Performance Comparison of a Low-E Retrofit Window at the Kevon Office Building

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Disclaimer

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Background

Controlling rising energy costs in older multistory office buildings can take various pathways such as envelope or equipment improvements. Equipment upgrades, such as the use of high efficiency motors or boilers can result in reduced energy costs. However, for older building envelopes with lower wall insulation levels and lower performance windows with high U-factors, the efficiency gains from equipment improvements may be hindered. While the equipment may be more efficient, the discomfort of the occupants in inefficient buildings often leads to increased energy use (e.g., supplemental heaters are used in office spaces near windows). Furthermore, the equipment upgrades in older buildings must be sized to service the same loads whereas in more efficient envelopes, the equipment upgrades can be sized smaller thus saving upfront costs as well as ongoing fuel costs.

Envelope upgrades; however, can be very expensive for building owners. Envelope upgrade costs may include not only the installation of new materials, but also include removal and disposal of old materials, displacement of occupants during renovations, and modification of office sizes and floor space.

Addressing these concerns for envelope upgrades, an innovative retrofit window technology has been installed to decrease the window U-factor and add a low emissivity (low-E) coating. The window retrofit was performed on The Kevon Center located on McClellan Ave in Pennsauken, NJ. The project structure is a four-story office building built in 1970, and comprises 100,000-square-feet of offices. It features 651 windows that cover 19,000 square feet. Prior to this retrofit, the only window alteration which had been performed was the addition of a window film on the interior surface. The window retrofits are performed such that occupants are not required to vacate office space and no existing materials other than the existing window film requires disposal.

The purpose for the window upgrade was to reduce operating energy costs; increase the comfort of the occupants, especially those located near windows; and provide a more uniform interior temperature, less affected by large temperature changes at the windows. The window upgrade technology selected is a unique retrofit panel product that effectively converts the original single-pane window into a triple-pane low-E window system. Installed from the interior of the building, the Low-E Retrofit Panel is a double-pane, dual low-E coated glass panel installed on the interior of the existing window separated with a ½" gasket and held into place with an aluminum extruded frame.

The Low-E Retrofit Panel manufactured by JE Berkowitz, LP, is also called the Renovate system. The system features two lites of low-E glass, separated by an argon-gas-filled cavity. A spacer system hermetically seals the insulated glass unit to the interior surface of the existing glass window panel, creating a permanent, no maintenance attachment. Two variations of the Renovate system were used. The RbB Platinum Plus II is featured on all but the south facing elevation, and incorporates one solar control low-E coating contained within the insulated glass unit, and a second durable pyrolytic low-E coating on the surface facing the room. The center-of-glass U-factor of the final installed assembly (including the existing glass) is 0.15 Btu/hr·ft^2·°F and the solar heat gain coefficient is 0.35. For comparison, this center-of-glass U-factor is 85 percent lower than the U-factor for the original single glazing (1.0 Btu/hr·ft^2·°F).

The RbB Platinum Plus II XL is featured on the south facing elevation, and incorporates a lower solar heat gain low-E coating within the insulated glass unit, and the same durable pyrolytic low-E coating on the surface facing the room. The center-of-glass U-factor of this final installed assembly (all three panes) is also 0.15 Btu/hr·ft^2·°F, but the solar heat gain coefficient is lower at 0.27. There is a slight difference in center-of-glass visible transmittance (57% and 50%, respectively), but this difference is not noticeable, especially with the different low-E coating being behind the existing glazing.

Test and Analysis Methodology

The purpose of this study is to quantify potential improvements in thermal comfort before and after retrofit, as well as assess whether there is any significant thermal stress on the glazing. The building energy savings due to the retrofit is being measured and reported separately by CDH Energy Corporation as part of a Greater Philadelphia Innovation Cluster (GPIC) and Energy Efficient Buildings Hub project.

In order to understand the characteristics of the installed low-E window retrofit panel upgrade, two offices were instrumented with temperature sensors located in various locations in the room – on the windows surfaces and in the space between the existing and retrofit window panels. One office exposure was to the west and one was to the south (Figure 2). Each office had two sets of identical windows.

Figure 2. West and South Facing Test Offices (indicated by floor cables)

Figure 3. Test Office with One Low-E Retrofit Panel Installed (left side)

For each test office, one window was kept with the original single-pane window with an interior film and the adjacent window was retrofitted with the low-E retrofit panel (Figure 3)[1]. Prior to the installation of the low-E retrofit panel, the existing window film was removed to provide a clean surface on the existing window.

The office window pairs provide a side-by-side comparison of the window surface and room temperature and light characteristics over a six-month period from the winter solstice to the summer solstice. The temperature analysis provides a general profile of the:

- temperatures between the existing glass and the retrofit panel;
- temperature on the interior surface of the glass;
- room temperature and the radiant effect on the interior office space; and
- difference in light levels through the windows.

[1] To the left in Figure 3 is the Retrofit Panel to be installed at the test conclusion.

The temperature profile is considered a marker for comfort based on the range of interior window surface temperatures and the relative change in the radiant component of the solar energy through the window.

Additionally, the potential thermal stress experienced by the glass was examined using temperature sensors on different locations of the glass. Thermal stress can develop in glass as it is subjected to changing temperatures through the day, driven by both outside conditions and solar gains. Thermal stress occurs when there is a temperature difference between the glass center and the edge when expansion of the material is restricted. This effect can be increased by the presence of shading on the glass, leading to warmer and cooler areas. This study provides a range of temperatures across the face of the glass as an indicator only of the potential for thermal stress.

The offices and the common space outside of the offices were not occupied for the entire monitoring period.

Instrumentation and Monitoring

For each of the WEST and SOUTH facing test office thermocouples (Type-T, low mass) were installed on both windows for each office:

- Low-E Retrofit Panel Window
    - Interior surface of the existing window (two locations)
    - Air gap between the existing window and the low-E retrofit panel (two locations)
    - Exterior-facing surface of the low-E retrofit panel, facing the air gap between the retrofit panel and exiting window (two locations)
    - Interior surface of the low-E retrofit panel facing the room (six locations)
- Existing single-pane glazing with Solar Control Film
    - Interior surface of the existing window (six locations)
- Radiant temperature globe in direct proximity to each window
- Solar radiation sensor (pyranometer) in direct proximity to each window
- Room temperature

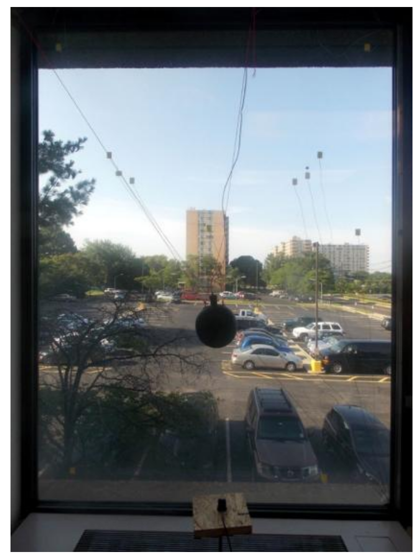

Figure 4. Temperature Sensor Locations

The temperatures of six different locations on each window interior surface facing the room were measured. The layouts of the sensors are shown in Figure 5 and Figure 6.

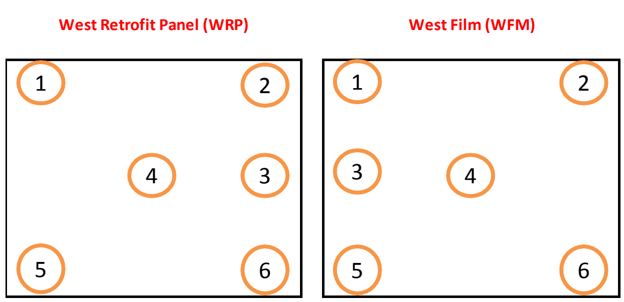

Figure 5. Interior Glass Temperature Sensors – West Facing Office

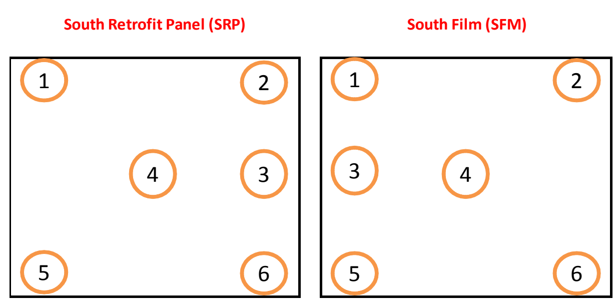

Figure 6. Interior Glass Temperature Sensors – South Facing Office

For those sensors located between the retrofit panel and the existing window, Figure 7 diagrams the sensor locations relative to the room in section and Figure 8 diagrams the sensor location in a planar view across the surfaces.

A programmable data logging system was used to record the sensors. The data logger recorded measurements every five seconds and averaged measurements over 15-minute periods.

Solar radiation levels were recorded using an Apogee silicon pyranometer sensor used to measure the solar radiation level through the window. Differences in solar radiation levels through the windows are based on the glazing coatings and films were intended to provide a qualitative, rather than quantitative, comparison between the adjacent test offices. The pyranometers were located in a horizontal position within approximately one foot from the window center to minimize the effects from the adjacent window (see Figure 3 for representative location).

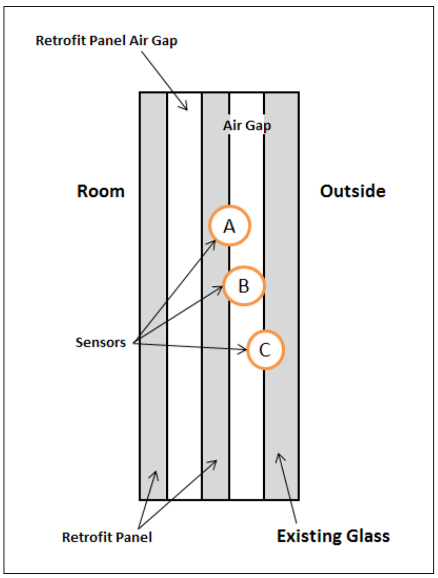

Figure 7. Planar View of Gap Sensors

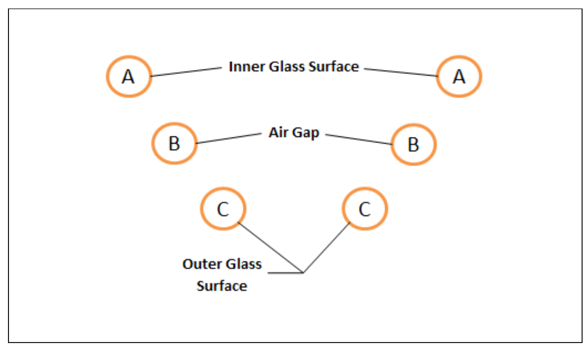

Figure 8. Section View of Gap Sensors

Monitoring Results

The temperature data presented in subsections below is based on the comparison between windows in each office. The data is analyzed to compare primarily, the temperature characteristics between windows in each office and secondarily to compare windows between office orientations. Nomenclature for the charts refer to four windows as:

- West Retrofit Panel (WRP)
- West Film (WFM), original window
- South Retrofit Panel (SRP)
- South Film (SFM), original window

Interior Glass Surface Temperatures

For the WEST office, Figure 9 and Figure 10 demonstrate the diurnal cycle and the range of temperatures on a daily basis and the change from the winter to the warmer periods. The detail data show the range of temperature changes that can be expected on the inside surface of the window facing the room. Figure 11 shows the maximum temperature at each sensor location over the monitoring period. Comparing the Retrofit Panel (WRP) with the original single pane with film (WFM), it is clear that the maximum surface temperature of the retrofit panel is over 20°F less than the maximum for the original windows. The overall average surface temperature of both windows over the monitoring period (Figure 12) is closer, with the retrofit panel averaging 5°F warmer than the original windows. For the minimum interior glass surface (Figure 13), the original single-pane windows have minimum temperatures at least 18°F colder than the low-E retrofit panel.

Finally for the WEST orientation, Figure 14 plots the daily average, maximum, and minimum temperature across the interior surface (average of all sensor locations). The daily data for the WEST facing windows highlights that the low-E retrofit panel provides a much more narrow swing in surface temperatures, and much closer average surface temperature to the room air temperature than the original windows. In essence, the low-E retrofit panel system does a superior job of moderating the environmental conditions than the original single-pane windows, by reducing heat transfer through both improved insulation (lower U-factor) and reduced solar heat gain. Results are consistent across all monitoring periods.

