EVALUATION OF VENETIAN BLIND ATTRIBUTES FOR ENERGY EFFICENCY

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ABSTRACT

The 2011 Building Energy Databook (DOE, 2011a) reported that buildings use approximately 40% of the nation's total energy use. One method of reducing this value is to utilize window retrofit solutions. While these products are often selected for aesthetic or privacy concerns, they can also provide an effective means of limiting heat transfer (Ariosto and Memari, 2013). Venetian blinds are one of the more common window retrofit solutions. Several researchers have investigated the thermal behavior of these systems. However these studies focused primarily on the heat transfer mechanisms themselves (typically convection and radiation) without translating results into the metrics often used to compare glazing systems - the U-value and SHGC. This makes it difficult for the layman to utilize their results. This paper provides an overview of an investigation of venetian blind performance conducted using the LBNL WINDOW software. A variety of venetian blind attributes were investigated including geometric attributes such as slat width, angle, and spacing as well as material properties such as conductivity and surface emissivity, on the performance indices (U-value, SHGC) of double glazed window systems. The study demonstrated that venetian blinds are capable of reducing the U-value by as much as 60% and the solar heat gain coefficient by nearly 100% depending on their design features and installation measures.

INTRODUCTION

According to the 2011 Buildings Energy Data Book (US DOE, 2011a), buildings consume approximately 40% of the nation's energy. Approximately 56% of this energy is used for space heating and cooling as well as lighting applications, while 25% to 35% of this energy is wasted due to inefficient windows. All of these factors are directly impacted by the building envelope (Totten and Pazera, 2010). In addition to other functions (Kazmierczak, 2010; Sanders, 2006), successful building envelopes shield occupants from outside weather conditions, whether that be excessively hot temperatures in the summer or extremely cold temperatures in the winter, as well as provide a connection to the outside in terms of natural lighting and views.

One of the major challenges facing homeowners is the high capital cost associated with fenestration upgrades. The cost of replacing all the windows in a residential building can be substantial. However, the energy savings associated with replacing windows with their higher efficiency counterparts is typically relatively small. The payback period for replacing single glazed windows with double glazed windows can be as long as 50 years for cold climates. This payback period will also increase as the quality of the existing windows increases. When double glazed uncoated windows are replaced with triple glazed units with argon fill and a low-e coating, the payback period is typically around 100 years for cold climates (Guler et al., 2001). Another study conducted by Frey et al. (2012) demonstrated that high performance window upgrades have a return on investment (ROI) of only between 1.2-1.8% based on climate. This translates to a simple payback period of 55-83 years. Therefore, for most homeowners it is necessary to determine low cost methods of reducing heat flow through their windows. In other cases, homeowners may seek further improvements in the performance of their higher quality window systems.

Several researchers have performed studies to analyze the effect of venetian blind performance on heat transfer. Machin et al. (1998) investigated the impact of slat angle on convective heat transfer. Oosthuizen et al. (2005) expanded this work using numerical solutions for both convective and radiative heat transfer. Shahid and Naylor (2005) analyzed a wide variety of venetian blind attributes on both convective and radiative heat transfer. Yahoda and Wright (2004) investigated the effects of slat angle, width and spacing on the radiative properties on blinds.

The study described herin involves an investigation of the characteristics of venetian blinds conducted using the publically available software WINDOW produced by the LBNL (2013). This analysis was conducted to determine which product characteristics are important when the homeowner is primarily concerned with energy efficiency.

VENETIAN BLIND ANALYSIS

Based on the previously mentioned studies, a set of criteria can be determined that are critical to the performance of venetian blinds. These criteria are slat angle, the distance from the blind to the glass surface, the emissivity of the blinds, the slat width and spacing, and lastly the height of the window.

Figure 1 shows the venetian blind characteristics that were modified using LBNL *WINDOW*. In addition, the slat material can also be modified based on parameters such as conductivity, solar, visible, and infrared transmittance, reflectance and/or emittance.

