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

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1. EXECUTIVE SUMMARY

The thermal and solar performance characteristics of seven window attachment secondary glazing systems (SGS), also known as Fixed Window Panels, are simulated and validated in this report using industry standard practices. Where industry standard practices do not exist, such as condensation resistance (CR) between base glazing and SGS, new methodology and software capabilities are introduced. Annual Energy savings and condensation potential of all SGS systems in prototype commercial buildings are also evaluated.

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 important assumption made in the development of CRU is that same humidity content of air was assumed as 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 was also an extension of THERM and WINDOW software tools to model condensation resistance of unsealed gaps and 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 that further research might be needed to establish expected moisture content in unsealed gaps for different product types and to relate them to indoor room air, so that more representative CRU procedure can be developed

Annual energy simulations of prototype commercial buildings using EnergyPlus simulation tool have been done 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 15 - 40%. CRU calculations shows that most SGS products significantly increase condensation risk in the unsealed gap, but real performance in buildings might not reflect this behavior, as pointed out above.

2. INTRODUCTION & BACKGROUND

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 March 3, 2014 report from The Façade Group, lists several recommendations to compare 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.

There are several objectives to this report. 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, we develop new methodology and software capabilities to accurately predict performance. Energy savings and condensation potential of various SGS systems is compared to a baseline system. Analysis is 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.

3. PRODUCT DEFINITIONS

A single clear glazed non-thermally broken aluminum commercial store front window frame is used as the baseline glazing system for this project. It is designated as representative of commercial windows constructed between the mid-1950s and the mid-1980s. A wide selection of SGS products representing the diversity of current commercially available products is used.

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. Alphabetic designations are used throughout this report in order to maintain anonymity of tested SGS. Detailed descriptions of each product are provided in Appendix A.

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, all of these air spaces are considered to be sealed and are 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 not 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. The rate of moisture transfer is not studied even though it may be an important factor in condensation resistance of windows in buildings under normal operation.

4. SOLAR HEAT GAIN

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.

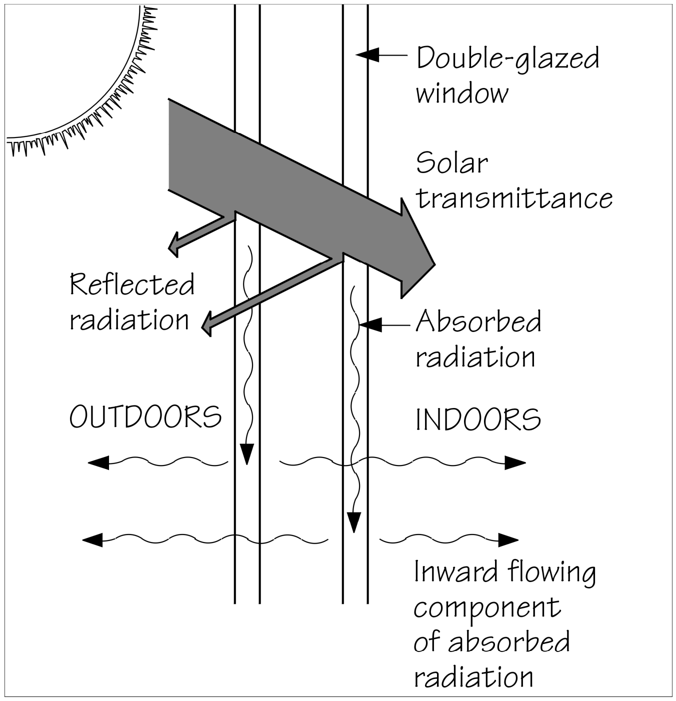

Figure 1. A glazing system's properties of reflection, transmission and absorption determine what happens to solar gain.

There are two means of indicating the amount of solar radiation that passes through a fenestration product. These are solar heat gain coefficient (SHGC) and 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 a different basis 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).

Validation Methods

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

Simulation

Simulated SHGC and visual transmittance (VT) are presented in Table 1 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

Product	SHGC (-) Center-of-glass	SHGC (-) Full frame (4'x5' window)	VT (-) 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

Validation

SHGC validation is performed on four products using the NFRC 201 method at an independent laboratory and the LBL MoWiTT facility. The simulated and measured SHGC are compared 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 though show agreement is within the uncertainty of the test equipment. The reported simulations are performed 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	SHGC (-) 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	*	

*Testing is scheduled and awaiting acceptable weather conditions at facility

5. THERMAL TRANSMITTANCE

Background

U-factor is the standard way to quantify 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 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, it can be misleading to compare U-factors if they are not carefully described. In order to address this problem, the concept of a total fenestration product U-factor is utilized by NFRC. A specific set of engineering assumptions and procedures must be followed 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).

Validation Methods

The U-factor is typically simulated by NFRC 100-2014 (National Fenestration Rating Council, 2013) and validated by NFRC 102-2014 (National Fenestration Rating Council, 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 NFRC 102 test was performed on one product as a sample for verification. In addition to the standard method, U-factor is also determined for three products by utilizing the LBL MoWiTT facility (Klems J. H., 1988) & (Klems J. , 1992).

<u>Simulation</u>

Simulated U-factor is presented in Table 3 for COG and in the NFRC standard fixed window size of 4’x5’. The products show a wide range of U-factor reduction 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-factor

Product	U-factor (BTU/h-ft2-F) 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

Validation

U-factor validation is performed on four products using the NFRC 102 method at an independent laboratory and at non-standard conditions with the LBL MoWiTT facility. The simulated and measured U-factors are compared 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 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 reveals 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. MoWiTT validation testing was performed with infiltration sealing on the outside surface.

The reported simulations are performed 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 40C. The reported MoWiTT measurements are the average of one or more trials with each product.

Table 4. Comparison of simulated and tested U-factor

Product	Method	Size	U-factor (BTU/h-ft2-F) 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%

6. CONDENSATION RESISTANCE

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 was 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 though 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 the NFRC 500: Procedure for Determining Fenestration Product Condensation Resistance Values (National Fenestration Rating Council, 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. 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 (National Fenestration Rating Council, 2013) contain more information about condensation resistance.

Simulation

The NFRC CR model outlined above is not applicable to most SGS products where 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.

<u>Condensation Resistance for Unsealed Glazing Gaps (CRU)</u>

The NFRC CR value is an indicator of condensation performance on the interior, or room side, surface of a product only. A new model, called the condensation resistance for unsealed glazing gaps (CRU), is developed 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.

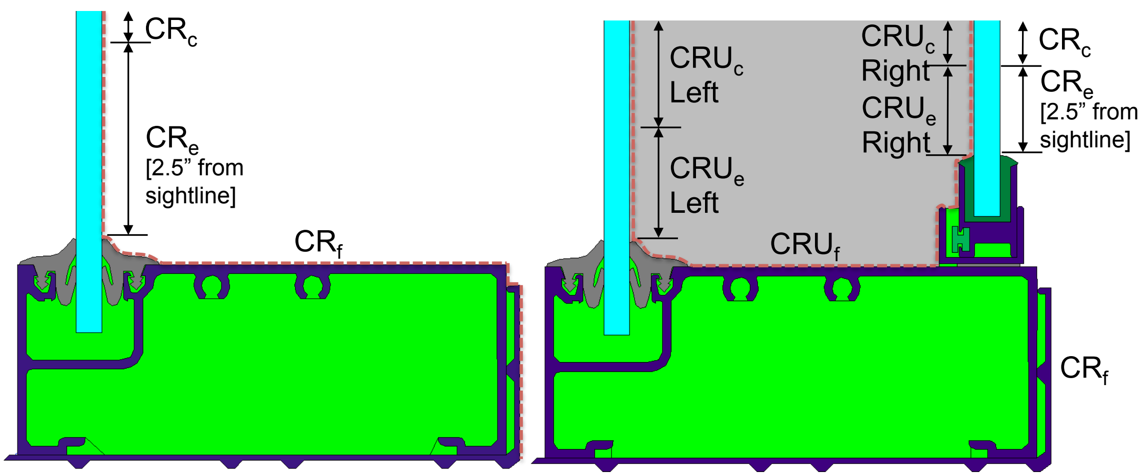

Figure 2. A) NFRC 500 CR areas. B) Proposed CRU areas

When implementing the CRU model there are two simulation limitations that must be considered. 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. Our 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). Figure 3 illustrates this area. In practice, this assumption results in simulated frame temperatures higher than real windows because the cold wash of air resulting from the convection loop on the outer glass pane to the frame surface is not accounted for. The 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 1.5C warmer on average than measured temperature.