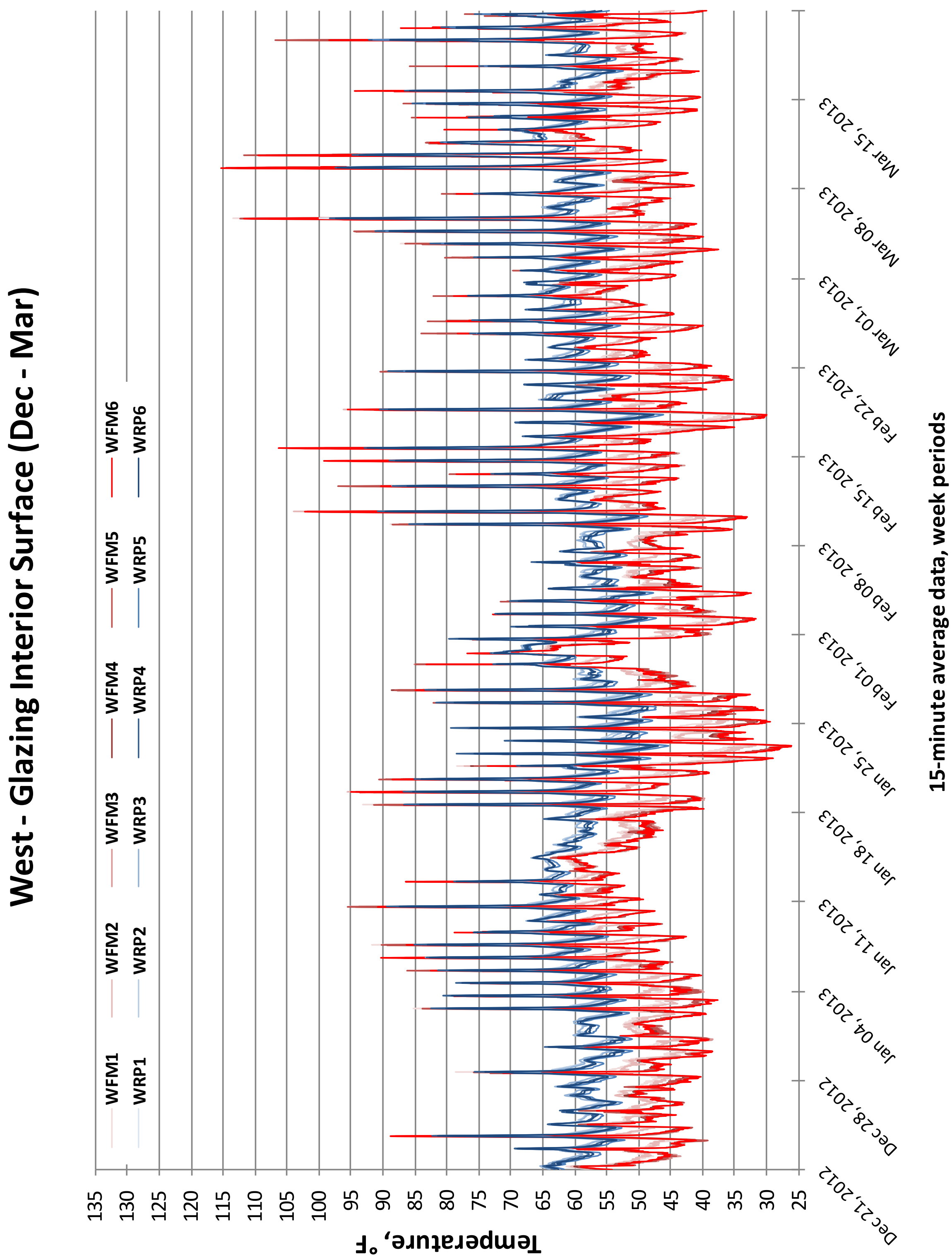

Figure 9. Window Surface Temperatures (Dec. – Mar.) – West Facing Office

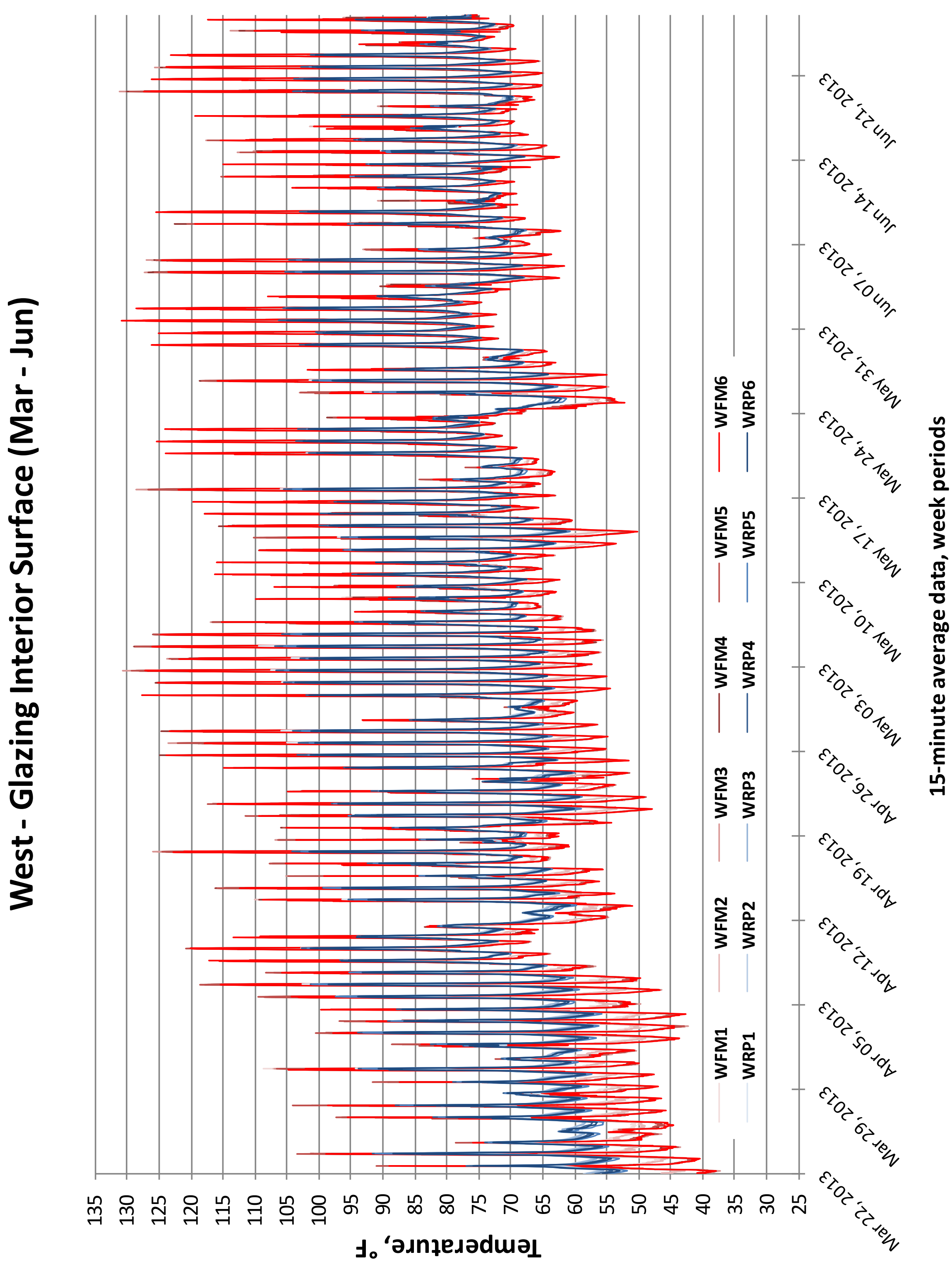

Figure 10. Window Surface Temperatures (Mar. – Jun.) – West Facing Office

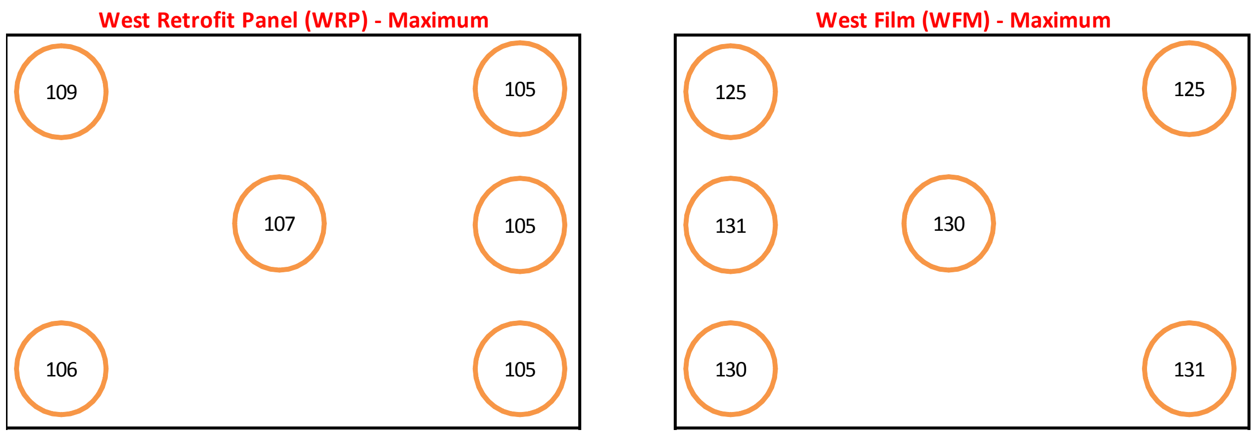

Figure 11. Maximum West Window Surface Temperature, °F

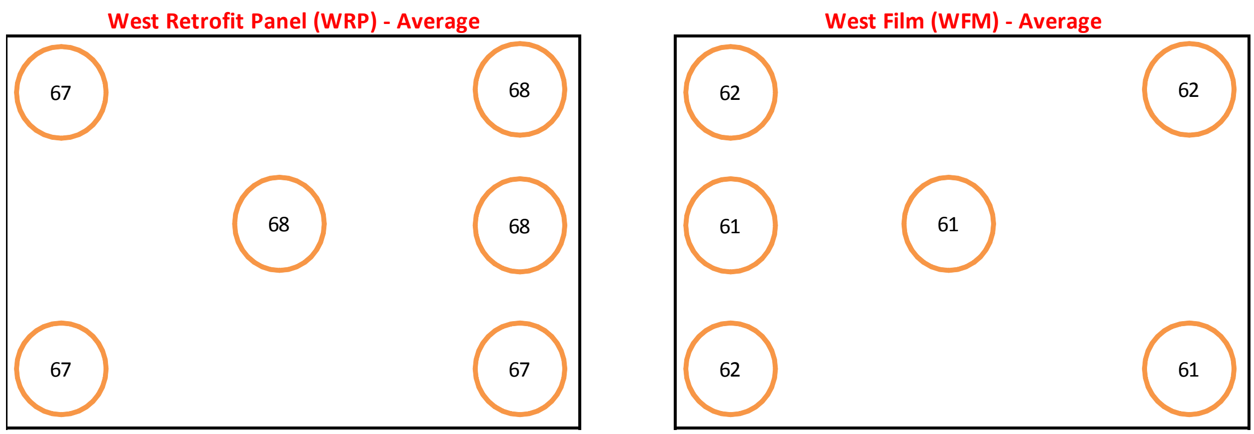

Figure 12. Average West Window Surface Temperature, °F

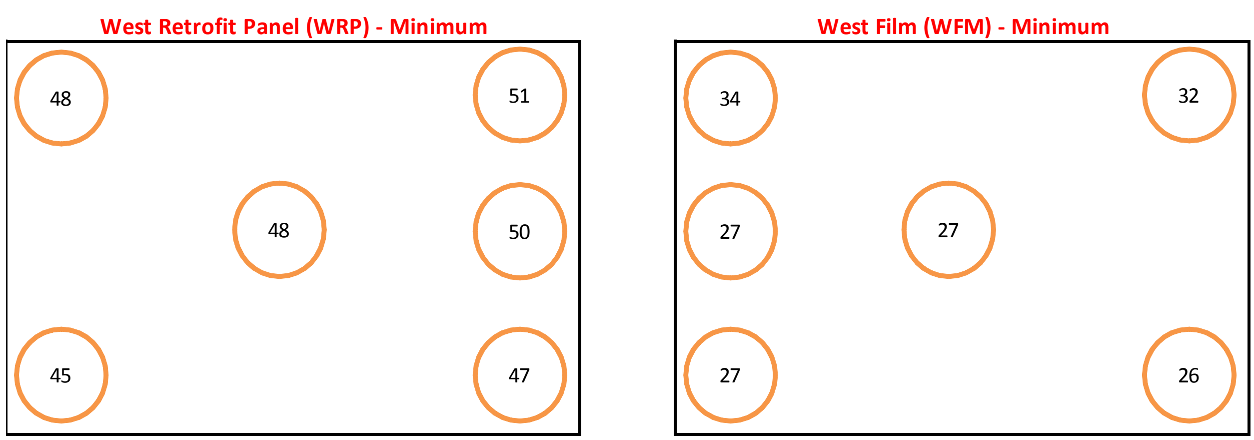

Figure 13. Minimum West Window Surface Temperature, °F

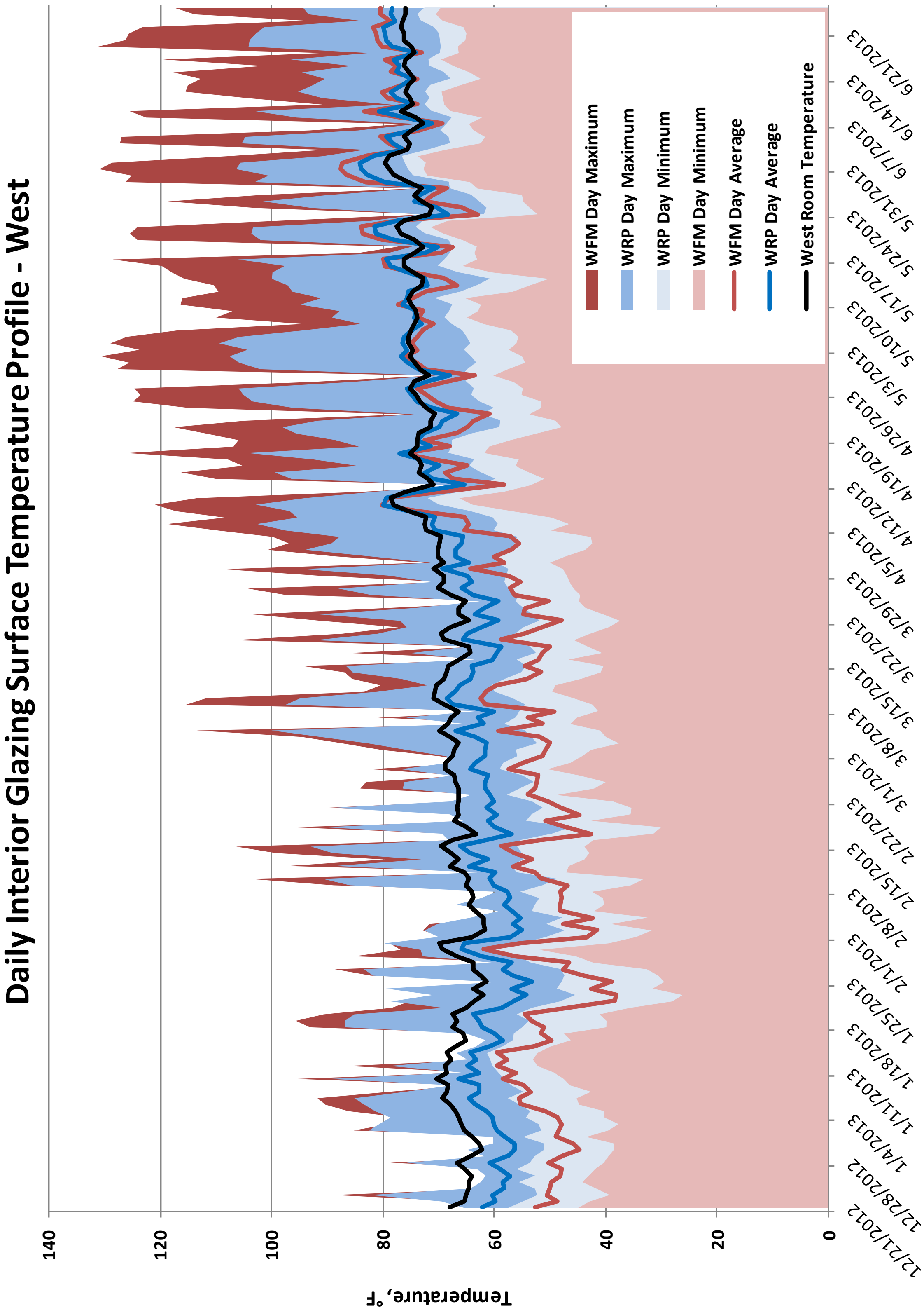

Figure 14. Daily Average Window Surface and Room Air Temperatures – West Facing Office

The SOUTH facing office demonstrates similar results as for the WEST office charts above as shown in Figure 15 through Figure 20. The sensor layout is shown in Figure 6 above. Differences between the SOUTH and WEST facing glazing consist of the evenly distributed peak temperatures across all seasons for the SOUTH window, while for the WEST glazing (and similar for the EAST), the maximum surface temperatures occur closer to the summer solstice.

Maximum temperatures for the SOUTH facing windows are lower than for the WEST facing windows but still demonstrate a similar difference between the low-E retrofit panel and the original windows. The data for the average and the minimum surface temperatures; however, are very similar between the SOUTH and WEST facing windows as would be expected since the average and minimum temperatures are less dependent on direct solar gains on the window than the maximum peak temperatures. Also note that the low-E retrofit panels on the SOUTH facing orientation have a lower solar heat gain coefficient than on the WEST orientation (center of glass SHGC 0.27 vs. 0.35).

