August 19, 2015

REPORT #E15-293

Secondary Glazing System (SGS) Thermal, Moisture, and Solar Performance Analysis and Validation

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Executive Summary

The Northwest Energy Efficiency Alliance (NEEA) is interested in accelerating the adoption of energy-saving building envelope products. The market NEEA is most interested in relative to secondary glazing systems (SGS) consists of existing multi-story office buildings with single glazed, non-thermally broken aluminum window frames constructed between the mid-1950s and the mid-1980s.

NEEA contracted with the Ernest Orlando Lawrence Berkeley National Laboratory to conduct a study, from which this report is based, which simulates and physically validates the thermal and solar performance characteristics of seven window attachment secondary glazing systems (SGS), also known as Fixed Window Panels, using industry standard practices. Where industry standard practices do not exist, such as condensation resistance (CR) between base glazing and SGS, this report introduces new methodology and software capabilities. This report also evaluates the annual energy savings and condensation potential of all SGS systems in prototype commercial buildings.

Solar heat gain coefficient (SHGC) and thermal transmittance (U-factor) simulation and validation methods are well-established for typical window products by the National Fenestration Rating Council (NFRC). These same procedures are shown to be translatable to SGS, and the performance values for SGS can be directly compared to other NFRC simulated products.

The NFRC CR rating is designed for comparison of room-side condensation potential. The condensation resistance of unsealed gaps (CRU) procedure developed in this report is intended to do the same for products with unsealed glazing cavities, such as SGS. The study team developed CRU assuming the same relative humidity of air as used in CR determination (30%, 50%, and 70% RH at 70 F), so that numbers are better comparable to CR.

A substantial part of the project constituted an extension of THERM and WINDOW software tools to model condensation resistance of unsealed gaps and to calculate CRU indices. The simulation and validation testing performed confirms that new revisions to WINDOW and THERM accurately predict local surface temperatures for unsealed gaps, and therefore provide accurate determination of CRU at predetermined humidity ratios. The reported CRU numbers seem to be mostly on the very low end (i.e., very poor performance) for all unsealed units due to the use of humidity ratios that are representative of indoor room air. This indicates the potential need for further research to establish expected moisture content in unsealed gaps for different product types and to relate them to indoor room air, so that researchers can develop more representative CRU procedures.

Researchers have conducted annual energy simulations of prototype commercial buildings using the EnergyPlus simulation tool for several different climates. The results show that all SGS products significantly reduce energy use in all climates and building types considered, with savings over the base single pane window of fifteen to forty percent. CRU calculations show that most SGS products significantly increase condensation risk in the unsealed gap; however, real performance in buildings might not reflect this behavior, as pointed out above.

1. Introduction

The Northwest Energy Efficiency Alliance (NEEA) is interested in accelerating the adoption of energy-saving building envelope products. The market NEEA is most interested in relative to secondary glazing systems (SGS) consists of existing multi-story office buildings with single glazed, non-thermally broken aluminum window frames constructed between the mid-1950s and the mid-1980s. For this project, SGS products are defined as one or more pane glazing units designed for insertion into existing commercial storefront or curtain wall systems with monolithic glazing. The SGS is installed from the interior with the intent of improving the thermal performance of the existing glazing system.

NEEA intends to encourage SGS manufacturers to measure the performance of their products using industry standard simulation or testing methods to allow building owners and design teams to effectively compare available product performance with consistent baseline conditions. A NEEA-contracted report by the Façade Group listed several recommendations for comparing performance characteristics of SGS. This proposal specifically addresses the performance testing and simulation of thermal transmittance (U-factor), solar heat gain coefficient (SHGC), visible transmittance (VT), and condensation resistance (CR) as outlined in that report.

This report has several objectives:

- First is to simulate and validate the performance characteristics of several SGS products using industry standard simulation methods to establish an initial database of SGS product performance. Where industry standard practices do not exist to quantify performance characteristics, such as CR between existing glazing and SGS, the project team has developed new methodologies and software capabilities to accurately predict performance.
- This report compares the energy savings and condensation potential of various SGS systems to a baseline system, with analysis performed using prototype commercial buildings.
- Finally, this report summarizes the work completed and methodology for simulation, validation, and energy analysis of additional SGS products that can be used in development of a SGS rating procedure.

2. Product Definitions

This project uses a single clear glazed non-thermally broken aluminum commercial storefront window frame as the baseline glazing system. It is designated as representative of commercial windows constructed between the mid-1950s and the mid-1980s. This project also uses a wide selection of SGS products representing the diversity of current commercially-available products.

All tested SGS use glass as the primary glazing material. Glazings vary from single pane glass to triple pane with a suspended center layer film. A minimum of one low-e coating is present in all systems, with the most-insulating products utilizing insulated glazing units (IGU) and multiple low-e coatings. Most systems support the glazing with aluminum framing that attaches directly to the inside dimensions of the base window, while one product attaches directly to the base window glass and another mounts external to the base frame. This report uses alphabetic designations throughout in order to maintain the anonymity of tested SGS.

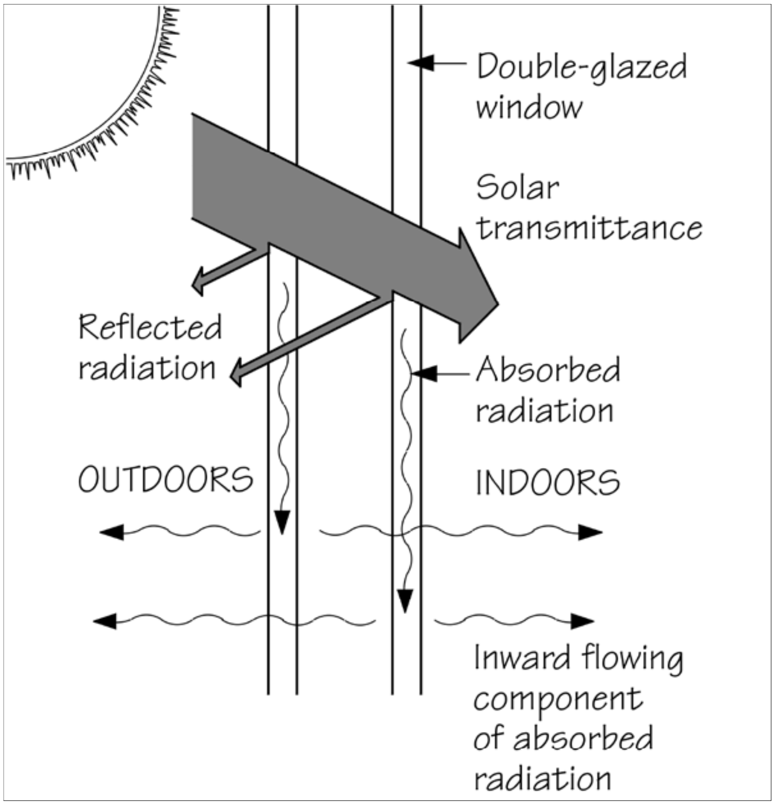
All tested SGS products create an insulating air space between the base window glass and the SGS glass. For the purposes of U-factor and SHGC calculations, this study considered all of these air spaces to be sealed and treated the same as a standard IGU. This assumption is shown to be valid under most conditions. For the purposes of condensation resistance, only hermetically sealed and desiccated cavities are considered sealed. All cavities that are neither hermetically sealed nor desiccated are considered unsealed, meaning they allow moisture to transfer from either the room-side or exterior environment. Only steady state conditions are simulated and tested in this report. This project did not study the rate of moisture transfer, even though it may be an important factor in condensation resistance of windows in buildings under normal operation.

3. Solar Heat Gain

3.1. Background

The intensity of building heat gain from solar radiation can greatly surpass heat gain from other sources, such as outdoor air temperature or humidity, and is therefore a primary energy performance characteristic of fenestration products. Solar heat gain is the direct and diffuse radiation coming directly from the sun and the sky or reflected from the ground and other surfaces. Some radiation is directly transmitted through the glazing to the space, and some may be absorbed in the glazing and then indirectly admitted to the space (Figure 1). While reducing solar radiation through fenestration products is a benefit in some climates and during some seasons, maximizing solar heat gain can be a significant energy benefit under winter conditions. These often-conflicting directives can make selection of the “best” product a challenging task.

Figure 1. A Glazing System’s Properties of Reflection, Transmission, and Absorption Determine What Happens to Solar Gain



Two means exist for indicating the amount of solar radiation that passes through a fenestration product: the solar heat gain coefficient (SHGC) and the shading coefficient (SC). In both cases, the solar heat gain is the combination of directly transmitted radiation and the inward-flowing portion of absorbed radiation. However, SHGC and SC have different bases for comparison or reference. SHGC is more commonly used than SC because it more correctly accounts for angle-dependent effects, so it will be utilized in this report.

SHGC represents the solar heat gain through the fenestration system relative to the incident solar radiation. Although SHGC can be determined for any angle of incidence, the most commonly-used reference is normal incidence solar radiation. The SHGC refers to total fenestration product system performance and is an accurate indication of solar gain under a wide range of conditions. SHGC is expressed as a dimensionless number from 0 to 1.0. A high SHGC value signifies high heat gain, while a low value means low heat gain (Mitchell et al. 2013).

3.2. Validation Methods

The SHGC is typically simulated for NFRC rating and certification. ANSI/NFRC 200-2014 (NFRC 2013) defines the procedure to simulate fenestration SHGC. When physical testing is required, NFRC 201-2014 (NFRC 2013) is used as the interim standard test method. The NFRC 200 simulation procedure is utilized by the LBNL-developed WINDOW simulation program and for all products in this report. The study team performed the NFRC 201 test on one product as a sample for verification. In addition to the standard methods, the team also determined SHGC for three products by utilizing the LBNL Mobile Window Thermal Test (MoWiTT) facility (Klems 1988).

3.2.1. Simulation

Table 1 presents simulated SHGC and visual transmittance (VT) for center-of-glass (COG) and in the NFRC standard fixed window size of 4’x5’. The products show a wide range of SHGC and VT reduction from the base window. The minimum impact/reduction is seen from Product E, while maximum impact is produced from Product D.

Table 1. Simulated Product SHGC and VT

	SHGC (-)	SHGC (-)	VT (-)
Product	Center-of-glass	Full frame (4’x5’ window)	
Base	0.82	0.72	0.75
A	0.37	0.30	0.45
B	0.43	0.37	0.52
C	0.35	0.31	0.47
D	0.27	0.24	0.41
E	0.66	0.54	0.58
F	0.42	0.34	0.43
G	0.57	0.49	0.51
H	0.38	0.32	0.48

3.2.2. Validation

Researchers performed SHGC validation on four products using the NFRC 201 method at an independent laboratory and at the LBNL MoWiTT facility. Researchers compared the simulated and measured SHGC for the specific product sizes required in the validation test method chosen. NFRC 200 does not give any tolerance limits for comparison of simulated and tested SHGC. The results shown in Table 2, however, show that agreement is within the uncertainty parameters of the test equipment. The researchers performed reported simulations for the same non-standard average sun angle and boundary conditions as were measured for each MoWiTT measurement. The reported MoWiTT measurements are the average of one or more trials with each product.

