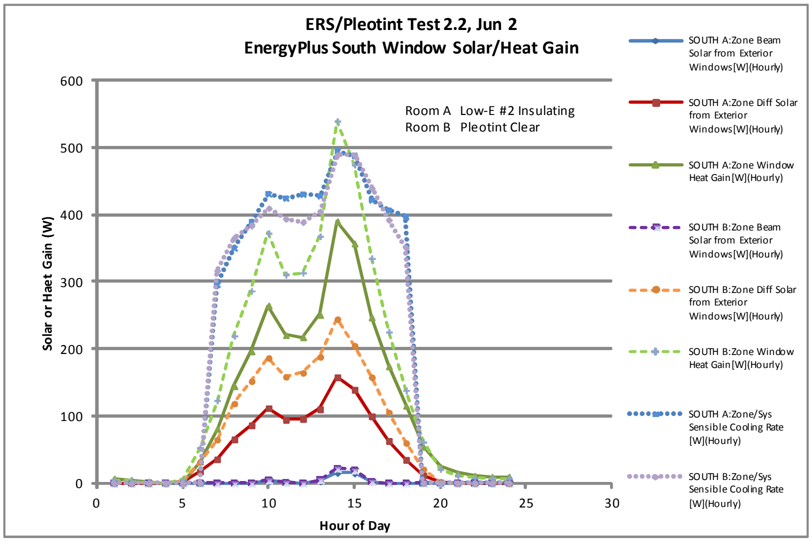
	Daily Zone Beam Solar (W)	Daily Zone Diffuse Solar (W)	Daily Zone Window Heat Gain (W)	Daily Zone Cooling Load (W)	Daily Zone Light Load (W)
Room A Low-E #2 Insulating	137	1099	2874	4722	2413
Room B Pleotint Azuria	104	1025	2655	4263	1527



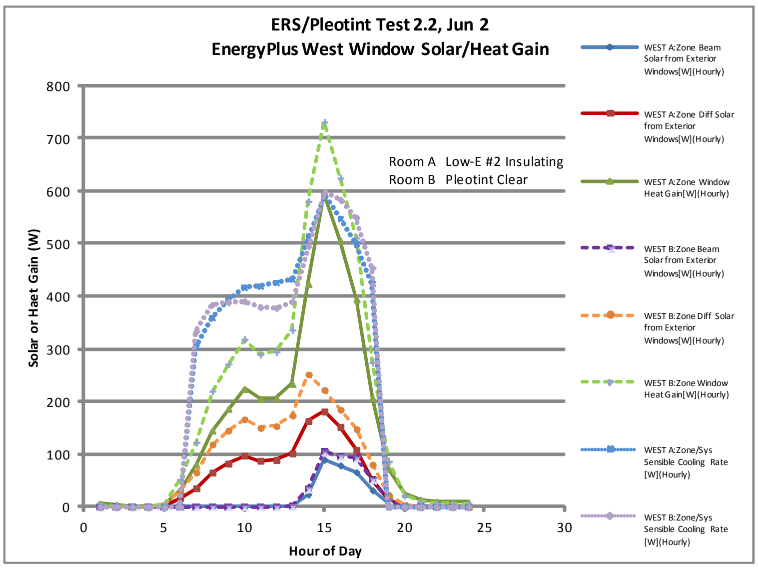
	Daily Zone Beam Solar (W)	Daily Zone Diffuse Solar (W)	Daily Zone Window Heat Gain (W)	Daily Zone Cooling Load (W)	Daily Zone Light Load (W)
Room A Low-E #2 Insulating	310	978	2870	4688	2981
Room B Pleotint Azuria	290	1037	2816	4229	1939



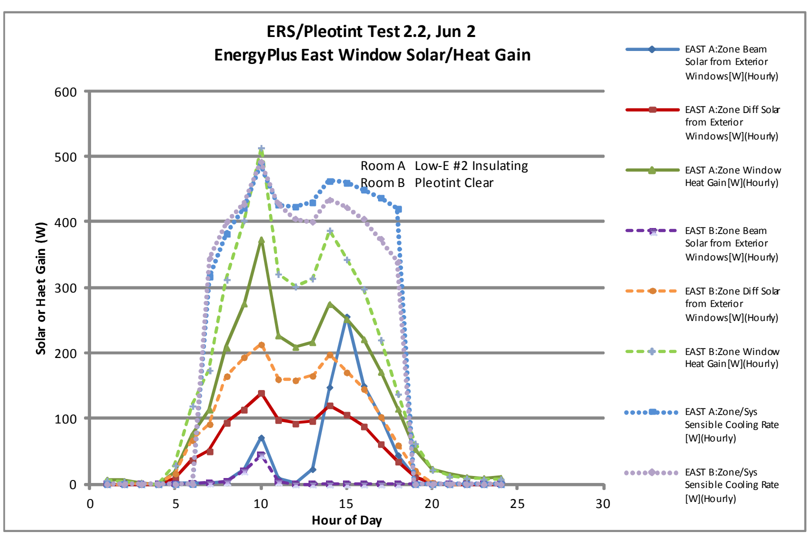
	Daily Zone Beam Solar (W)	Daily Zone Diffuse Solar (W)	Daily Zone Window Heat Gain (W)	Daily Zone Cooling Load (W)	Daily Zone Light Load (W)
Room A Low-E #2 Insulating	2057	1372	7255	7210	1304
Room B Pleotint Azuria	822	837	5265	6442	1397



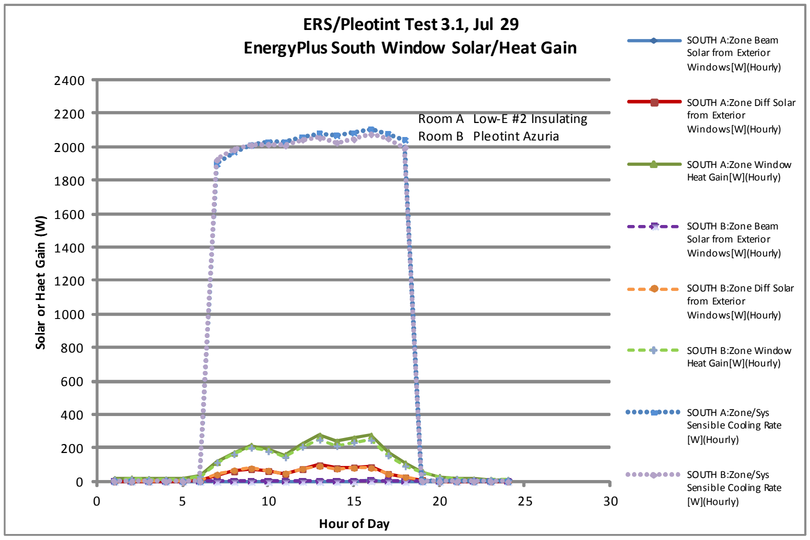
	Daily Zone Beam Solar (W)	Daily Zone Diffuse Solar (W)	Daily Zone Window Heat Gain (W)	Daily Zone Cooling Load (W)	Daily Zone Light Load (W)
Room A Low-E #2 Insulating	39	1128	2834	4955	2357
Room B Pleotint Clear	55	1867	3895	4825	684



