ORNL/TM-2013/560

High Performance Window Retrofit

December 2013

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Content

List of Figures

List of Tables

Abstract

The US Department of Energy (DOE) Office of Energy Efficiency and Renewable Energy (EERE) and Traco partnered to develop high-performance windows for commercial building that are cost-effective. The main performance requirement for these windows was that they needed to have an R-value of at least 5 $ft^2 \cdot F \cdot h/Btu$. This project seeks to quantify the potential energy savings from installing these windows in commercial buildings that are at least 20 years old. To this end, we are conducting evaluations at a two-story test facility that is representative of a commercial building from the 1980s, and are gathering measurements on the performance of its windows before and after double-pane, clear-glazed units are upgraded with R5 windows. Additionally, we will use these data to calibrate EnergyPlus models that we will allow us to extrapolate results to other climates. Findings from this project will provide empirical data on the benefits from high-performance windows, which will help promote their adoption in new and existing commercial buildings. This report describes the experimental setup, and includes some of the field and simulation results.

1. Introduction

Buildings consume approximately 40% of the energy used in the US. According to the 2003 Commercial Buildings Energy Consumption Survey (US Energy Information Administration 2003), light commercial buildings, which are defined in this report as structures with a floor area less than 50,000 ft^2, are responsible for about 20% of this energy usage. Given that nearly 70% of these buildings are at least 20 years old, their building envelopes likely have:

- Minimal or no thermal insulation
- High air leakage rates
- Clear-glazed, single-pane windows

Therefore, there is ample opportunity to improve the energy efficiency of light commercial structures by retrofitting their envelopes.

The Building Technology Research and Integration Center (BTRIC) at Oak Ridge National Laboratory (ORNL) has the expertise and facilities to assess the effectiveness of retrofitting techniques that are suitable for commercial buildings. In 2013, the Flexible Research Platforms (FRPs) were completed at the ORNL campus. These facilities consist of permanent structures where different building envelopes, as well as various heating, ventilation, and air conditioning (HVAC) systems can be evaluated while being subjected to natural environmental conditions (Figure 1). The one-story platform has a 40’×60’ footprint, and the two-story structure covers a 40’×40’ area. In order to expand the capabilities of these facilities, both FRPs have “active foundations” that can thermally isolate the buildings from the ground. A more detailed description of these platforms is provided by Hughes (2012).

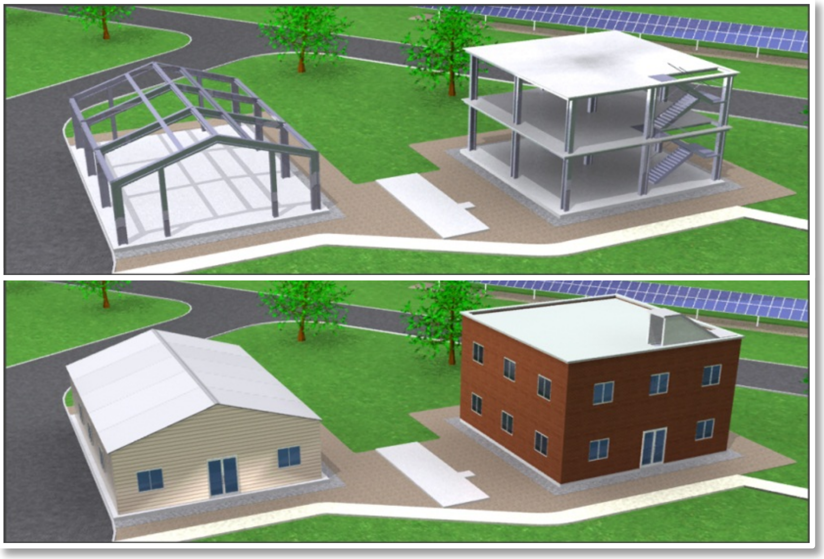

Figure 1. Renderings of the Flexible Research Platforms. Top: permanent structures. Bottom: cladded structures.

Current research at the FRPs focuses on how to effectively retrofit buildings from the 1980s (Figure 2). Work at the one-story FRP aims to improve the energy efficiency of metal buildings given that metal buildings account for about 40% of the nation's light commercial building construction based on floor area. The two-story FRP presently simulates commercial buildings from the 10-county Greater Philadelphia region, which are primarily steel structures with brick facades over masonry walls. The collection of 12-month baseline data was initiated in the summer of 2013; afterwards, various retrofitting techniques will be studied in detail.