Table 2. Comparison of Simulated and Tested SHGC

Product	Method	Size	SHGC (-) Simulated	Measured	% Diff
Base	MoWiTT	35.75” x 47.75”	0.72	0.71	<1%
H	MoWiTT	35.75” x 47.75”	0.34	0.35	3%
E	MoWiTT	35.75” x 47.75”	0.53	0.58	9%
F	NFRC 201	47.25” x 59.00”	0.34	0.41	21%

4. Thermal Transmittance

4.1. Background

U-factor is the standard way to quantify the insulating value of fenestration products. It indicates the rate of heat flow through the fenestration. The U-factor is the total heat transfer coefficient of the fenestration system, in W/m2-°C (Btu/hr-ft2-°F), which includes conductive, convective, and radiative heat transfer for a given set of environmental conditions. It depends on the thermal properties of the materials in the fenestration product assembly, as well as on the weather conditions, such as the temperature differential between indoor and outside, and wind speed.

The U-factor of a total fenestration assembly is a combination of the insulating values of the glazing assembly itself, the edge effects that occur in the insulated glazing unit, and the insulating value of the frame and sash. The glazing portion of the fenestration unit is affected primarily by the total number of glazing layers, the dimension separating the various layers of glazing, the type of gas that fills the separation, and the characteristics of coatings on the various surfaces. The U-factor for the glazing alone is referred to as the COG U-factor. Since the U-factors are different for the glazing, edge-of-glazing zone, and frame, comparing U-factors can be misleading if they are not carefully described. In order to address this problem, the NFRC utilizes the concept of a total fenestration product U-factor. Researchers must follow a specific set of engineering assumptions and procedures to calculate the overall U-factor of a fenestration unit using the NFRC method. In most cases, the overall U-factor is higher than the U-factor for the glazing alone, since the glazing remains superior to the frame in insulating value.

The U-factor of a product is calculated with the product in a vertical position. A change in mounting angle can affect its U-factor (Mitchell et al. 2013).

4.2. Validation Methods

The U-factor is typically simulated by NFRC 100-2014 (NFRC 2013) and validated by NFRC 102-2014 (NFRC 2013) by product group to obtain NFRC rating and certification. NFRC has standardized the exterior conditions (called environmental conditions) of U-factor calculations for product ratings as outlined in NFRC 100. The NFRC 100 simulation procedure is utilized in the WINDOW simulation program and for all products in this report. The project team performed the NFRC 102 test on one product as a sample for verification. In addition to the standard method, the project team utilized the LBNL MoWiTT facility to determine the U-factor for three products (Klems 1988) and (Klems 1992).

4.2.1. Simulation

Table 3 presents simulated U-factors for COG and in the NFRC standard fixed window size of 4’x5’. The products show a wide range of U-factor reductions from the base window. The minimum impact/reduction is seen from Product F, while maximum impact is produced from Product E.

Table 3. Simulated Product U-Factors

	U-factor (BTU/h-ft2-F)	
Product	Center-of-glass	Full frame (4'x5' window)
Base	1.03	1.11
A	0.18	0.37
B	0.18	0.41
C	0.15	0.38
D	0.15	0.38
E	0.12	0.34
F	0.37	0.51
G	0.37	0.43
H	0.20	0.44

4.2.2. Validation

Researchers performed U-factor validation on four products using the NFRC 102 method at an independent laboratory and at non-standard conditions within the LBNL MoWiTT facility. The project team compared simulated and measured U-factors for the specific product sizes required in the validation test method chosen. Table 4 lists a summary of the results. Validation of simulated performance through NFRC 100 is achieved with a difference between tested and simulated U-factor of less than 10% when simulated U-factor is greater than or equal to 0.3 BTU/h-ft2-F, and less than 0.03 BTU/h-ft2-F when simulated U-factor is less than 0.3 BTU/h-ft2-F. All products tested in MoWiTT meet this validation requirement. Product E, tested according to the NFRC 102 requirements, did not. Investigation into the drivers behind the failed validation revealed that significant infiltration occurred from the cold side into the unsealed air space between the base window glazing and the SGS product. The product was sealed against infiltration, as is typically the case, on the room side only. This method is effective with typical window systems but is shown insufficient with SGS testing. Researchers performed MoWiTT validation testing with infiltration sealing on the outside surface.

The researchers performed reported simulations for the same non-standard boundary conditions as were measured for each MoWiTT measurement. In order to increase the measured heat flow signal, room temperature was held at 40°C. The reported MoWiTT measurements are the average of one or more trials with each product.

Table 4. Comparison of Simulated and Tested U-factor

			U-factor (BTU/h-ft2-F)		
Product	Method	Size	Simulated	Measured	% Diff
Base	MoWiTT	35.75" x 47.75"	1.03	1.01	1.7%
H	MoWiTT	35.75" x 47.75"	0.52	0.53	1.9%
F	MoWiTT	35.75" x 47.75"	0.50	0.54	8.7%
E	NFRC 101	47.25" x 59.00"	0.34	0.40	18%

5. Condensation Resistance

5.1. Background

Condensation has been a persistent and often misunderstood problem associated with windows. It occurs when the surface temperature of a window component drops below either the dew point or frost point of the air adjacent to the surface. In cold climates, single-glazed windows characteristically suffer from water condensation and the formation of frost on the inside surface of the glass in winter. Excessive condensation can contribute to the growth of mold or mildew, occurrences of rot, and damage to painted surfaces.

Condensation can also be a problem on the interior surfaces of window frames. Metal frames, in particular, conduct heat very quickly, and will “sweat” or frost up in cool weather. Solving this condensation problem constituted a major motivation for the development of thermal breaks for aluminum windows. Infiltration effects can also combine with condensation to create problems. If a path exists for warm, moisture-laden air to move through or around the window frames, the moisture will condense wherever it hits its dew point temperature, often inside the building wall. This condensation can contribute to the growth of mold in frames or wall cavities, causing health problems for some people, and it encourages the rotting or rusting of window frames. Frames must be properly sealed within the wall opening to prevent this potential problem. In some instances, the infiltration air will be dry, such as on cold winter days, and it will thus help eliminate condensation on the window surfaces.

Condensation forms at the coldest locations, typically the lower corners or edges of an insulated product even when the center of glazing is above the limit for condensation. Generally, as the insulating value of the glazing is improved, the area where condensation can occur is diminished. With SGS products, however, condensation potential may increase with the insulating value of the product. This is because the temperature of the glass closest to the exterior becomes colder and is adjacent to an un-desiccated air space. Condensation potential increases as the outdoor temperature is lowered and the indoor relative humidity increases.

NFRC has developed a condensation resistance (CR) value for rating for how well a fenestration product can resist the formation of condensation on the room-side surface of the product at a specific set of environmental conditions. The CR calculation method is defined in NFRC 500: Procedure for Determining Fenestration Product Condensation Resistance Values (NFRC 2013). The condensation resistance model outlined in NFRC 500 is developed around condensation on room-side exposed surfaces because factory-sealed insulated glazing utilizes a permanent seal to prevent the introduction of moisture between glass panes. The void may be filled with air or dry gases, such as argon. A desiccant material in the edge spacer between the panes is used to absorb any residual moisture in the unit when it is fabricated or any small amount that might migrate into the unit over many years. NFRC 500 and its accompanying user guide NFRC 501 (NFRC 2013) contain more information about condensation resistance.

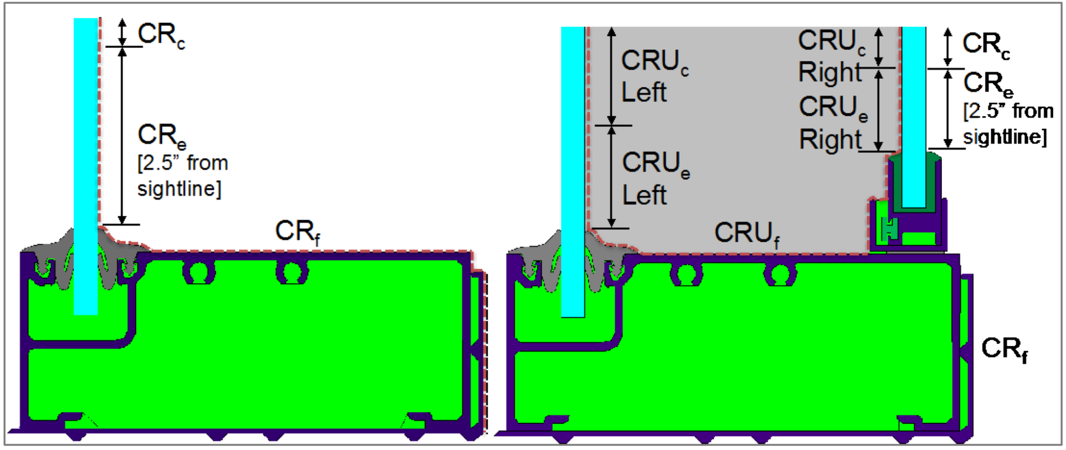
5.2. Simulation

The NFRC CR model outlined above is not applicable to most SGS products, in which condensation between the panes is more likely to develop due to the unsealed air space created when installing the SGS. The following sections outline a new simulation method for CR that accounts for condensation potential between glass layers, simulation results of the new model, and validation results of the model through laboratory testing of SGS.

5.3. Condensation Resistance for Unsealed Glazing Gaps (CRU)

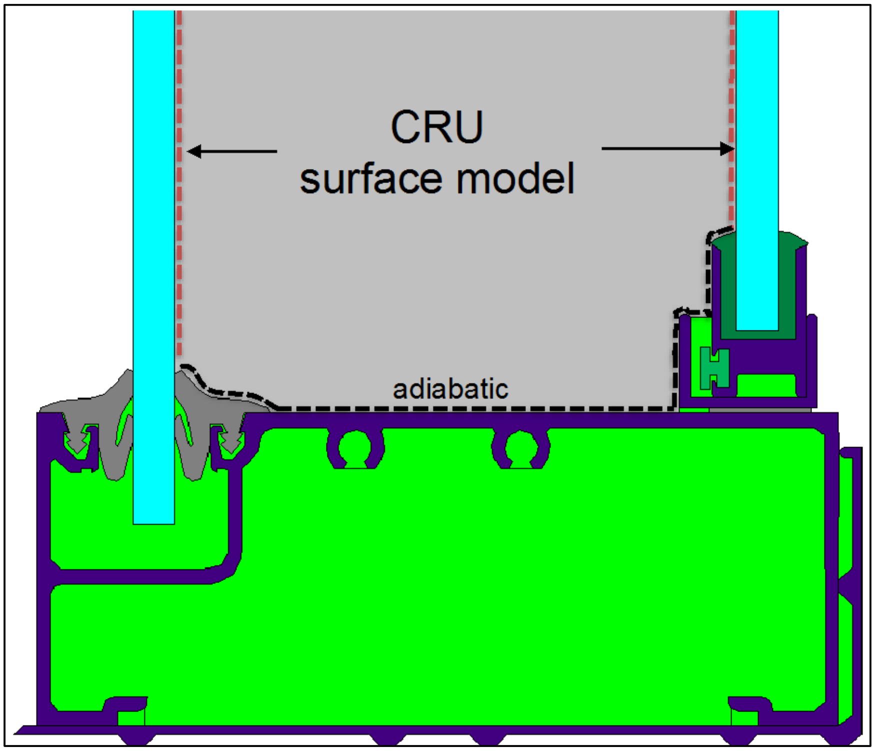
The NFRC CR value is an indicator of condensation performance on the interior, or room-side, surface of a product only. The project team has developed a new model, called the condensation resistance for unsealed glazing gaps (CRU), as part of this report. The primary differentiators between the models are shown in Figure 2. The NFRC CR surfaces are adapted to include the left and right sides of each unsealed gap and the frame surface between them.