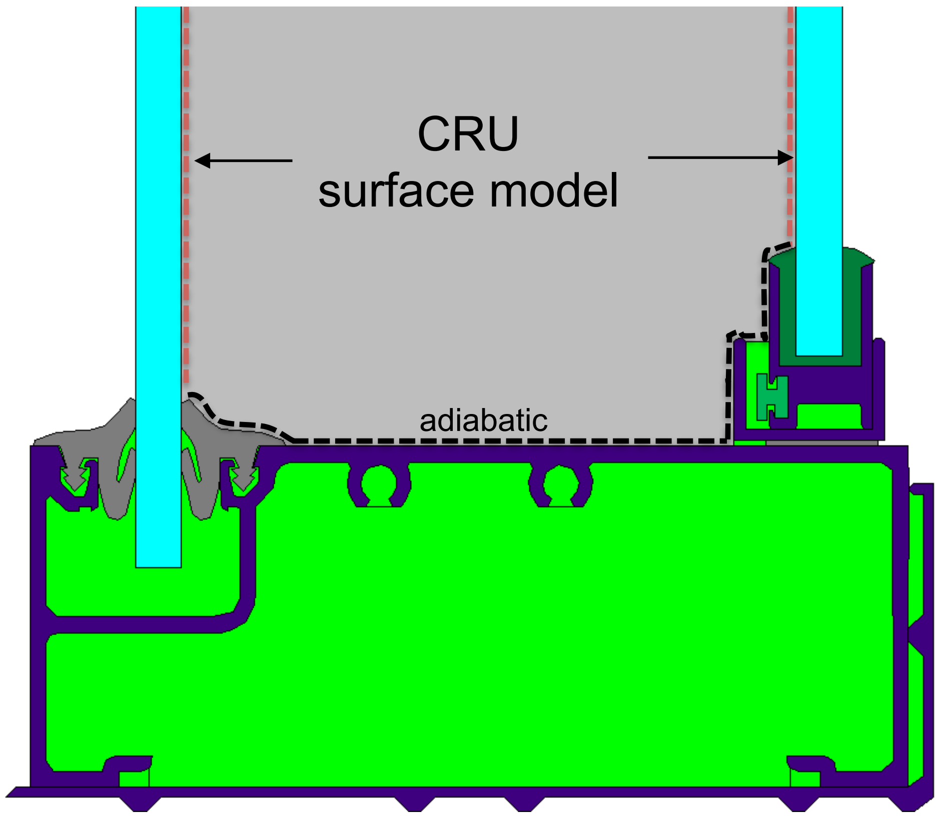

Figure 3. Surfaces marked with black dashed line are adiabatic in the CRU model.

Validation

The simulated CR and CRU values are highly dependent on accurate prediction of surface temperatures. To verify the simulated surface temperatures, the base window and a selection of three SGS systems were tested in the LBNL laboratory over a range of outdoor temperatures from 15C to -15C with the room temperature held at a constant 21C. Thermocouples were placed 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. A typical example of the thermocouple placement is given in Figure 4.

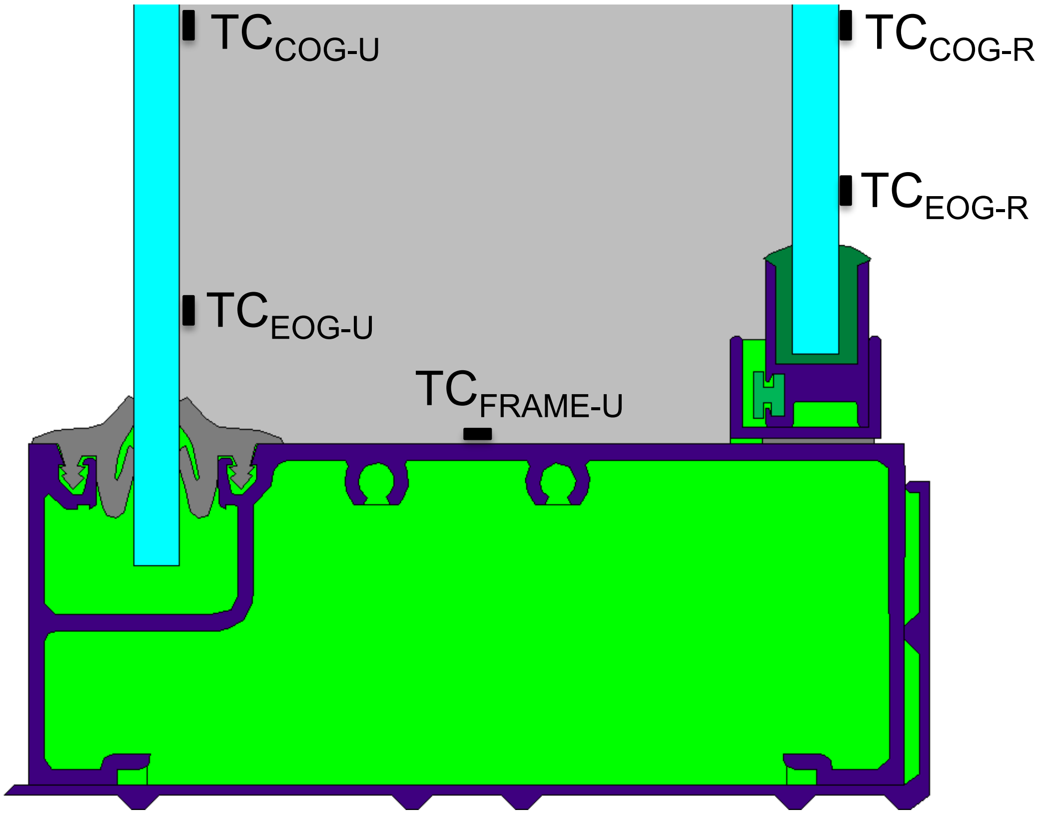

Figure 4. Typical thermocouple (TC) placement for validation testing

Cold side conditions were held for a minimum of one hour in 5C increments between 15C and -15C. 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 and a NFRC CR is possible to generate while a CRU number is not. The results show agreement between simulated and measured performance within 1C throughout.

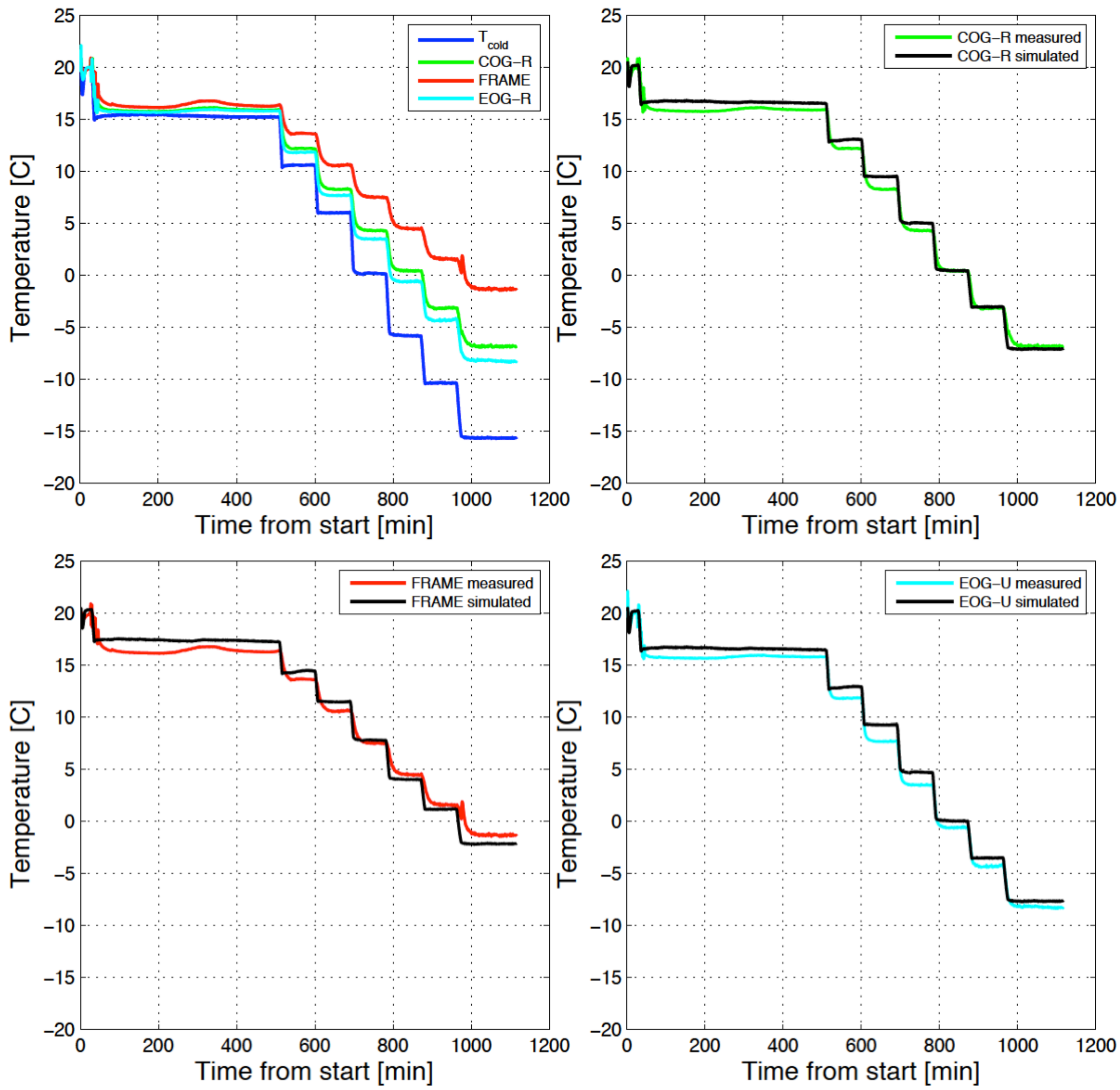

Figure 5. Measured surface temperatures on base window

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 though shows that the simulated and measured surface temperatures again match within 1C for all surfaces.