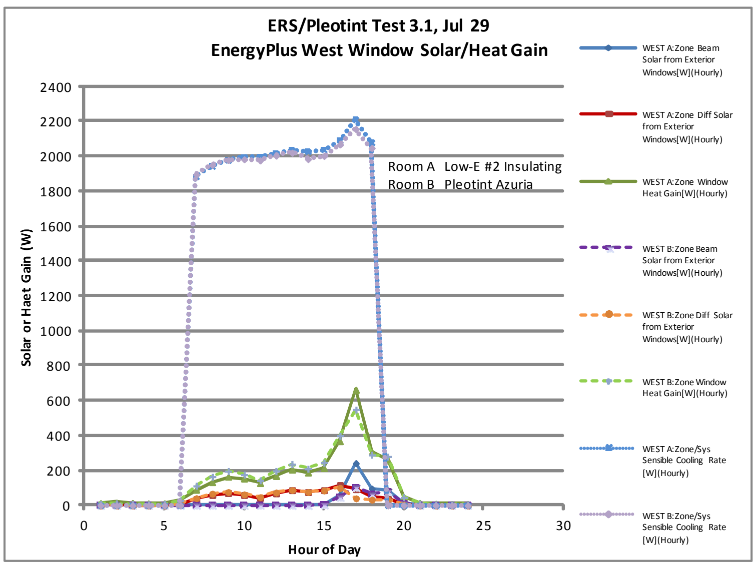
	Daily Zone Beam Solar (W)	Daily Zone Diffuse Solar (W)	Daily Zone Window Heat Gain (W)	Daily Zone Cooling Load (W)	Daily Zone Light Load (W)
Room A Low-E #2 Insulating	299	1251	3590	5327	2130
Room B Pleotint Clear	393	1922	4776	5325	636



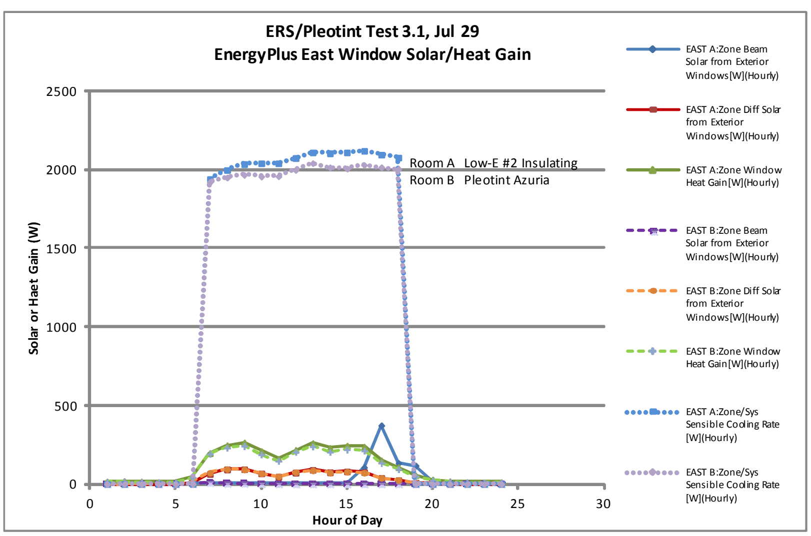
	Daily Zone Beam Solar (W)	Daily Zone Diffuse Solar (W)	Daily Zone Window Heat Gain (W)	Daily Zone Cooling Load (W)	Daily Zone Light Load (W)
Room A Low-E #2 Insulating	843	1152	2889	5121	2648
Room B Pleotint Clear	75	1931	4005	4878	643



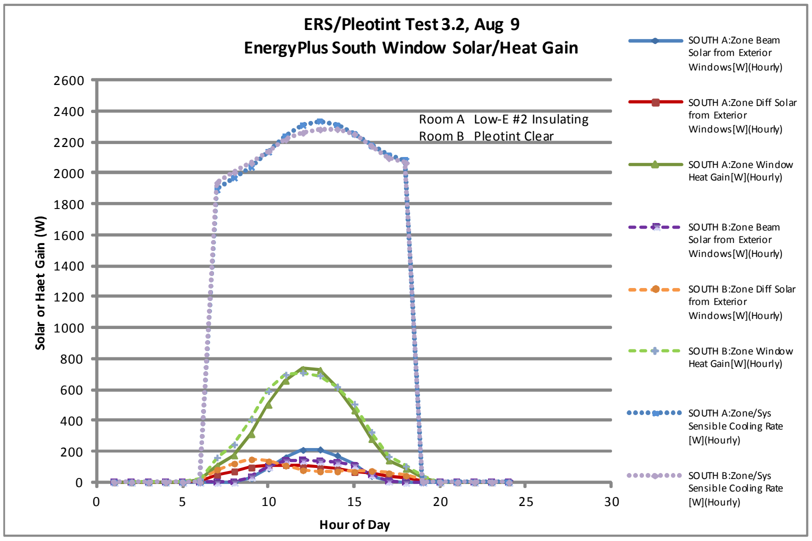
	Daily Zone Beam Solar (W)	Daily Zone Diffuse Solar (W)	Daily Zone Window Heat Gain (W)	Daily Zone Cooling Load (W)	Daily Zone Light Load (W)
Room A Low-E #2 Insulating	8	789	2661	24450	2851
Room B Pleotint Azuria	7	803	2411	24238	1794



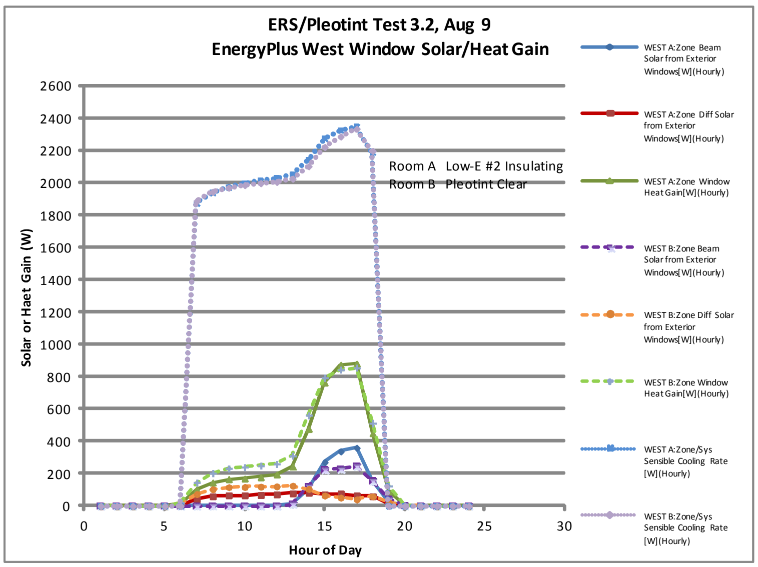
	Daily Zone Beam Solar (W)	Daily Zone Diffuse Solar (W)	Daily Zone Window Heat Gain (W)	Daily Zone Cooling Load (W)	Daily Zone Light Load (W)
Room A Low-E #2 Insulating	496	893	3212	24285	2765
Room B Pleotint Azuria	302	839	3345	24063	1946



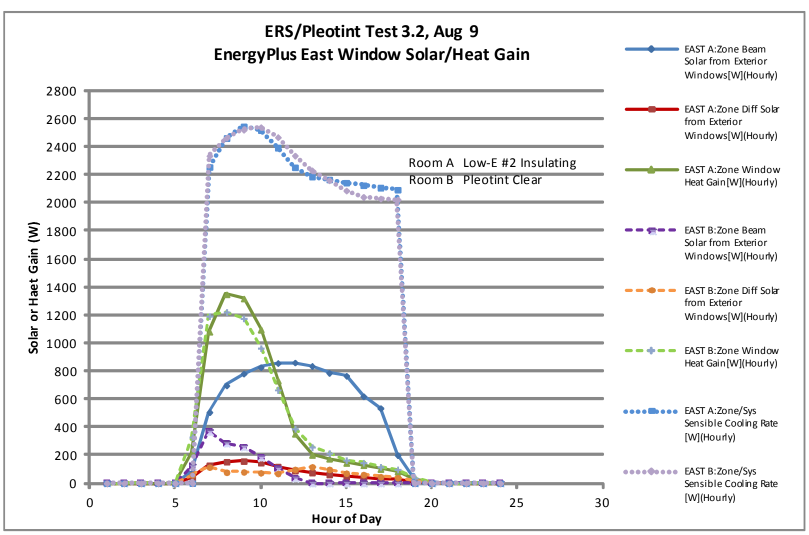
	Daily Zone Beam Solar (W)	Daily Zone Diffuse Solar (W)	Daily Zone Window Heat Gain (W)	Daily Zone Cooling Load (W)	Daily Zone Light Load (W)
Room A Low-E #2 Insulating	780	835	2779	24744	2848
Room B Pleotint Azuria	18	845	2515	0	1424