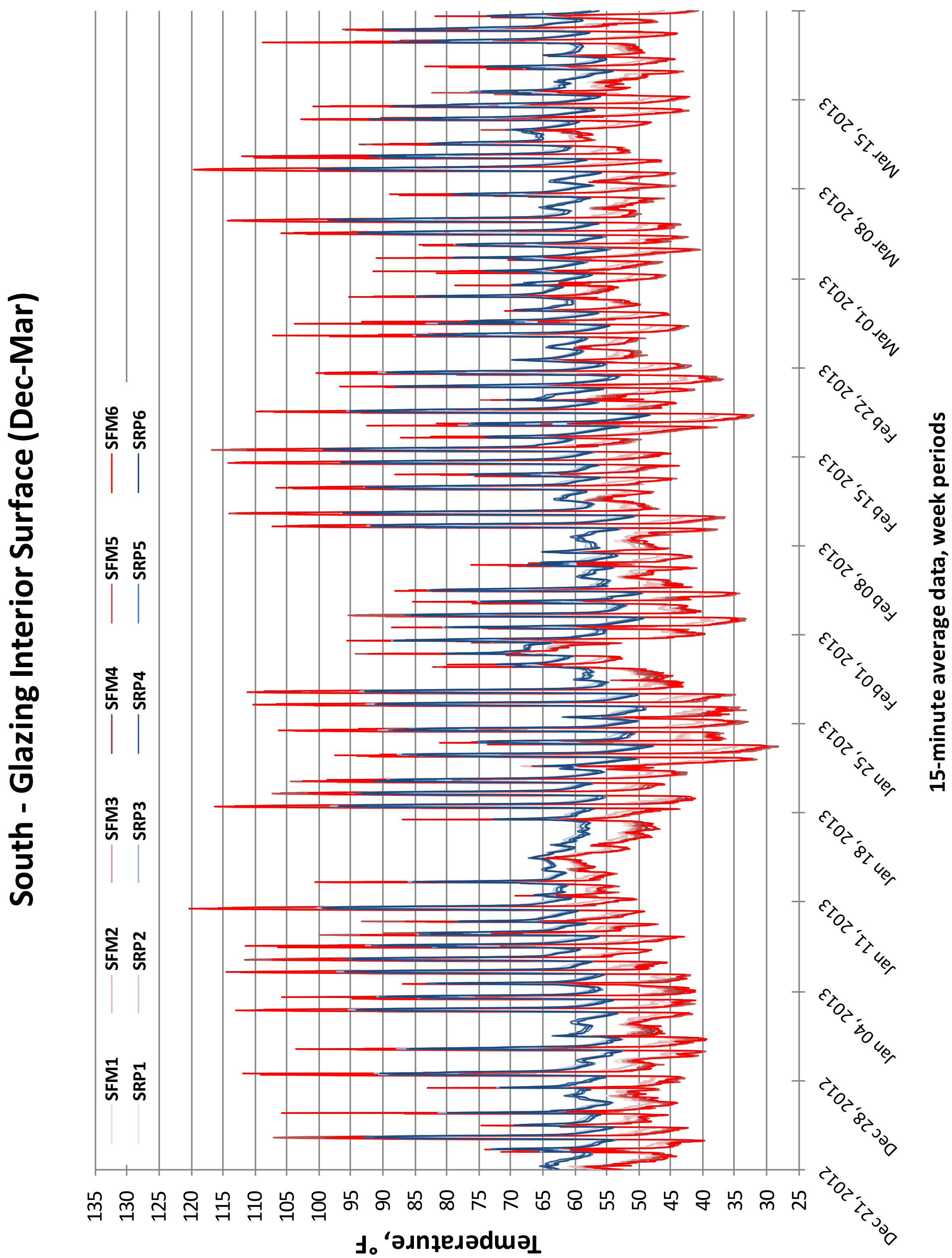

Figure 15. Window Surface Temperatures (Dec. – Mar.) – South Facing Office

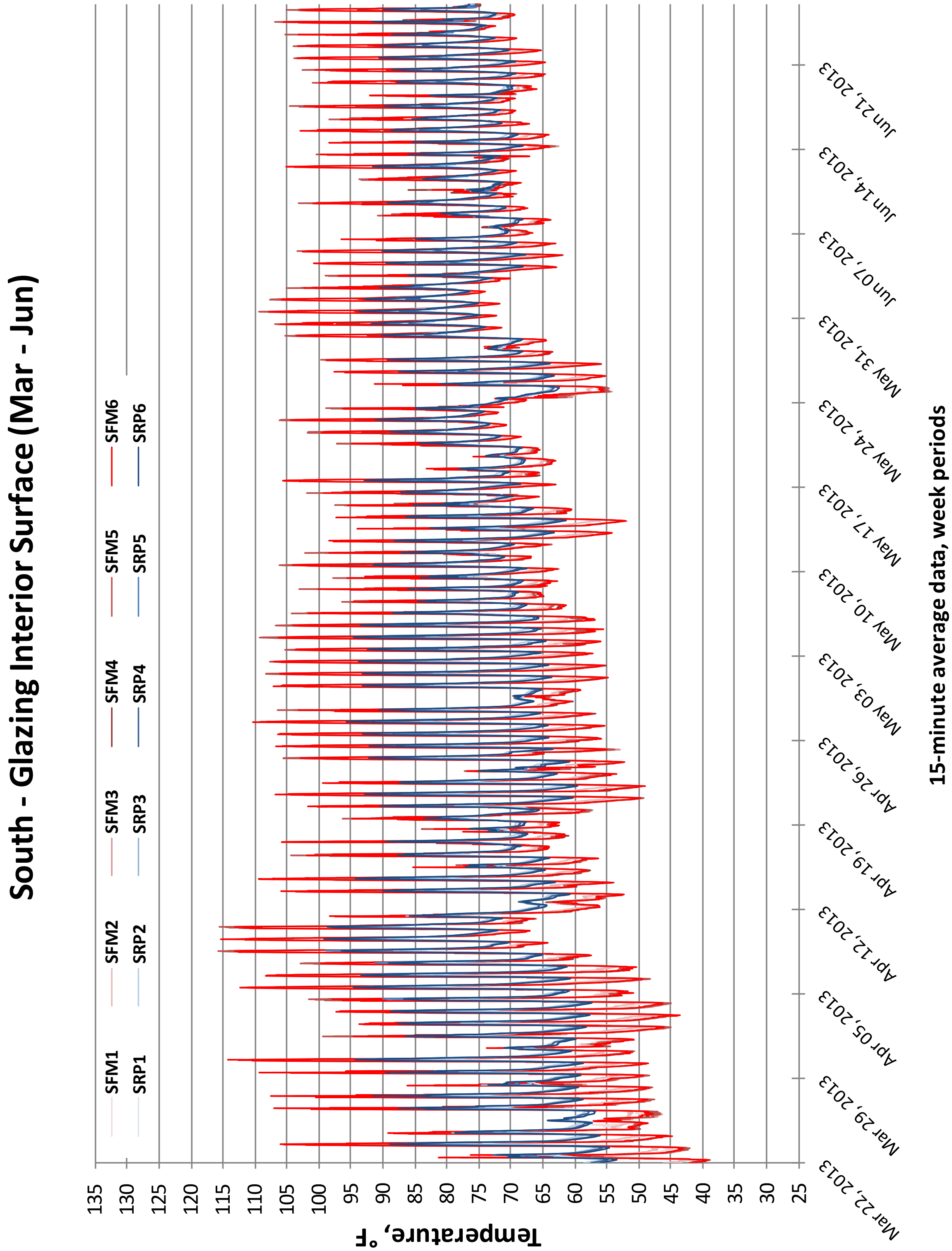

Figure 16. Window Surface Temperatures (Mar. – Jun.) – South Facing Office

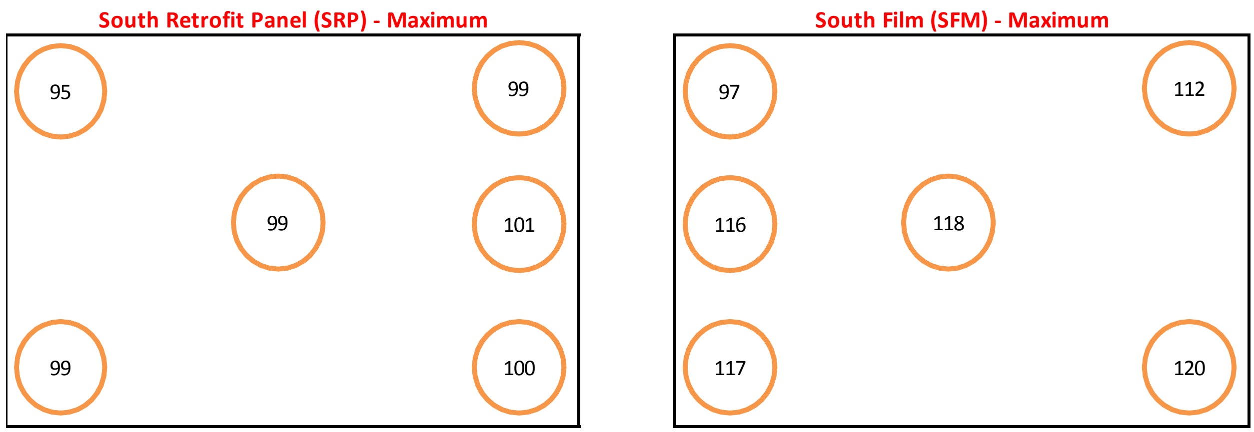

Figure 17. Maximum South Window Surface Temperature, °F

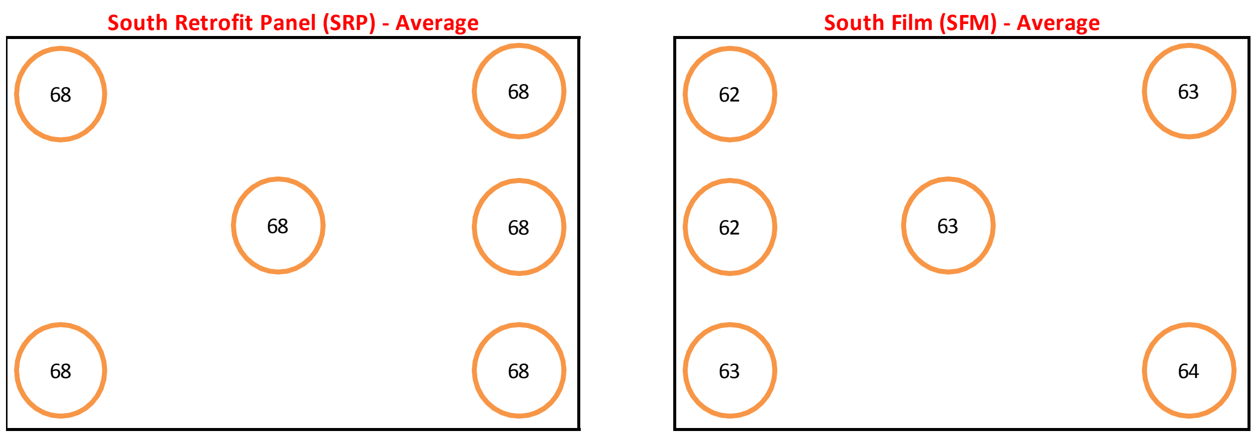

Figure 18. Average South Window Surface Temperature, °F

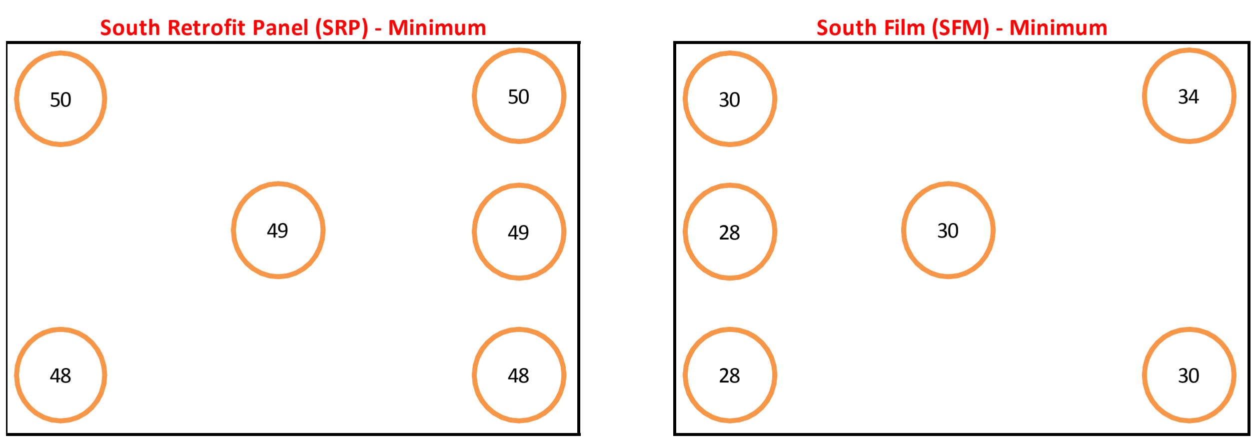

Figure 19. Minimum South Window Surface Temperature, °F

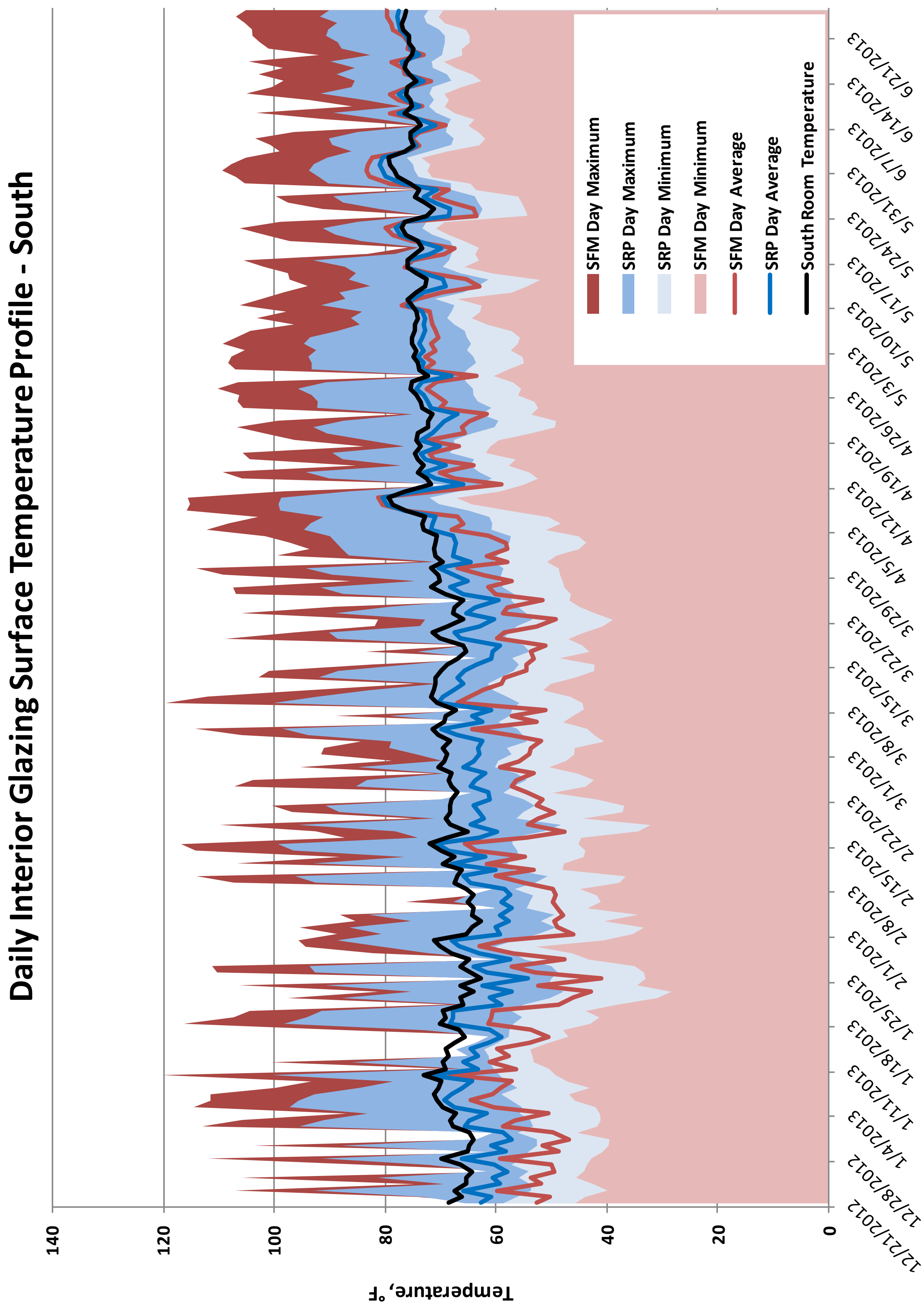

Figure 20. Daily Average and Room Air Temperatures – South Window Surface

Temperatures in Gap between Existing Window and Retrofit Panel

The temperature characteristic in the gap between the existing window and the retrofit panel is of particular interest due to the potential for heat buildup and thermal stress on the glass surfaces. This data is of course only available for the windows with the retrofit panels in the WEST and SOUTH orientations. Low mass temperature sensors (2 each) were installed on the inside surface of the existing window (C), in the air gap between the existing window and the retrofit panel (B), and on the outside surface of the retrofit panel (surface facing the gap, A – refer to Figure 7 and Figure 8 for sensor locations).

Plots of the temperatures in the gap are shown in Figure 21 for the WEST facing window and Figure 22 for the SOUTH facing window.

As expected based on the solar angles at various times of the year, the WEST facing window will have higher temperatures in the gap nearer the spring equinox to the summer solstice, and the SOUTH facing glazing will have higher temperatures nearer the winter solstice to the spring equinox.

When comparing the maximum (Figure 23), average (Figure 24), and minimum (Figure 25) temperatures in the gap between the WEST and SOUTH facing windows, it is clear that the SOUTH facing windows do not experience as high a temperature swing as with the WEST facing windows (as much as 16°F less in the SOUTH orientation). As with the inside surface temperatures, the average and minimum temperatures in each orientation are much closer due to the dilution of the solar effects across the full day cycle and when averaging over cloudy periods.