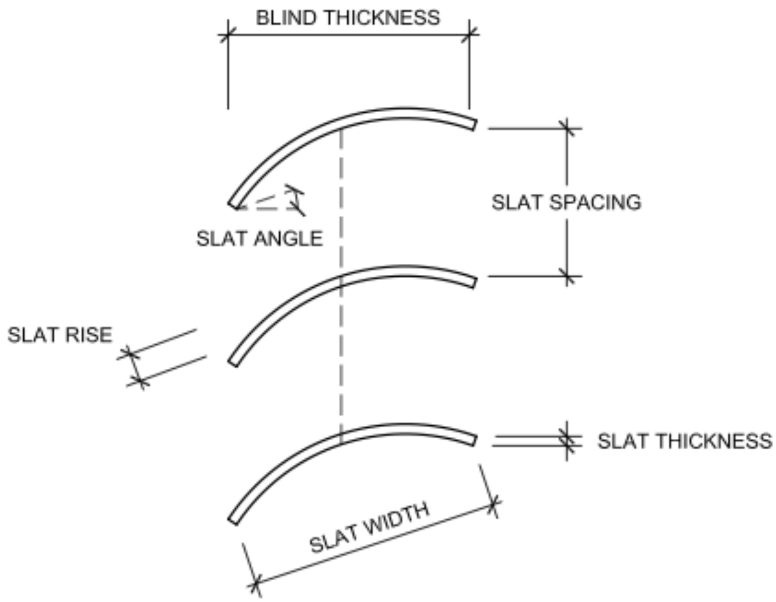

Figure 1: Illustration of venetian blind geometric parameters used in WINDOW.

Each of these properties was evaluated individually and/or in combination with each other to determine the effect of various blind designs. An IGU with a low-e coating on the interior surface of the exterior pane of glass was used for the glazing system in order to establish a baseline for performance. Single-glazed systems will experience greater reductions, while those for triple-glazed systems will be lower. It is important to note that a positive percent reduction translates to improved thermal performance and reduced solar heat gain, while negative values translate to decreased thermal performance and increased solar heat gain. In order to determine the impact of the blinds for a wide variety of different window systems, whole product U-values were assumed for wood, vinyl, and aluminum frames with thermal breaks. In addition, a "center-of-glass" U-value was determined, which assumes an infinitely large glazing area so that "edge-of-glass" framing effects are not present. For each part of the analysis, this data was then converted to a percentage improvement over the glazing system with no venetian blind.

WINDOW uses two standard sets of calculations for the U-value and SHGC analysis. The first is ISO 15099 (ISO, 2003b), "Thermal Performance of Windows, doors, and shading devices – Detailed calculations." The second is ISO/EN 10077 (ISO, 2003a) "Thermal performance of windows, doors, and shutters – Calculation of thermal transmittance."

ISO 15099 specifies the calculation procedures that should be used to determine thermal and optical properties for window and door systems, including single- and multi-pane glazing products with low-emissivity coating, suspended films, gas fills, metallic and nonmetallic spacers, frames and shading devices. ISO/EN 10077 deals with the calculation procedures for thermal and optical transmittance for glazing systems. These algorithms, however, are greatly simplified in comparison to ISO 15099.

One important piece of the discussion that will follow is how the shading layers being modeled relate to the windows. This is especially important when the heat transfer processes of conduction, convection, and radiation are considered. WINDOW works under the assumption that the shading device is mounted inside the frame. The top, left, right, and bottom openings shown in Figure 2 represent the opening area between the shading layer and the frame. Modifying this area is achieved using the D_{top}, D_{left}, D_{right}, and D_{bot} distances found in the glazing system definitions in the glazing system library within WINDOW. The center openings represent the amount of air that is able to move through the shading device. This area is specified as the "openness factor" found in the shading layer library. An openness factor of 1 implies that the shading layer has no effect on limiting transmittance to the surface of the glazing. Conversely, an openness factor of 0 implies that the shading layer is completely effective at limiting air flow.