Figure 2. A) NFRC 500 CR Areas. B) Proposed CRU Areas



Two simulation limitations must be considered when implementing the CRU model. First, the model is based on the assumption that the unsealed air space can be represented as a sealed cavity with a convection air loop. The project team's validation testing confirms that the sealed model assumption is suitable for all products examined in this report. Second, the model assumes non-glazing surfaces within the unsealed gap are adiabatic (no heat transfer through the surface). In practice, this assumption results in simulated frame temperatures higher than real windows because it does not account for the cold wash of air resulting from the convection loop on the outer glass pane to the frame surface. The edge-of-glass (EOG) surface is typically of greatest concern, but in certain configurations the frame surface may be the condensation driver and condensation potential will be under-predicted. For the validation cases examined in this project, the predicted frame temperature was 1.5°C warmer on average than measured temperature.

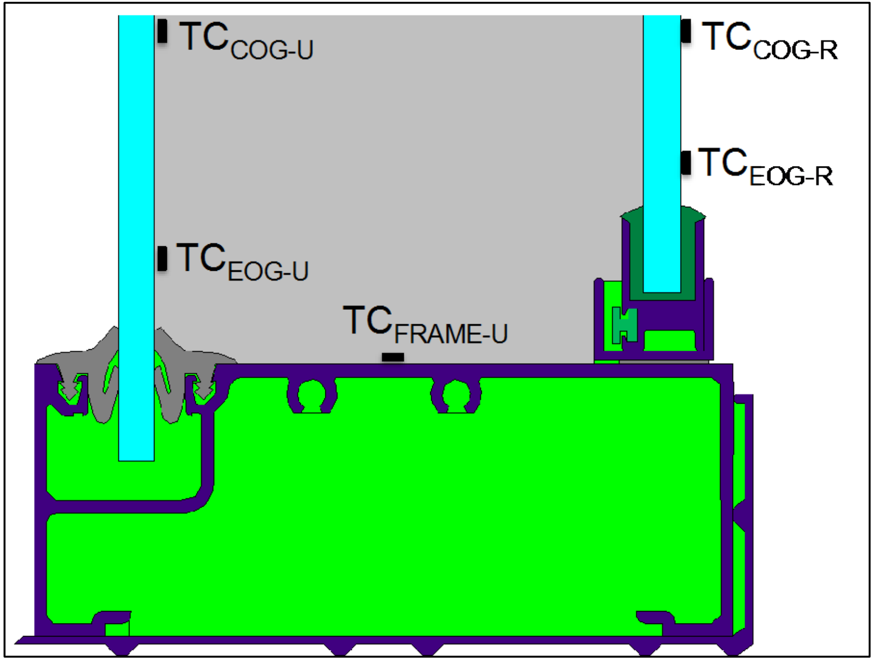
Figure 3. Surfaces Marked with Black Dashed Line Are Adiabatic in the CRU Model



5.4. Validation

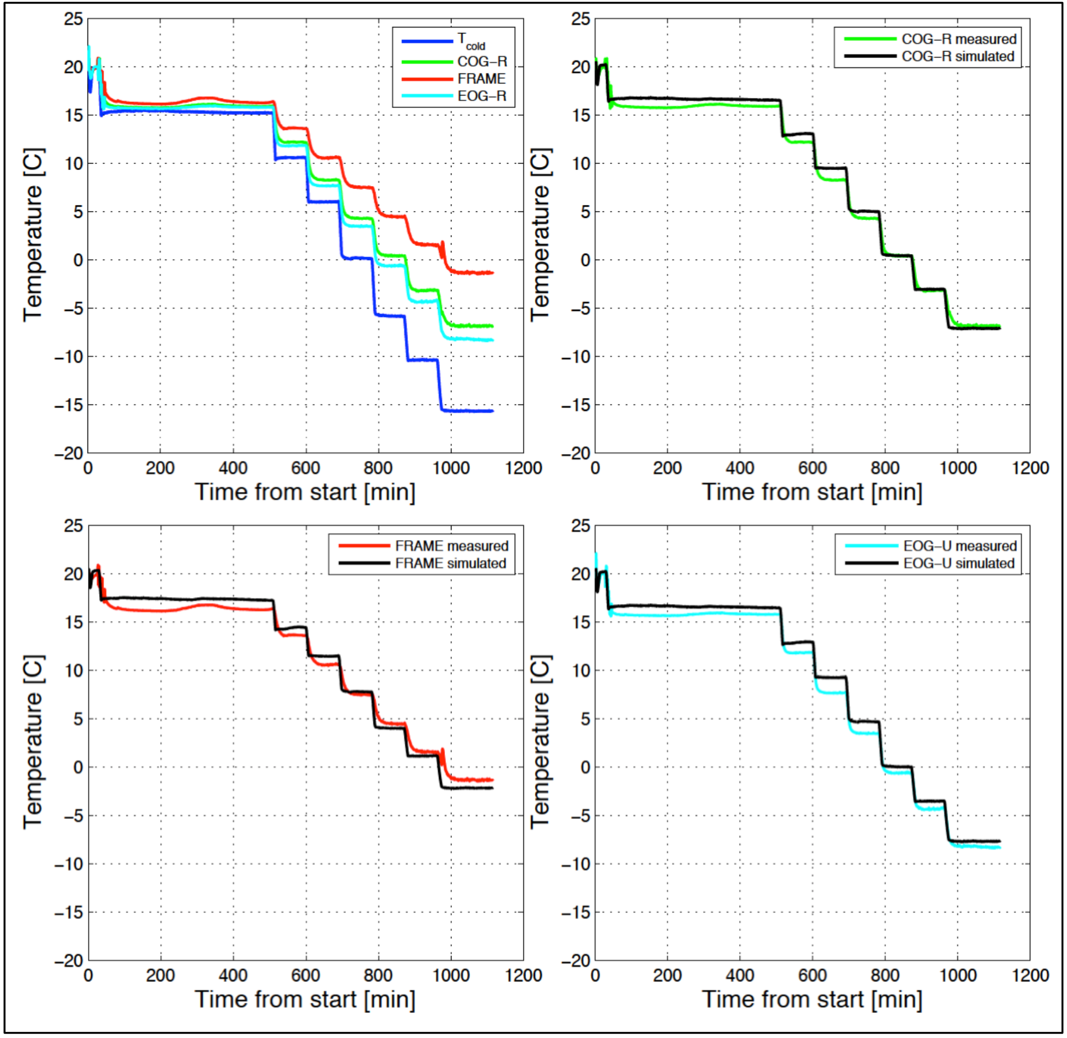
The simulated CR and CRU values are highly dependent on accurate prediction of surface temperatures. To verify the simulated surface temperatures, the project team tested the base window and a selection of three SGS systems in the LBNL laboratory over a range of outdoor temperatures from 15°C to -15°C with the room temperature held at a constant 21°C. The researchers placed thermocouples at the COG and EOG of surface #2, on the frame in the unsealed cavity space, and the COG and EOG of the room-side surface. Figure 4 illustrates a typical example of the thermocouple placement.

Figure 4. Typical Thermocouple (TC) Placement for Validation Testing



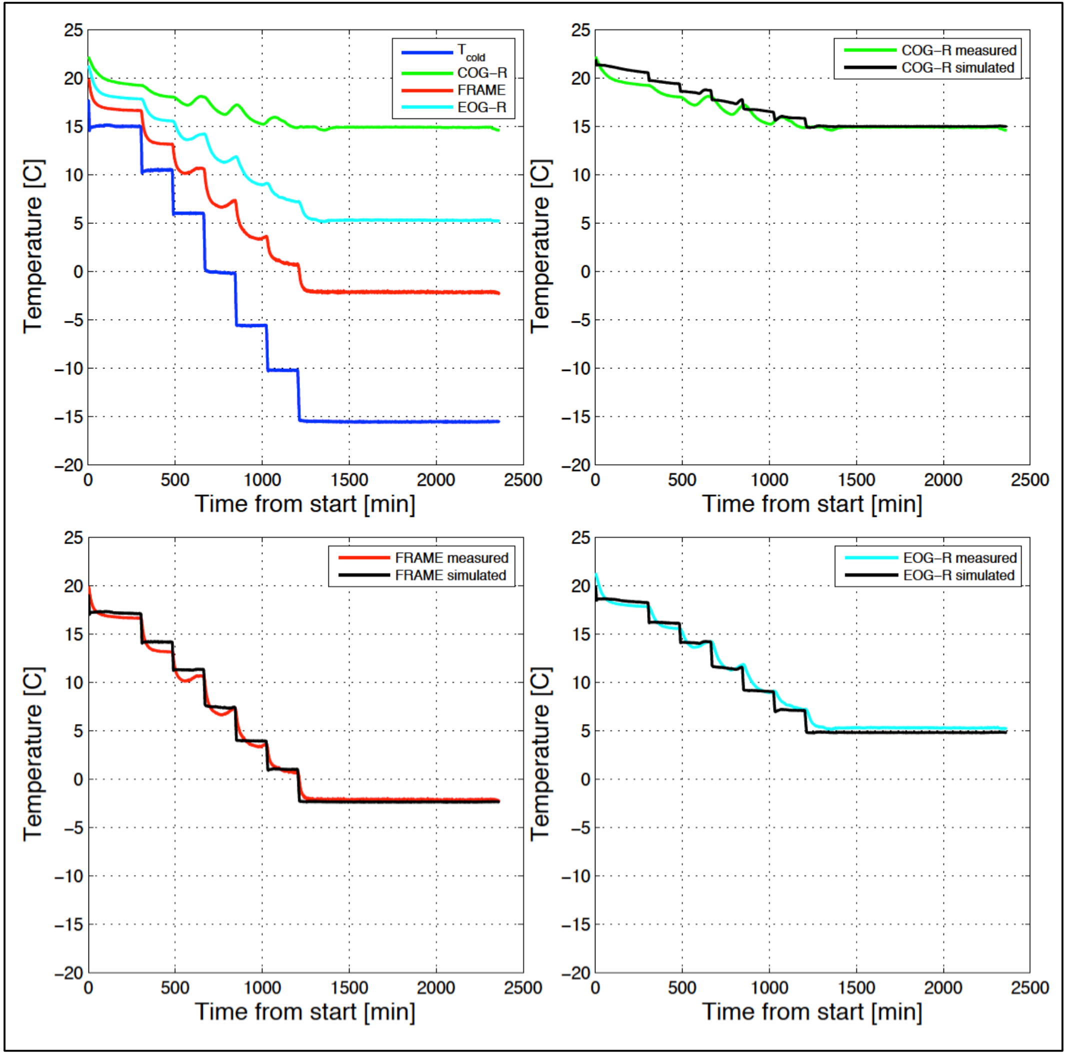
Cold side conditions were held for a minimum of one hour in 5°C increments between 15°C and -15°C. Figures 5 - 8 show the simulation-predicted surface temperatures compared to the measured surface temperatures for four cases: Base, H, G, and A respectively. The Base frame is single glazing, and therefore only room-side surface temperatures are recorded; generation of a NFRC CR is possible, while generating a CRU number is not. The results show agreement throughout between simulated and measured performance within 1°C.

Figure 5. Measured Surface Temperatures on Base Window



Product H in Figure 6 creates a triple pane IGU by sealing and desiccating the air space between the base window and SGS glazing. Thus, the NFRC CR calculation methodology used for the base window applies to this product as well. The created triple-pane IGU is highly insulating, so the time to reach steady state temperatures on most surfaces is greater than the allotted three hours at each cold side condition. The extended duration at the final cold side state, however, shows that the simulated and measured surface temperatures again match within 1°C for all surfaces.