Figure 2. Flexible Research Platforms cladded to emulate 1980s metal buildings (left) and office buildings from the 10-county Greater Philadelphia region (right).

One of the first retrofits that will take place in the two-story FRP is to upgrade the baseline windows. This effort is a continuation of the project "R5 Commercial Windows" where the Department of Energy and Traco partnered to develop cost-effective, high-performance windows for commercial buildings. DOE's interest in windows is based on computer simulations that indicate that heat losses through these units account for approximately 22% of the heating loads in commercial buildings (Huang and Franconi 1999). The present project seeks to use data from the 2 story FRP to quantify the potential energy savings from changing double-pane, clear-glazed units (R-value = 2 ft^2·F·h/Btu) with Traco's OptiQTM Ultra Thermal windows (Figure 3) that have an R-value of 5 ft^2·F·h/Btu due to triple glazing and insulated framing. To this end, we will gather measurements before and after the retrofit. Furthermore, we will use these data to calibrate EnergyPlus models that will allow us to extrapolate our findings to other climates. In this report we describe the experimental setup, include a sample of the data collected thus far, and show how the field measurements compare to results from our simulations.

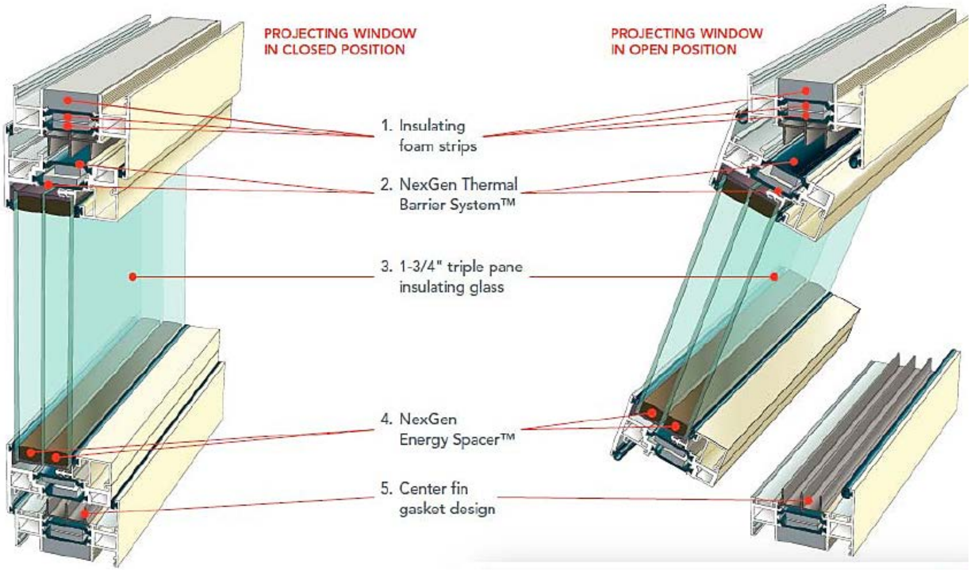

Figure 3. Traco's OptiQ^{TM} Ultra Thermal windows (Source: http://www.kawneer.com/kawneer/north_america/en/product.asp?prod_id=4306).

2. Methodology

The performance of the baseline windows is being evaluated by monitoring a few key parameters. Solar radiation transmitted through windows to the conditioned space is being measured with precision spectral pyranometers installed on the east, south, and west facing units. In order to calculate convection and radiation heat exchanges between the windows and the indoor space, temperature measurements are being collected at the center of the glass, glass temperatures at 6 cm from the window frame, the window frame and the temperature of each room.

A weather station sits on the roof of the two-story FRP. The station measures the following radiation parameters: direct beam radiation, global horizontal radiation, and infrared radiation from the sky. Other outdoor parameters being monitored include barometric pressure, wind speed and direction, rainfall, air temperature, and relative humidity. EnergyPlus weather file (epw) was created using data from the weather station. The epw file was used to run EnergyPlus to benchmark simulation results against field-measured data, and to predict net heat gain/loss through windows.

2.1 Sensors

Table 1 describes the sensors being used at the FRPs. Figure 4 shows some of the instruments installed at FRP.

Table 1. Sensor description.