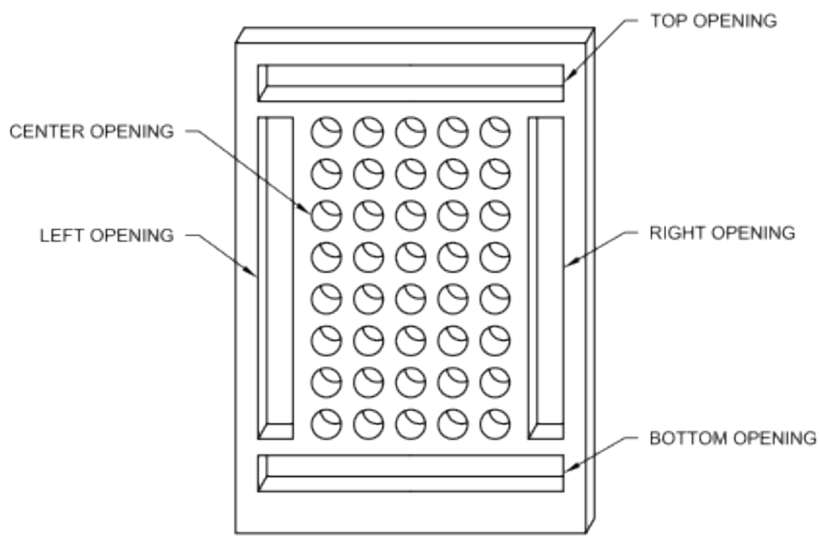

Figure 2: Generalized shading layer geometry.

The openness factor is taken into account in the calculation for the pressure loss through ventilated cavity. A cavity formed by a shading device is considered a ventilated cavity. This value is important for thermally driven ventilation with the glazing system.

The challenges associated with the openness fraction can be illustrated by examining the case of venetian blinds. When the blinds are in use, WINDOW uses a default openness fractions of 0, 0.5, and 1.0 for slat angles of 90°, 45°, and 0°, respectively. However, it is realistic to assume that these values will change continuously based on the configuration of the specific blind. In particular, an openness factor of 0 is unrealistic, as the blinds will never form a perfect seal even when closed. Machin et al. (1998) noted that even if the blinds can reach the full 90° rotation, which most systems will not, "slight axial undulations" of each slat would prevent a tight seal from ever being formed. Therefore, for this analysis, an openness fraction of 0.05 will be assumed for blinds in 90° position.

The first criteria to be investigated was the slat angle. This analysis was first performed for the center-of-glass region for several different slat width to spacing (w/s) ratios. Note that w/s ratio less than one means that the blind will not completely close in the 90° position, as the slat width is less than the spacing between adjacent slats. When the w/s is greater than one, there will be an overlap in the slats when closed. The results of this study are shown in Figure 3. The results were then repeated for a w/s of 1.33 and for several different framing options (Figure 4).