Figure 6. Measured Surface Temperatures on Product H



Products G and A in Figures 7 and 8 introduce the use of the newly-developed CRU model. The COG-U and EOG-U temperatures match within 1°C, similar to the NFRC CR models above. The FRAME temperatures, however, are not within this tolerance, and show differences of up to 2°C. This discrepancy is the result of using an equivalent conductivity for the gas space adiabatic boundary condition, designated by adiabatic in Figure 3. This boundary coundition is used below the top-most base frame sight line. The previous section provides the explanation for this simulation method. The equivalent conductivity assumption always results in under-prediction of the sill frame temperature (in cases where T_{cold} is less than T_{room}), as can be seen in both Figure 7 and Figure 8.

Figure 7. Measured Surface Temperatures on Product G

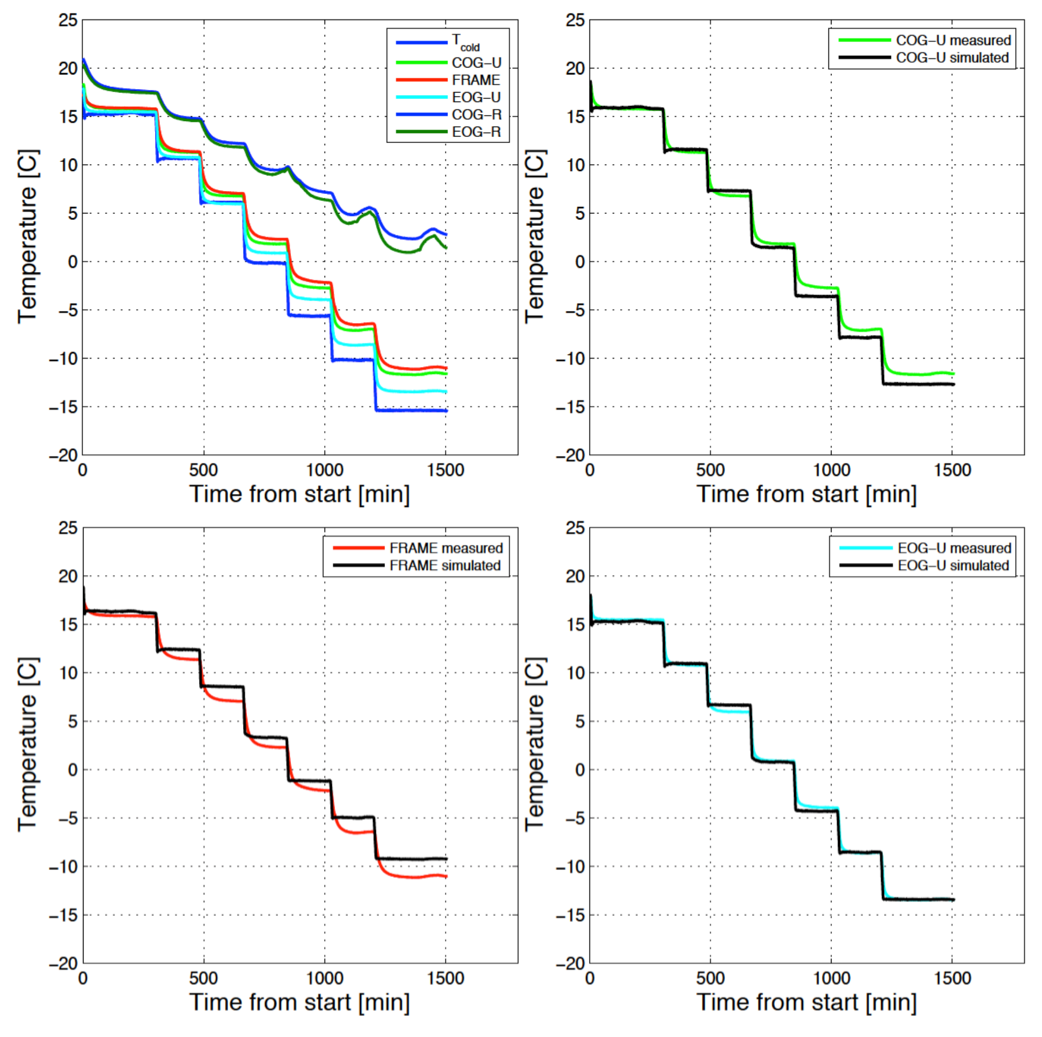


Figure 8. Measured Surface Temperatures on Product A

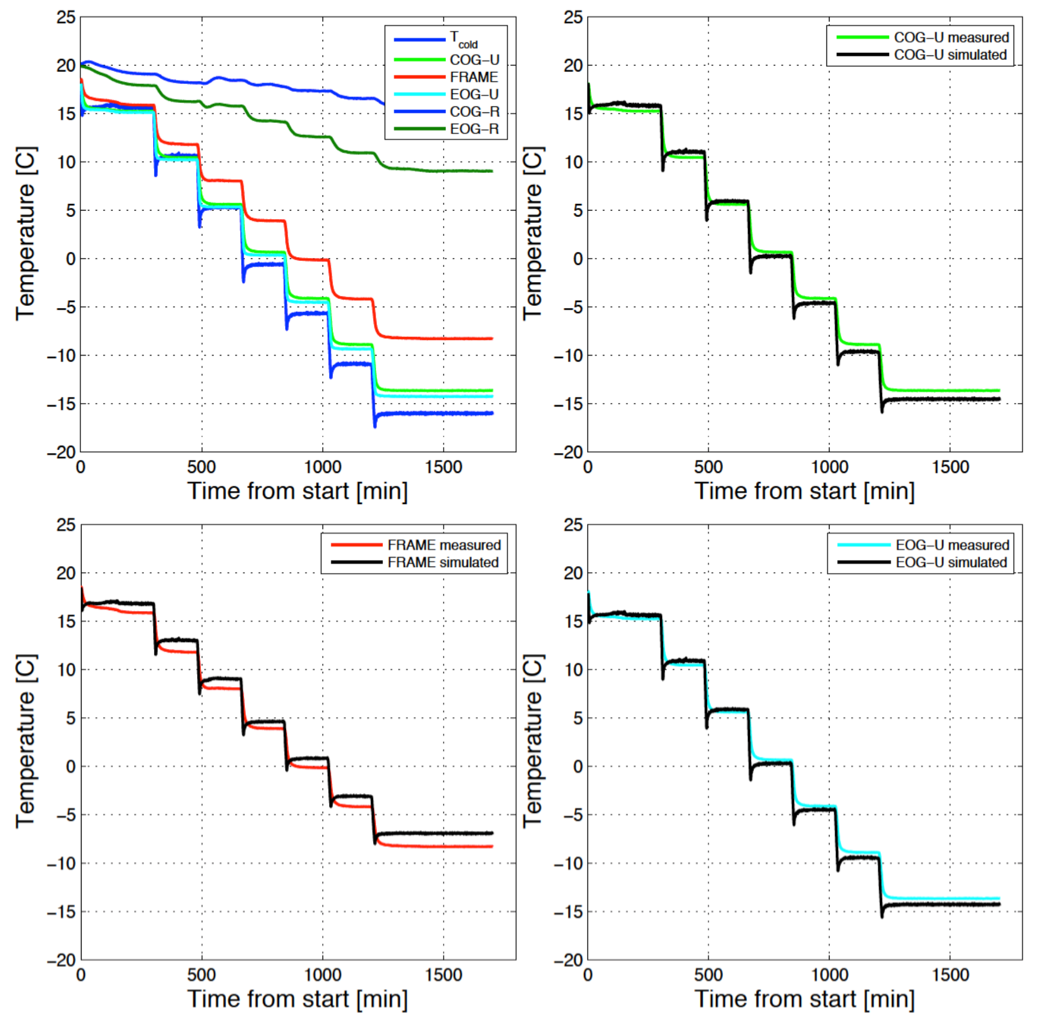


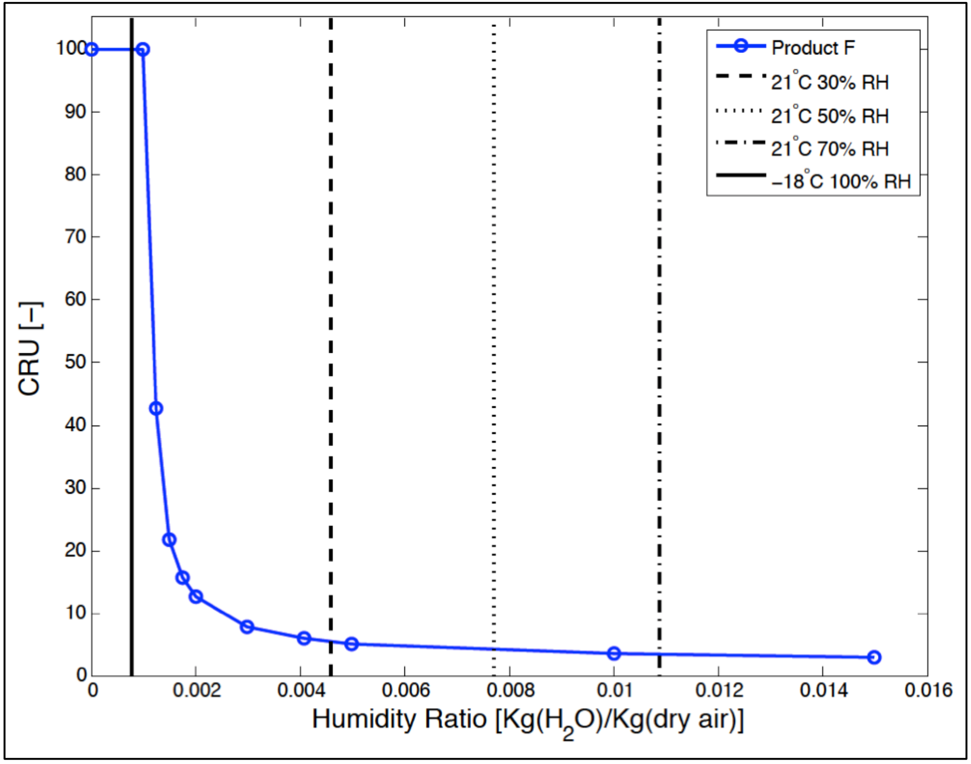
Table 5 shows the simulated CR and CRU values for each window. In the cases for which the CRU calculation is not applicable because the system does not contain an unsealed gap, the field is left blank. It is clear from the CRU – Vented to the Interior Boundary Condition (BC) that the condensation resistance is significantly decreased when an SGS product vents solely to room air. The primary driver for low CRU values is the temperature reduction on the base window glass coupled with the high dew point of room air. The test results illustrate the significant surface temperature reductions when comparing Figure 5 (base window) to Figure 7 and Figure 8. Many real building base windows are not completely sealed to outside air infiltration, so the CRU for the unsealed gap vented to a mixture of exterior and interior air is also of interest.

Table 5. Simulated CR and CRU

Product	CR	CRU Vented to Interior BC
Base	12.2	-
A	21.6	1.96
B	27.0	-
C	26.8	-
D	26.8	-
E	22.1	1.38
F	22.0	4.23
G	26.0	4.24

Figure 9 shows the simulated CRU for Product F over a range of unsealed gap air humidity ratios. The humidity ratio of the simulated exterior boundary condition is around 0.001 Kg (H_2O)/Kg (dry air) as shown by the solid black vertical line, so a CRU of 100 is expected for all humidity ratios below that level since no condensation can occur. Since the SGS product shown insulates the base window glass and reduces its temperature, the CRU exhibits a drastic drop once the humidity ratio is increased above the exterior humidity ratio. This drop explains the relatively low CRU numbers reported in Table 5.