Parameter	Manufacturer	Sensor Model
Wall panels and indoors		
Temperature	Honeywell/Fenwal	192-103LET-A01
Relative humidity	Honeywell	HIH-4000
Heat flux	Concept Engineering	F-002-4
Transmitted solar radiation through windows	Eppley	PSP
Pressure	Energy Conservatory	APT
Weather station		
Temperature	Campbell Scientific	CS215
Relative humidity	Campbell Scientific	CS215
Wind speed/direction	Gill	WindSonic
Rainfall	Texas Electronics	TE525WS
Global Horizontal solar radiation	LI-COR	LI-200X
Direct beam radiation	Eppley	NIP
IR radiation from sky	Eppley	PIR
Solar radiation on vertical surfaces	Campbell Scientific	LI-200X
Atmospheric pressure	Vaisala	CS106

Figure 4. Weather station and windows performance evaluation sensors.

2.2 EnergyPlus Model

An EnergyPlus model of the two-story FRP building was developed using actual construction details. Important parameters such as the location and properties of windows were verified with field measurements. The “WindowMaterial:SimpleGlazingSystem” option was used to model the windows in EnergyPlus. Figure 5 shows a rendering of the EnergyPlus model of the building. The building has window-to-wall ratios of about 27%.

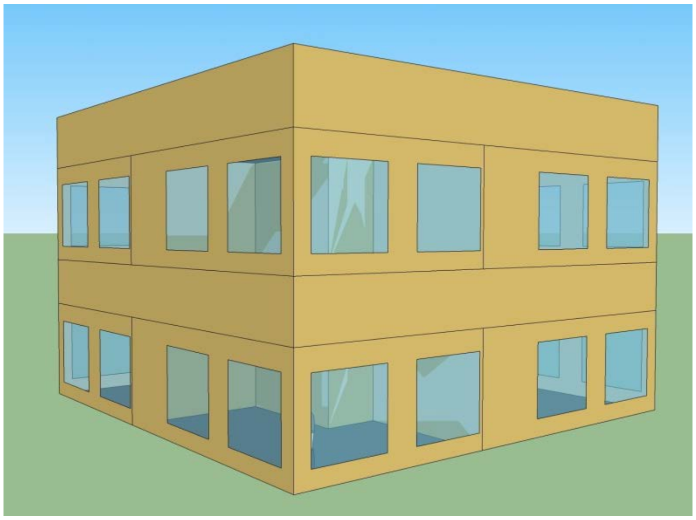

Figure 5. Rendering of the EnergyPlus model of the two-story FRP building.

3. Results and Discussion

3.1 Baseline Window Properties

The installed baseline windows have a thermally-broken aluminum frame and two layers of clear glass with ½” air gap between panes. The solar transmittance and solar heat gain coefficient (SHGC) of the glazing was measured using the EDTM Window Energy Profiler. Figure 6 shows the dimensions of the baseline windows and Table 2 lists the measured properties at four sides of the windows (M1 to M4) and their average values.

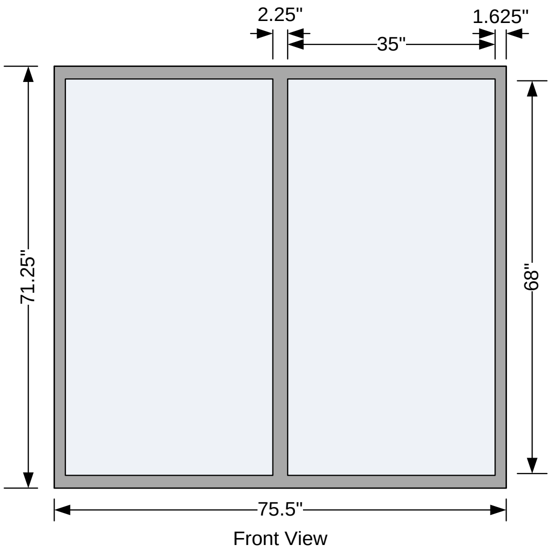

Figure 6. Dimensions of the baseline windows.

Table 2. Measured properties of the baseline window glazing.