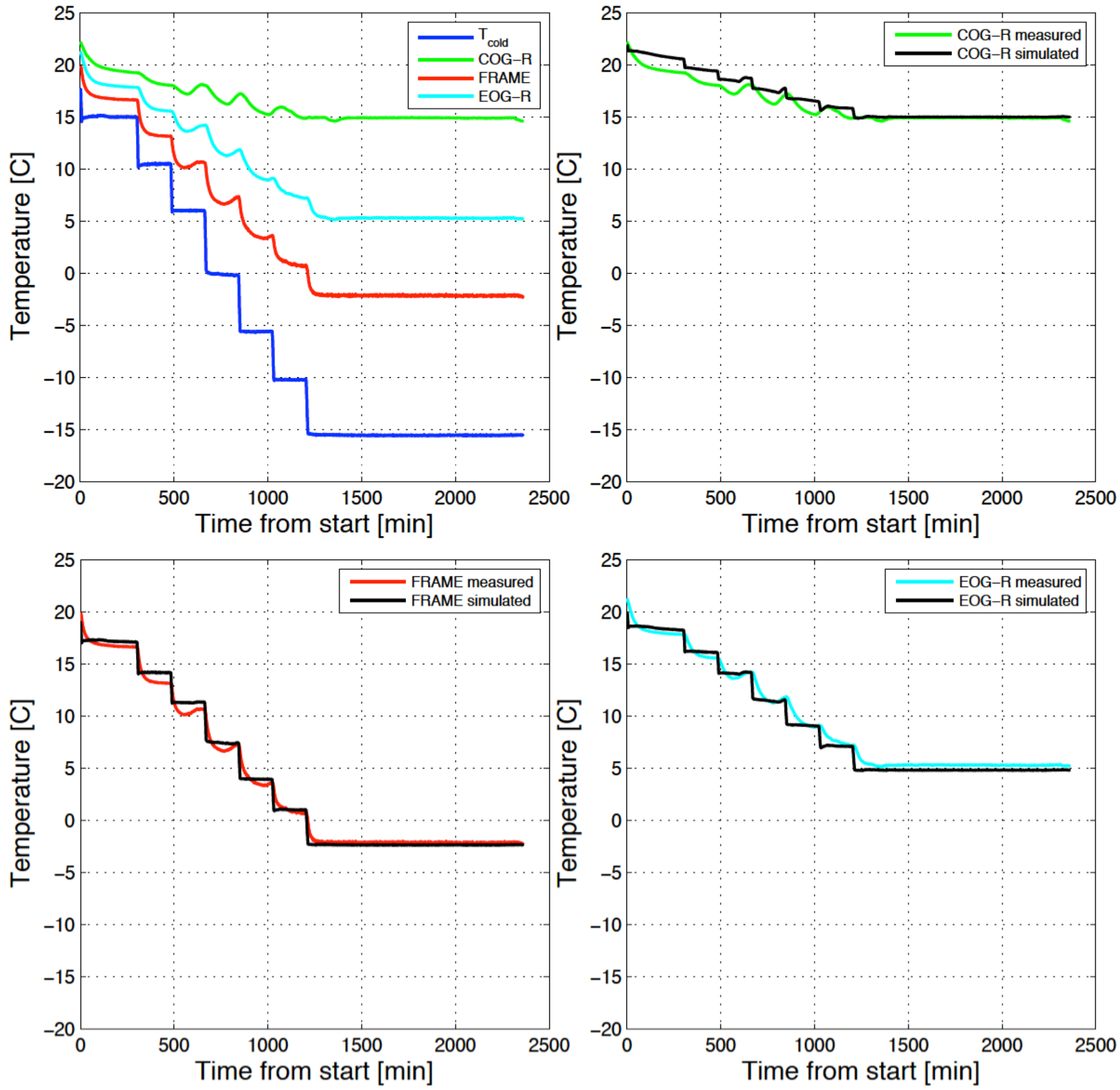

Figure 6. Measured surface temperatures on product H

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 1C, similar to the NFRC CR models above. The FRAME temperatures though are not within this tolerance, and differences of up to 2C shown. This discrepancy is the result of using an equivalent conductivity for the gas space below the top most base frame sight line, designated by h_{base} in Figure 3. The explanation for this simulation method is given in the previous section. The equivalent conductivity assumption always results in under prediction of the sill frame temperature (in cases where T_{cold} is less than T_{room}). This can be seen in both Figures 7 and 8.