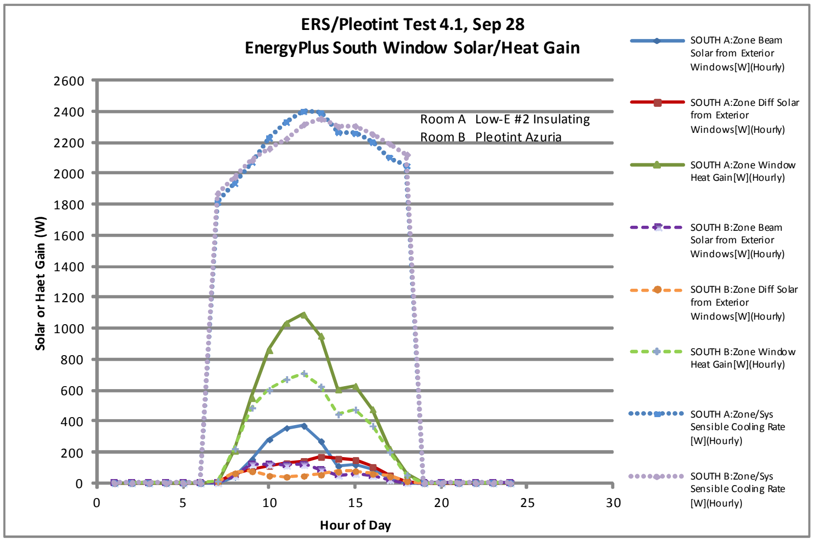
	Daily Zone Beam Solar (W)	Daily Zone Diffuse Solar (W)	Daily Zone Window Heat Gain (W)	Daily Zone Cooling Load (W)	Daily Zone Light Load (W)
Room A Low-E #2 Insulating	1042	927	4844	25849	2518
Room B Pleotint Clear	846	1100	5287	25778	973



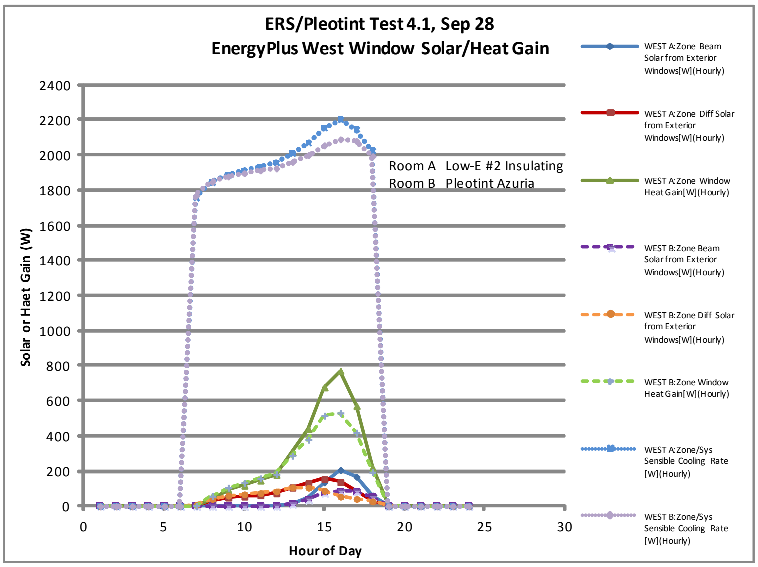
	Daily Zone Beam Solar (W)	Daily Zone Diffuse Solar (W)	Daily Zone Window Heat Gain (W)	Daily Zone Cooling Load (W)	Daily Zone Light Load (W)
Room A Low-E #2 Insulating	1260	836	4748	25137	2469
Room B Pleotint Clear	1025	1144	5361	24951	1336



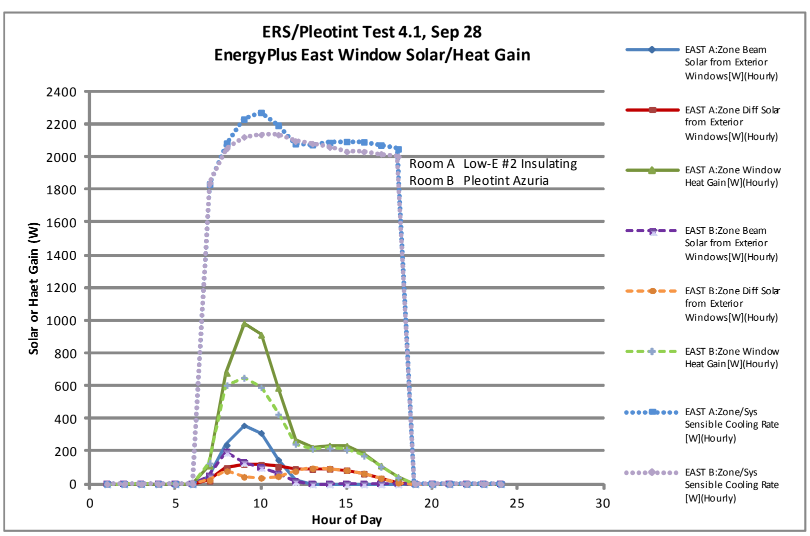
	Daily Zone Beam Solar (W)	Daily Zone Diffuse Solar (W)	Daily Zone Window Heat Gain (W)	Daily Zone Cooling Load (W)	Daily Zone Light Load (W)
Room A Low-E #2 Insulating	8401	1112	7002	27268	1946
Room B Pleotint Clear	1353	1031	6977	27258	1553



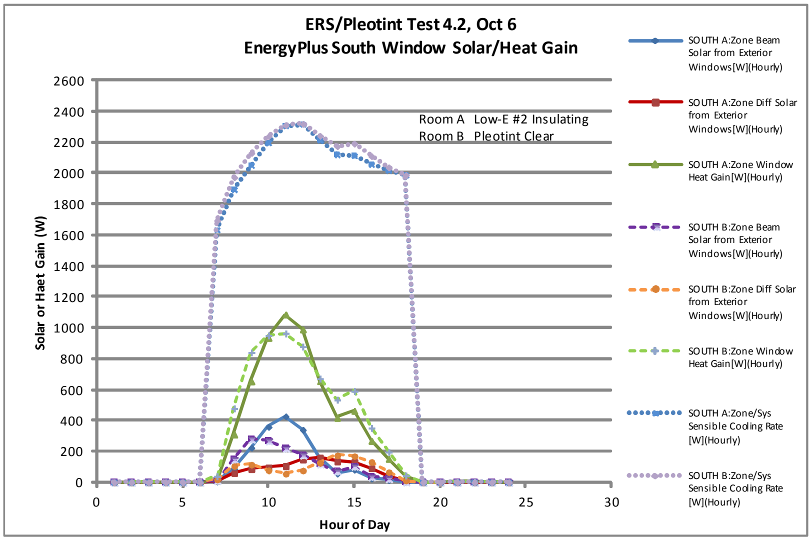
	Daily Zone Beam Solar (W)	Daily Zone Diffuse Solar (W)	Daily Zone Window Heat Gain (W)	Daily Zone Cooling Load (W)	Daily Zone Light Load (W)
Room A Low-E #2 Insulating	1825	1183	6688	26026	1306
Room B Pleotint Azuria	799	610	4874	26152	2606