Figure 9. CRU for Product F as a Function of Unsealed Gap Humidity Ratio



6. Whole Building Analysis

6.1. Background

Researchers use annual energy simulations to predict energy performance impacts of building components. In this report, the project team used the EnergyPlus simulation engine to predict building energy use based solely on changes to building fenestration. EnergyPlus is an energy analysis and thermal load simulation program. Based on the description of a building, EnergyPlus calculates heating and cooling loads necessary to maintain thermal control setpoints. Simultaneous integration of these—and many other—details verifies that the EnergyPlus simulation performs as a real building would (US DOE 2013).

The US Department of Energy (DOE), in conjunction with three of its national laboratories, has developed commercial reference buildings that provide complete descriptions for whole-building energy analysis using EnergyPlus simulation software. Sixteen building types represent approximately seventy percent of the commercial buildings in the US. These modules provide a consistent baseline of comparison. Reference builds are provided for new construction, existing buildings constructed after 1980, and for existing buildings constructed before 1980.

In addition to the sixteen building types, the DOE used sixteen climate zones, which represent all US climates, to create the reference buildings. The climates are simulated using typical meteorological year (TMY) datasets derived from the 1961-1990 and 1991-2005 National Solar Radiation Data Base archives. The TMY3s are datasets of hourly values of solar radiation and meteorological elements for a one-year period. Because they represent typical rather than extreme conditions, they are not suited for designing systems to meet the worst-case conditions occurring at a particular location (NREL 2015).

6.2. Annual Energy Analysis

The project team selected the EnergyPlus prototype buildings and climates investigated in this study to match NEEA’s requirements based on its target market for the SGS products. Table 6 summarizes the selected building and climate simulation parameters.

Table 6. EnergyPlus Prototype Building Parameters

Parameter	Description
Construction type	Existing buildings constructed before 1980 ("pre-1980")
Building type	Large Office
	Medium Office
	Small Office
Climate zone	Zone 3: Oakland, CA
	Zone 4: Portland, OR
	Zone 5: Spokane, WA
	Zone 6: Missoula, MT

The three building types and four climate zones combine with eight window options for a total of 96 annual energy simulations. All building HVAC systems are sized for the base window system, and then the researchers re-run the simulations with each SGS product. Figures 10 - 12 show the total predicted source energy use (3x multiplier for electricity, 1x for gas) by building type along with the energy savings of each SGS product compared to the base window. In general, Product E saves the most energy and Product G saves the least. The percent savings for the small office is relatively low compared to the other two office types, primarily due to the low window to wall area of approximately ten percent. The large office by comparison has about sixty percent window to wall area.

Figure 10. Annual Energy Simulation for Small Office

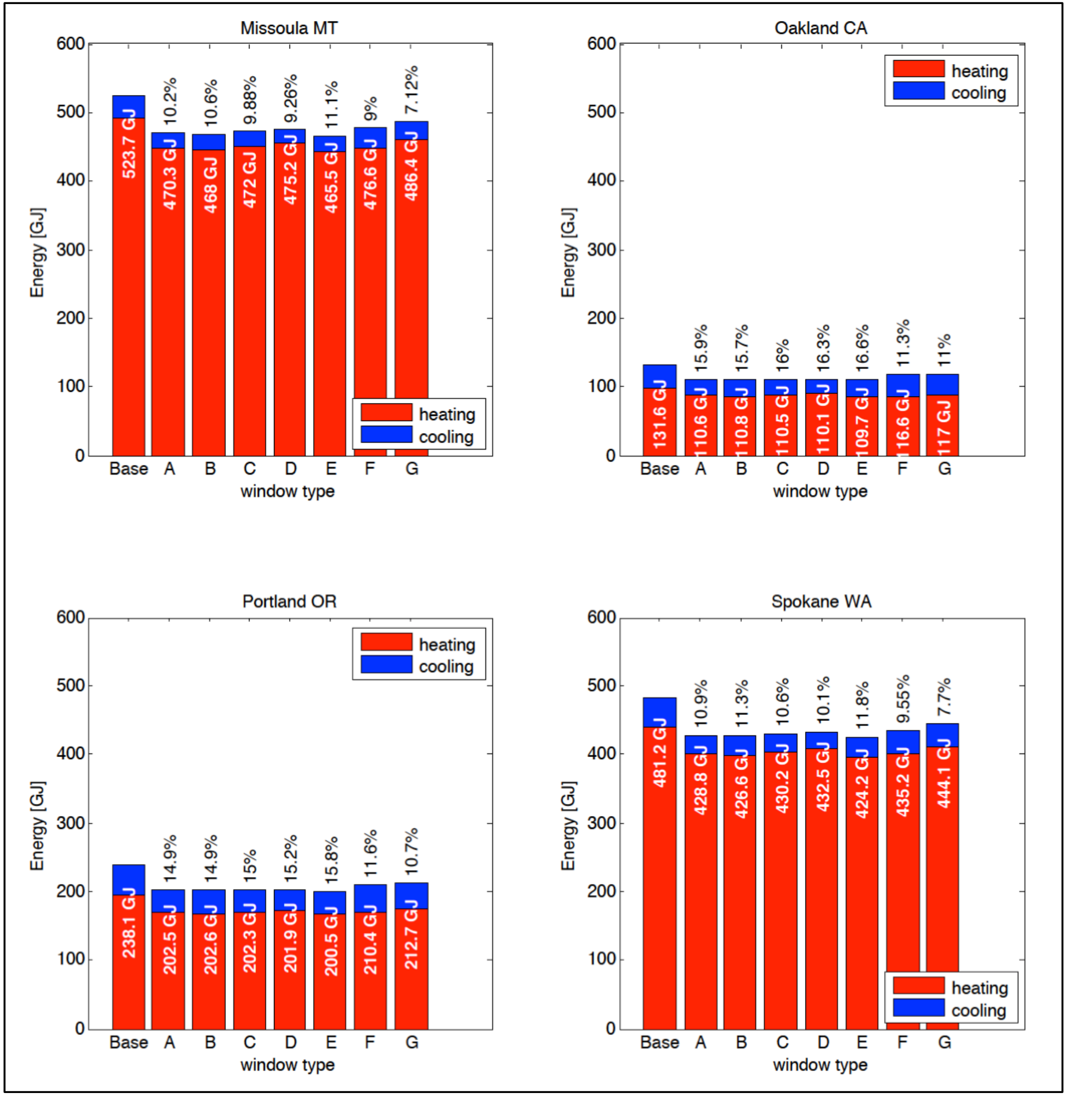


Figure 11. Annual Energy Simulation for Medium Office

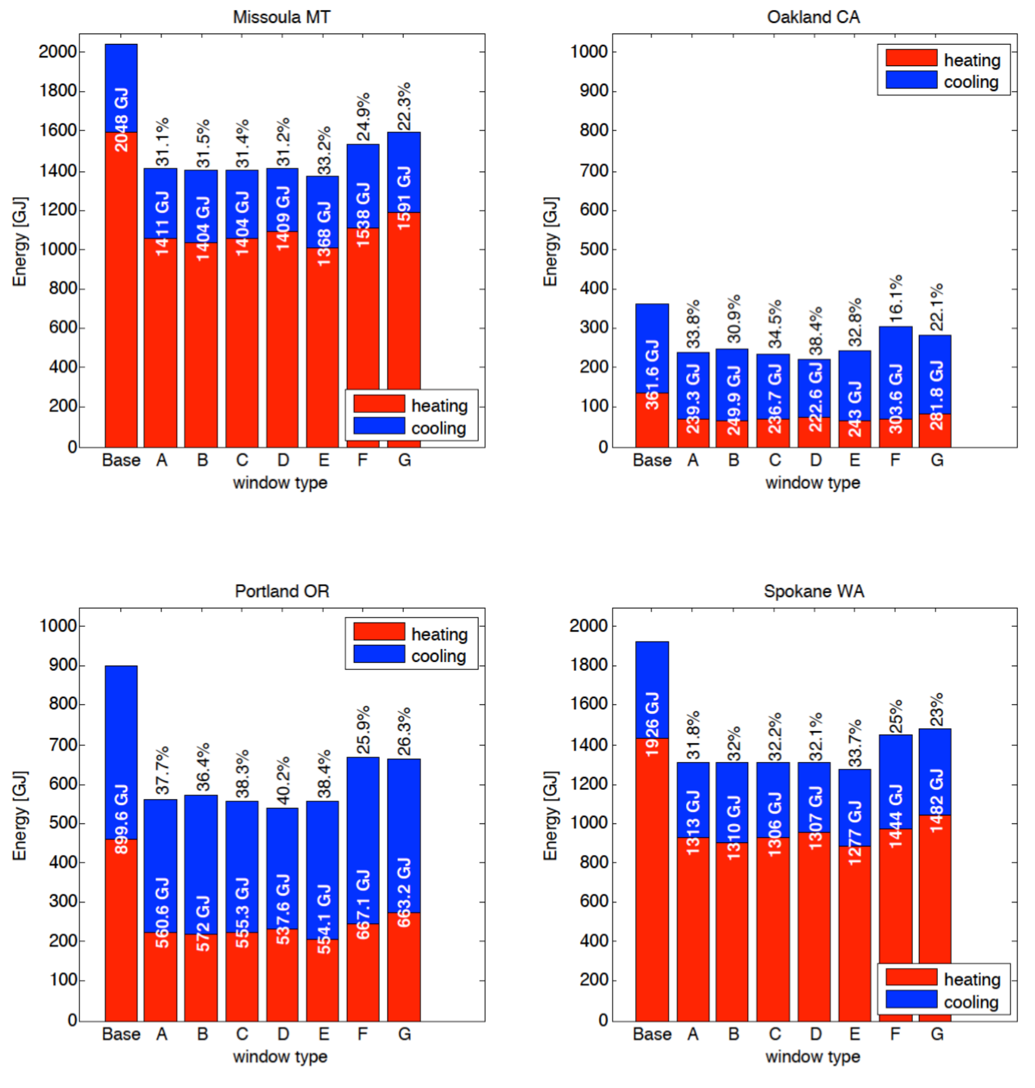
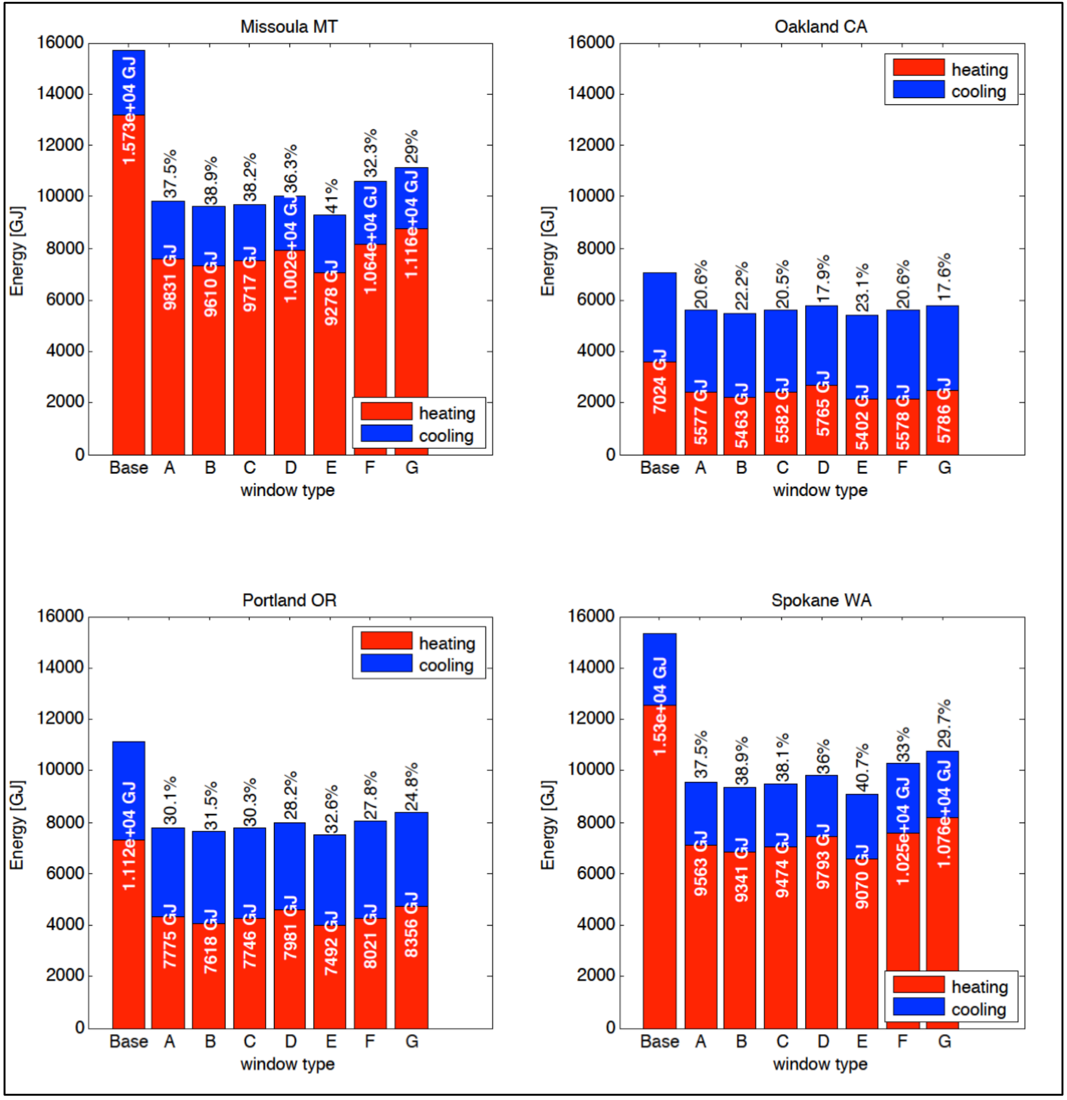