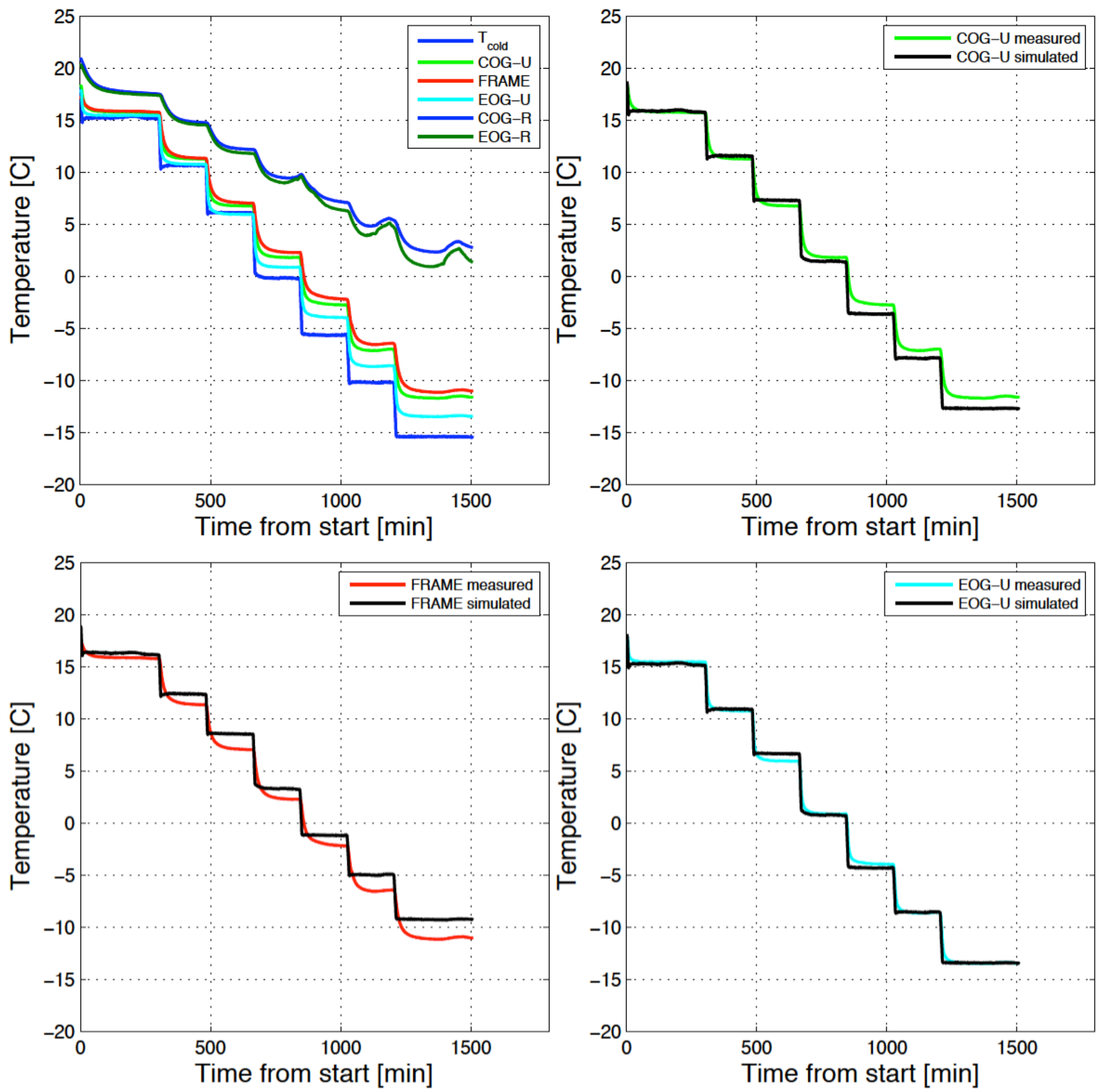

Figure 7. Measured surface temperatures on product G

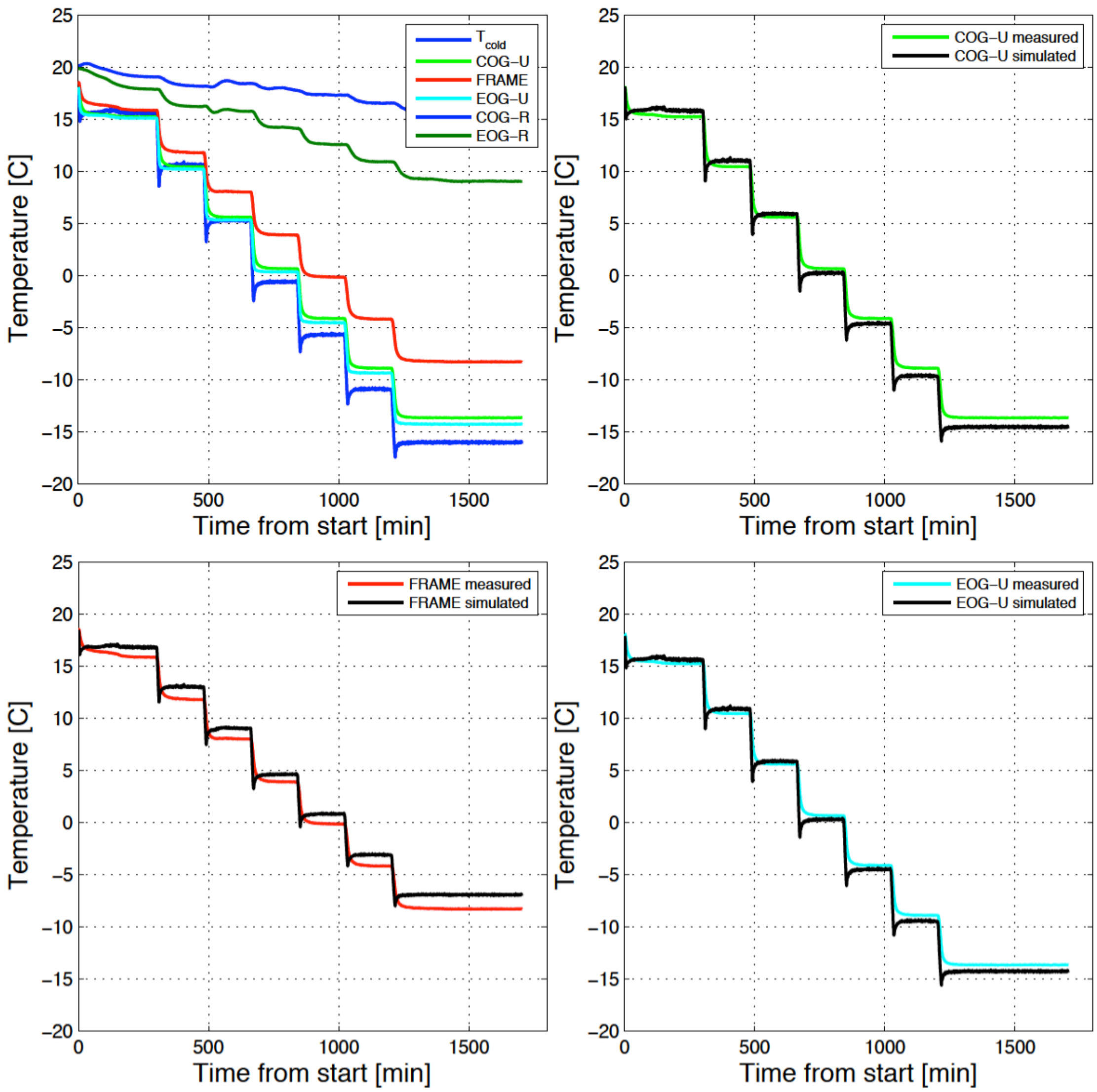

Figure 8. Measured surface temperatures on product A

The simulated CR and CRU values for each window are shown in Table 5. Where 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 significant surface temperature reductions can be seen in the test results when comparing Figures 5 (base window) to Figures 7 and 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, there is a drastic drop in CRU once the humidity ratio is increased above the exterior humidity ratio. This drop explains the relatively low CRU numbers reported in Table 5.

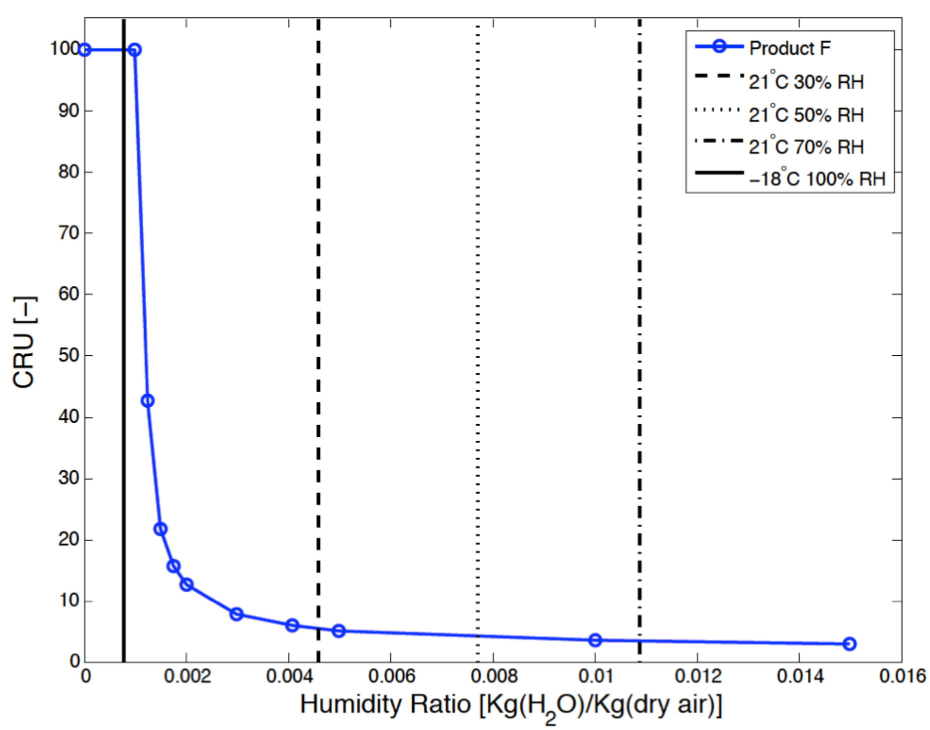

Figure 9. CRU for Product F as a function of unsealed gap humidity ratio

7. WHOLE BUILDING ANALYSIS

Background

Annual energy simulations are used to predict energy performance impacts of building components. In this report, the EnergyPlus simulation engine is used 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 set points. Simultaneous integration of these—and many other—details verify that the EnergyPlus simulation performs as a real building would (U.S. Department of Energy, 2013).

The DOE, in conjunction with three of its national laboratories, has developed commercial reference buildings. These reference buildings provide complete descriptions for whole building energy analysis using EnergyPlus simulation software. There are 16 building types that represent approximately 70% of the commercial buildings in the U.S. These modules provide a consistent baseline of comparison. Reference builds are provided for new construction, existing buildings constructed after 1980, and existing buildings constructed before 1980 (US Department of Energy).

In addition to the 16 building types, 16 climate zones, which represent all U.S. climates, were used to create the reference buildings. The climates are simulated using typical meteorological year (TMY) data sets derived from the 1961-1990 and 1991-2005 National Solar Radiation Data Base archives. The TMY3s are data sets of hourly values of solar radiation and meteorological elements for a 1-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 location (The National Renewable Energy Laboratory, 2015).

Annual Energy Analysis

The EnergyPlus prototype buildings and climates investigated in this study were selected to match NEEAs requirements based on their 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 then the simulations are rerun 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 small office are relatively low compared to the other two office types. This is primarily due to the low ~10% window to wall area. The large office by comparison has ~60% window to wall area.