Location	Measurement	UV (A) (< 400 nm) Transmittance	Visible (400 - 700 nm) Transmittance	Near Infrared (> 700 nm) Transmittance	Estimated SHGC
Stairwell	M1	0.53	0.79	0.65	0.78
	M2	0.53	0.79	0.65	0.78
	M3	0.53	0.79	0.66	0.78
	M4	0.52	0.79	0.66	0.78
	Average	**0.53**	**0.79**	**0.66**	**0.78**
North Room	M1	0.52	0.79	0.66	0.78
	M2	0.53	0.79	0.66	0.78
	M3	0.53	0.80	0.66	0.78
	M4	0.53	0.79	0.65	0.78
	Average	**0.53**	**0.79**	**0.66**	**0.78**
North-West Room	M1	0.54	0.80	0.65	0.78
	M2	0.51	0.79	0.65	0.78
	M3	0.52	0.80	0.65	0.78
	Average	**0.52**	**0.80**	**0.65**	**0.78**
South-West Room	M1	0.53	0.79	0.65	0.78
	M2	0.53	0.79	0.65	0.78
	M3	0.53	0.80	0.65	0.78
	M4	0.51	0.79	0.65	0.78
	Average	**0.53**	**0.79**	**0.65**	**0.78**
South-East Room	M1	0.52	0.79	0.65	0.78
	M2	0.51	0.79	0.65	0.78
	M3	0.53	0.80	0.65	0.78
	M4	0.54	0.80	0.65	0.78
	Average	**0.53**	**0.80**	**0.65**	**0.78**

3.2 Field Measured Data

The accuracy of measured solar data from the weather station is an important parameter required by EnergyPlus to predict solar radiation transmitted through windows. To assure that the measured solar radiation was reasonable, the field measured data were compared to solar radiation predictions from the ASHRAE clear sky model during a fairly clear sky day in September. Figure 7 compares the measured direct beam solar radiation to the model predicted values. The measured data matched fairly well with the model predicted values. However, early morning and late evening measurements were cutoff because of shadows casted by small hills on east and north-west side of the building.

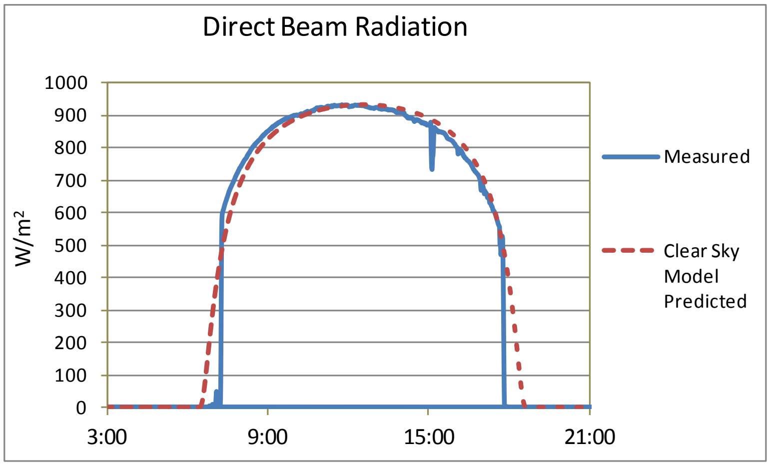

Figure 7. Comparison of direct beam radiation measured at the two-story Flexible Research Platform and estimated with the ASHRAE clear sky model.

3.3 Comparison between Field Measured Data and EnergyPlus Simulation Results

Figures 8 to 10 compare measured transmitted solar radiation through east, south, and west-facing windows with EnergyPlus predicted values during two days in September. The two days were selected such that one day had fairly clear sky condition (first day) and another day was partly cloudy (second day). Table 3 presents the maximum, minimum, and average difference between measured and EnergyPlus predicted hourly transmitted solar radiation through windows. Only the data from dawn to dusk (6:00 am to 7:00 pm) was used for this analysis. Even though the average difference is fairly low, the maximum differences were significantly high at some hours. In general, EnergyPlus predicted values were higher than measured values during morning hours and lower during noon and evening hours. Additionally, the measured and model predicted transmitted solar radiation were in better for agreement in the south window than in the east and west windows. As discussed earlier, “WindowMaterial:SimpleGlazingSystem” was used to model the windows in EnergyPlus. Reasons for the observed discrepancies will be explored as this study progresses.