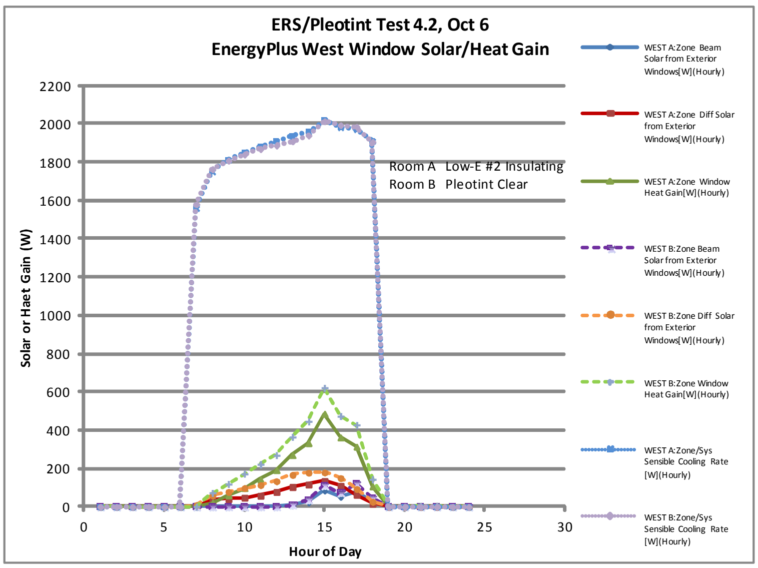
	Daily Zone Beam Solar (W)	Daily Zone Diffuse Solar (W)	Daily Zone Window Heat Gain (W)	Daily Zone Cooling Load (W)	Daily Zone Light Load (W)
Room A Low-E #2 Insulating	629	926	3557	23904	2255
Room B Pleotint Azuria	338	762	2971	23416	1814



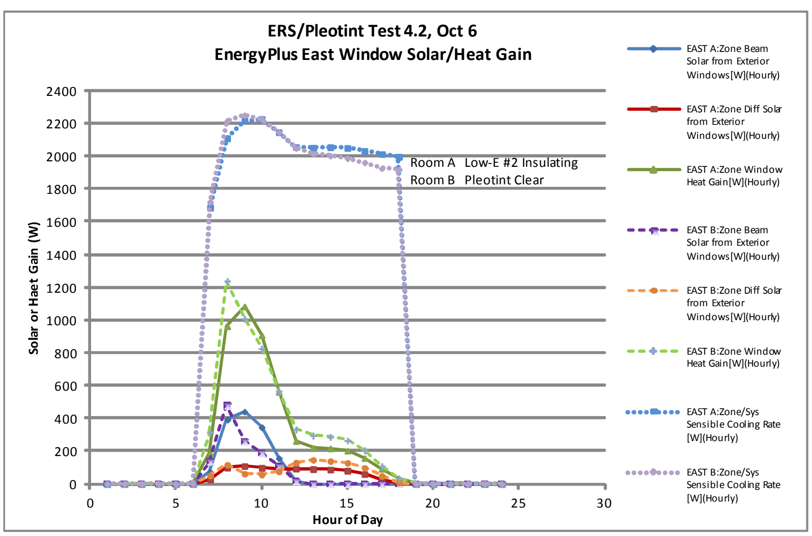
	Daily Zone Beam Solar (W)	Daily Zone Diffuse Solar (W)	Daily Zone Window Heat Gain (W)	Daily Zone Cooling Load (W)	Daily Zone Light Load (W)
Room A Low-E #2 Insulating	1117	926	4571	25163	2049
Room B Pleotint Azuria	550	696	3609	24613	2041



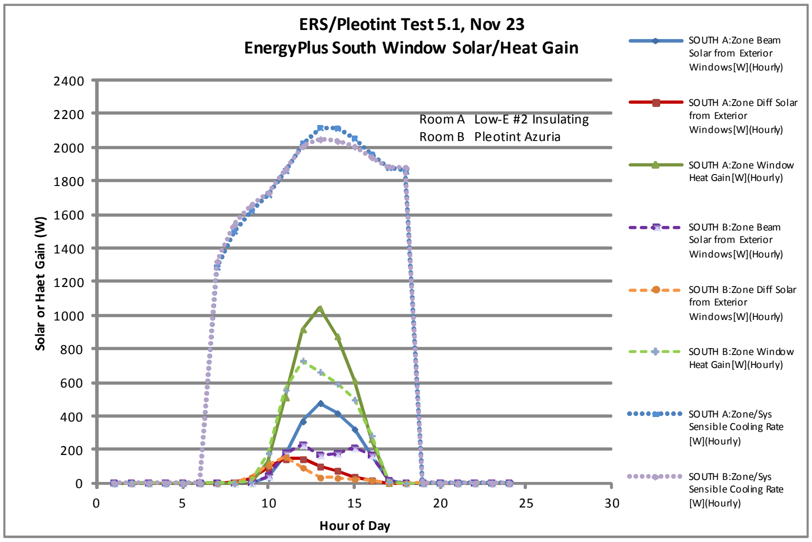
	Daily Zone Beam Solar (W)	Daily Zone Diffuse Solar (W)	Daily Zone Window Heat Gain (W)	Daily Zone Cooling Load (W)	Daily Zone Light Load (W)
Room A Low-E #2 Insulating	1781	1076	5996	24893	1559
Room B Pleotint Clear	1459	1133	6545	25404	902



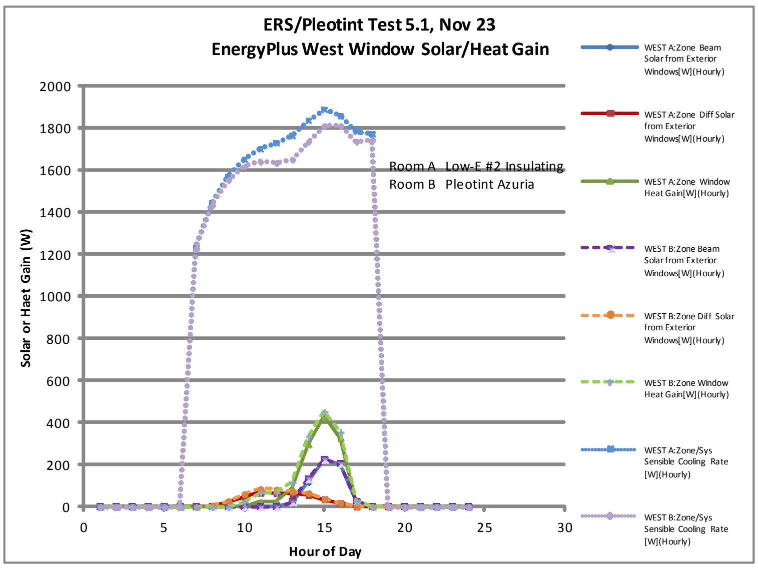
	Daily Zone Beam Solar (W)	Daily Zone Diffuse Solar (W)	Daily Zone Window Heat Gain (W)	Daily Zone Cooling Load (W)	Daily Zone Light Load (W)
Room A Low-E #2 Insulating	274	810	2411	22548	2266
Room B Pleotint Clear	393	1294	3359	22506	1205



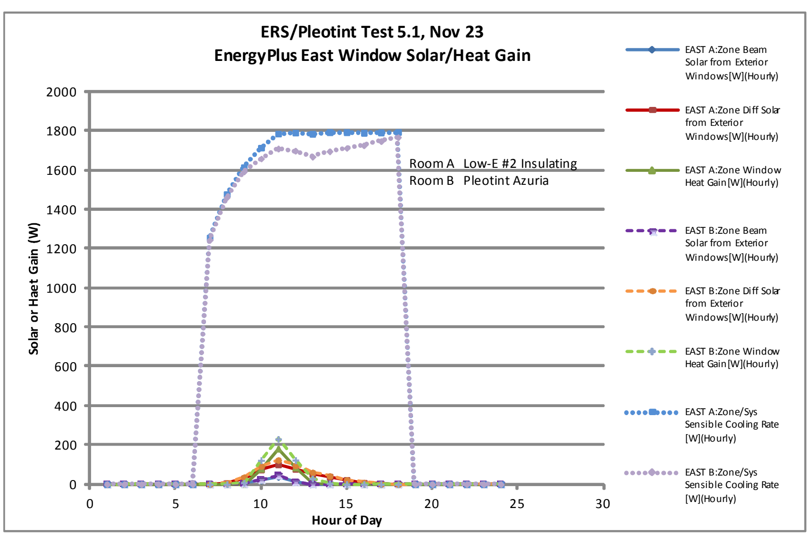
	Daily Zone Beam Solar (W)	Daily Zone Diffuse Solar (W)	Daily Zone Window Heat Gain (W)	Daily Zone Cooling Load (W)	Daily Zone Light Load (W)
Room A Low-E #2 Insulating	1427	869	4896	24644	2012
Room B Pleotint Clear	1192	1065	5500	24432	733