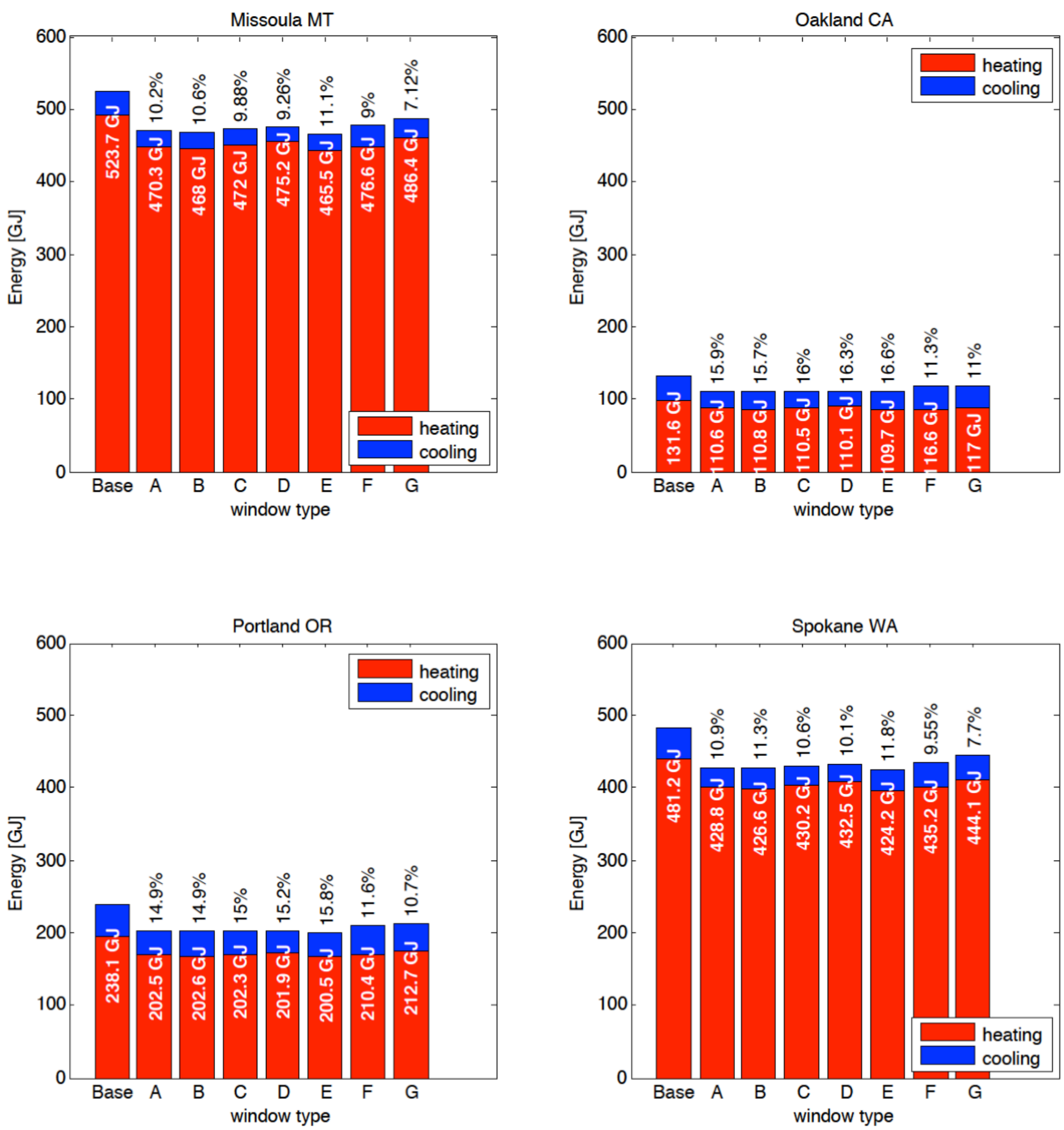

Figure 10. Annual energy simulation for small office

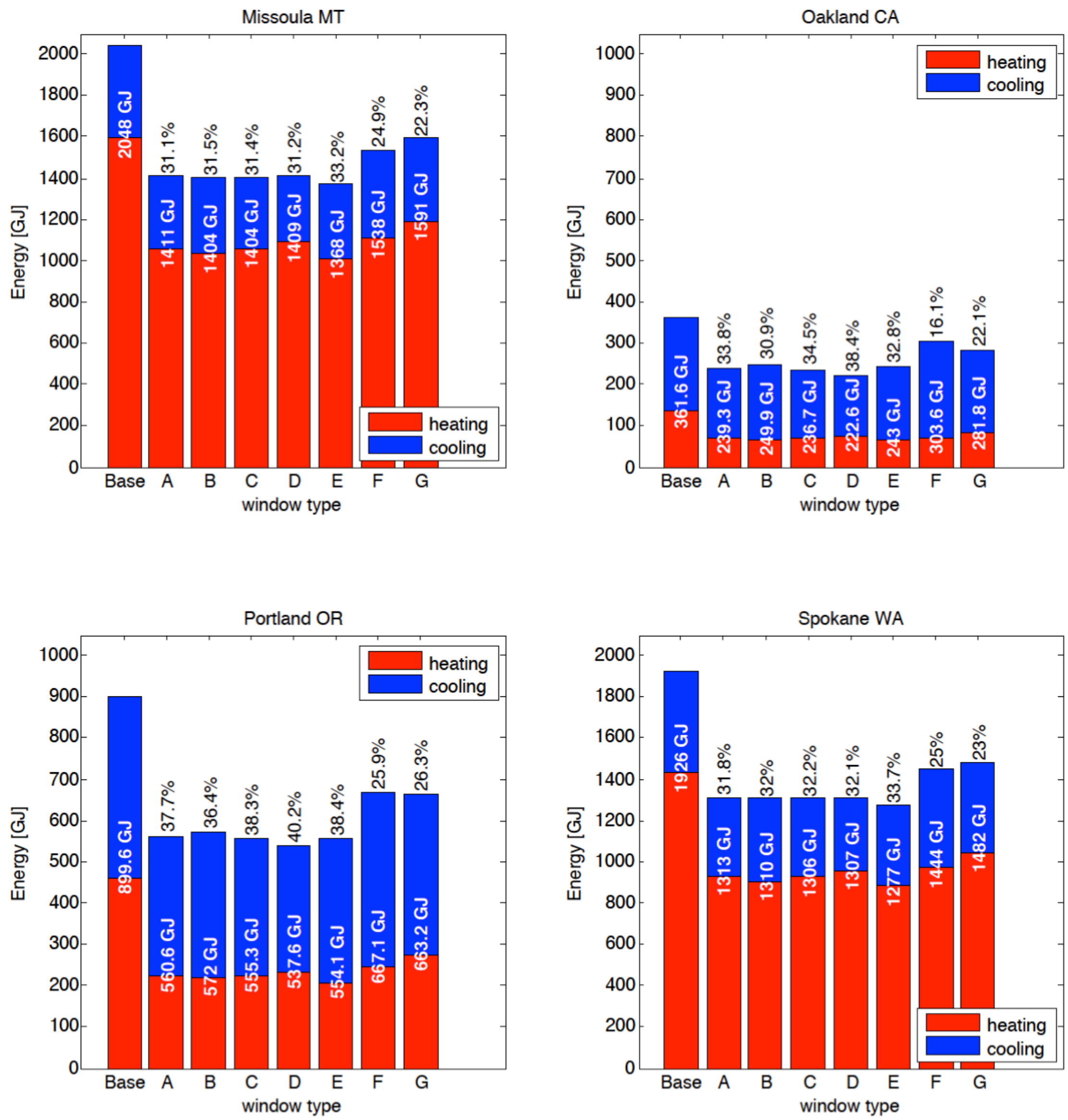

Figure 11. Annual energy simulation for medium office

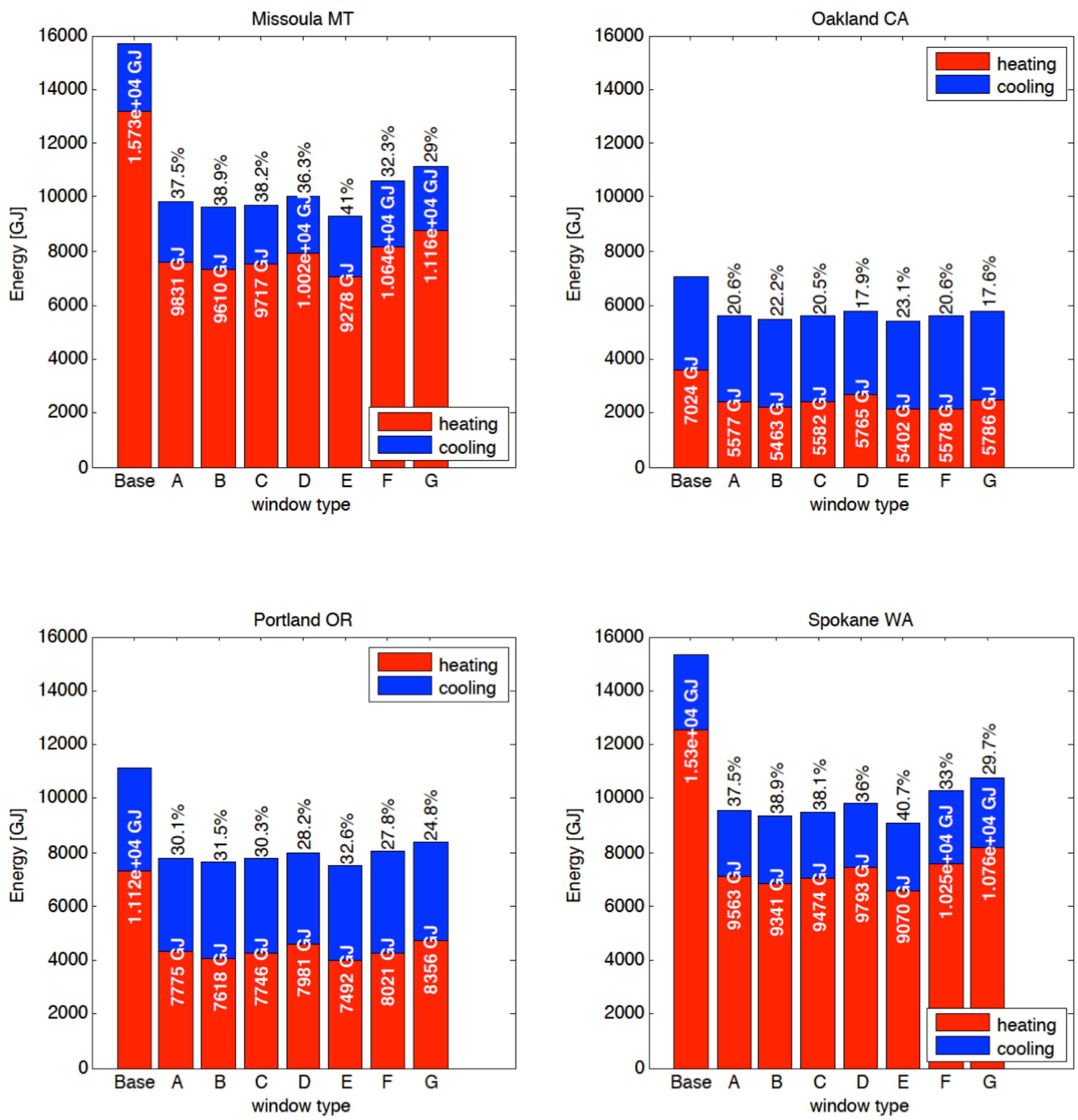

Figure 12. Annual energy simulation for large office

Condensation Analysis

EnergyPlus simulations are run in 15-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, the temperature on the glazing surfaces predicted by WINDOW and THERM for the given indoor temperature, outdoor temperature, and wind speed is compared 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, which may or may not be correct assumption, as the moisture content in the unsealed gap will be function of the level of SGS sealing to the room side, level of air infiltration from the outdoor side, dynamics of moisture migration, presence and quantity of any desiccant in the gap, etc. which was not subject of this study. Indoor dew point temperature is typically higher than outdoor for the climates included in this investigation, so we are examining the worst-case scenario for condensation resistance. This assumption may not be valid for existing buildings where 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 15-mintue time step for one window system. Figure 14 accumulates the 15-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. We also observe that condensation typically occurs within the first and last 100 days of the calendar year.