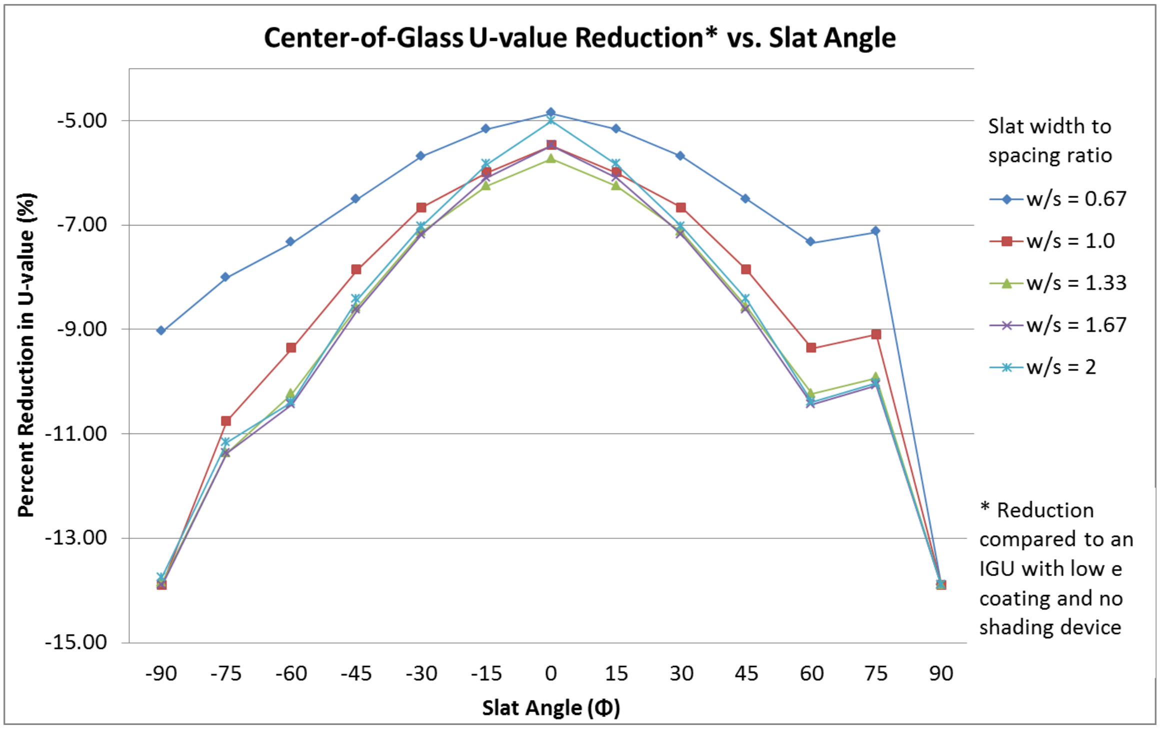

Figure 3: Reduction in center-of-glass U-value vs. slat angle for several different slat width-to-spacing ratios.

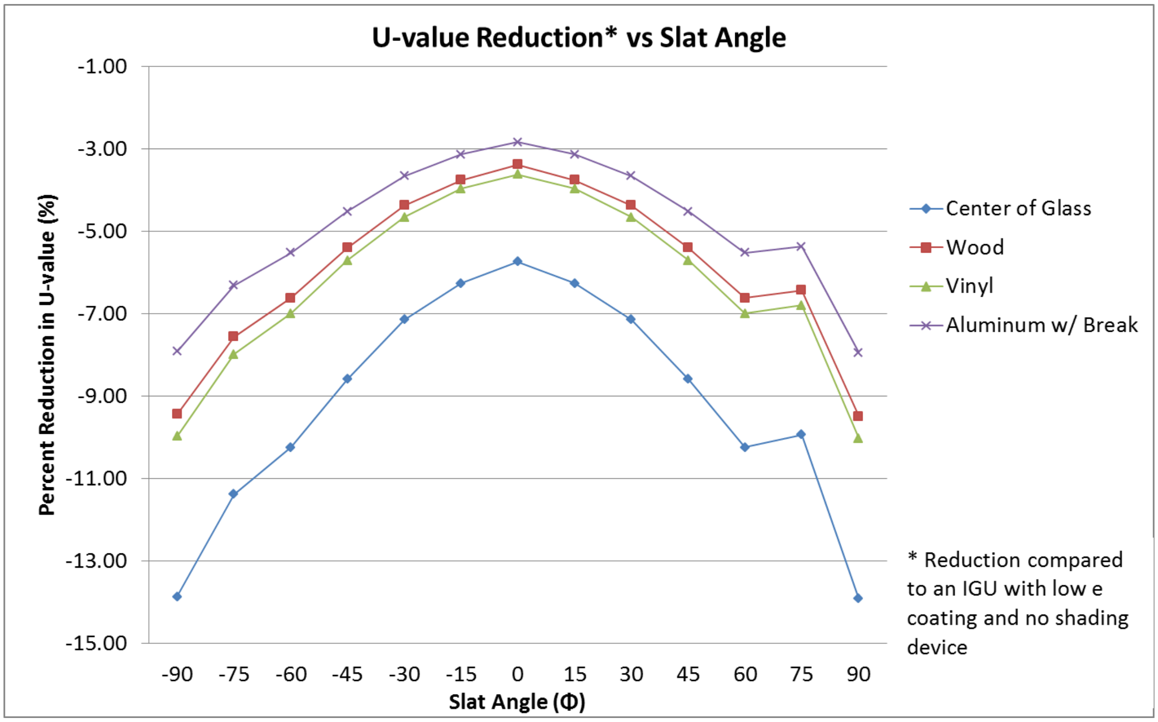

Figure 4: Reduction in U-value vs. slat angle.

Figure 3 illustrates the importance of the w/s ratio for various slat angles. When the slat angle does not equal 0°, the variance for w/s ratios greater than 1 is marginal. When the slat angle is 0°, there is about a 1% variance in performance for w/s greater than one. Based on the findings of Yahoda and Wright (2004), this variance can be attributed to a decreased shading absorptance and transmittance properties at this angle. When w/s is less than 1, the variance from the rest of the ratios is more pronounced. This variance is also in line with Yahoda and Wright, who found that the absorptance, reflectance, and transmittance properties of the blind vary more dramatically for w/s less than one.