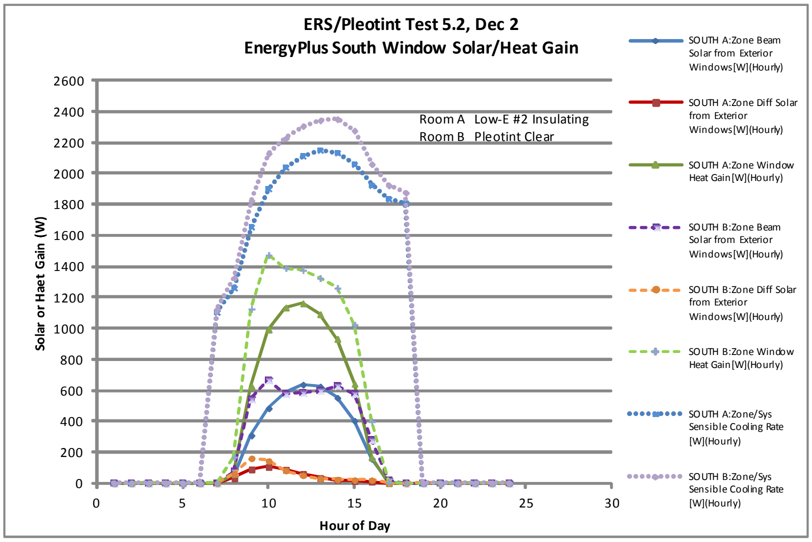
	Daily Zone Beam Solar (W)	Daily Zone Diffuse Solar (W)	Daily Zone Window Heat Gain (W)	Daily Zone Cooling Load (W)	Daily Zone Light Load (W)
Room A Low-E #2 Insulating	1970	642	4354	22000	1929
Room B Pleotint Azuria	1187	509	3523	21926	1737



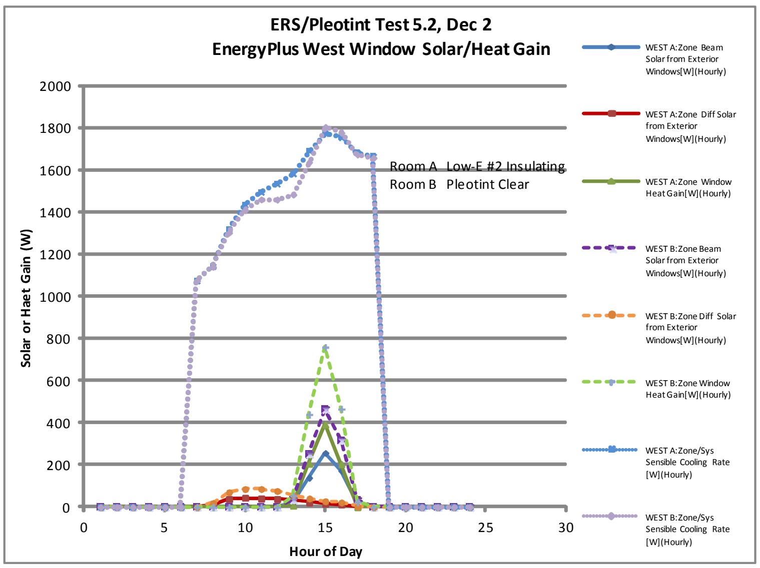
	Daily Zone Beam Solar (W)	Daily Zone Diffuse Solar (W)	Daily Zone Window Heat Gain (W)	Daily Zone Cooling Load (W)	Daily Zone Light Load (W)
Room A Low-E #2 Insulating	580	384	1210	20216	2941
Room B Pleotint Azuria	614	461	1444	19582	1756



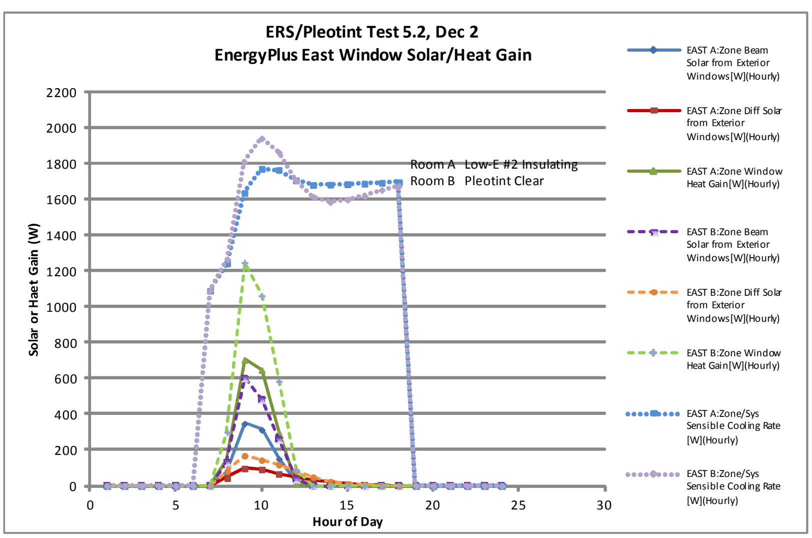
	Daily Zone Beam Solar (W)	Daily Zone Diffuse Solar (W)	Daily Zone Window Heat Gain (W)	Daily Zone Cooling Load (W)	Daily Zone Light Load (W)
Room A Low-E #2 Insulating	67	409	349	20387	3352
Room B Pleotint Azuria	81	489	517	19685	2375



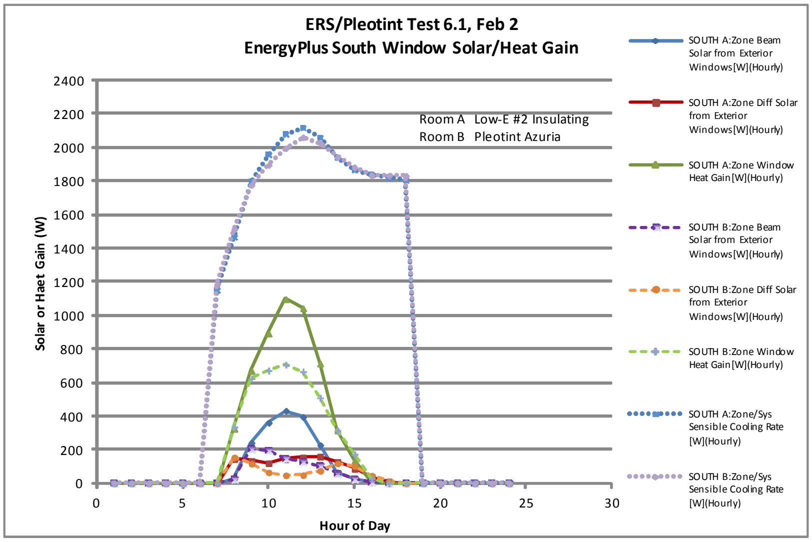
	Daily Zone Beam Solar (W)	Daily Zone Diffuse Solar (W)	Daily Zone Window Heat Gain (W)	Daily Zone Cooling Load (W)	Daily Zone Light Load (W)
Room A Low-E #2 Insulating	3810	464	6806	21965	1517
Room B Pleotint Clear	4557	604	9548	23764	1310