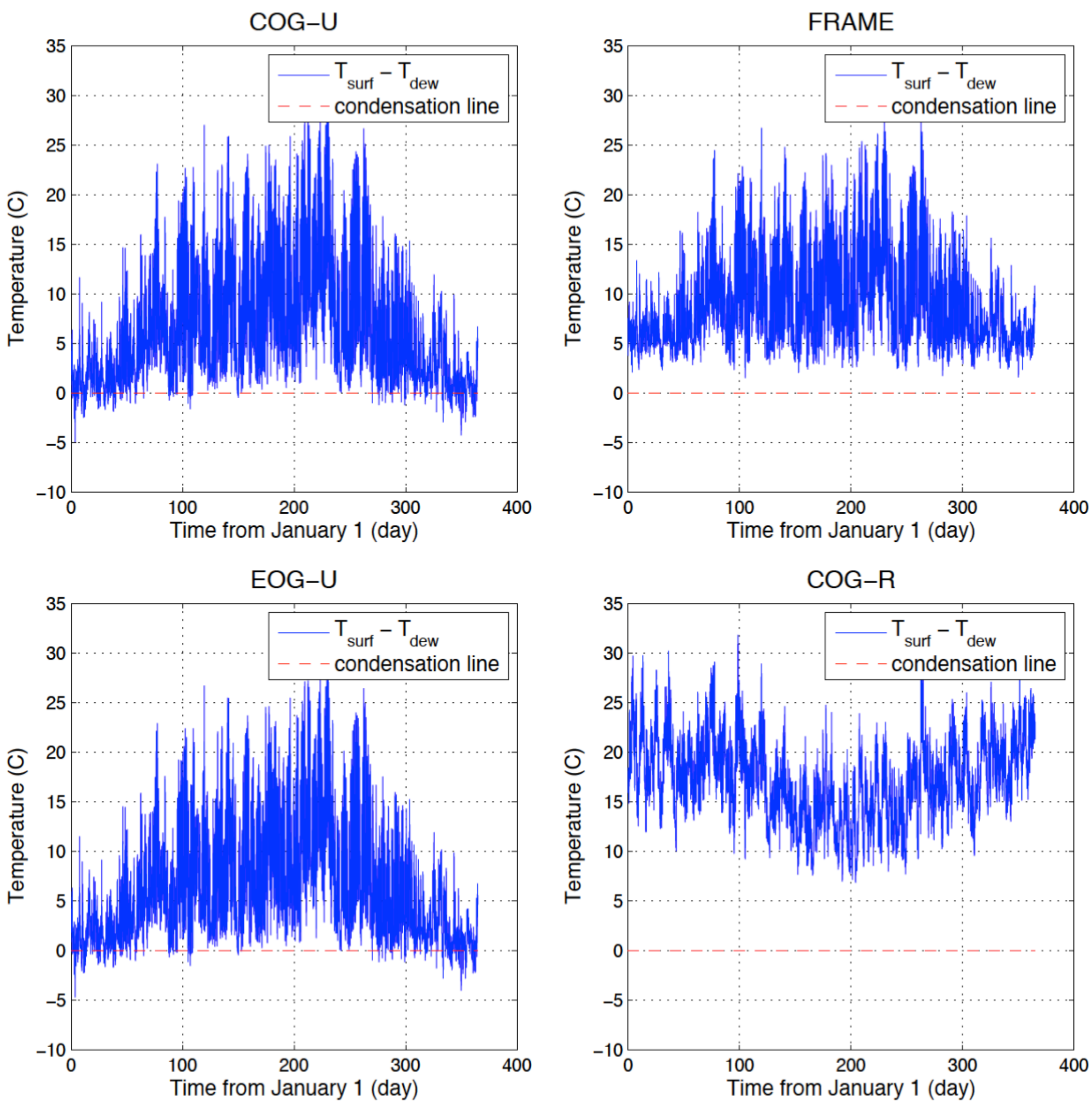

Figure 13. Difference of window surface temperature and adjacent dew point temperature. Large Office, Missoula MT, Product A

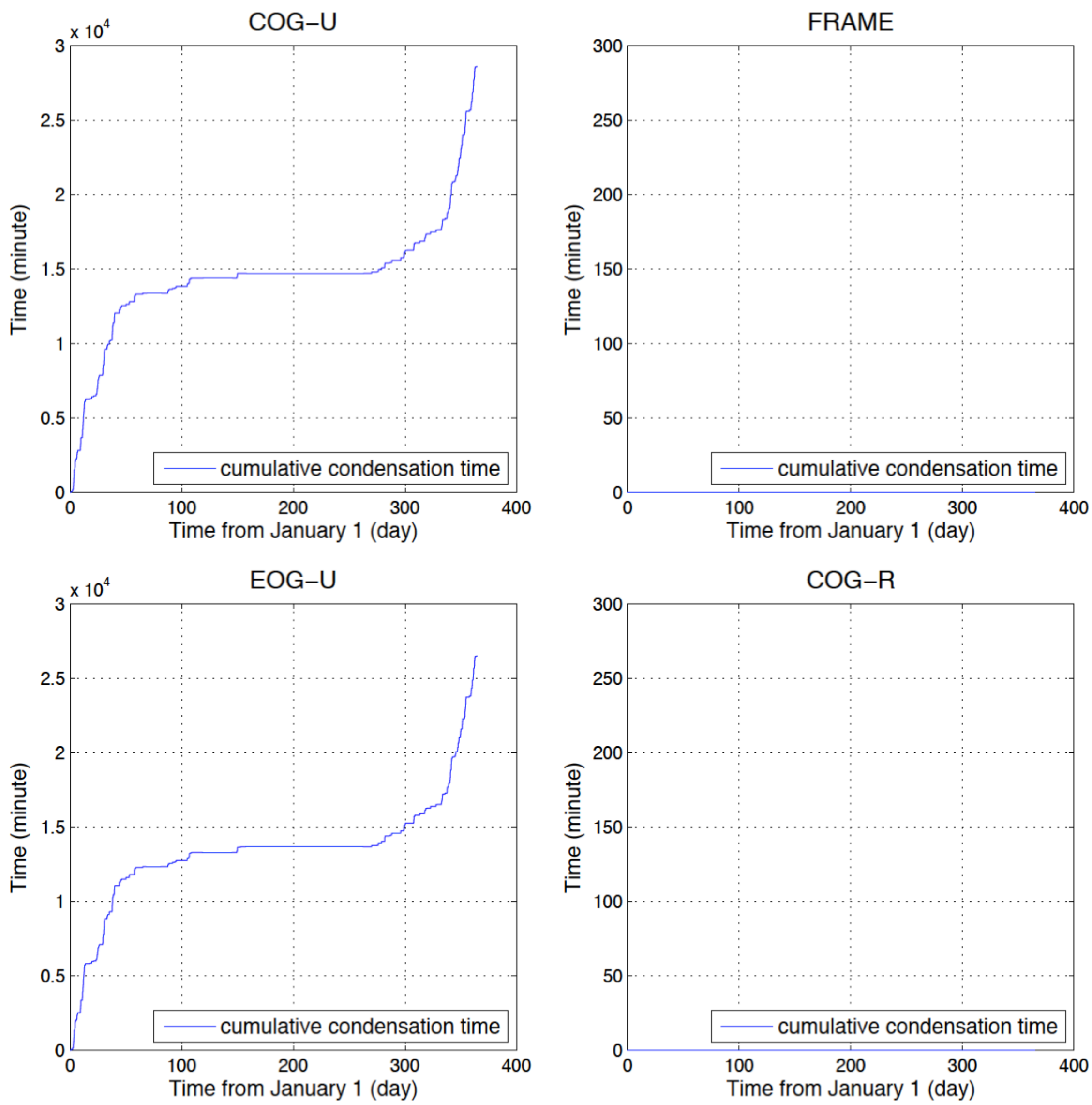

Figure 14. Cumulative time for window surface condensation risk.
Large Office, Missoula MT, Product E

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. Summarized condensation times based on a typical building schedule with open hours of 7am – 7pm is provided in Figures 18-20. The information in Figures 13-20 should be observed for relative product performance only since worst case condensation potential is studied here, which may be unrealistic for many buildings.