Figure 12. Annual Energy Simulation for Large Office



6.3. Condensation Analysis

The project team ran EnergyPlus simulations in fifteen-minute time steps, allowing for detailed analysis of building components as a function of time. In order to predict if condensation may occur at each time step, researchers compared the temperature on the glazing surfaces predicted by WINDOW and THERM for the given indoor temperature, outdoor temperature, and wind speed to the dew point temperature of the air adjacent to that surface. All unsealed cavities are assumed to be vented to the room-side and therefore have the same dew point temperature as the adjacent room. This may or may not be the correct assumption, as the moisture content in the unsealed gap will be a function of conditions such as the level of SGS sealing to the room side, level of air infiltration from the outdoor side, dynamics of moisture migration, and presence and quantity of any desiccant in the gap, which were not subjects of this study.

Indoor dew point temperature is typically higher than outdoor for the climates included in this investigation, so this report is examining the worst-case scenario for condensation resistance.

This assumption may not be valid for existing buildings in which the base windows could experience significant infiltration of outdoor air. In such cases, the methods used in this analysis can be easily modified to adjust dew point temperatures. Figure 13 shows the difference between all relevant window surface temperatures and the dew point temperatures of the adjacent air for each simulated fifteen-minute time step for one window system. Figure 14 accumulates the fifteen-minute time steps when T_{dew} is greater than T_{surf} to provide an idea of total condensation risk. For the case shown, and typically for all units examined, EOG has the greatest condensation risk. The figure also shows that condensation typically occurs within the first and last 100 days of the calendar year.

Figure 13. Difference of Window Surface Temperature and Adjacent Dew Point Temperature. Large Office, Missoula MT, Product A

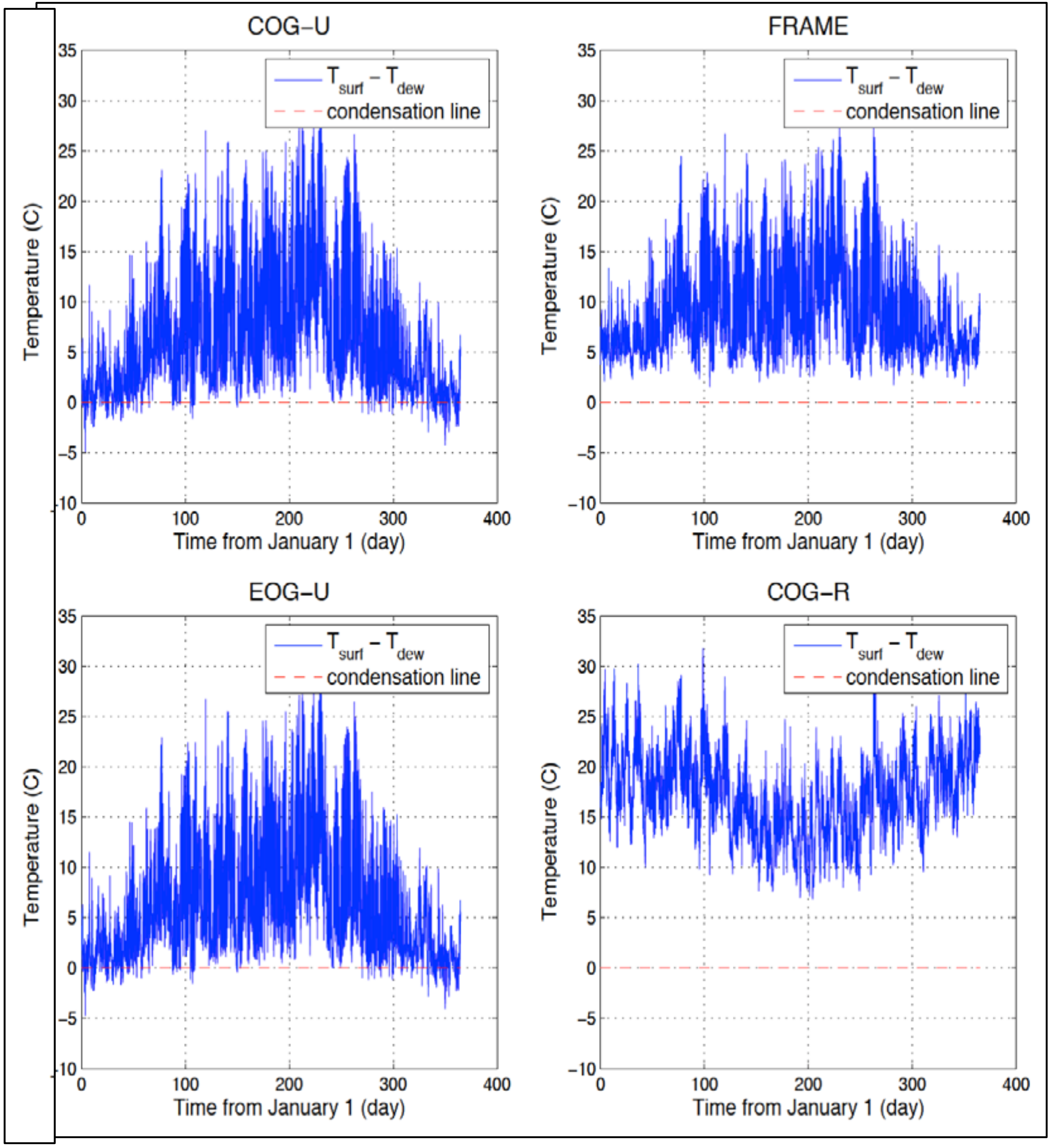
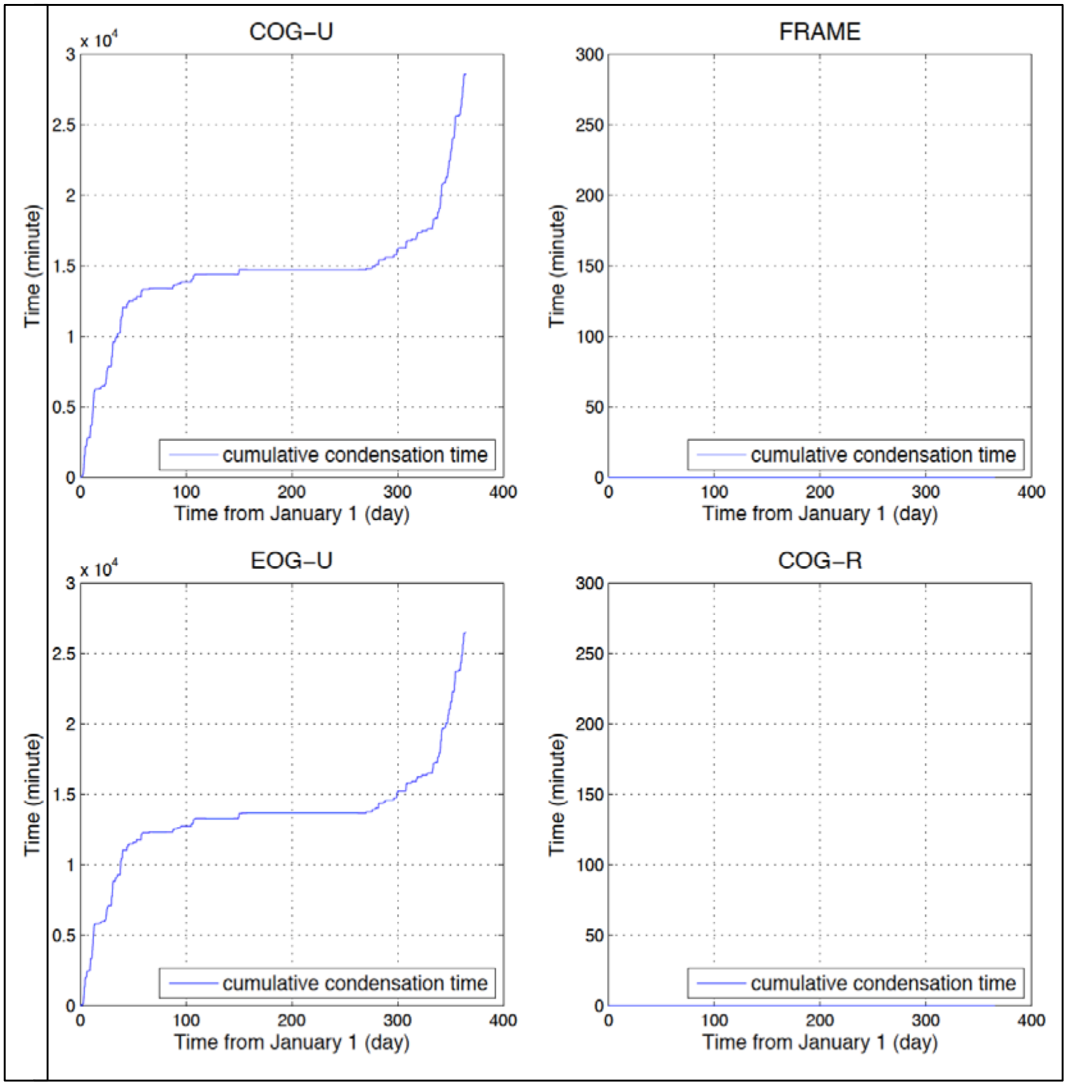


Figure 14. Cumulative Time for Window Surface Condensation Risk. Large Office, Missoula MT, Product E



The time of day when condensation may occur is of interest to building owners and occupants. Figures 15-17 split total predicted condensation time by building type and hour of day for one product in Missoula, MT. The majority of condensation occurs at the end of the day when the building systems utilize setback space temperatures and the space still contains significant occupant moisture load. Figures 18-20 provide summarized condensation times based on a typical building schedule with open hours of 7:00 a.m. to 7:00 p.m. The information in Figures 13-20 should be observed for relative product performance only, since this paper addresses worst-case condensation potential, which may be unrealistic for many buildings.