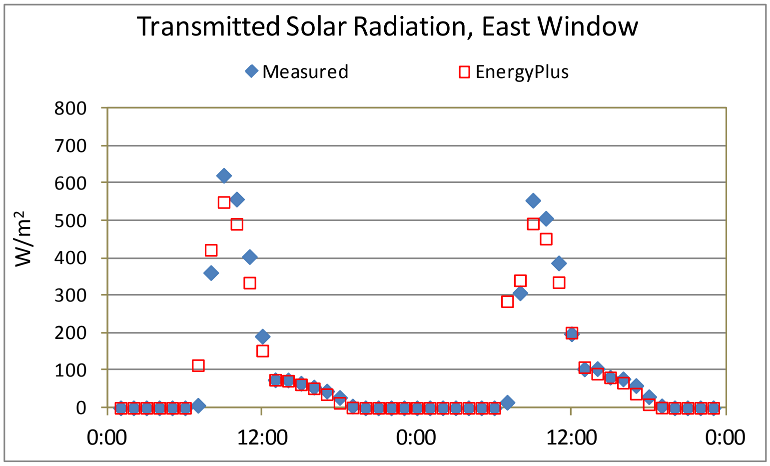

Figure 8. Comparison between measured and EnergyPlus predicted transmitted solar radiation through the east-facing window.

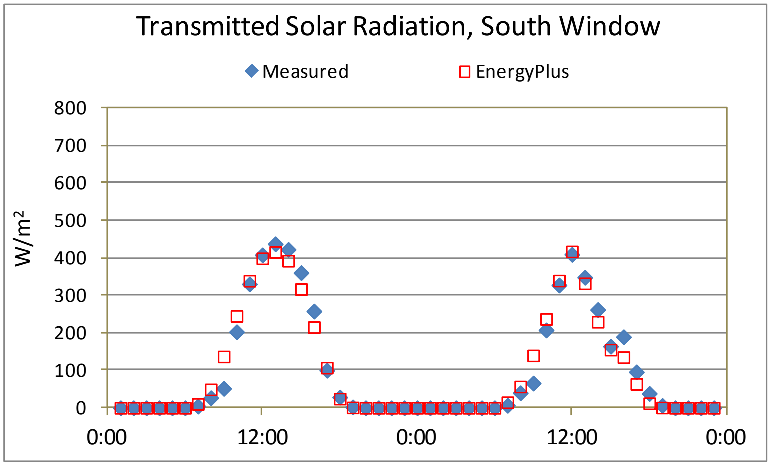

Figure 9. Comparison between measured and EnergyPlus predicted transmitted solar radiation through the south-facing window.

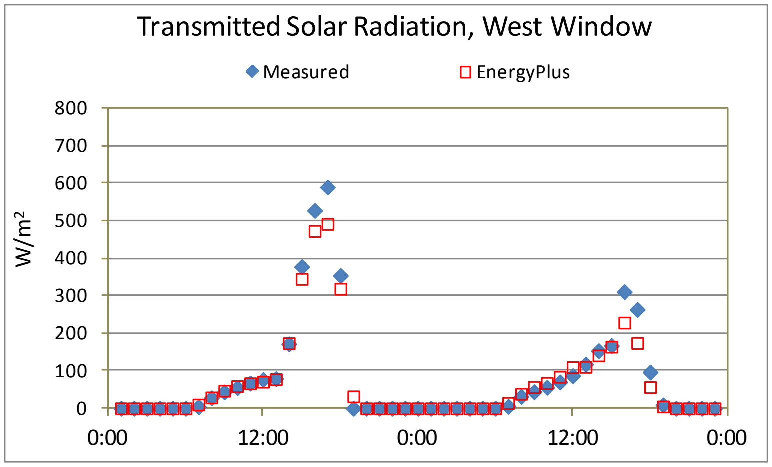

Figure 10. Comparison between measured and EnergyPlus predicted transmitted solar radiation through the west-facing window.

Table 3. Difference between measured and EnergyPlus predicted transmitted solar radiation, W/m^2.

	Maximum	Minimum	Average
East Window	71.3	-269.7	1.5
South Window	54.3	-85.0	0.4
West Window	98.2	-31.9	13.1

For the same two days in September, Figures 11 to 13 compare measured and model predicted temperatures of the indoor and outdoor center of the glass surfaces of the east, south, and west-facing windows. Table 4 presents the maximum, minimum, and average differences between measured and EnergyPlus predicted hourly surface temperatures. Results indicate that EnergyPlus predicted surface temperatures were higher than measured values, except for the outdoor surface measurements from the south-facing window. As noted earlier, reasons for the discrepancies will be examined in the near future.