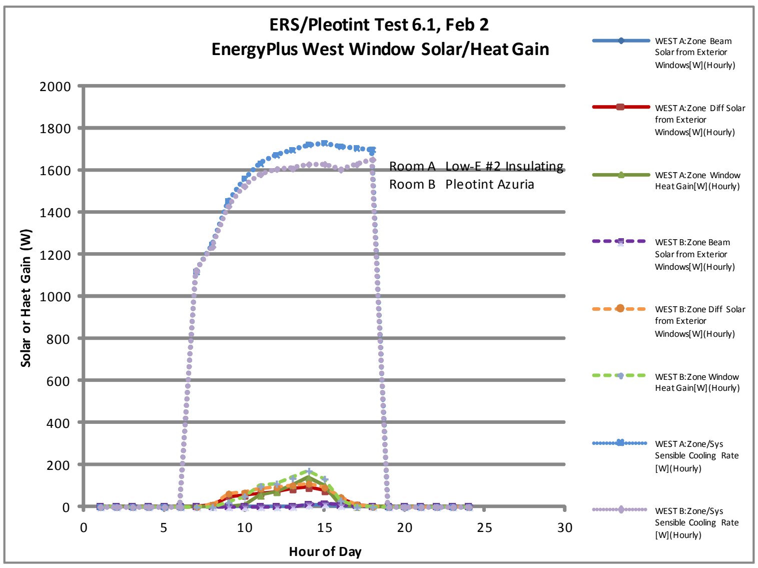
	Daily Zone Beam Solar (W)	Daily Zone Diffuse Solar (W)	Daily Zone Window Heat Gain (W)	Daily Zone Cooling Load (W)	Daily Zone Light Load (W)
Room A Low-E #2 Insulating	608	254	809	18150	3272
Room B Pleotint Clear	1100	490	1742	17884	1804



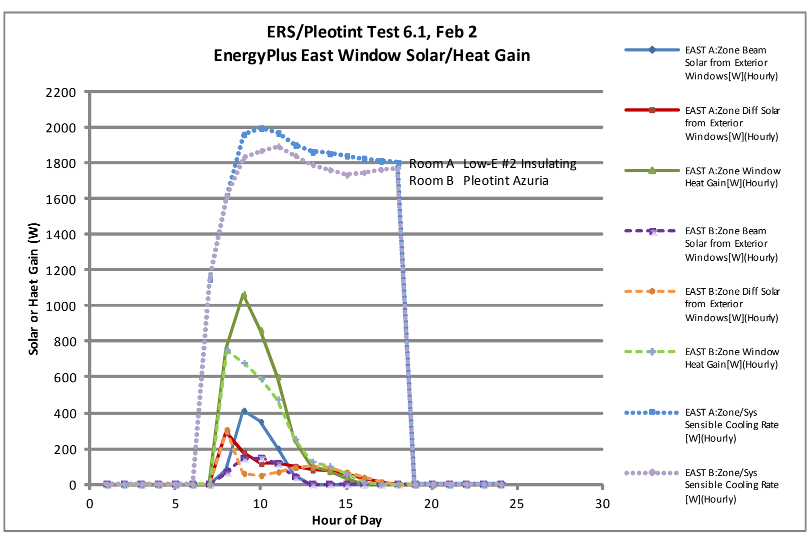
	Daily Zone Beam Solar (W)	Daily Zone Diffuse Solar (W)	Daily Zone Window Heat Gain (W)	Daily Zone Cooling Load (W)	Daily Zone Light Load (W)
Room A Low-E #2 Insulating	905	411	1803	19332	2766
Room B Pleotint Clear	1508	693	3282	19417	1705



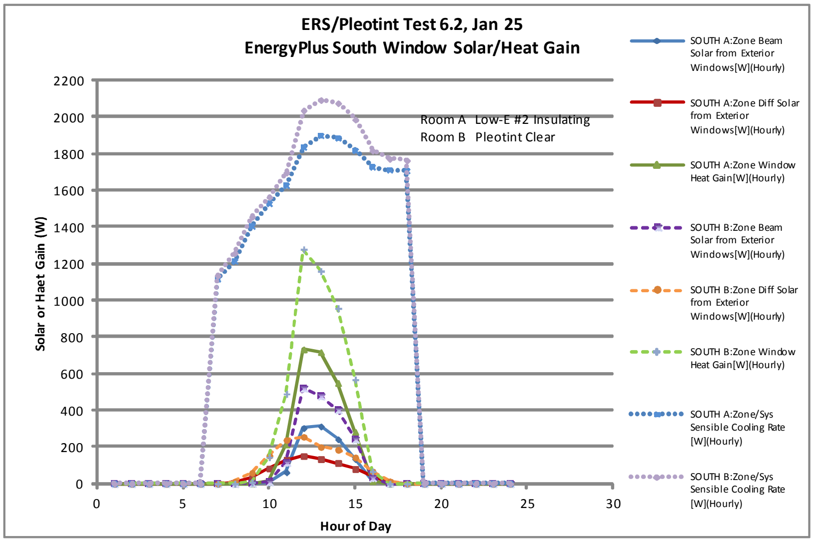
	Daily Zone Beam Solar (W)	Daily Zone Diffuse Solar (W)	Daily Zone Window Heat Gain (W)	Daily Zone Cooling Load (W)	Daily Zone Light Load (W)
Room A Low-E #2 Insulating	1784	1120	5202	21898	1761
Room B Pleotint Azuria	898	792	4031	21785	1854



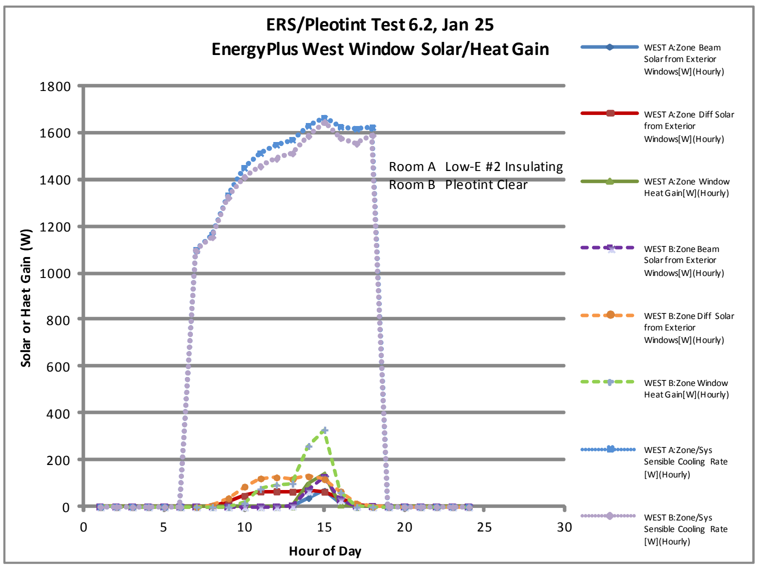
	Daily Zone Beam Solar (W)	Daily Zone Diffuse Solar (W)	Daily Zone Window Heat Gain (W)	Daily Zone Cooling Load (W)	Daily Zone Light Load (W)
Room A Low-E #2 Insulating	31	553	489	18930	3134
Room B Pleotint Azuria	38	694	754	18234	1881



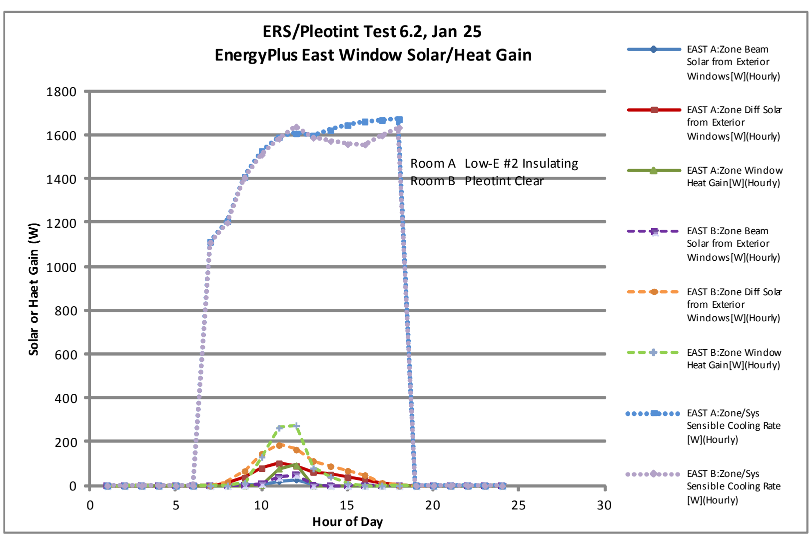
	Daily Zone Beam Solar (W)	Daily Zone Diffuse Solar (W)	Daily Zone Window Heat Gain (W)	Daily Zone Cooling Load (W)	Daily Zone Light Load (W)
Room A Low-E #2 Insulating	1099	1054	3751	21590	2350
Room B Pleotint Azuria	515	890	3056	20781	1730