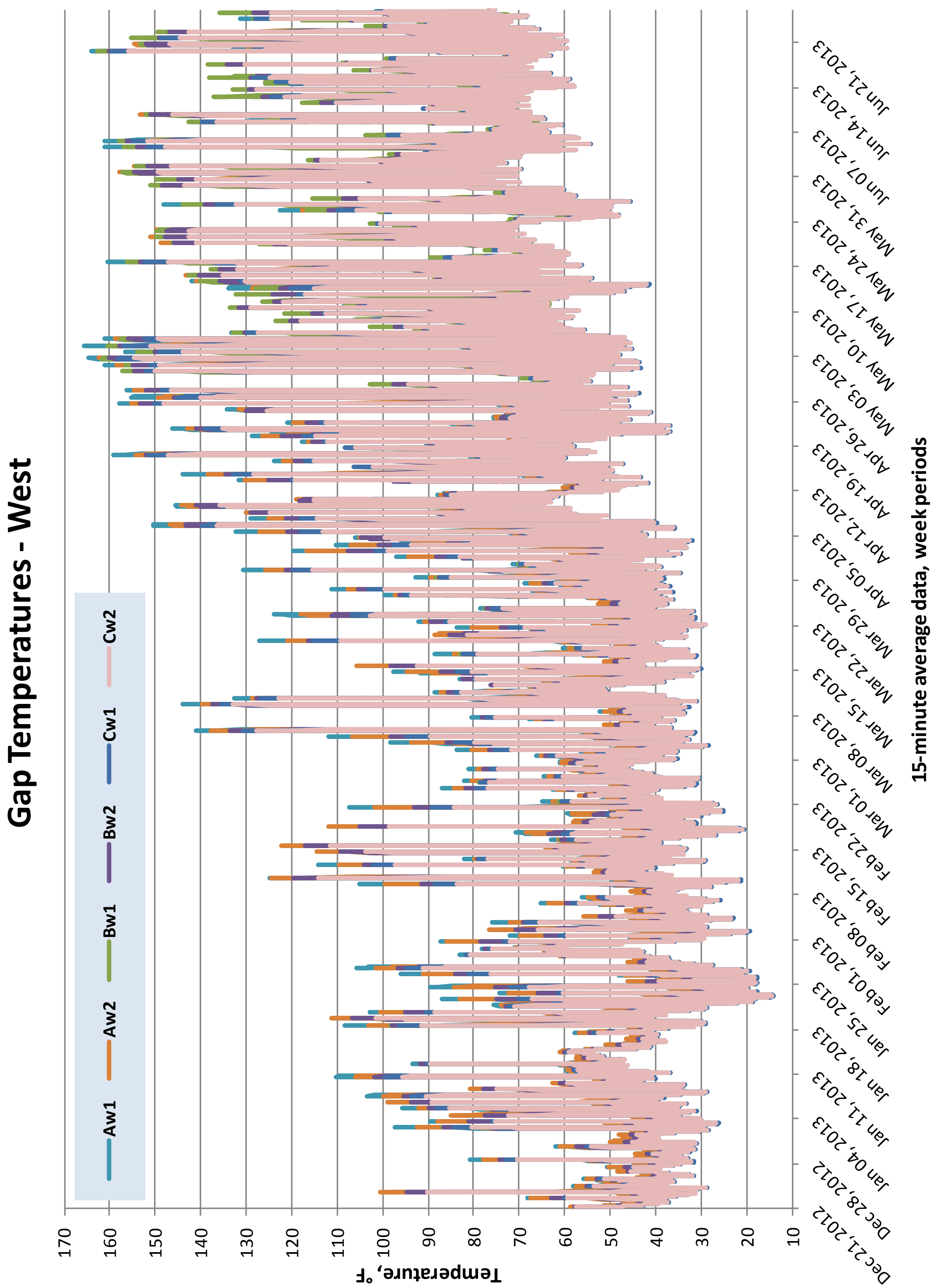

Figure 21. Gap Temperatures – West Facing Office

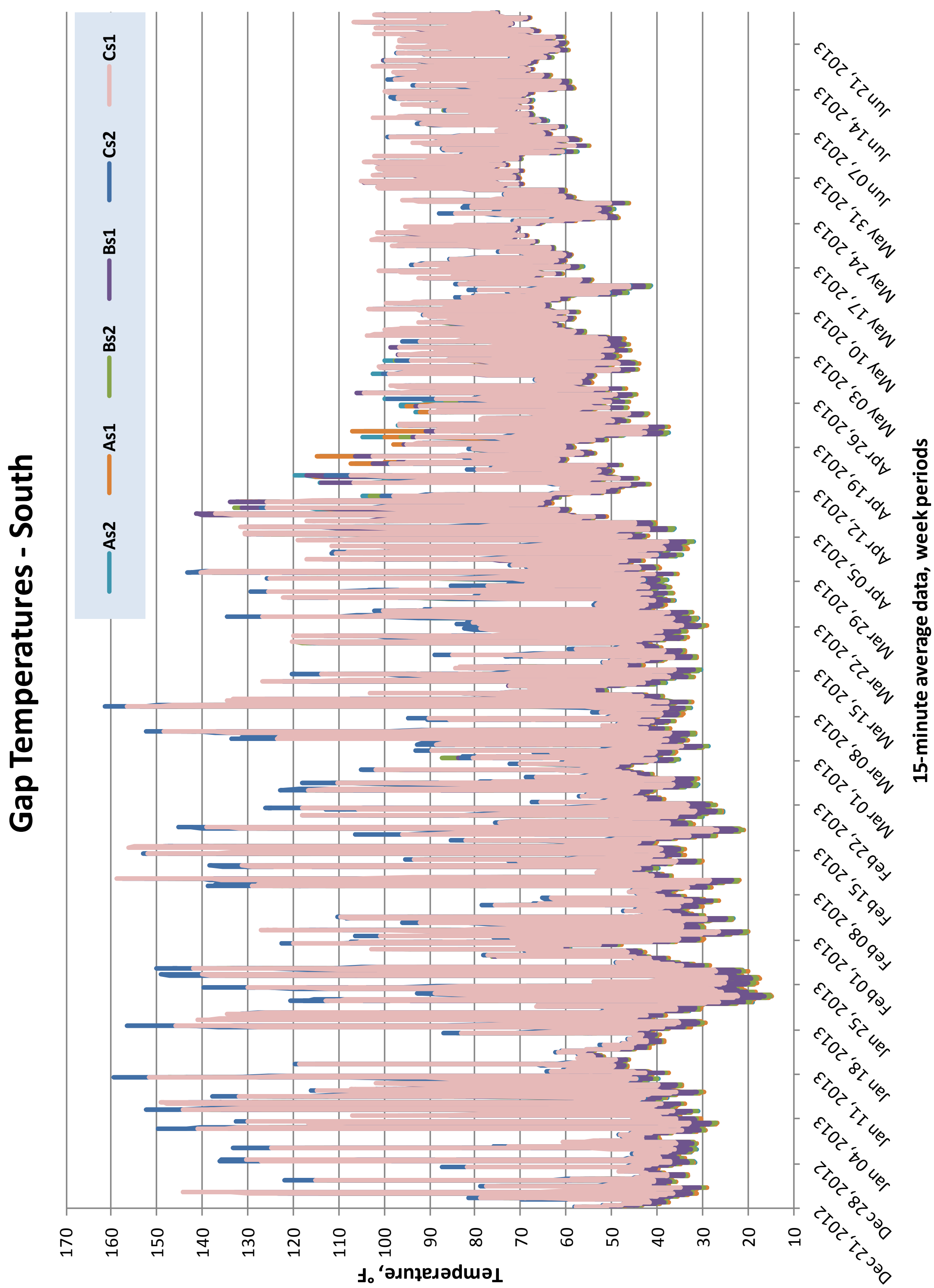

Figure 22. Gap Temperatures – South Facing Office

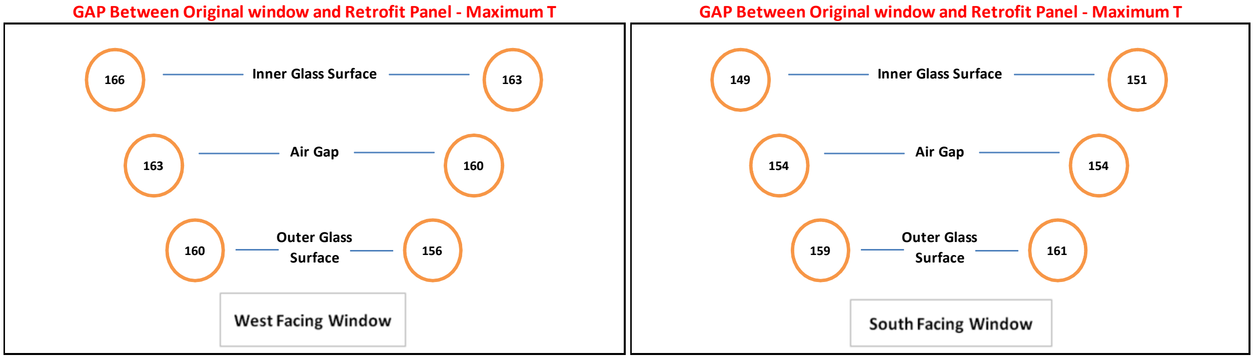

Figure 23. Maximum Gap Temperatures of Low-E Retrofit Panel Windows

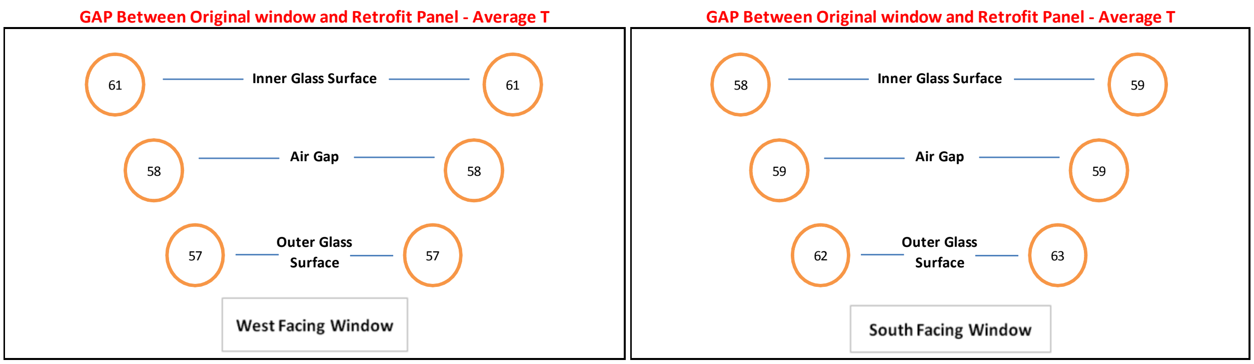

Figure 24. Average Gap Temperatures of Low-E Retrofit Panel Windows

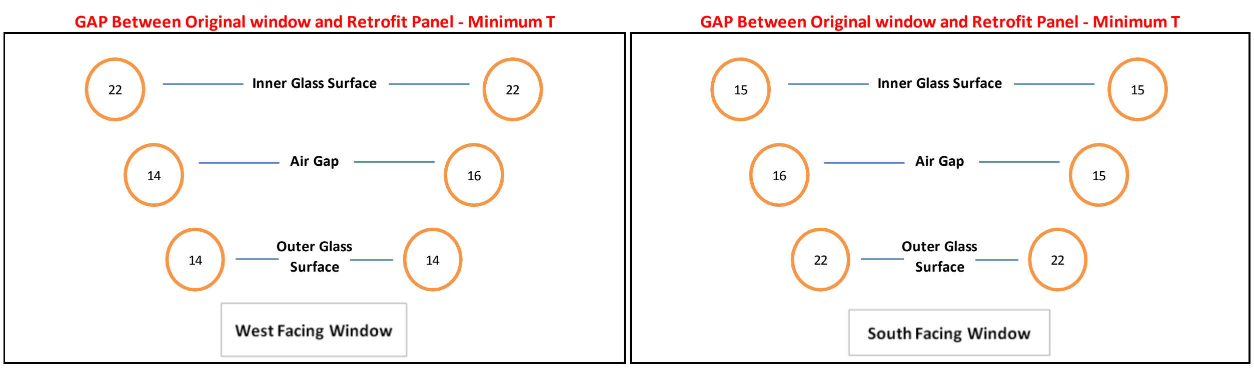

Figure 25. Minimum Gap Temperatures of Low-E Retrofit Panel Windows

In addition to the temperature change throughout the day and seasons, the temperature difference across the plane of the glass is also of interest due to the thermal stress that may be exerted on the glass when thermal expansion or contraction of the glass is restricted in the surrounding frame. The internal thermal stress may be estimated by the formula:

$$\sigma = E \cdot \varepsilon = E \cdot \alpha \cdot dt$$

where

σ = thermal stress,
E = Young's modulus,
ε = strain,
α = thermal expansion coefficient of the material, and
dt = temperature difference across two points where thermal expansion is restricted

For soda lime window glass, this ends up simply being:

σ (psi) = 50 psi/°F x dt (°F)

The mean strength of glass (average breakage point, or modulus of rupture) is typically between 7,000-18,000 psi depending on whether it is annealed, heat strengthened, or tempered. The strength also depends on the quality of the edge cut because crack propagation starts at flaws at the edge. However, average strength is not the relevant measure, as that would imply 50 percent breakage, and 8 /1000 probability of breakage is the more common metric. In practice, when the thermal stress gets above 2,000-3,000 psi, then potential breakage starts to be of concern. A common situation where maximum thermal stress typically occurs is on cold sunny days, especially if part of the glass is shaded, where the center of the glass is relatively warm, but the edges of the glass are cold from both the frame and any shading.

Figure 26 shows the temperature difference across the plane of the glass layers and the air gap for any 15-minute period. The data is sorted to show the largest difference and the duration (in hours, x-axis).

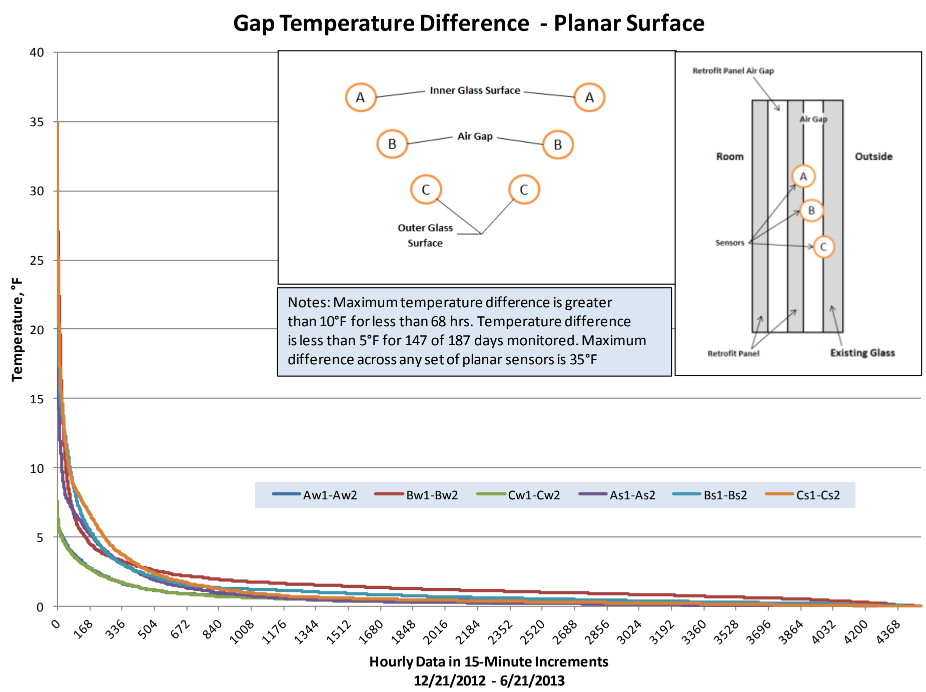

Figure 26. Planar Sensor Temperature Difference in Gap of Retrofit Panel Window

The maximum temperature difference (typically on the inside surface of the original pane, Cs1-Cs2) was only more than 10°F (500 psi) for 68 hours out of 187 days monitored, or 1.5 percent of the time. In all cases, the maximum temperature difference was no more than 35°F, or 1,750 psi. The placement of the temperature sensors may have missed some effects in the corners where the temperature difference may be more than measured here, but overall, there does not appear to be any significant concern with thermal stress when using the low-E retrofit panel. Furthermore, when comparing to similar sensor positions on the original single pane with the solar control film, there are no significant differences in the maximum surface temperature differences, and no reason to expect any difference in the potential for thermal stress breakage.

In addition to the planar temperature difference for each set of sensors, the maximum temperature difference across all positions on both sides and within the gap (censor locations A, B, and C) for all 15-minute periods, sorted by magnitude, is shown in Figure 27.

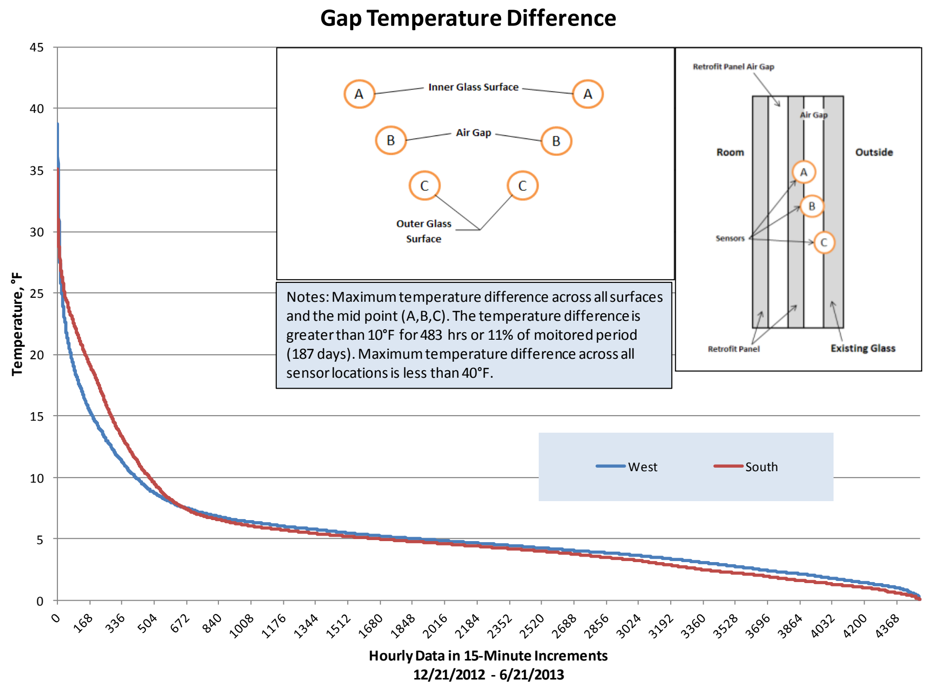

Figure 27. Maximum Temperature Difference between Gap Sensors of the Retrofit Panel Window

In all cases, there is no more than 35°F temperature difference within the gap space between the existing window and the retrofit panel during the monitoring period.

Average Temperature Profiles

Summarizing the window interior surface temperatures and the room ambient temperatures demonstrates the differences that occur when the retrofit panels are installed. The data is divided into approximately three-month periods for more clarity. Figure 28, Figure 29, Figure 30, and Figure 31 provide the average temperature detail for each orientation.

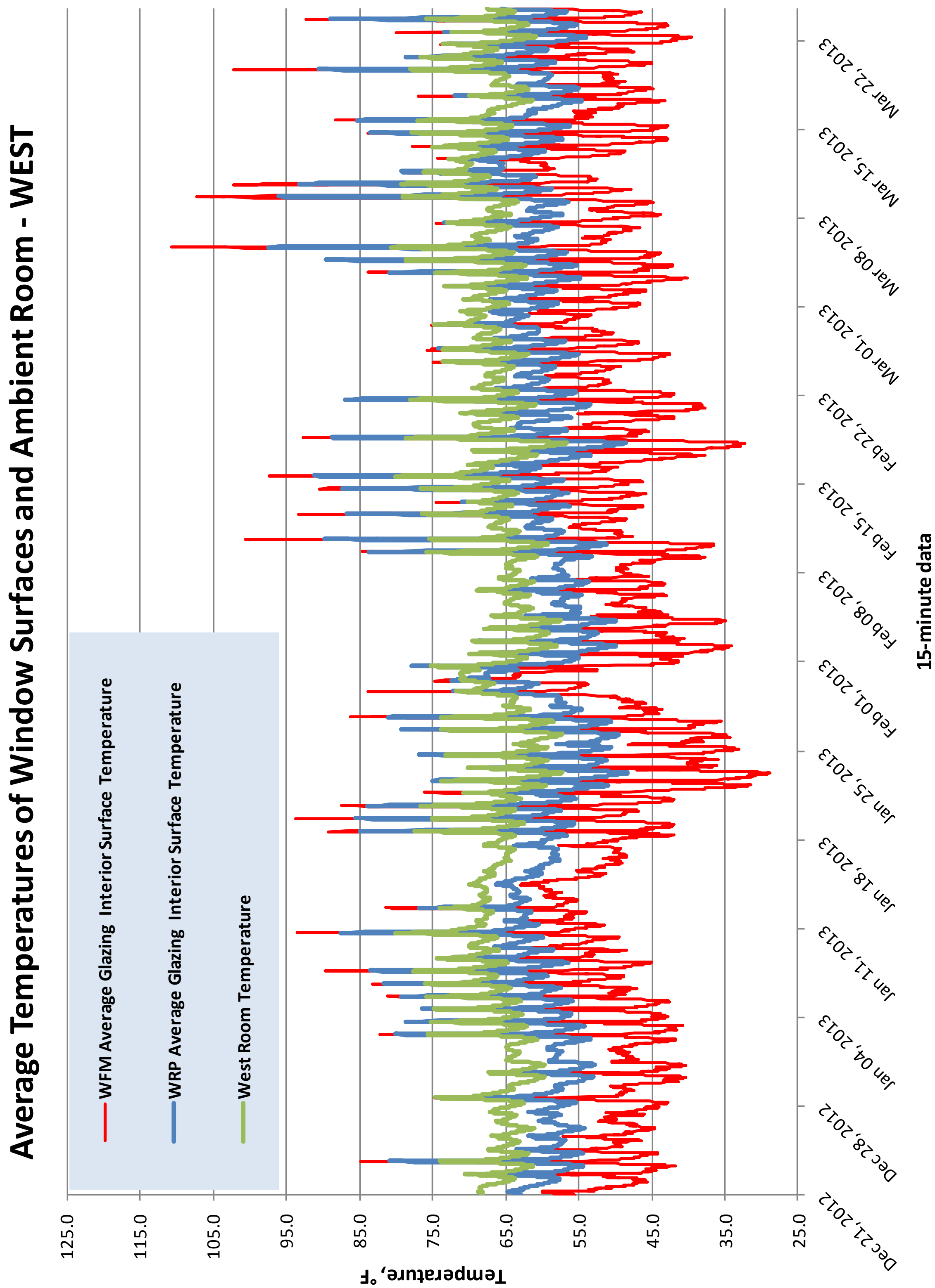

Figure 28. Average Temperatures on Interior Glass Surface (Dec. – Mar.) – West Facing Office