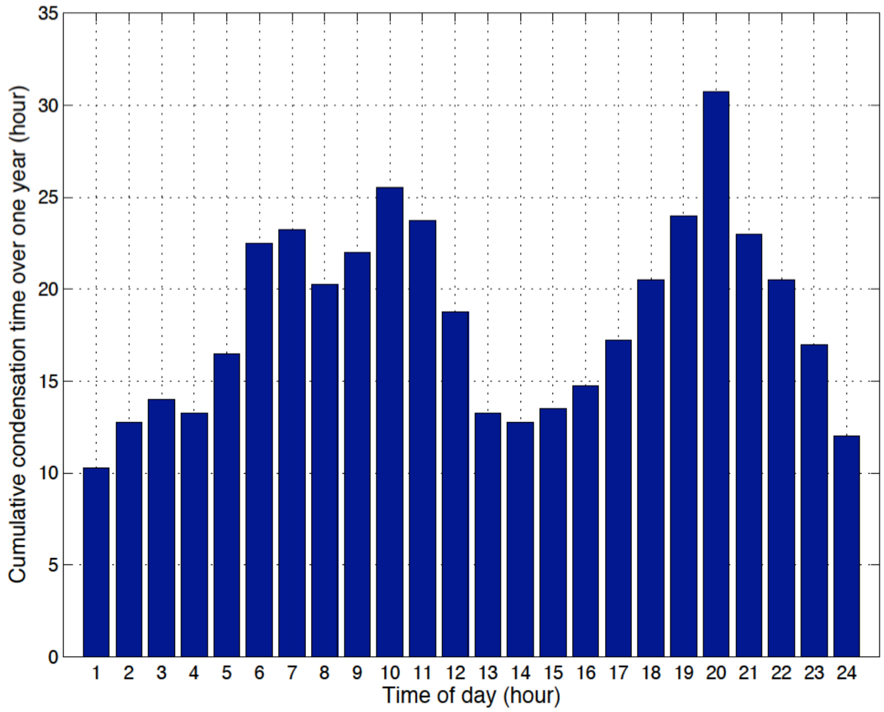

Figure 15. Window cavity condensation risk based on time of day for one year.
Large Office, Missoula MT, Product A

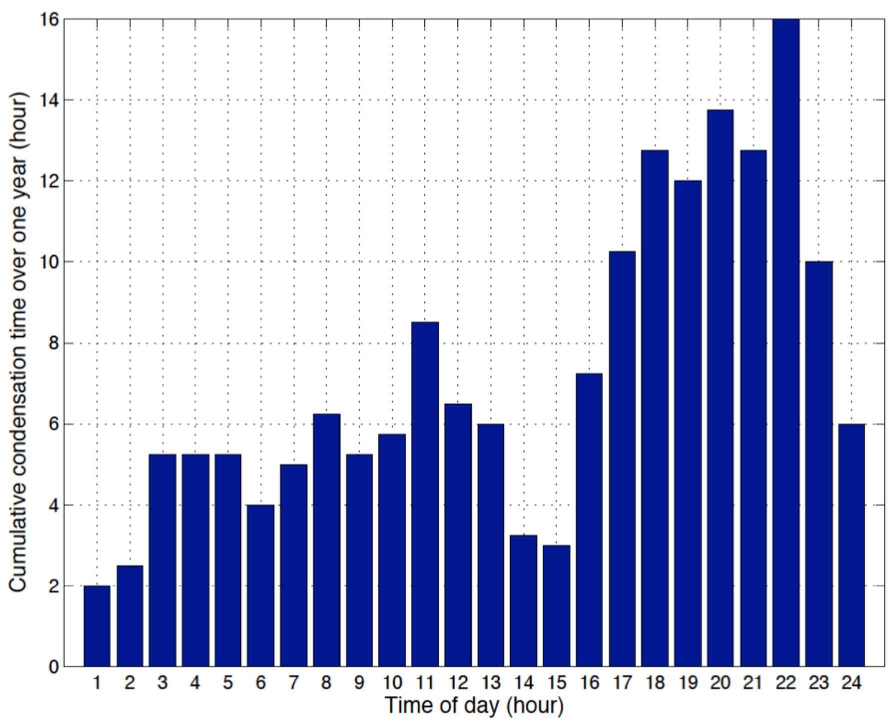

Figure 16. Window cavity condensation risk based on time of day for one year.
Medium Office, Missoula MT, Product A

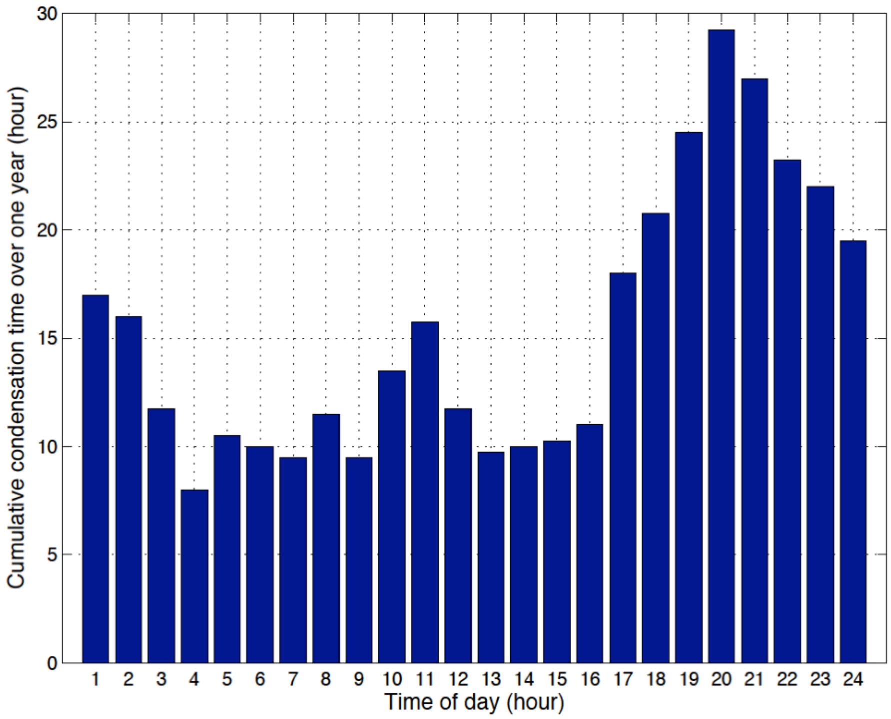

Figure 17. Window cavity condensation risk based on time of day for one year.
Small Office, Missoula MT, Product A

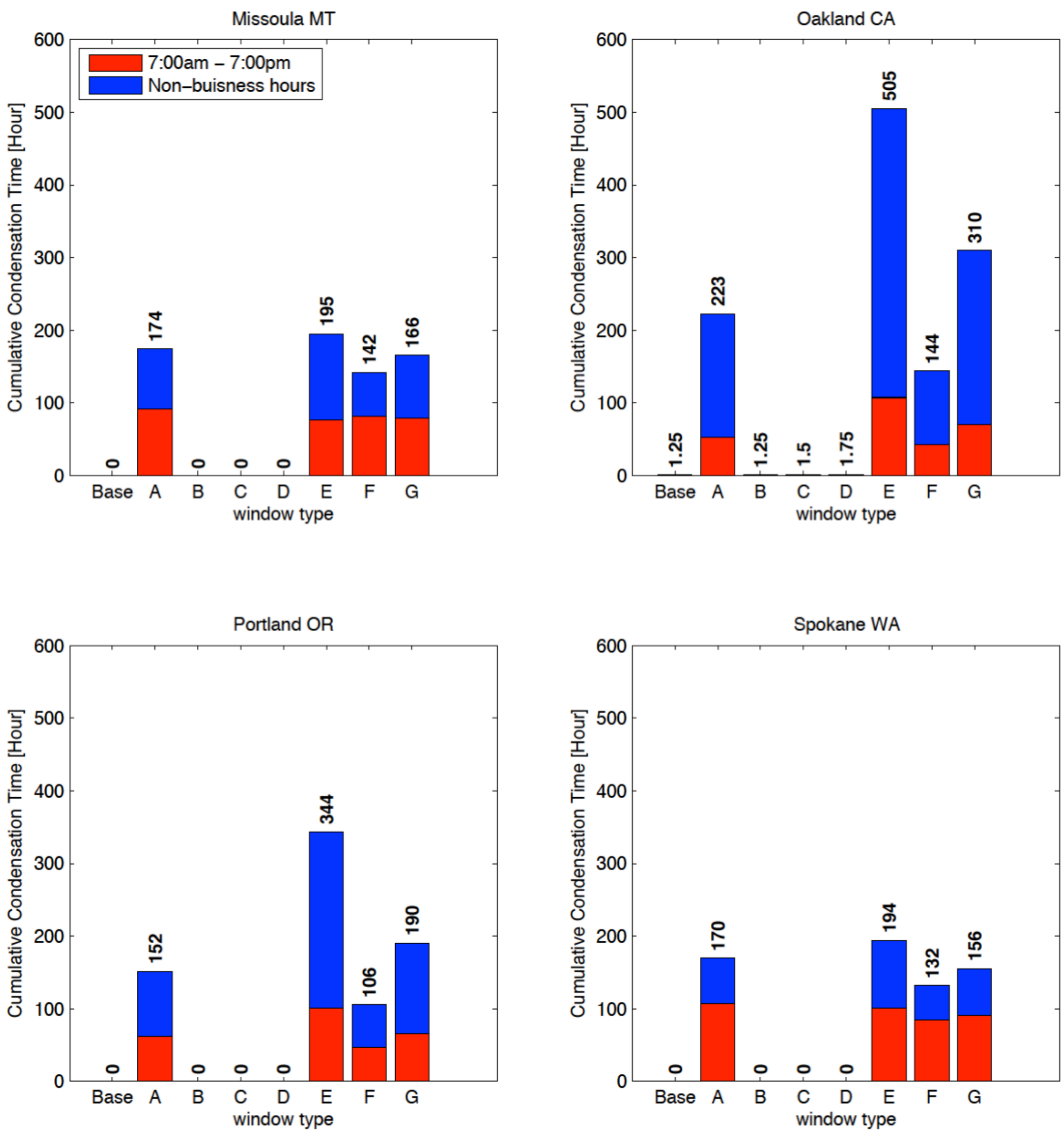

Figure 18. Cumulative condensation hours by window type and location. Small office