	Daily Zone Beam Solar (W)	Daily Zone Diffuse Solar (W)	Daily Zone Window Heat Gain (W)	Daily Zone Cooling Load (W)	Daily Zone Light Load (W)
Room A Low-E #2 Insulating	1081	776	2523	19470	2148
Room B Pleotint Clear	1803	1329	4675	20660	1729



	Daily Zone Beam Solar (W)	Daily Zone Diffuse Solar (W)	Daily Zone Window Heat Gain (W)	Daily Zone Cooling Load (W)	Daily Zone Light Load (W)
Room A Low-E #2 Insulating	126	449	249	17813	2971
Room B Pleotint Clear	227	828	938	17378	1591



	Daily Zone Beam Solar (W)	Daily Zone Diffuse Solar (W)	Daily Zone Window Heat Gain (W)	Daily Zone Cooling Load (W)	Daily Zone Light Load (W)
Room A Low-E #2 Insulating	55	503	172	18326	2831
Room B Pleotint Clear	97	913	810	17963	1798

Appendix E
Comparison of Room Cooling Loads Over Test Periods

Room Sensible Cooling Load Comparison (Btu) - ERS Versus EnergyPlus
ERS/Pleotint Test 2.1
May 24 - 31, 2011

Test Room	ERS (BTU)	EnergyPlus (BTU)	Difference (%)
East A	161,328	130,976	-18.8%
East B	170,412	114,726	-32.7%
South A	148,421	115,859	-21.9%
South B	150,181	102,915	-31.5%
West A	135,017	127,251	-5.8%
West B	141,209	111,358	-21.1%
Internal A	174,261	104,346	-40.1%
Internal B	172,660	104,705	-39.4%

Room Sensible Cooling Load Comparison (Btu) - Room B versus Room A
ERS/Pleotint Test 2.1
May 24 - 31, 2011

	ERS - >				EnergyPlus - >			
Exposure	**Room A**	**Room B**	**Diff**	**% Diff**	**Room A**	**Room B**	**Diff**	**% Diff**
South	148,421	150,181	1,760	1.2%	115,859	102,915	(12,944)	-11.2%
West	135,017	141,209	6,192	4.6%	127,251	111,358	(15,894)	-12.5%
East	161,328	170,412	9,085	5.6%	130,976	114,726	(16,250)	-12.4%
Internal	174,261	172,660	(1,601)	-0.9%	104,346	104,705	359	0.3%
Totals	619,027	634,462	15,435	2.5%	478,432	433,703	(44,729)	-9.3%

Room Sensible Cooling Load Comparison (Btu) - ERS Versus EnergyPlus
ERS/Pleotint Test 2.2
June 2 - 12, 2011

Test Room	ERS (BTU)	EnergyPlus (BTU)	Difference (%)
East A	303,179	244,666	-19.3%
East B	330,838	238,928	-27.8%
South A	297,724	211,392	-29.0%
South B	288,264	204,251	-29.1%
West A	290,864	223,716	-23.1%
West B	278,398	217,207	-22.0%
Internal A	282,701	163,080	-42.3%
Internal B	266,204	163,720	-38.5%

Room Sensible Cooling Load Comparison (Btu) - Room B versus Room A
ERS/Pleotint Test 2.2
June 2 - 12, 2011

	ERS - >				EnergyPlus - >			
Exposure	Room A	Room B	Diff	% Diff	Room A	Room B	Diff	% Diff
South	297,724	288,264	(9,460)	-3.2%	211,392	204,251	(7,141)	-3.4%
West	290,864	278,398	(12,466)	-4.3%	223,716	217,207	(6,508)	-2.9%
East	303,179	330,838	27,659	9.1%	244,666	238,928	(5,738)	-2.3%
Internal	282,701	266,204	(16,497)	-5.8%	163,080	163,720	640	0.4%
Totals	1,174,468	1,163,704	(10,764)	-0.9%	842,854	824,106	(18,747)	-2.2%

Room Sensible Cooling Load Comparison (Btu) - ERS Versus EnergyPlus
ERS/Pleotint Test 3.1
July 29 - August 7, 2011

Test Room	ERS (BTU)	EnergyPlus (BTU)	Difference (%)
East A	1,133,107	885,302	-21.9%
East B	1,091,775	880,120	-19.4%
South A	839,625	872,727	3.9%
South B	930,981	867,118	-6.9%
West A	1,082,785	867,957	-19.8%
West B	935,711	846,967	-9.5%
Internal A	861,109	828,329	-3.8%
Internal B	792,565	820,361	3.5%

Room Sensible Cooling Load Comparison (Btu) - Room B versus Room A
ERS/Pleotint Test 3.1
July 29 - August 7, 2011

	ERS - >				EnergyPlus - >			
Exposure	**Room A**	**Room B**	**Diff**	**% Diff**	**Room A**	**Room B**	**Diff**	**% Diff**
South	839,625	930,981	91,355	10.9%	872,727	867,118	(5,609)	-0.6%
West	1,082,785	935,711	(147,074)	-13.6%	867,957	846,967	(20,990)	-2.4%
East	1,133,107	1,091,775	(41,333)	-3.6%	885,302	880,120	(5,182)	-0.6%
Internal	861,109	792,565	(68,544)	-8.0%	828,329	820,361	(7,968)	-1.0%
Totals	3,916,626	3,751,031	(165,595)	-4.2%	3,454,315	3,414,566	(39,749)	-1.2%

Room Sensible Cooling Load Comparison (Btu) - ERS Versus EnergyPlus
ERS/Pleotint Test 3.2
August 9 - 15, 2011

Test Room	ERS (BTU)	EnergyPlus (BTU)	Difference (%)
East A	781,204	635,635	-18.6%
East B	740,067	630,577	-14.8%
South A	589,960	609,681	3.3%
South B	661,991	613,062	-7.4%
West A	731,954	602,692	-17.7%
West B	627,282	598,211	-4.6%
Internal A	613,675	579,346	-5.6%
Internal B	574,648	573,804	-0.1%

Room Sensible Cooling Load Comparison (Btu) - Room B versus Room A
ERS/Pleotint Test 3.2
August 9 - 15, 2011

	ERS - >				EnergyPlus - >			
Exposure	**Room A**	**Room B**	**Diff**	**% Diff**	**Room A**	**Room B**	**Diff**	**% Diff**
South	589,960	661,991	72,031	12.2%	609,681	613,062	3,381	0.6%
West	731,954	627,282	(104,672)	-14.3%	602,692	598,211	(4,481)	-0.7%
East	781,204	740,067	(41,138)	-5.3%	635,635	630,577	(5,058)	-0.8%
Internal	613,675	574,648	(39,027)	-6.4%	579,346	573,804	(5,542)	-1.0%
Totals	2,716,794	2,603,988	(112,806)	-4.2%	2,427,354	2,415,654	(11,700)	-0.5%

Room Sensible Cooling Load Comparison (Btu) - ERS Versus EnergyPlus
ERS/Pleotint Test 4.1
Sep 28 - Oct 4, 2011

Test Room	ERS (BTU)	EnergyPlus (BTU)	Difference (%)
East A	727,735	579,998	-20.3%
East B	568,887	565,873	-0.5%
South A	634,013	609,623	-3.8%
South B	640,910	608,123	-5.1%
West A	608,290	560,661	-7.8%
West B	530,702	546,727	3.0%
Internal A	617,085	563,011	-8.8%
Internal B	580,517	557,427	-4.0%

Room Sensible Cooling Load Comparison (Btu) - Room B versus Room A
ERS/Pleotint Test 4.1
Sep 28 - Oct 4, 2011