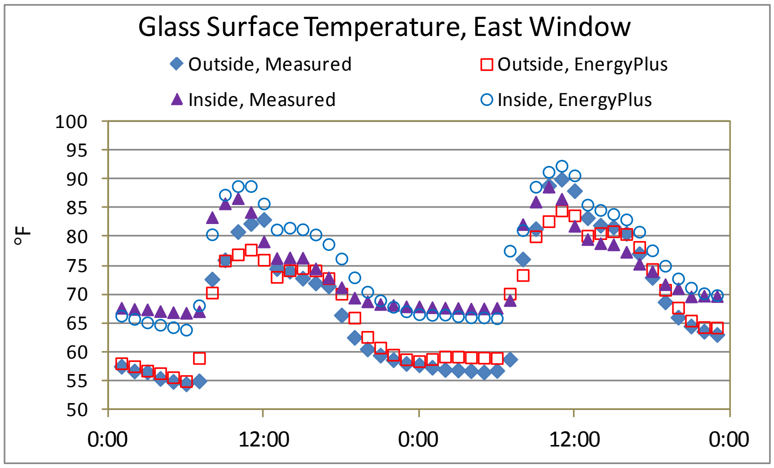

Figure 11. Comparison between measured and EnergyPlus predicted glass surface temperature at the east-facing window.

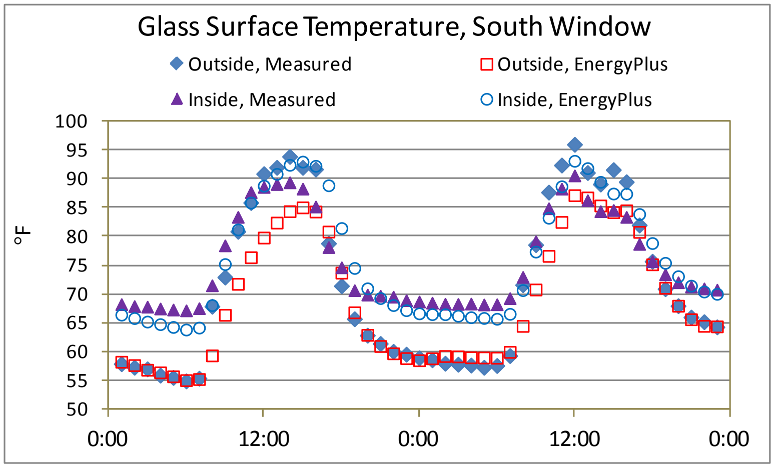

Figure 12. Comparison between measured and EnergyPlus predicted glass surface temperature at the south-facing window.

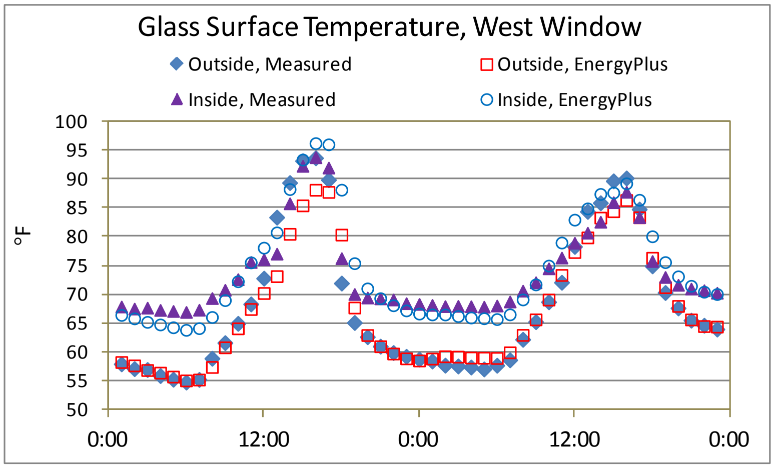

Figure 13. Comparison between measured and EnergyPlus predicted glass surface temperature at the west-facing window.