When the effect of this criterion was evaluated for the SHGC (Figure 5), it was found that blinds with a width-to-spacing ratio of greater than 1 all performed similarly, reducing between 0% and 50% for blinds in the 0° and ±90° positions, respectively. For blinds with width-to-spacing ratios less than 1, the blinds increased the solar heat gain in the 0° position by nearly 15% and reduced the SHGC by about 23% in the ±90° position. Since the blinds are located on the interior of the glazing, they have a limited effectiveness at reducing solar heat gain. As will be seen later, blinds located on the exterior of the glazing are much more effective in this regard.

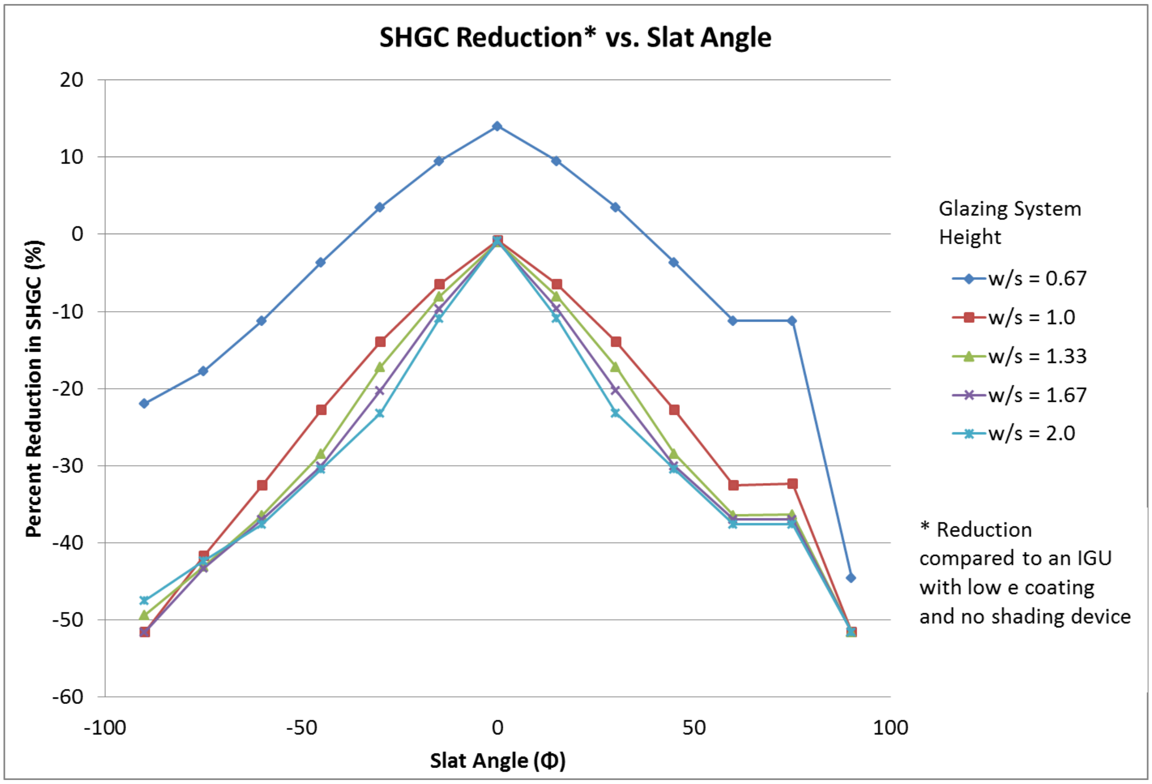

Figure 5: Reduction in SHGC vs. slat angle for several width-to-spacing ratios.

The next criterion investigated was the effect of the width of the shading cavity. This width is defined as the distance between the interior surface of the glass to the centerline of the shade. For this analysis, the shades were in the closed (90°) position. The study was then repeated for several other glazing system heights. The results are shown in Figure 6. For a window with a height of 1500mm (that of the previous investigations), the width of the shading cavity can affect the performance of the system by about 1%. As the height of the glazing system is increased, the effect of the size of the shading cavity becomes slightly more pronounced, resulting in closer to 2% of a variance.

The results of the study by Machin et al. (1998) show that there was a performance peak at about 14.5 mm. This particular feature was not found in the present study. In fact, for short windows, it was found that a shading cavity of ~15mm actually produces the *worst* results. However, it should be noted that those results were specifically for convective heat transfer. In addition, the role of the framing was not taken into account in that study. This seems to indicate that the role of radiative heat transfer is less dependent on the cavity width. In addition, the effect of the more highly conductive framing has the effect of lessening the effect of this particular feature for the size of windows investigated.