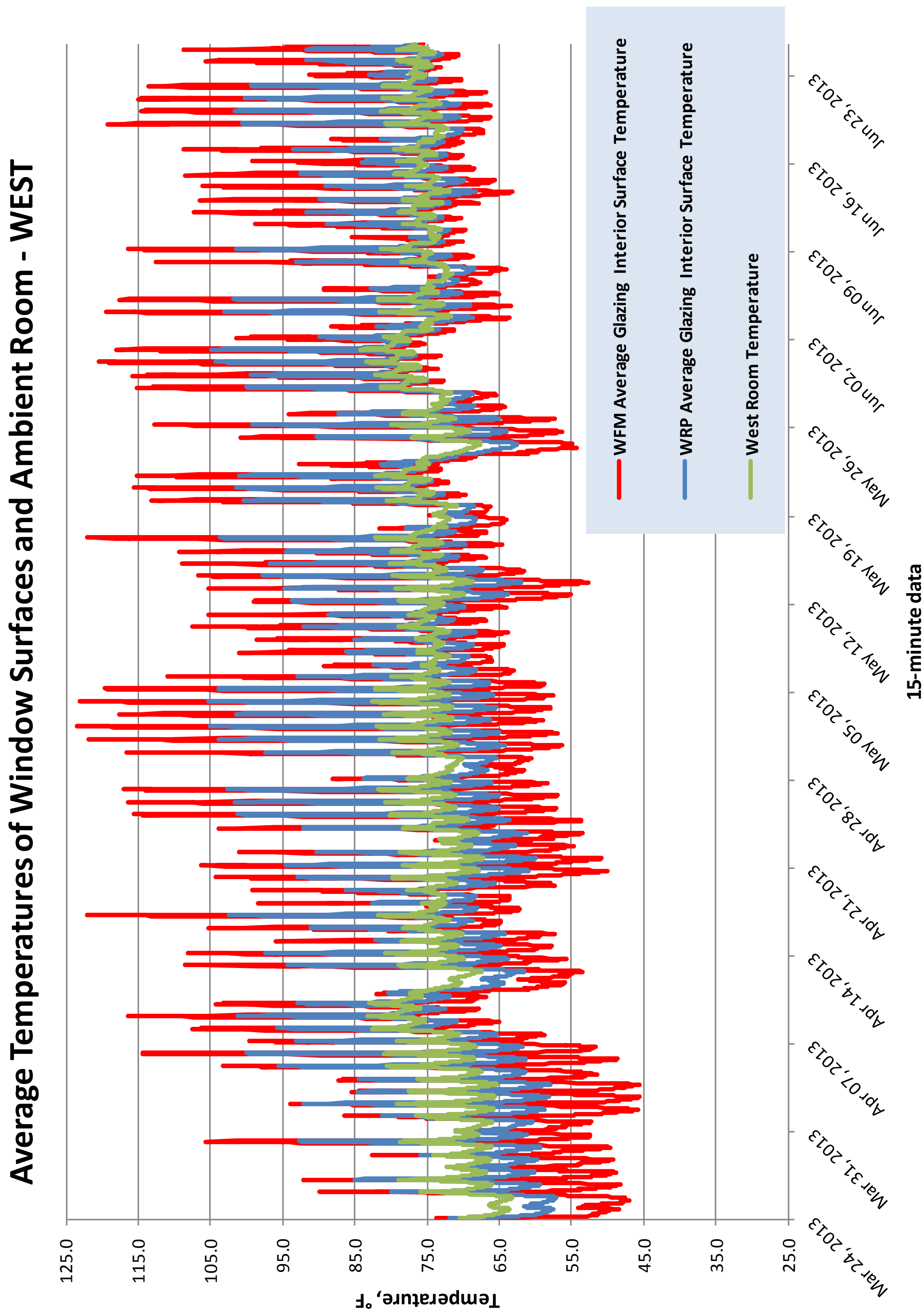

Figure 29. Average Temperatures on Interior Glass Surface (Mar. – Jun.) – West Facing Office

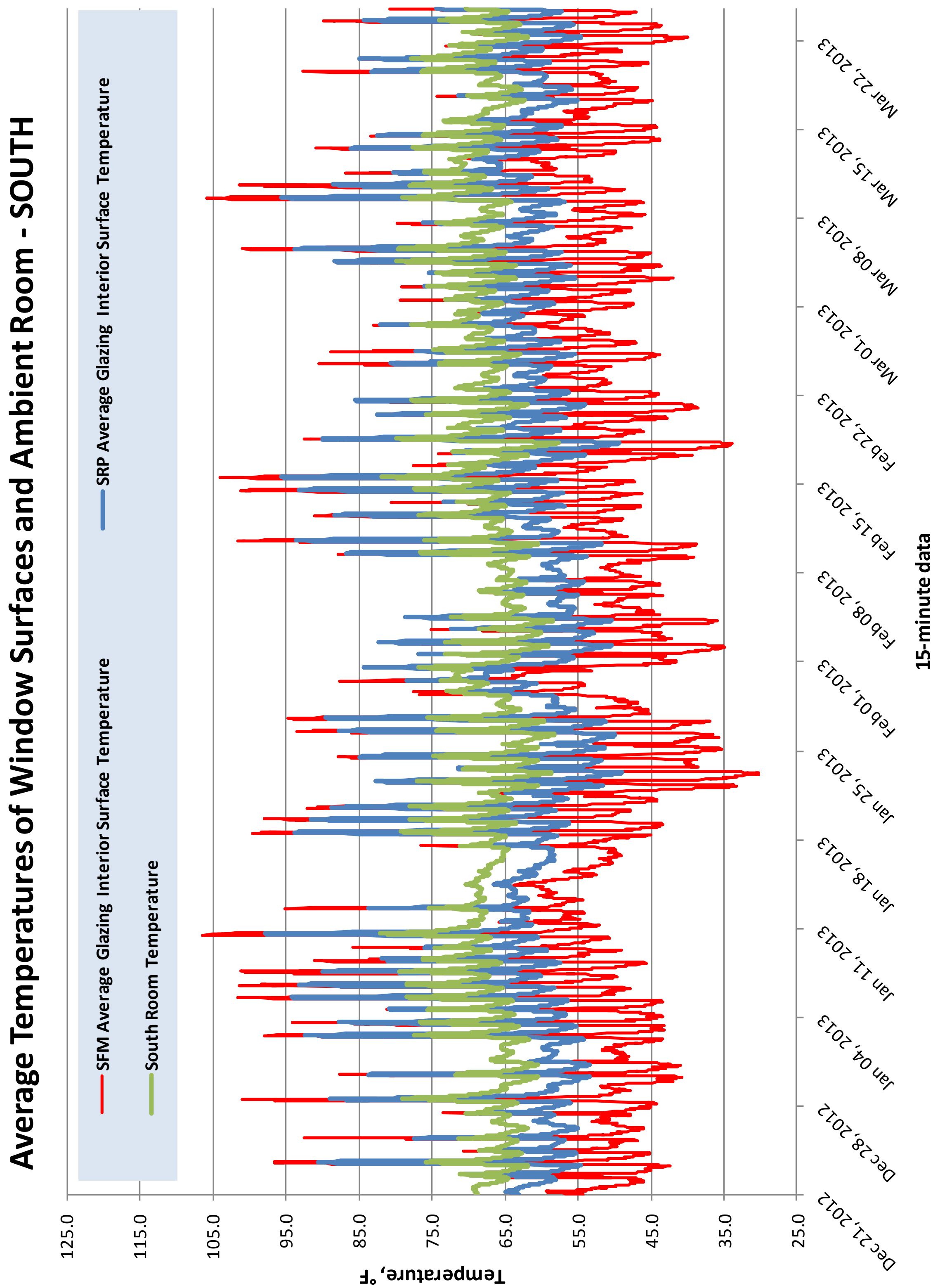

Figure 30. Average Temperatures on Interior Glass Surface (Dec. – Mar.) – South Facing Office

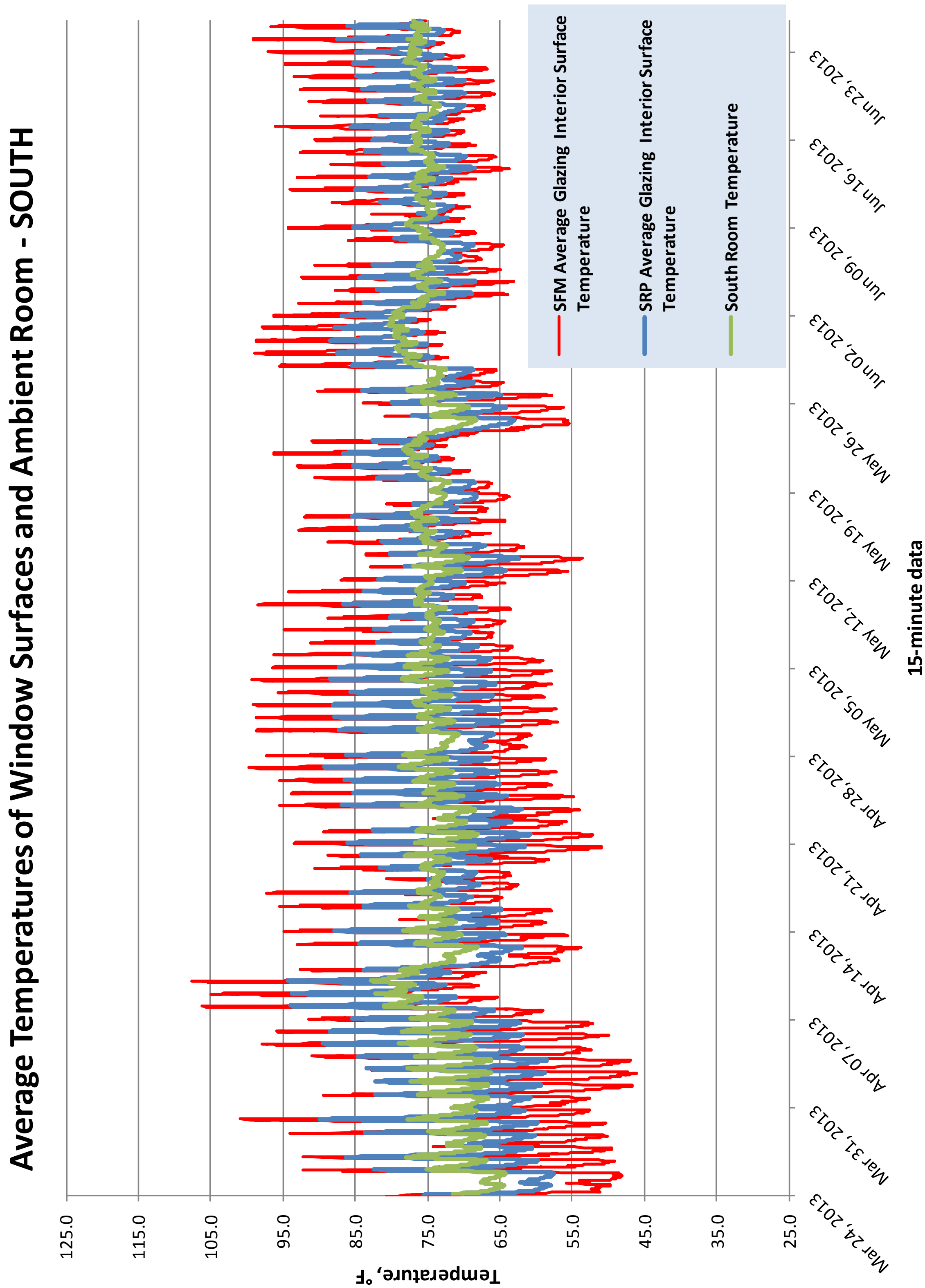

Figure 31. Average Temperatures on Interior Glass Surface (Mar. – Jun.) – South Facing Office

The summary charts showing 15-minute average temperatures demonstrate that the retrofit panel consistently results in interior glass surface temperatures that are much closer to the room temperature than the interior surface of the existing single-pane windows, warmer in the winter and cooler in the summer.

Room Temperature Profiles and Thermal Comfort

To quantify differences in thermal comfort between the low-E retrofit window and the original single-pane windows, both the mean radiant temperature and the room air temperature were measured. In this study and in a room with still air, the mean radiant temperature (a component of thermal comfort responding to radiant effects of various room surfaces) is approximated by the globe temperature. Each globe is painted black and is located in very close proximity to the window to minimize measurement effects from the adjacent window and to maximize measurement of radiant temperature asymmetry between the window and the rest of the room. In this study, the issue of occupant comfort is considered most critical when the mean radiant temperature diverges, either positive or negative, from the ambient air temperature. This is because one side of the body facing the window potentially experiences a mean radiant temperature different than the other side of the body facing the room, leading to temperature asymmetry and discomfort. Figure 32 through Figure 35 compare the room ambient temperature with the globe temperature and window average interior surface temperature for both the original window and the retrofit panel window in each orientation. The time period for each orientation is divided into three-month periods for readability.

When evaluating the temperature difference between the mean radiant temperature (assuming no air movement) and the room air temperature, it becomes clear that the colder periods demonstrate a larger divergence between the radiant and the room temperatures. A larger difference would indicate more discomfort when working within proximity of the window. Figure 36 details this phenomenon for the WEST facing office and Figure 37 for the SOUTH facing office.