Table 4. Difference between measured and EnergyPlus predicted glass surface temperature, °F

	Maximum	Minimum	Average
East Facing, Indoor Side	3.0	-8.8	-1.9
South Facing, Indoor Side	3.4	-10.7	-0.3
West Facing, Indoor Side	3.3	-11.9	-0.5
East Facing, Outdoor Side	7.0	-11.4	-0.3
South Facing, Outdoor Side	11.1	-2.3	2.8
West Facing, Outdoor Side	10.2	-8.4	0.6

For the same two days, Figure 14 shows the EnergyPlus predicted net heat gain rate through the windows. The net heat gain rate is calculated as the difference between window heat gain rate and heat loss rate for a given time interval. EnergyPlus considers window heat gain rate as the total heat flow to the conditioned space from the glazing, frame and divider of an exterior window when the total heat flow is positive. The opposite is true for the window heat loss.

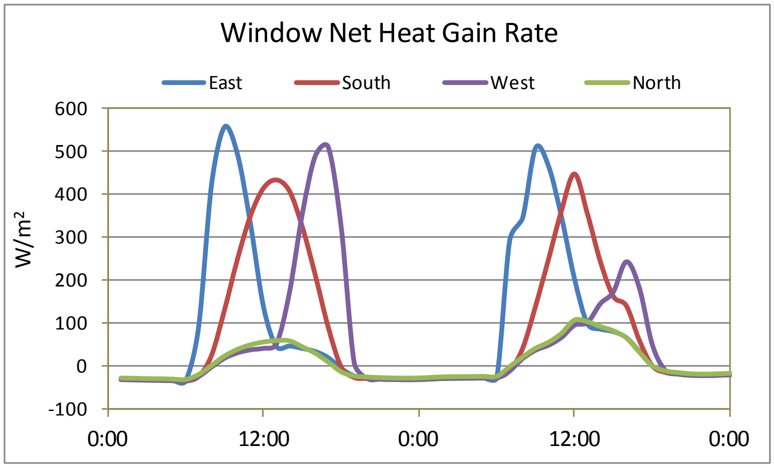

Figure 14. Net heat gain rate through windows.

Figure 15 shows the EnergyPlus calculated monthly net heat gain per unit area through the windows during August and September 2013. While the heat gain through the east and south-facing windows were greater during September compared to that during August, the opposite was true for the west and north-facing windows.

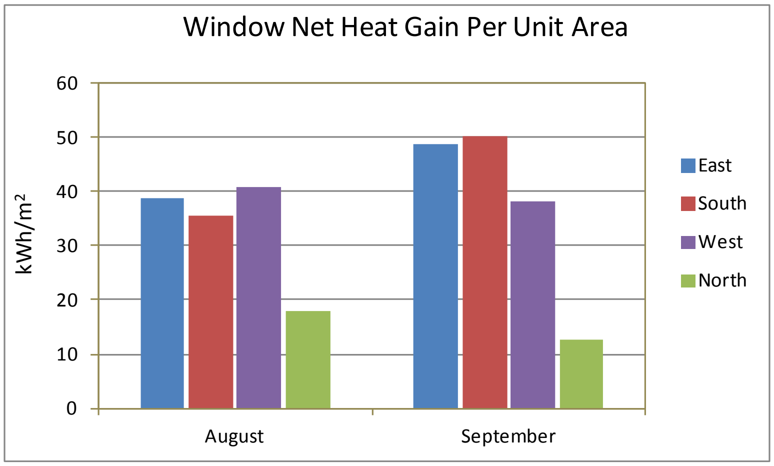

Figure 15. EnergyPlus predicted monthly net heat gain rate through windows.

4. Summary

This preliminary report describes the ongoing research at ORNL that intends to evaluate performance of high-performance R5 windows for commercial buildings that were developed by Traco with support from DOE, and to estimate potential energy savings from the usage of these windows in various climates. To that end, baseline windows with an R-value of 2 $ft^2 \cdot F \cdot h/Btu$ were installed at the two-story Flexible Research Platform building at ORNL, and their performance is being monitored. This report presents some of the data collected during August and September of 2013. EnergyPlus predicted transmitted solar radiation and glass surface temperatures were compared against the field measured data. Some discrepancies between the measured and EnergyPlus predicted values were noted. Reasons behind these differences will be assessed as this project continues. As a next step, a more detailed window model will be created in EnergyPlus that might reduce the observed discrepancies.

The baseline windows will be monitored for a year. Afterwards, these units will be replaced with R5 windows, and data will be collected for 12 months. The two-year database will be used to estimate the potential energy savings from the deployment of R5 windows to new and existing light commercial buildings. Results from this analysis will be strengthened by the fact that it will be based on empirical data. A final report will be issued summarizing all of these findings.

Acknowledgements

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