Figure 15. Window Cavity Condensation Risk Based on Time of Day for One Year, Large Office, Missoula MT, Product A

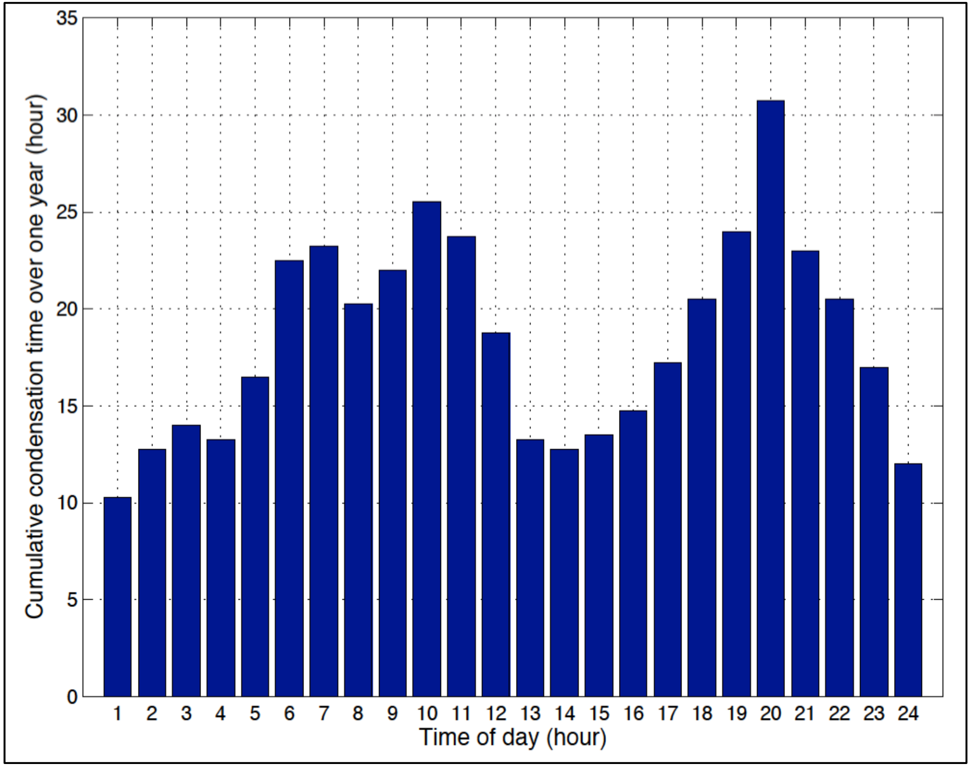


Figure 16. Window Cavity Condensation Risk Based on Time of Day for One Year, Medium Office, Missoula MT, Product A

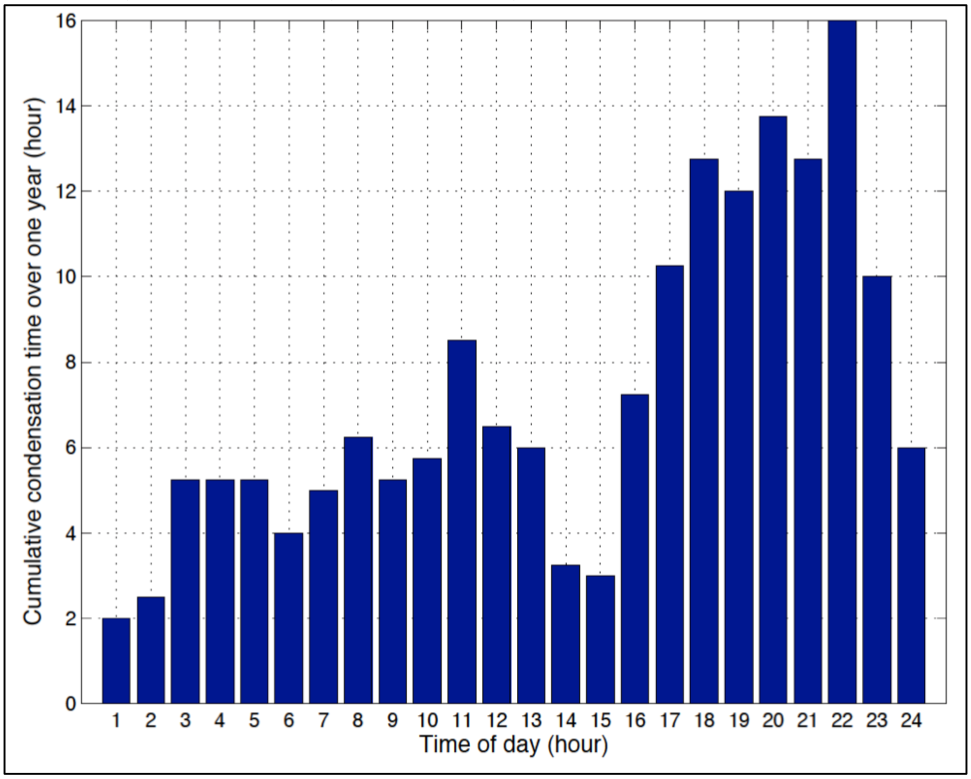


Figure 17. Window Cavity Condensation Risk Based on Time of Day for One Year, Small Office, Missoula MT, Product A

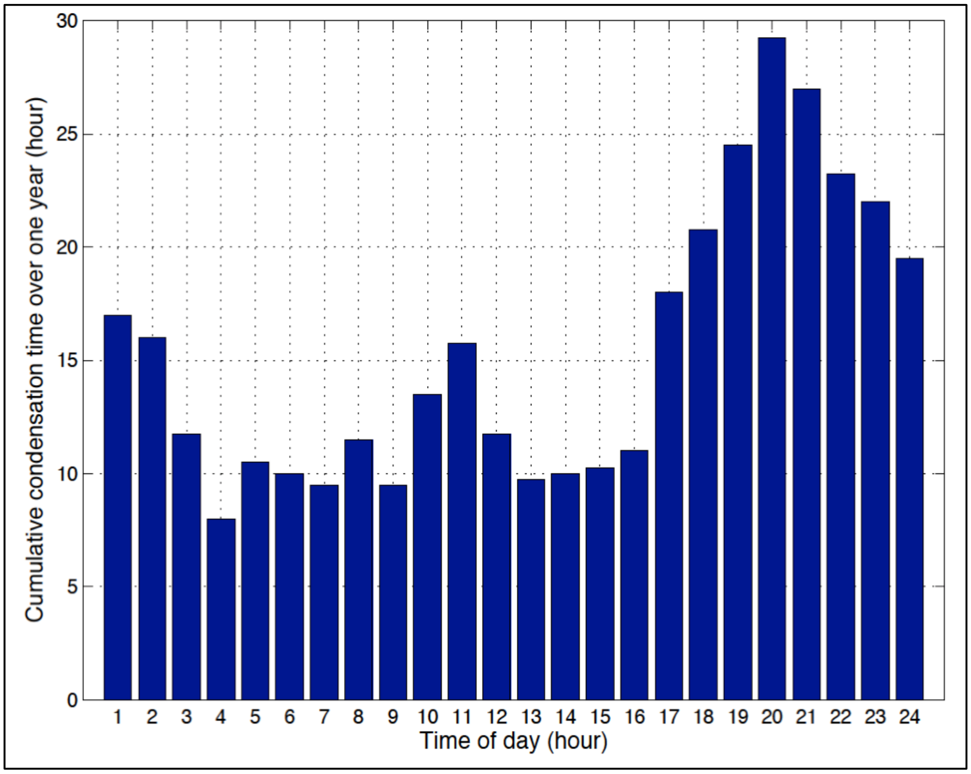


Figure 18. Cumulative Condensation Hours by Window Type and Location, Small Office

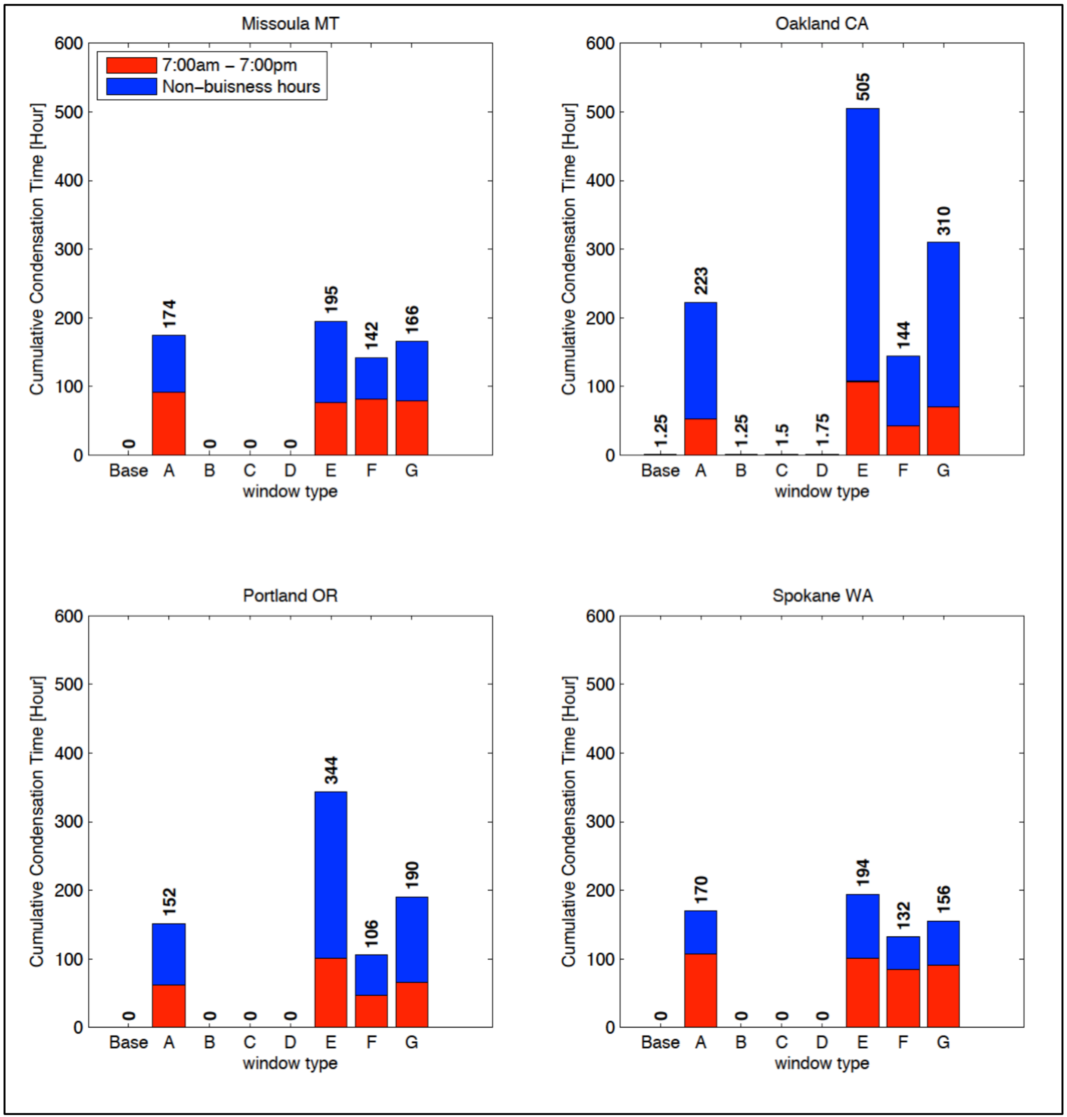


Figure 19. Cumulative Condensation Hours by Window Type and Location, Medium Office