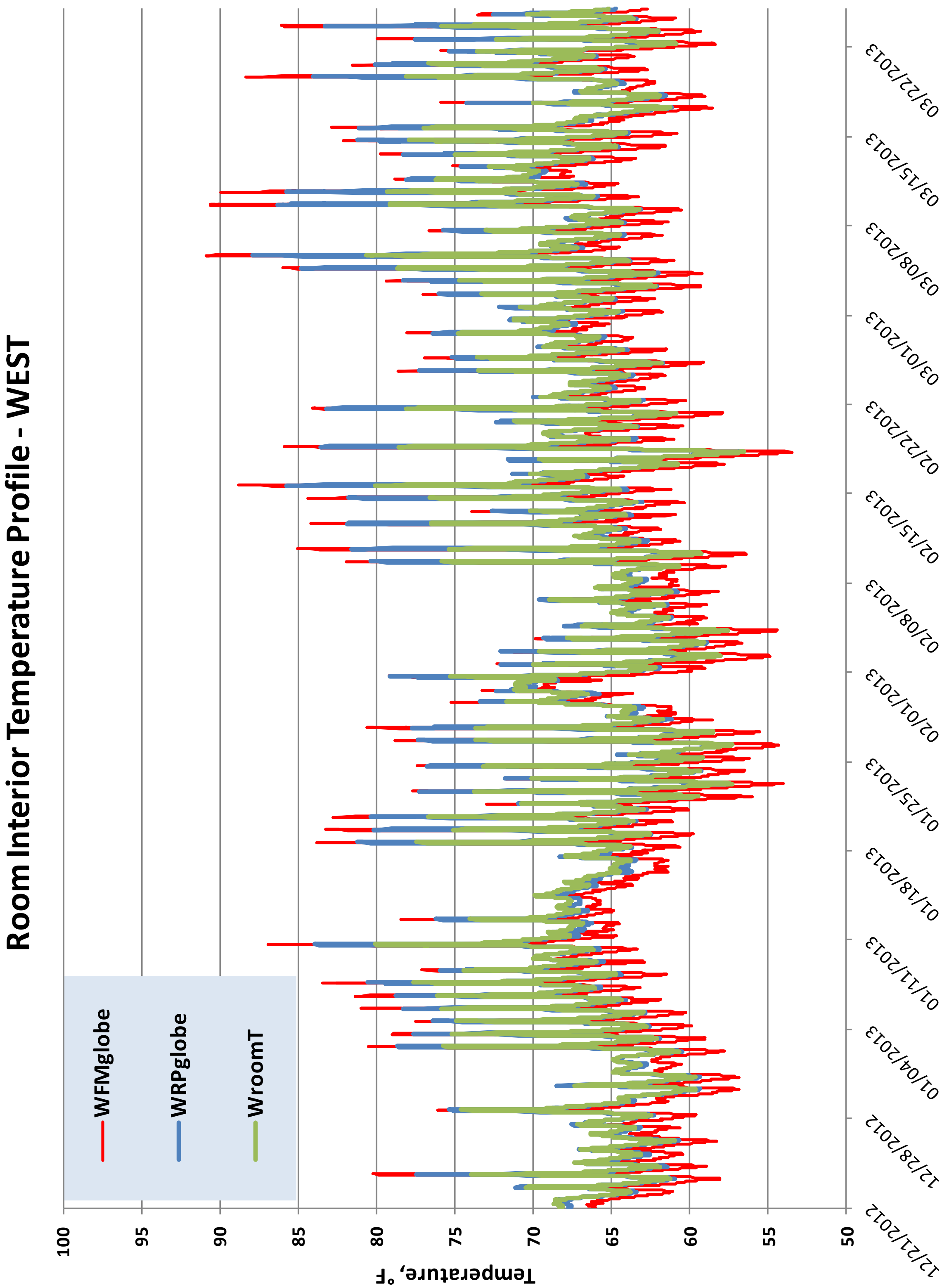

Figure 32. Interior Temperatures (Dec. – Mar.) – West Facing Office

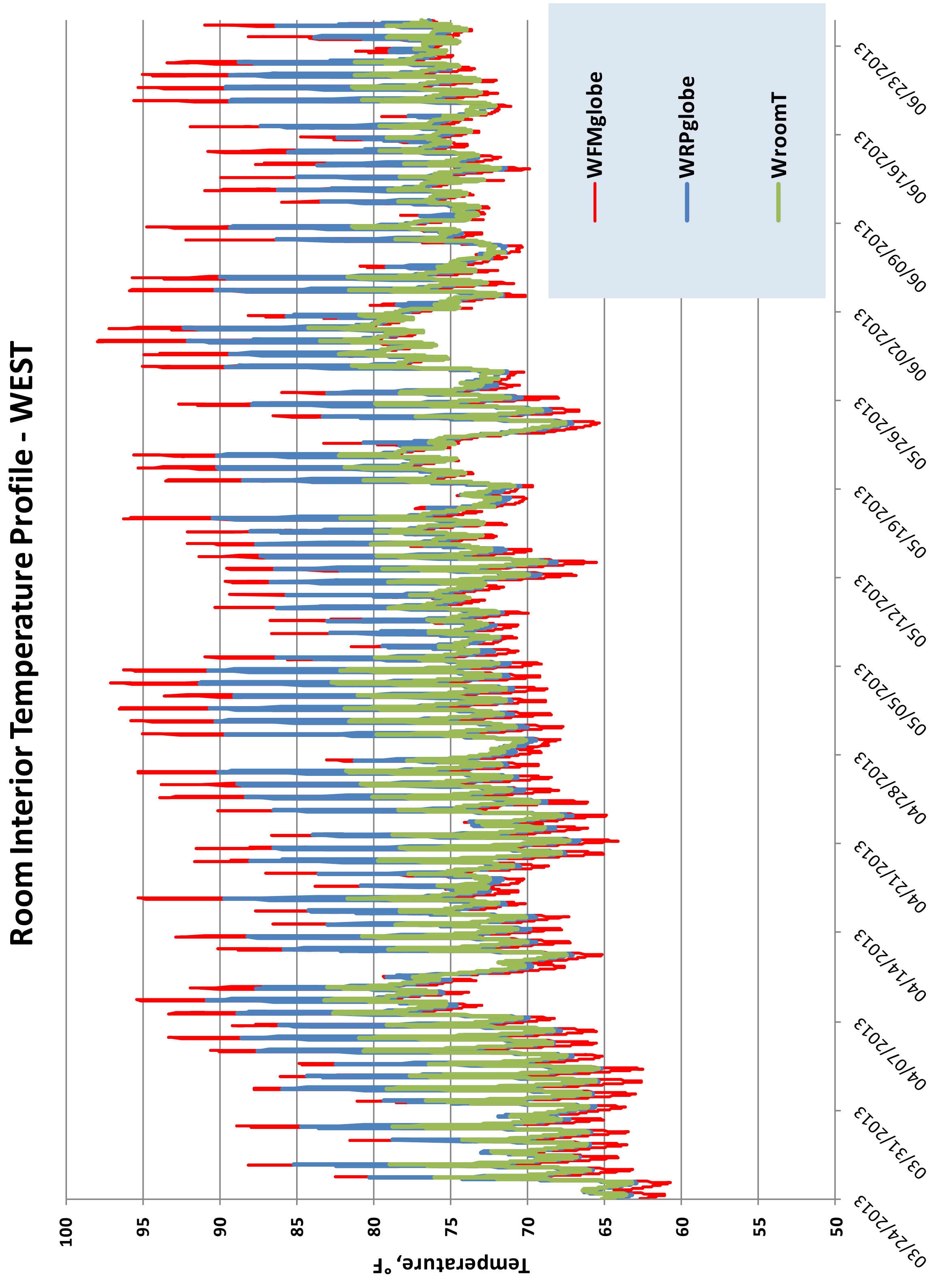

Figure 33. Interior Temperatures (Mar. – Jun.) – West Facing Office

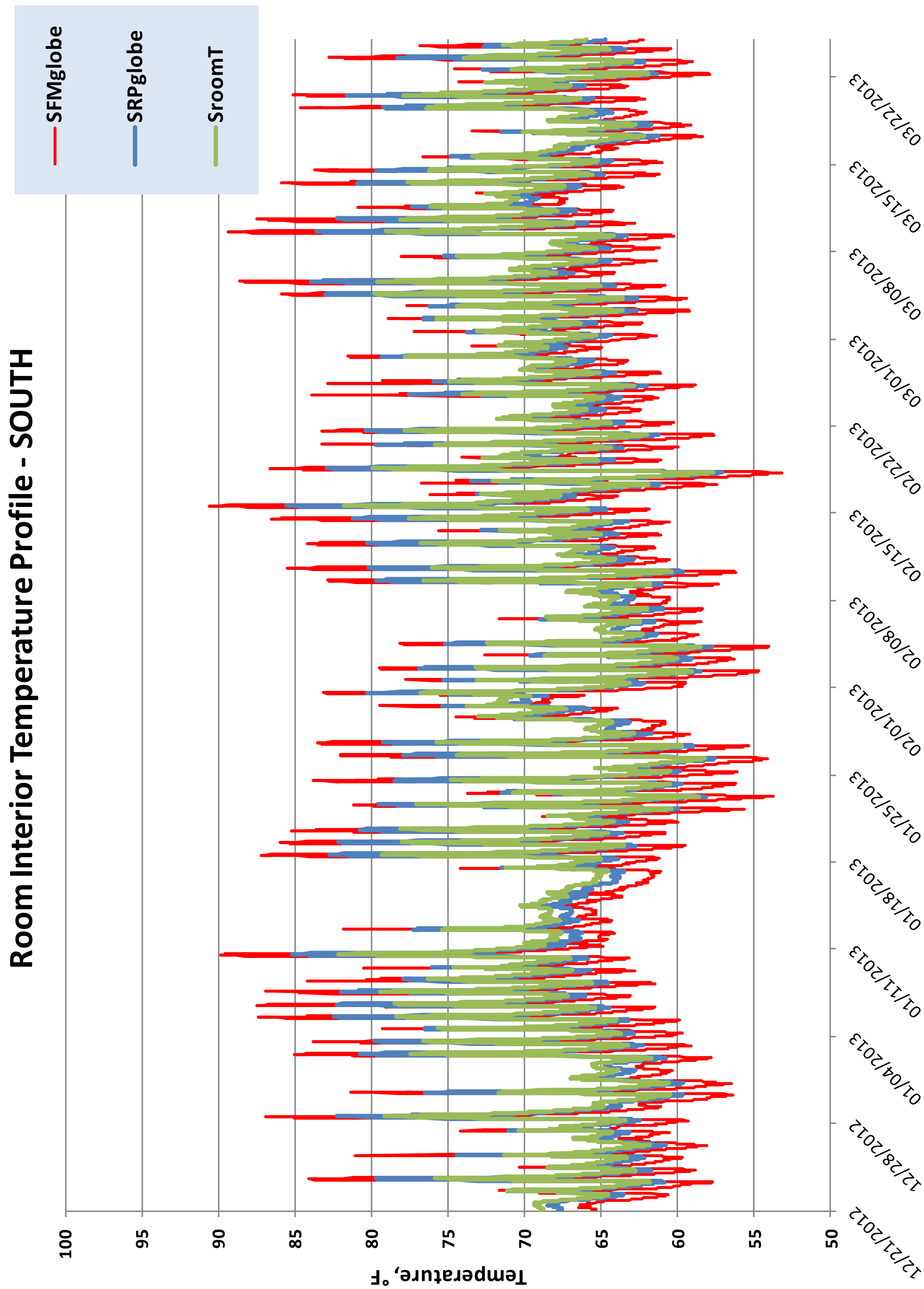

Figure 34. Interior Temperatures (Dec. – Mar.) – South Facing Office

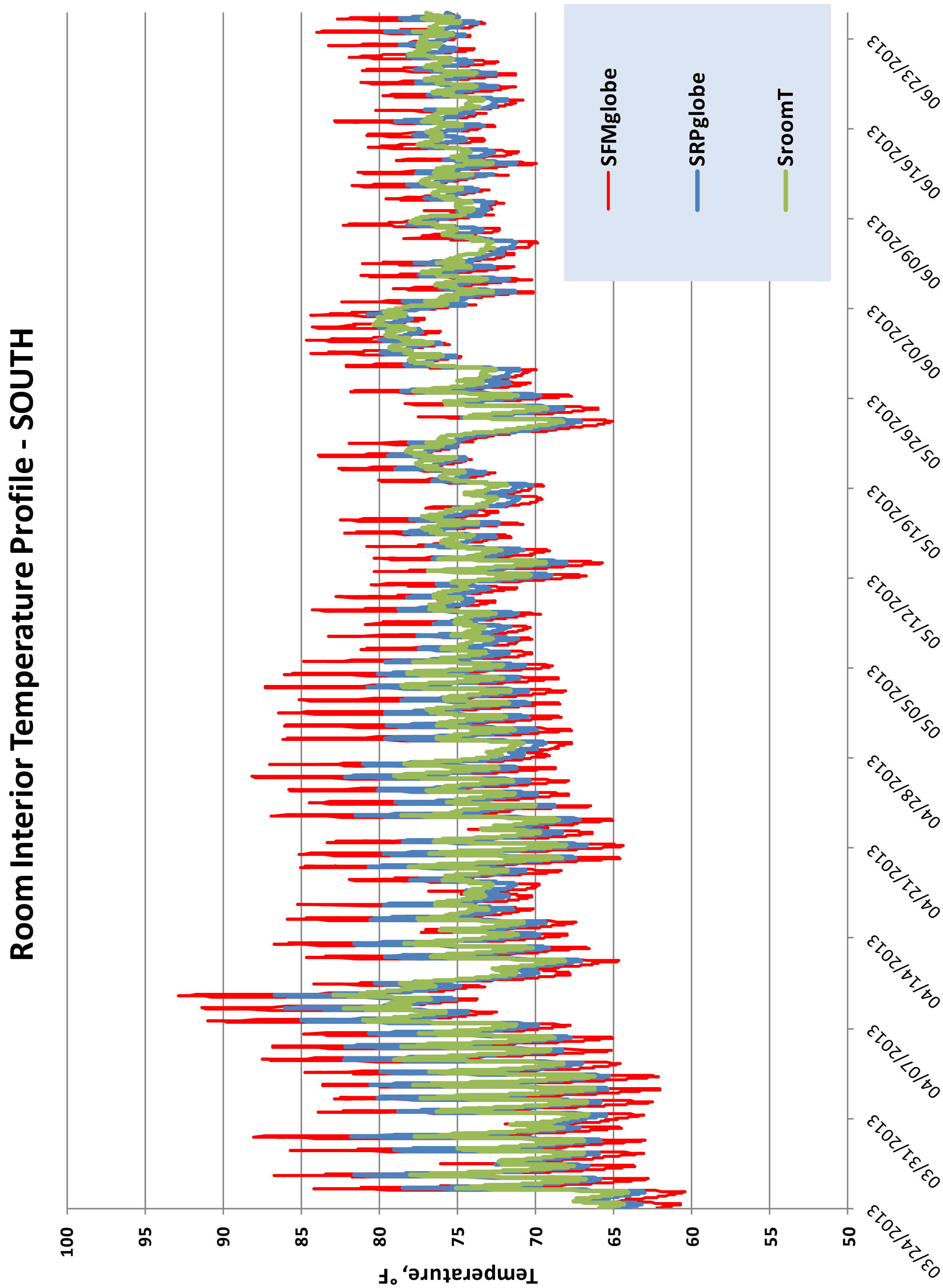

Figure 35. Interior Temperatures (Mar. – Jun.) – South Facing Office

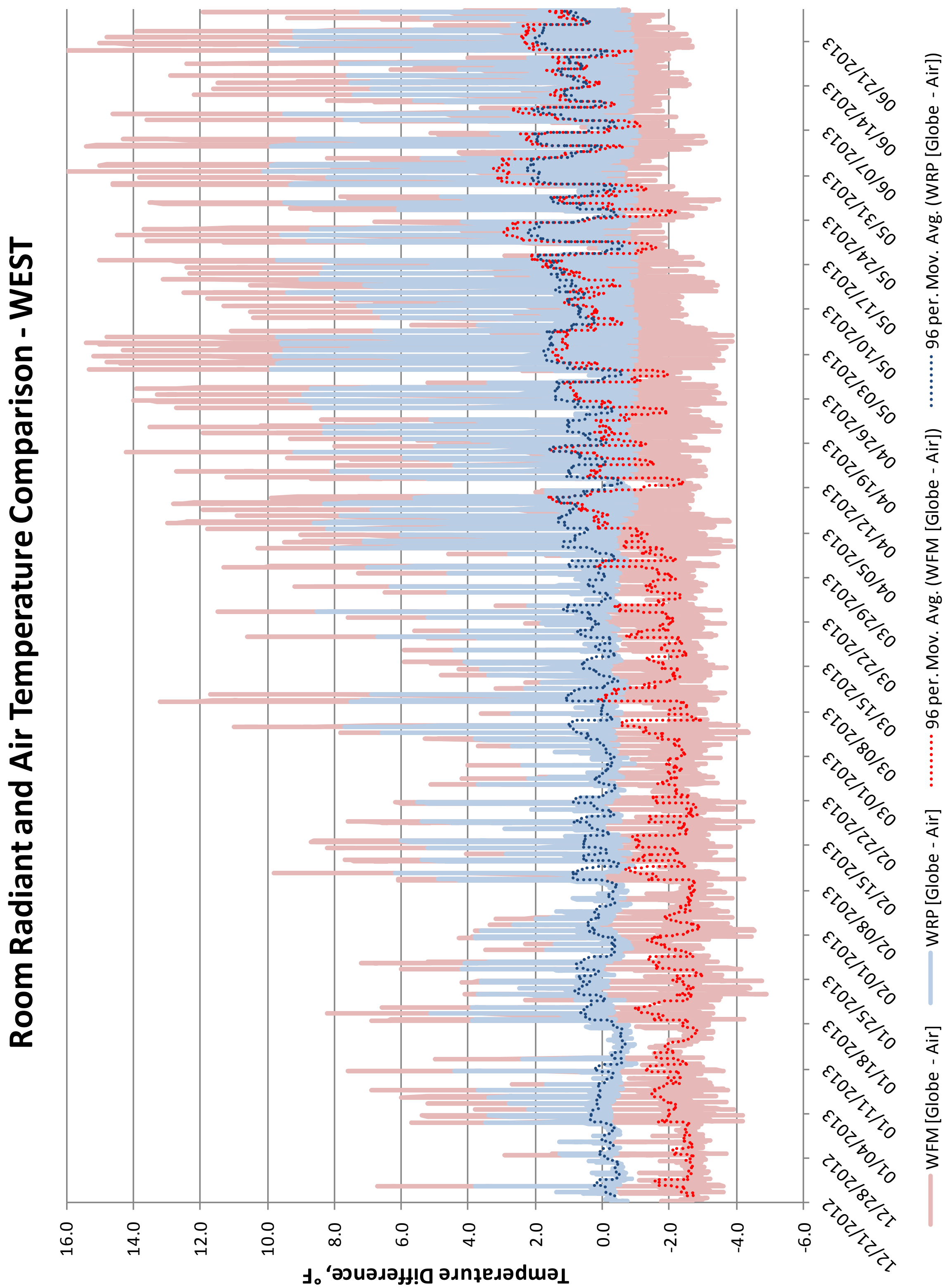

Figure 36. Radiant-Air Temperatures – West Facing Office

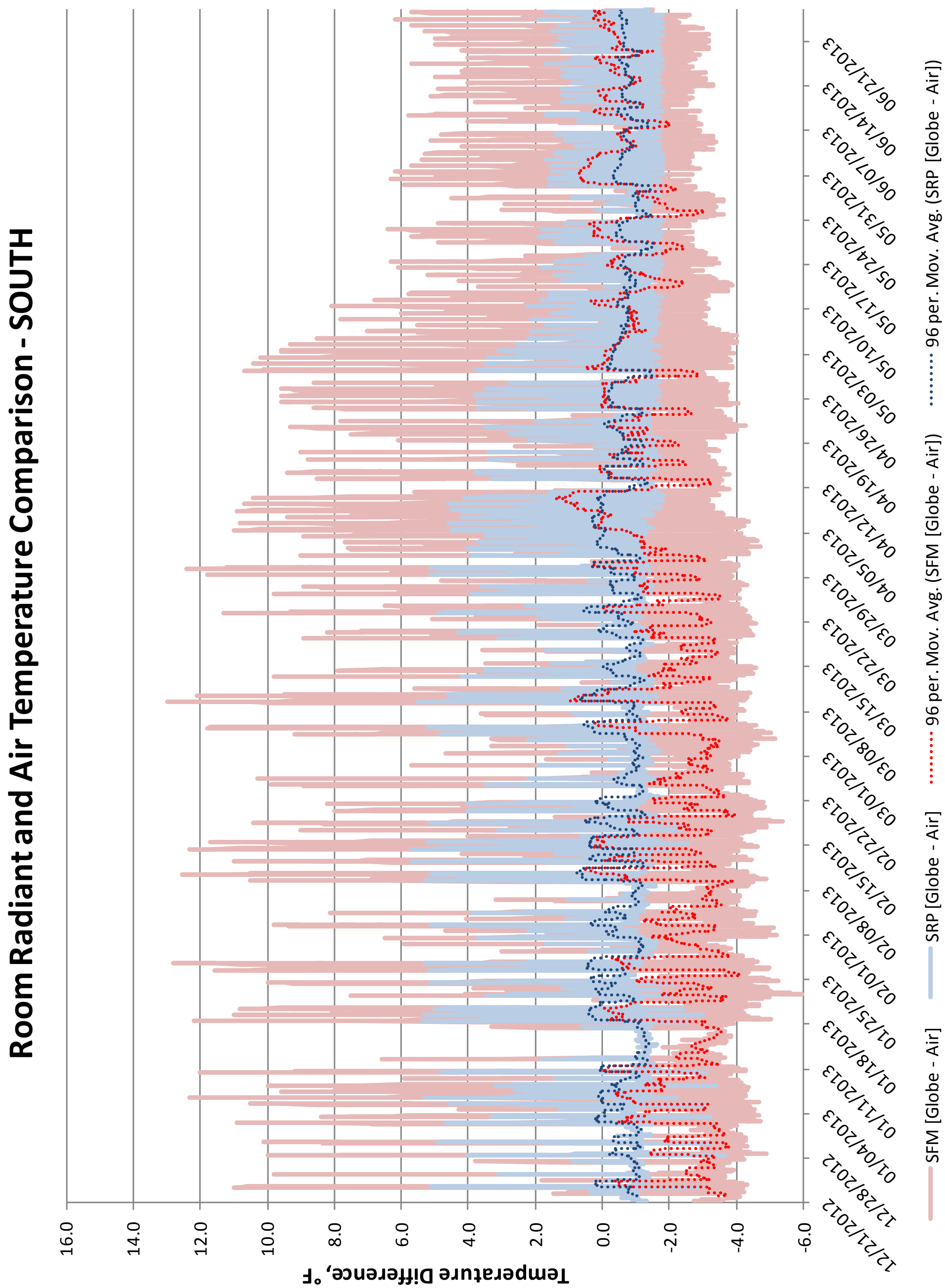

Figure 37. Radiant-Air Temperatures – South Facing Office

When comparing the measured mean radiant temperature (MRT) to the air temperature the ideal condition would see a convergence between these characteristics. When influenced by solar gains through glazing, the mean radiant temperature can cause discomfort, either hot or cold, depending on the outdoor conditions. While thermal comfort standards such as ASHRAE 55, Thermal Environmental Conditions for Human Occupancy, also include air movement and relative humidity, these effects are minor in this test. However, the effects of the MRT compared with the air temperature are a reasonable approximation for evaluating comfort in the rooms with and without the low-E retrofit panels.