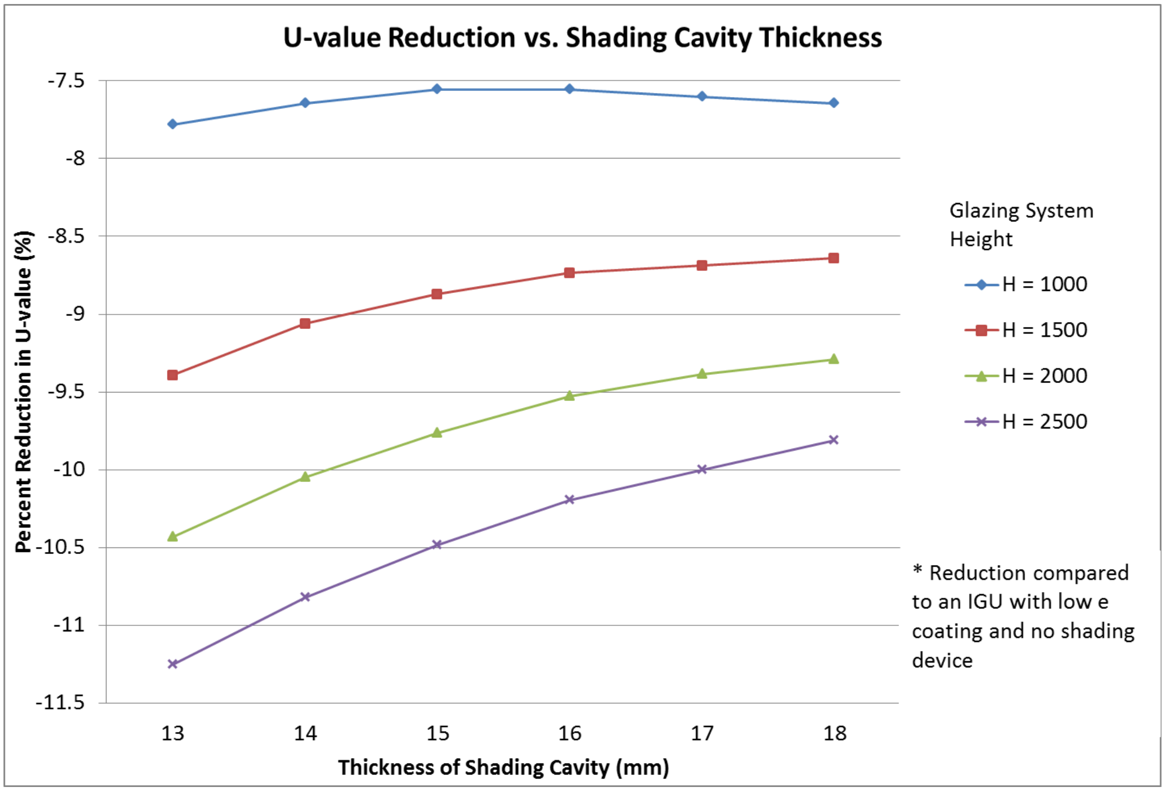

Figure 6: Reduction in center of glass U-value vs. shading cavity thickness for several different window heights.

The next criterion investigated involved the optical qualities of the material used for the slats. There are three types of radiation that are of interest to the performance of shading systems. The first two types are radiation in the solar or visible portions of the electromagnetic spectrum. These wavelengths can be either transmitted through the blind or reflected. Variations in these variables will primarily affect the SHG (solar spectrum) and visual transmittance (visible spectrum) of the system. The default values for opaque white blinds were used ($T_{sol} = 0$, $R_{sol} = 0.7$, $T_{vis} = 0$, $R_{vis} = 0.7$) to account for these effects. The third type of radiation is in the infrared spectrum (heat). This quantity will be of primary interest for the purposes of reducing the thermal transmittance of a glazing system. To determine the effect of these variations, the transmittance (T_{IR}) was set to 0, and values for the emissivity were varied between 0 and 1.0. The results of this variation are shown in Figure 7.