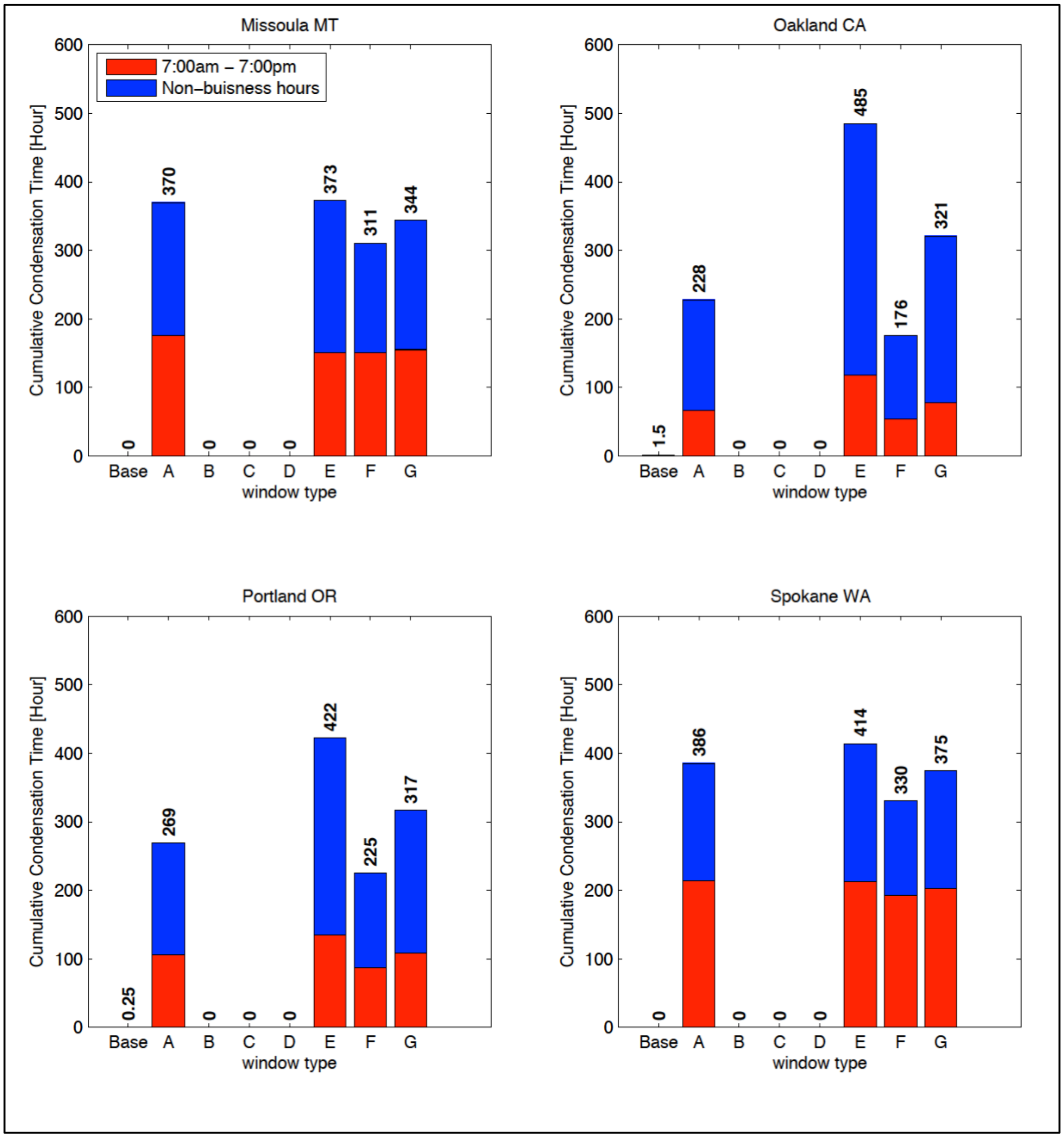
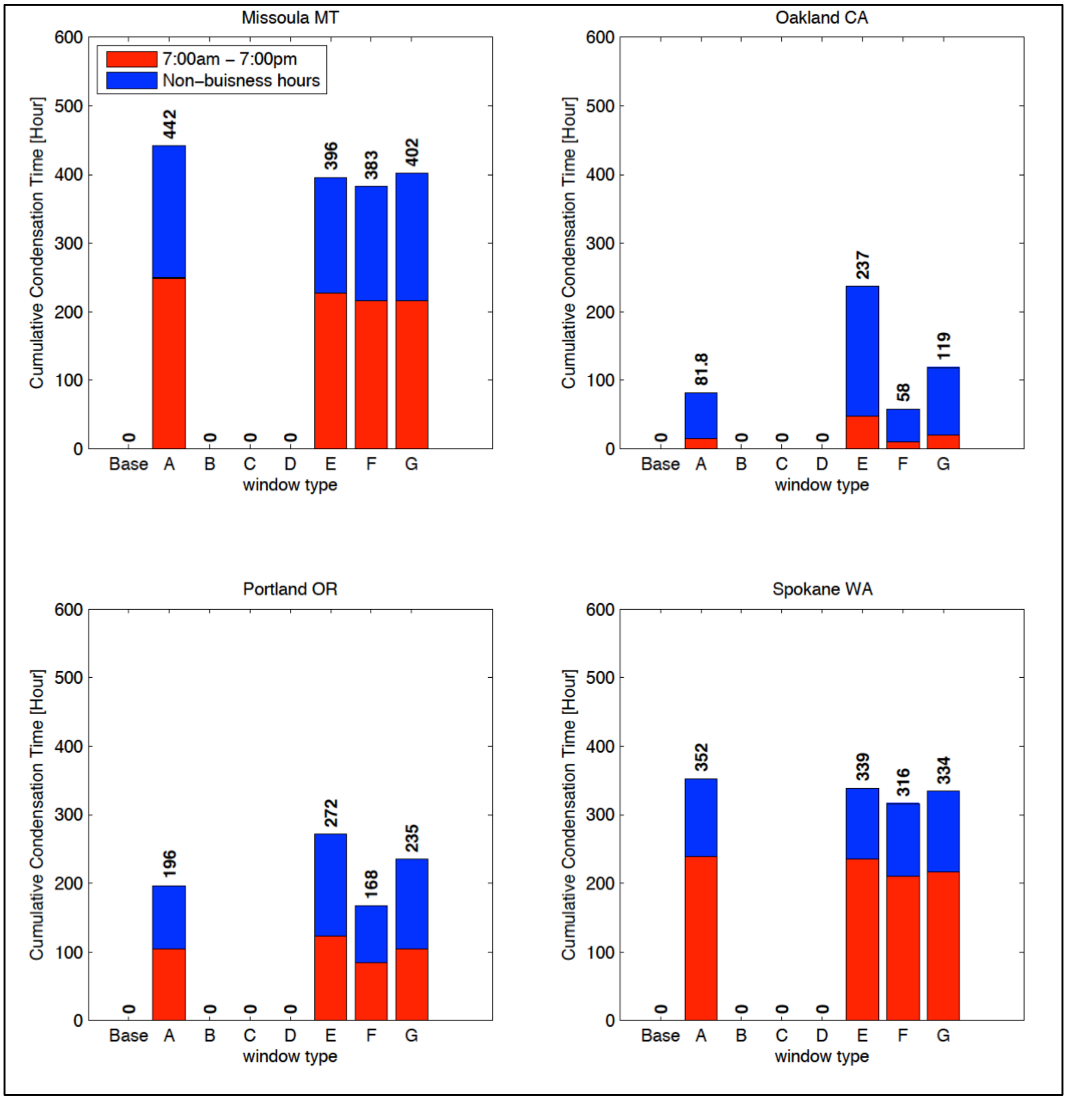


Figure 20. Cumulative Condensation Hours by Window Type and Location, Large Office



7. Summary and Conclusions

This report described the simulation and validation of the performance characteristics of several SGS products using industry standard practices. Where industry standard practices do not exist, such as CR between existing glazing and SGS, this report introduced new methodologies and software capabilities. It also compared energy savings and condensation potential of various SGS systems in prototype commercial buildings.

The NFRC has clearly established SHGC and thermal transmittance simulation and validation methods for typical prime window products. In general, these same procedures may be translated directly to SGS, as has been the case for this report. The only significant modification of note is to minimize infiltration into the unsealed gap by sealing both the exterior and room sides of the window system prior to validation testing. When researchers did so for this project, all validation testing was within acceptable NFRC tolerances. The reported performance values for each product can be directly compared to other NFRC simulated products. These findings show that Product E had the maximum reduction in SHGC and U-factor of all products examined, while Product D had the least impact to SHGC and Product F the least impact to U-factor.

The NFRC CR rating is meant to differentiate products by comparing their room-side surface temperatures under several set conditions. The CRU procedure shown in this report is intended to do the same for products with unsealed glazing cavities, such as SGS. The simulation and validation testing performed confirms that the new revisions to WINDOW and THERM accurately predict local surface temperatures for unsealed gaps, and therefore provide accurate determinations of CRU at predetermined humidity ratios. The reported CRU numbers are intended to be used to compare the condensation potential of the products. However the reported CRU numbers seem to be mostly on the very low end (i.e., very poor condensation performance) for all unsealed units due to the use of the humidity ratios that are representative of indoor room air. This indicates the potential need for further research to establish expected moisture content in unsealed gaps for different product types and to relate them to indoor room air, to facilitate development of more representative CRU procedures. Also, unsealed gap frame surface temperature calculations in THERM could be improved to achieve tighter agreement with measurements.

The annual energy simulations showed that all SGS products significantly reduce energy use in all climates and building types considered, with savings over the base window of fifteen to forty percent. Condensation analysis shows that in the worst case, most SGS products increase condensation risk. The condensation analysis performed for this report assumes no infiltration of air or moisture from the exterior and an unsealed gap dew point temperature equal to that of the adjacent room. In real buildings this would be a highly simplified and possibly unrealistic assumption, so the exact condensation times are unreliable. The reported values should instead be used to compare relative performance, where Products B, C, and D show they do not increase condensation potential over the base unit and Product E increases risk by the greatest amount. However, even for comparison purposes, a greater understanding of moisture migration would help to improve CRU determination as a more realistic measuring stick.

8. Acknowledgement

This work was supported by the Northwest Energy Efficiency Alliance (NEEA- Robert Curry) and the Assistant Secretary for Energy Efficiency and Renewable Energy, Building Technologies Program, of the US Department of Energy under Contract No. DE-AC02-05CH11231.

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