Figure 38 through Figure 41 compare the MRT at the low-E retrofit panel to the MRT at the existing window with the interior air temperature (the interior air temperature is the same for the south and west comparisons). The charts clearly indicate that the retrofit panels are much closer to the indoor air temperature during both heating and cooling periods and for both the south and west facing rooms. This will lead to improved occupant comfort, both in terms of more comfortable overall temperature, and also reduced discomfort due to temperature asymmetry.

Based on the MRT comparison with the indoor air temperature, the total number of hours over the six-month monitoring period when the MRT excursions from the air temperature exceed either 3°F or 5°F are determined and outlined in Table 1. The data shows a clear reduction in the number of hours of potential discomfort when using the low-E retrofit system. The reduction of hours of potential discomfort is greater on the SOUTH than on the WEST, due to differences in direct solar gains on the WEST side. Both orientations show similar improvement in keeping the space and comfort level warm during cold / dark periods. Also note that the low-E retrofit panels on the SOUTH facing orientation have a lower solar heat gain coefficient than on the WEST orientation (center of glass SHGC 0.27 vs. 0.35).

Table 1. MRT to Indoor Air Temperature Difference

	Hours When Temperature Difference is Greater Than	
	5°F	3°F
South, Existing Film	402.25	2805.00
South, Low-E Retrofit Panel	8.25	200.25
Low-E Panel Reduction	98%	93%
West, Existing Film	337.25	1097.50
West, Low-E Retrofit Panel	222.00	369.25
Low-E Panel Reduction	34%	66%

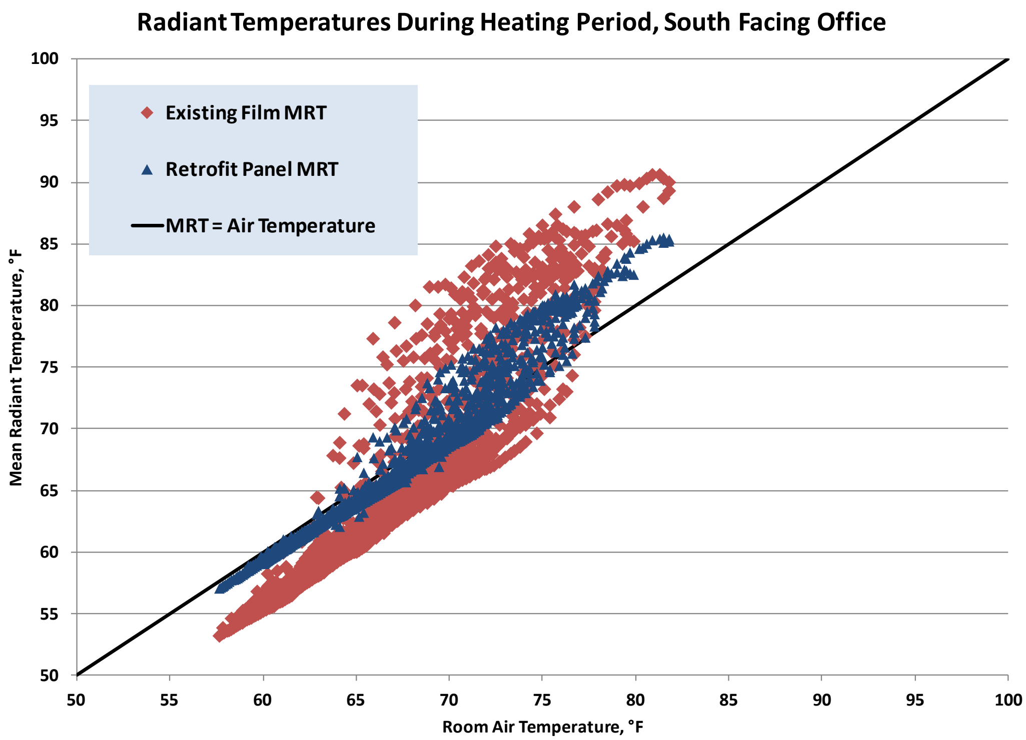

Figure 38. Heating Period MRT Compared to Indoor Air Temperature – South Facing Office

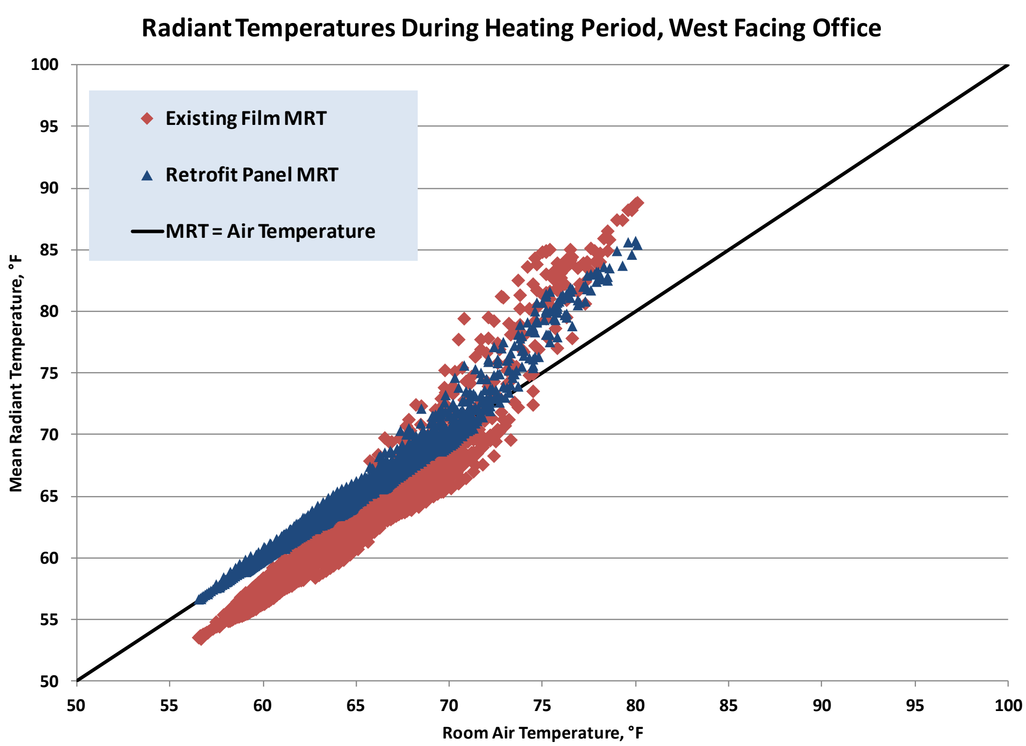

Figure 39. Heating Period MRT Compared to Indoor Air Temperature – West Facing Office

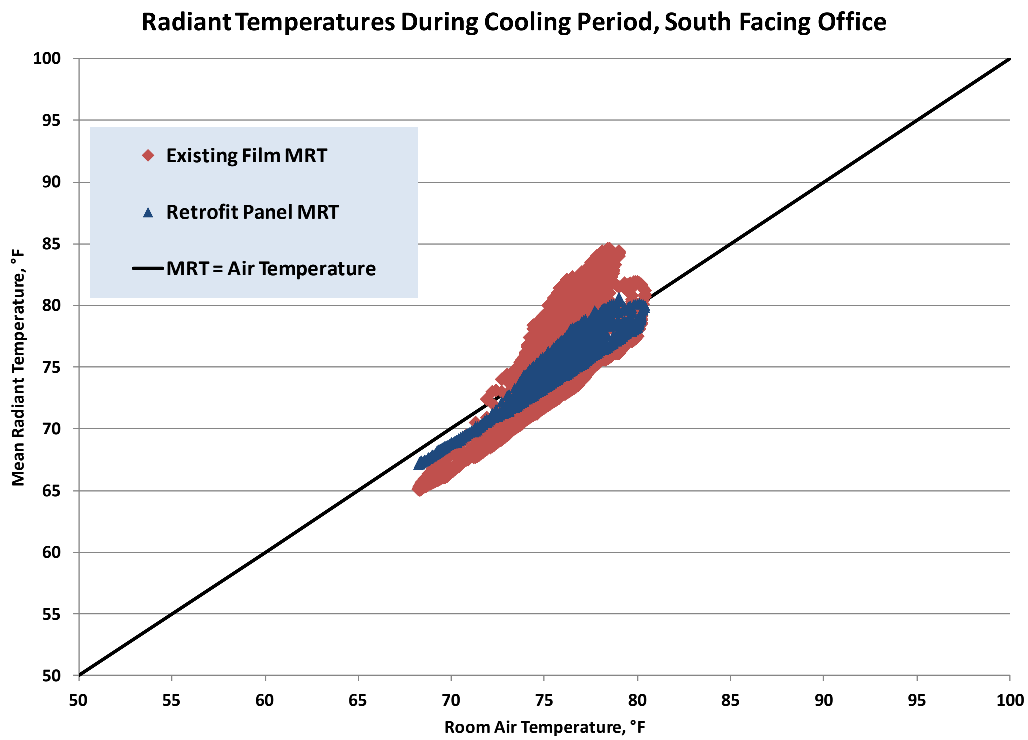

Figure 40. Cooling Period MRT Compared to Indoor Air Temperature – South Facing Office

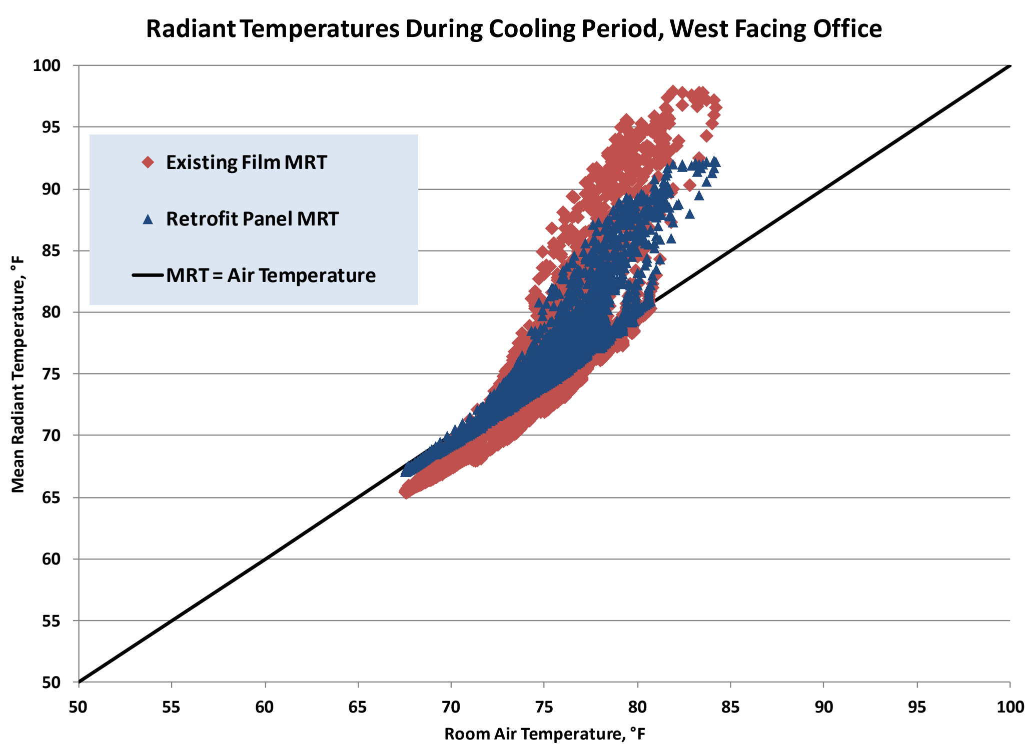

Figure 41. Cooling Period MRT Compared to Indoor Air Temperature – West Facing Office

Room Window Solar and Light Levels

An initial investigation was made into the difference in solar intensity levels in the rooms measured in this study through the solar radiation impinging on pyranometers on a horizontal surface inside the office near the windows. This is a relative measurement only and does not provide detail on other light levels in the room not from the window.

Figure 42 shows the horizontal solar radiation level for the WEST facing office and Figure 43 for the SOUTH facing office.

In the WEST facing office, the installation of the retrofit panel results in very little change in the solar intensity through the window. There is less than 0.5 percent difference over the course of the six-month monitoring period and the daily running average shows little change as the sun angle changes. This shows that the low-E retrofit panel is providing roughly equivalent solar control as the solar control film on the original window, while admitting more visible light (for example, see Figure 3). This is not surprising, as low-E glass coatings are generally more solar selective than window films with a higher ratio of visible light transmission to solar transmission.

The SOUTH facing office does demonstrate an additional reduction in solar gains (as measured by the pyranometer on a horizontal surface) for the low-E retrofit panel than the original window with the solar control film. The effect is larger with lower sun angles and appears to diminish when the sun does not directly impinge on the vertical SOUTH facing windows. The overall difference for the measurement period is about 23 percent. This is explained by the fact that the SOUTH facing low-E retrofit panels have a lower solar heat gain coefficient than the WEST facing windows (and the East and North as well). If the window film has a solar heat gain coefficient roughly equivalent to the WEST facing low-E retrofit panel, then the center-of-glass SHGC is approximately 0.35 (ignoring inward-flowing-fraction effects due to the different U-factor). Then the SOUTH facing low-E retrofit panel will have a solar heat gain coefficient approximately 23 percent lower than the window film (0.27 vs. 0.35), matching the measured data.

Overall, the WEST facing low-E retrofit panel (Platinum Plus II) provides similar solar control as the original window with film, and the SOUTH facing low-E retrofit panel (Platinum Plus II XL) yeilds even better solar control, both while admitting more visible light and providing much better insulating performance (U-factor of 0.15 Btu/hr·ft2·°F vs. 1.0 Btu/hr·ft2·°F).