Compared to the other variables examined thus far, it is clear that emissivity has a dramatic effect on the performance of venetian blinds. Variations in emissivity can account for between ~8 and ~15% reduction in U-value. These center-of-glass results are consistent with those of Shahid and Naylor (2005). The effect of the framing materials on the performance of the system is also shown. The increased performance obtained from using low-emissivity solutions is lessened for highly conductive frames (~11%) compared to low-conductivity framing solutions (~15%).

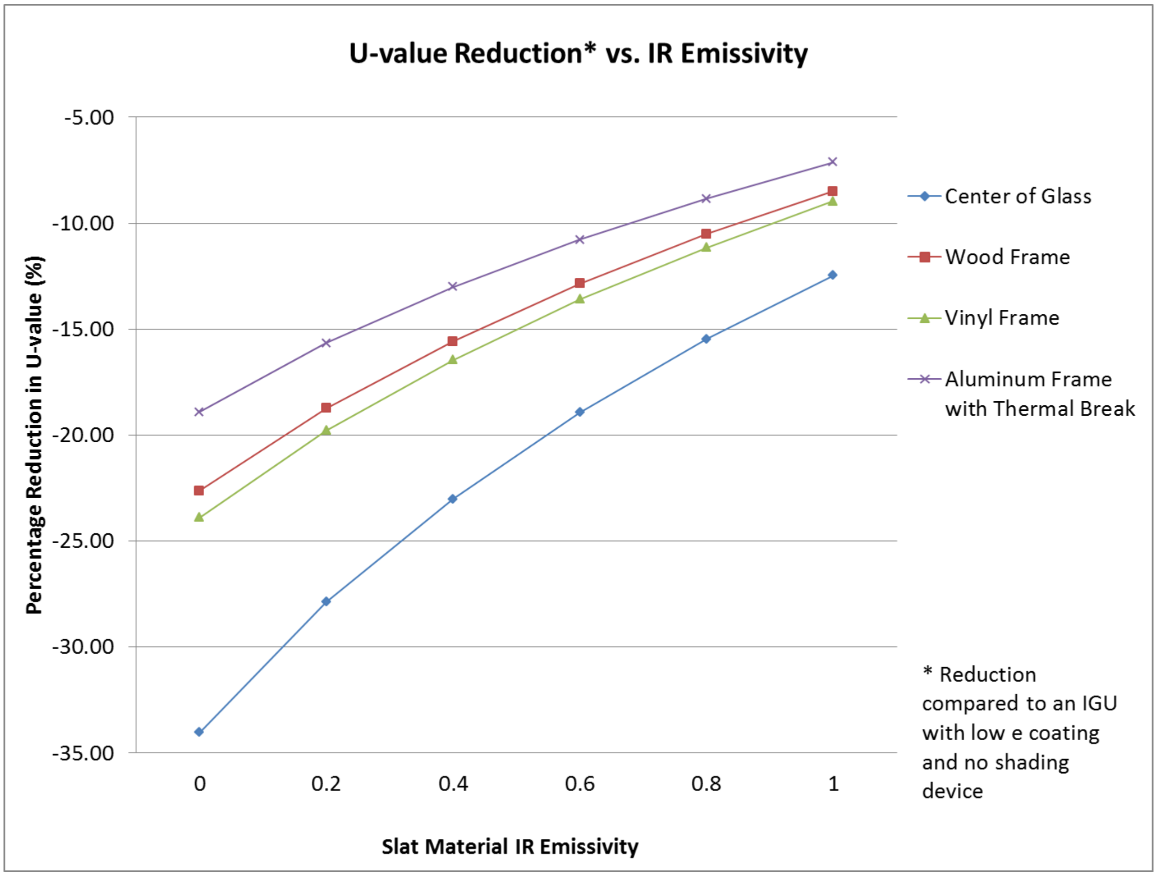

Figure 7: Reductions in U-value obtained based on variations in IR emissivity.

The effect of slat rise was investigated next. Recall from Figure 1 that this characteristic is essentially a description of the curvature of the slats. This criterion was investigated for slats with rises between 0.25-2.25 mm (0.009-0.088 inches). The slat thickness and width were maintained at 0.6mm and 16mm, respectively. The results are shown in Figure 8. For variations in the range of slat rises investigated, it was found that regardless of frame type used, the rise of the slats will only account for a variation in U-value of less than 0.5%. It can therefore be concluded that the impact of slat rise is negligible.