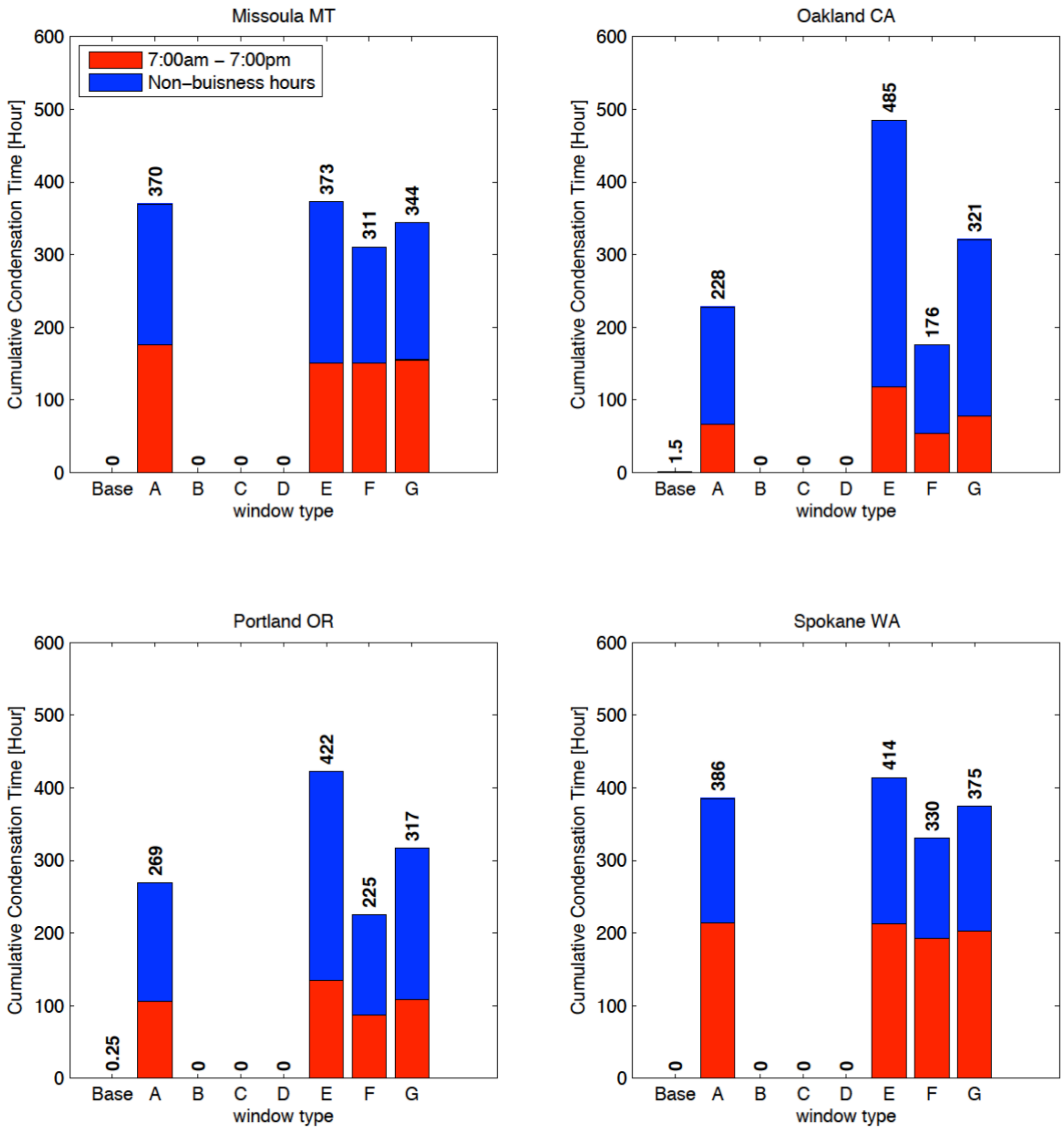

Figure 19. Cumulative condensation hours by window type and location. Medium office

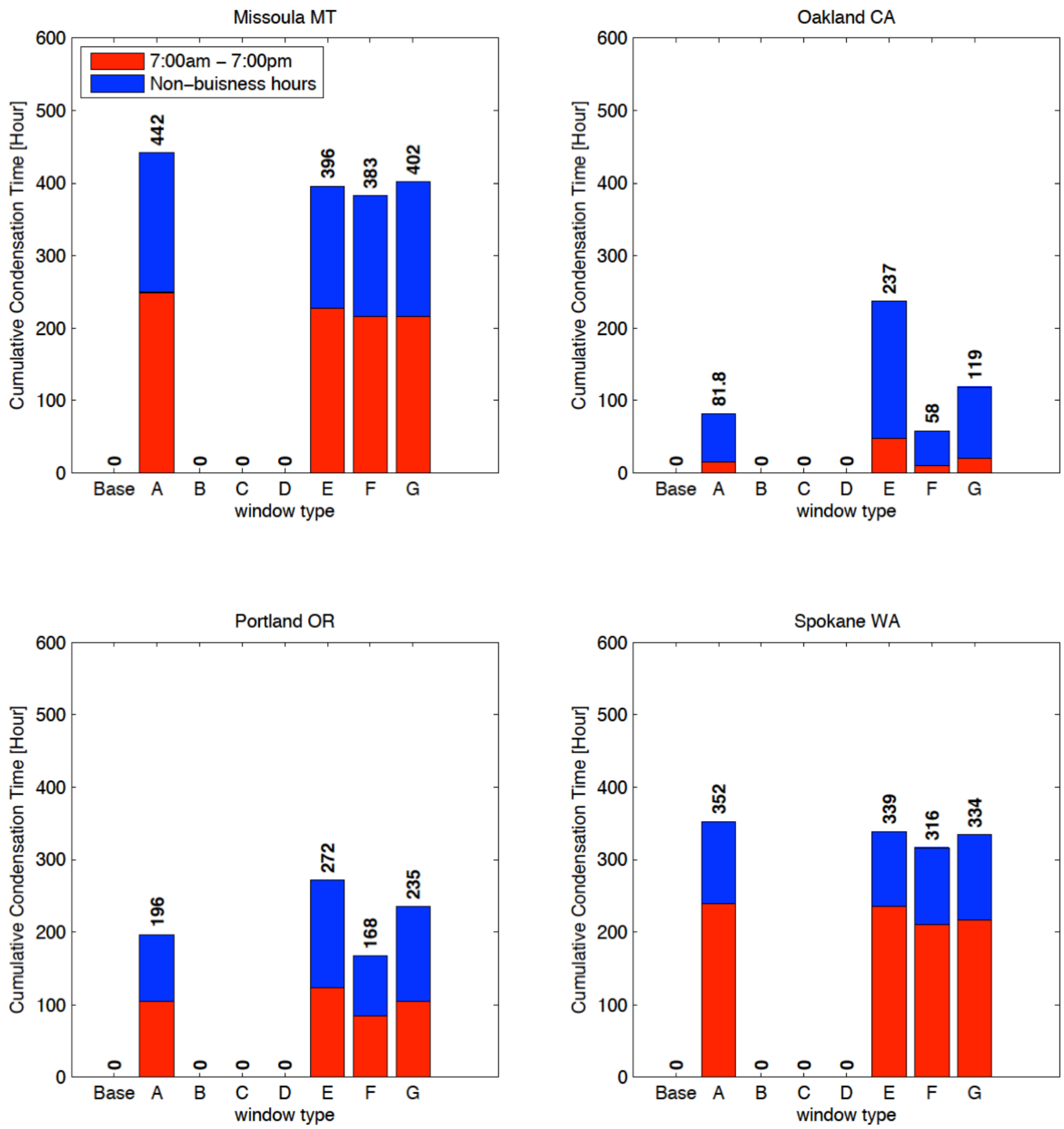

Figure 20. Cumulative condensation hours by window type and location. Large office

8. SUMMARY & CONCLUSIONS

The performance characteristics of several SGS products are simulated and validated in this report using industry standard practices. Where industry standard practices do not exist, such as CR between existing glazing and SGS, new methodology and software capabilities are introduced. Energy savings and condensation potential of various SGS systems in prototype commercial buildings are also compared.

SHGC and thermal transmittance simulation and validation methods are well established for typical prime window products by the NFRC. In general, these same procedures may be translated directly to SGS as is 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 this was done, all validation testing was within acceptable NFRC tolerances. The reported performance values for each product can be directly compared to other NFRC simulated products. Product E is shown to have the maximum reduction in SHGC and U-factor of all products examined, while product D has 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 determination 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 that further research might be needed to establish expected moisture content in unsealed gaps for different product types and to relate them to indoor room air, so that more representative CRU procedure can be developed. Also, unsealed gap frame surface temperature calculations in THERM could be improved to achieve tighter agreement with measurements.

Annual energy simulations show that all SGS products significantly reduce energy use in all climates and building types considered, with savings over the base window of 15 to 40%. 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 is 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, more understanding of moisture migration would help improve CRU determination as a more realistic measuring stick.

9. ACKNOWLEDGEMENT

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