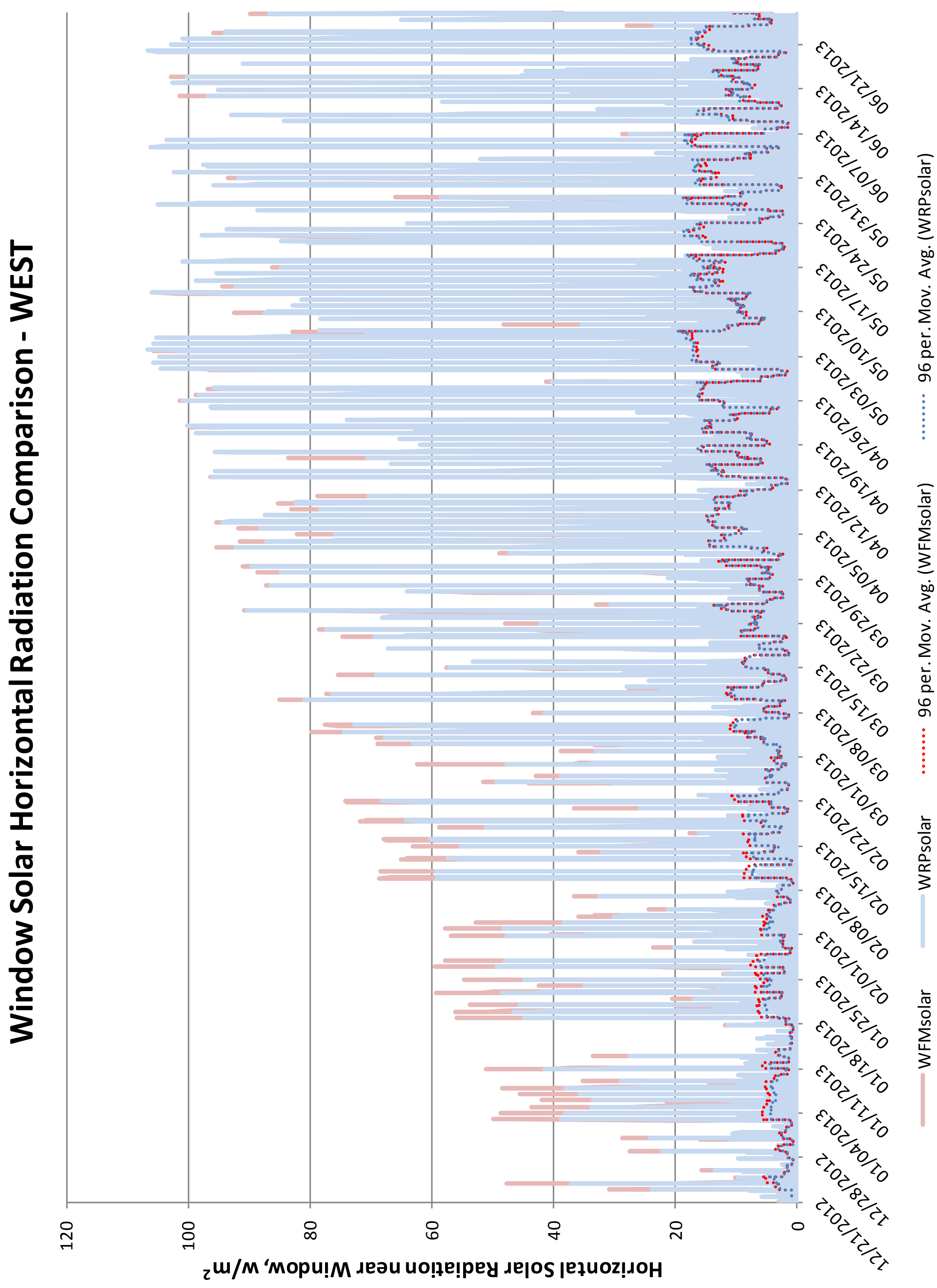

Figure 42. Solar Radiation through Window – West Facing Office

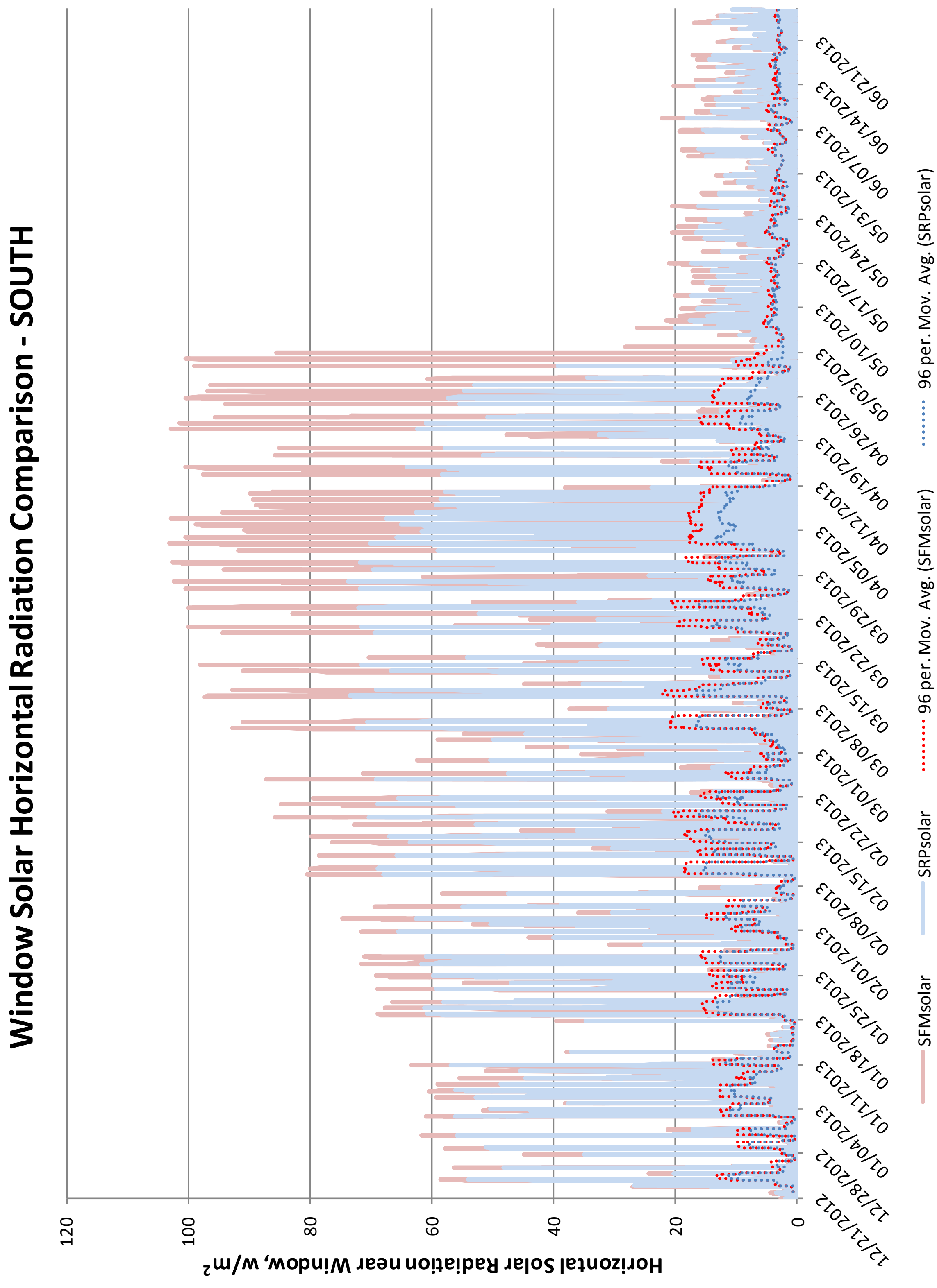

Figure 43. Solar Radiation through Window – South Facing Office

Daily Temperature Profile

One cold and one warm sunny day were selected for a more detailed review of the temperature profile for all sensors located on each window and in the offices. The daily profile is a snapshot of the diurnal change in temperature for each sensor in response to exterior temperatures and sunlight impinging on the window. The daily temperature profile demonstrates a more narrow time frame, whereas the results described above examine more of a seasonal basis. Figure 44 through Figure 47 graph temperature and sunlight data for one day in January and one day in May for both the WEST and SOUTH facing offices.

Consistent with the previous data, the daily temperature profiles show reduced temperature swing throughout the day with the low-E retrofit as compared to the original single-pane windows, as well as interior surface and mean radiant temperatures more closely matching room temperatures, increasing overall comfort for building occupants. Additionally, the low-E retrofit generally has less variation in temperature across the panel (see as spread across the green WRP1-6 lines and splits in the Cw1-2 blue lines) than in the original window with the solar control film (see as spread across the red WFM1-6 lines), suggesting that there is less potential for thermal stress in the glass.

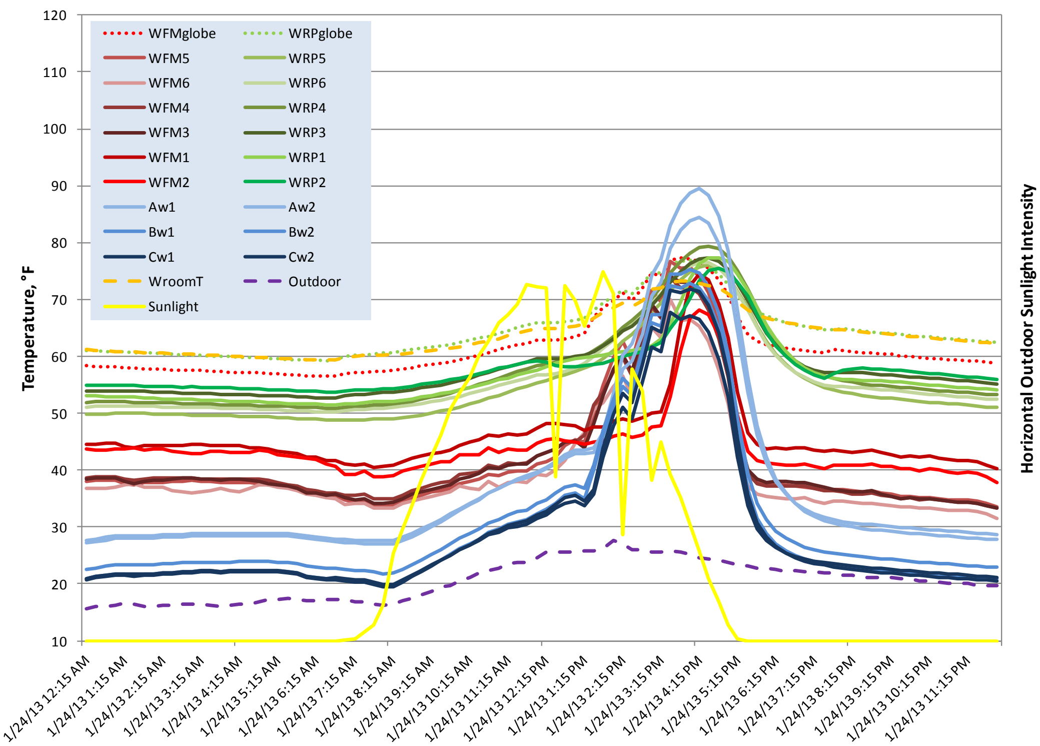

Figure 44. Temperature Profile for a Cold Sunny Winter Day – West Facing Office

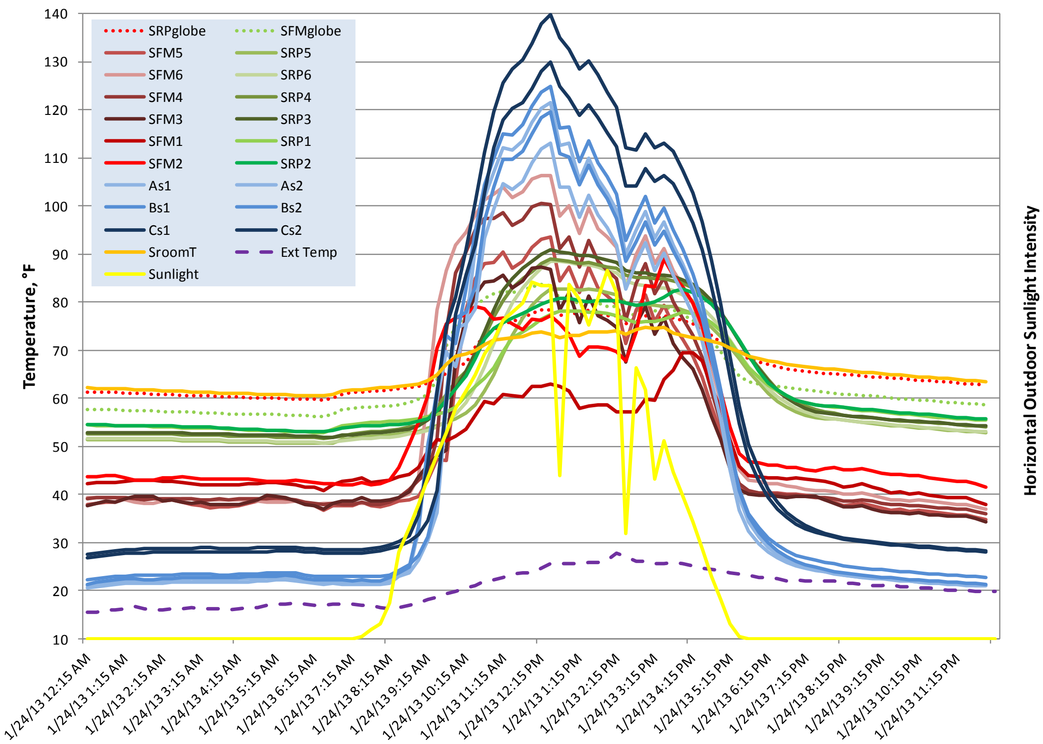

Figure 45. Temperature Profile for a Cold Sunny Winter Day – South Facing Office

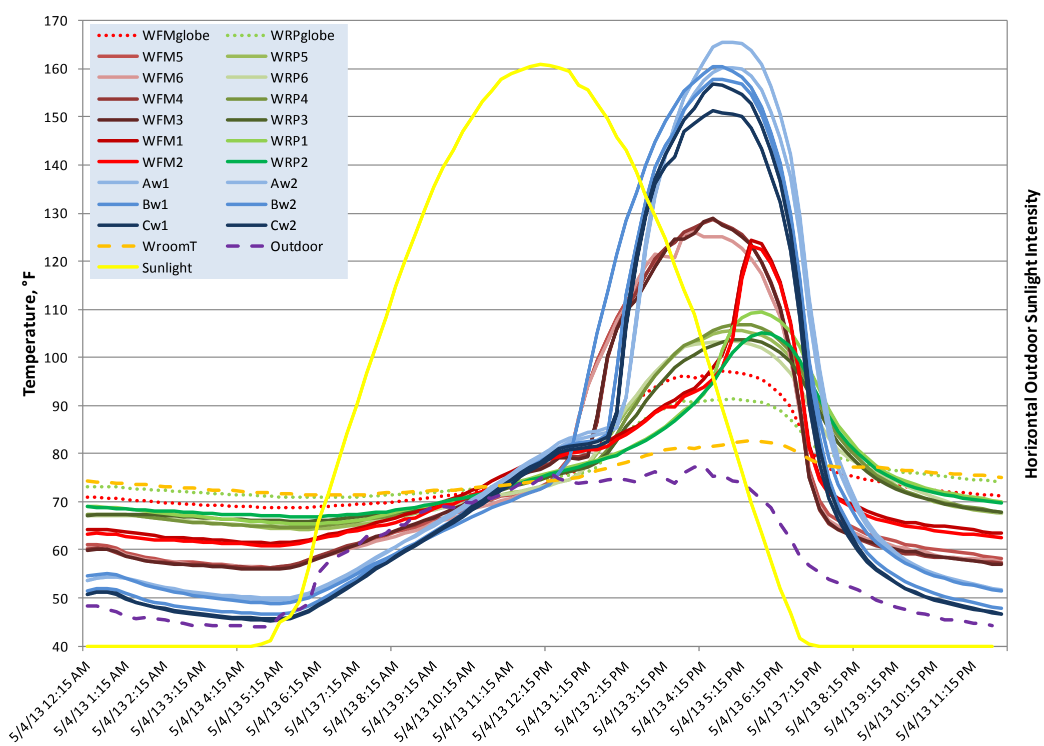

Figure 46. Temperature Profile for a Warm Sunny Spring Day – West Facing Office

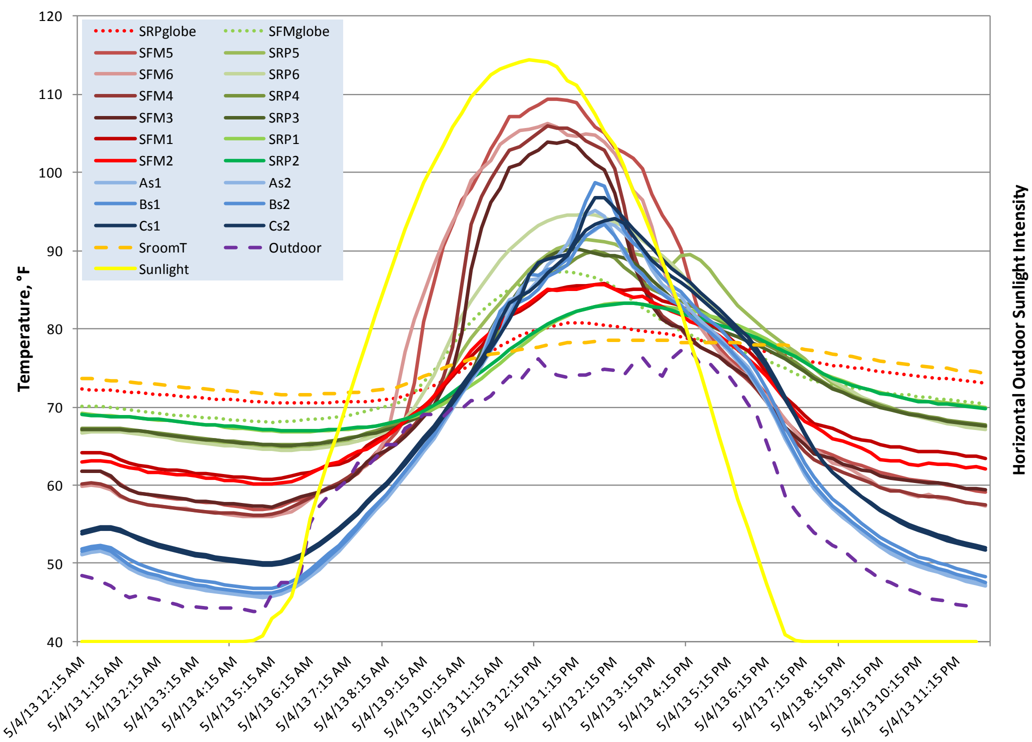

Figure 47. Temperature Profile for a Warm Sunny Spring Day – South Facing Office

Conclusions

The window upgrade using low-E window retrofit panels at the Kevon Office Building has demonstrated significantly improved thermal comfort as compared to the original single-pane windows, as measured by the effects of the windows on the mean radiant temperature difference from the indoor air temperature. Larger temperature excursions, exceeding 5°F, between the MRT and the indoor air are reduced by 98 percent in the south facing office and over one-third in the west facing office. Excursions of over 3°F are reduced by 93 percent in the south facing office and over two-thirds in the west facing office.

Additionally, the low-E retrofit panels greatly reduce daily variations in the interior window surface temperatures, lowering the maximum temperature and raising the minimum temperature by over 20°F compared to the original windows. The average window surface temperature over the monitoring period is more than 8°F colder than the air temperature for the original window, and no more than 3°F for the low-E retrofit panel window. This result is consistent for both orientations.

Furthermore, no significant thermal stress was observed when using the low-E retrofit system, as measured by temperature differences across the outer pane of glass over a variety of weather conditions. The surface temperature difference only exceeded 10°F (500 psi thermal stress) for less than 1.5 percent of the monitored time, and in all cases, the maximum surface temperature difference never exceeded 35°F, or 1,750 psi. While the sensor locations in this study may have missed some corner effects, and each building situation (geometry, exposure, shading, etc.) should be assessed individually, there does not appear to be any significant concern with thermal stress when using the low-E retrofit panel.

The mean radiant temperature, the solar radiation, and the fluctuations in the window surface temperatures are all markedly improved as intended through the upgrades.

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