	ERS - >				EnergyPlus - >			
Exposure	**Room A**	**Room B**	**Diff**	**% Diff**	**Room A**	**Room B**	**Diff**	**% Diff**
South	634,013	640,910	6,897	1.1%	609,623	608,123	(1,500)	-0.2%
West	608,290	530,702	(77,589)	-12.8%	560,661	546,727	(13,934)	-2.5%
East	727,735	568,887	(158,848)	-21.8%	579,998	565,873	(14,125)	-2.4%
Internal	617,085	580,517	(36,567)	-5.9%	563,011	557,427	(5,584)	-1.0%
Totals	2,587,123	2,321,016	(266,107)	-10.3%	2,313,293	2,278,150	(35,143)	-1.5%

Room Sensible Cooling Load Comparison (Btu) - ERS Versus EnergyPlus
ERS/Pleotint Test 4.2
October 6 - 12, 2011

Test Room	ERS (BTU/Hr)	EnergyPlus (BTU/Hr)	Difference (%)
East A	703,276	566,235	-19.5%
East B	602,444	560,423	-7.0%
South A	609,268	583,537	-4.2%
South B	660,476	595,695	-9.8%
West A	622,137	545,669	-12.3%
West B	557,746	542,750	-2.7%
Internal A	621,040	557,723	-10.2%
Internal B	585,622	552,143	-5.7%

Room Sensible Cooling Load Comparison (Btu) - Room B versus Room A
ERS/Pleotint Test 4.2
October 6 - 12, 2011

	ERS - >				EnergyPlus - >			
Exposure	**Room A**	**Room B**	**Diff**	**% Diff**	**Room A**	**Room B**	**Diff**	**% Diff**
South	609,268	660,476	51,209	8.4%	583,537	595,695	12,158	2.1%
West	622,137	557,746	(64,391)	-10.3%	545,669	542,750	(2,919)	-0.5%
East	703,276	602,444	(100,832)	-14.3%	566,235	560,423	(5,812)	-1.0%
Internal	621,040	585,622	(35,418)	-5.7%	557,723	552,143	(5,580)	-1.0%
Totals	2,555,721	2,406,289	(149,432)	-5.8%	2,253,164	2,251,011	(2,153)	-0.1%

Room Sensible Cooling Load Comparison (Btu) - ERS Versus EnergyPlus
ERS/Pleotint Test 5.1
Nov 23 - 30, 2011

Test Room	ERS (BTU)	EnergyPlus (BTU)	Difference (%)
East A	473,278	552,401	16.7%
East B	370,010	539,763	45.9%
South A	485,018	584,427	20.5%
South B	530,306	583,682	10.1%
West A	340,150	472,027	38.8%
West B	359,537	525,056	46.0%
Internal A	679,382	616,561	-9.2%
Internal B	635,874	610,035	-4.1%

Room Sensible Cooling Load Comparison (Btu) - Room B versus Room A
ERS/Pleotint Test 5.1
Nov 23 - 30, 2011

	ERS - >				EnergyPlus - >			
Exposure	**Room A**	**Room B**	**Diff**	**% Diff**	**Room A**	**Room B**	**Diff**	**% Diff**
South	485,018	530,306	45,288	9.3%	584,427	583,682	(744)	-0.1%
West	340,150	359,537	19,386	5.7%	472,027	525,056	53,029	11.2%
East	473,278	370,010	(103,268)	-21.8%	552,401	539,763	(12,639)	-2.3%
Internal	679,382	635,874	(43,508)	-6.4%	616,561	610,035	(6,526)	-1.1%
Totals	1,977,827	1,895,726	(82,101)	-4.2%	2,225,416	2,258,536	33,120	1.5%

Room Sensible Cooling Load Comparison (Btu) - ERS Versus EnergyPlus
ERS/Pleotint Test 5.2
December 2 - 9, 2011

Test Room	ERS (BTU)	EnergyPlus (BTU)	Difference (%)
East A	354,131	499,959	41.2%
East B	275,452	477,824	73.5%
South A	375,915	512,306	36.3%
South B	406,075	532,033	31.0%
West A	280,402	484,873	72.9%
West B	259,932	474,797	82.7%
Internal A	685,306	599,958	-12.5%
Internal B	650,113	593,429	-8.7%

Room Sensible Cooling Load Comparison (Btu) - Room B versus Room A
ERS/Pleotint Test 5.2
December 2 - 9, 2011

	ERS - >				EnergyPlus - >			
Exposure	**Room A**	**Room B**	**Diff**	**% Diff**	**Room A**	**Room B**	**Diff**	**% Diff**
South	375,915	406,075	30,161	8.0%	512,306	532,033	19,727	3.9%
West	280,402	259,932	(20,470)	-7.3%	484,873	474,797	(10,076)	-2.1%
East	354,131	275,452	(78,679)	-22.2%	499,959	477,824	(22,135)	-4.4%
Internal	685,306	650,113	(35,193)	-5.1%	599,958	593,429	(6,529)	-1.1%
Totals	1,695,754	1,591,572	(104,182)	-6.1%	2,097,096	2,078,083	(19,013)	-0.9%

Room Sensible Cooling Load Comparison (Btu) - ERS Versus EnergyPlus
ERS/Pleotint Test 6.1
Feb 2 - 7, 2012

Test Room	ERS (BTU)	EnergyPlus (BTU)	Difference (%)
East A	298,485	386,112	29.4%
East B	216,588	373,961	72.7%
South A	293,353	392,300	33.7%
South B	300,659	391,376	30.2%
West A	227,412	367,358	61.5%
West B	198,651	356,988	79.7%
Internal A	520,790	448,034	-14.0%
Internal B	477,040	443,161	-7.1%

Room Sensible Cooling Load Comparison (Btu) - Room B versus Room A
ERS/Pleotint Test 6.1
Feb 2 - 7, 2012

	ERS - >				EnergyPlus - >			
Exposure	**Room A**	**Room B**	**Diff**	**% Diff**	**Room A**	**Room B**	**Diff**	**% Diff**
South	293,353	300,659	7,306	2.5%	392,300	391,376	(924)	-0.2%
West	227,412	198,651	(28,761)	-12.6%	367,358	356,988	(10,369)	-2.8%
East	298,485	216,588	(81,897)	-27.4%	386,112	373,961	(12,152)	-3.1%
Internal	520,790	477,040	(43,750)	-8.4%	448,034	443,161	(4,873)	-1.1%
Totals	1,340,040	1,192,937	(147,102)	-11.0%	1,593,804	1,565,486	(28,318)	-1.8%

Room Sensible Cooling Load Comparison (Btu) - ERS Versus EnergyPlus
ERS/Pleotint Test 6.2
Jan 25 - 31, 2012

Test Room	ERS (BTU)	EnergyPlus (BTU)	Difference (%)
East A	391,028	474,691	21.4%
East B	282,272	465,574	64.9%
South A	384,700	504,786	31.2%
South B	463,441	533,225	15.1%
West A	272,568	445,079	63.3%
West B	229,998	436,955	90.0%
Internal A	608,834	522,434	-14.2%
Internal B	564,451	516,752	-8.5%

Room Sensible Cooling Load Comparison (Btu) - Room B versus Room A
ERS/Pleotint Test 6.2
Jan 25 - 31, 2012

	ERS - >				EnergyPlus - >			
Exposure	**Room A**	**Room B**	**Diff**	**% Diff**	**Room A**	**Room B**	**Diff**	**% Diff**
South	384,700	463,441	78,741	20.5%	504,786	533,225	28,440	5.6%
West	272,568	229,998	(42,570)	-15.6%	445,079	436,955	(8,123)	-1.8%
East	391,028	282,272	(108,756)	-27.8%	474,691	465,574	(9,117)	-1.9%
Internal	608,834	564,451	(44,382)	-7.3%	522,434	516,752	(5,682)	-1.1%
Totals	1,657,130	1,540,163	(116,967)	-7.1%	1,946,989	1,952,507	5,517	0.3%