One interesting effect can be observed in Figure 8. As the slat rise increases, there is a slight oscillating behavior in the performance of the blind. Yahoda and Wright (2004) noted that the effect of slat curvature was minimal for large curvatures (low rises using our terminology), but that it is likely that the effect would become more pronounced when the radius of curvature is very slight (large rise values). However, the oscillating behavior of the shades was not noted in their study. This likely indicates that the oscillations are a function of the algorithms used by WINDOW.

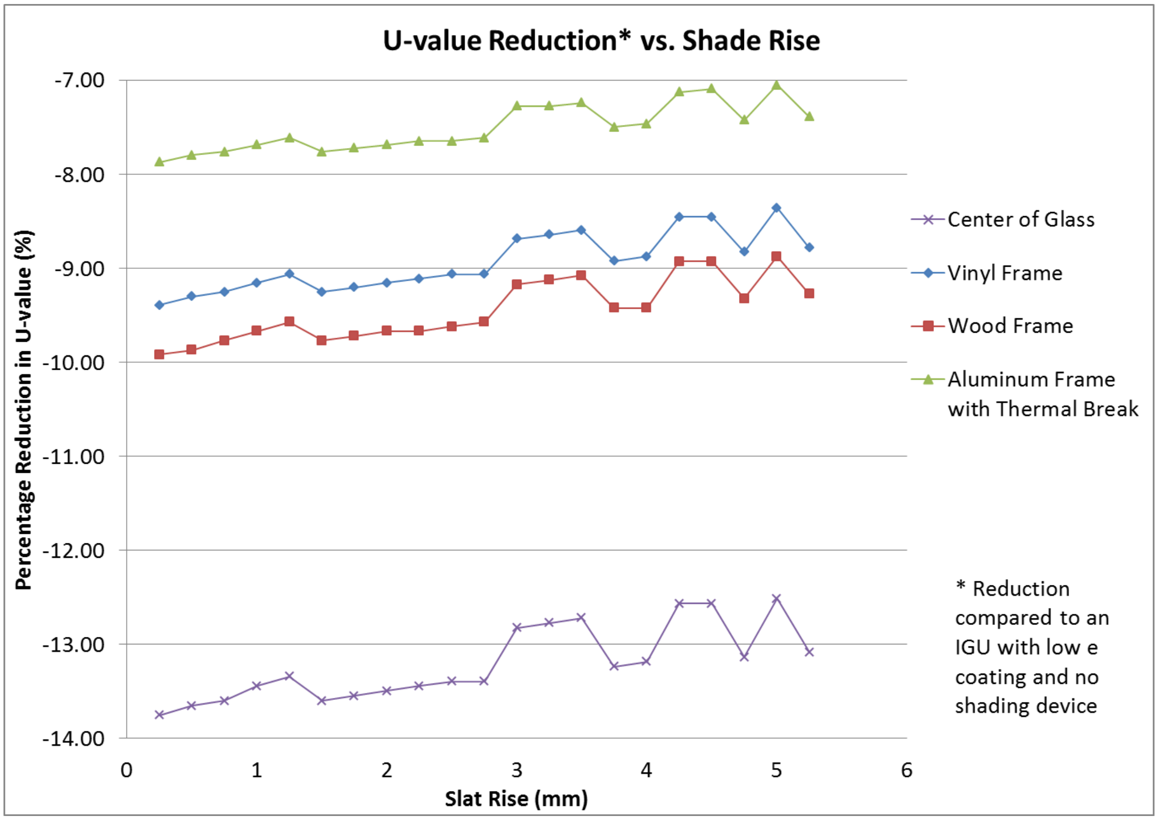

Figure 8: U-value reduction based on variations in slat rise.

The effect of the openness fraction (effective openness) was then investigated. Recall that the openness factor is a measure of the open areas or "holes" in the central portion of the shade through which air can move. In effect, this is a measure of how ventilated the cavity is. The results for openness factors of between 0 (perfectly sealed) and 1 (perfectly open) are shown in Figure 9 for shades in the 90° position. Shades with less than five percent openness are able to achieve significant improvements in performance, while those with greater than 5% openness were very consistent. It is important to remember, however, that most shades currently on the market are not able to achieve a completely sealed condition when closed (Machin et al., 1998) and that a 5% openness was assumed to be the standard conditions for shades at 90°. Investigation of designs that could allow for the 0% openness condition could be an area for future study.

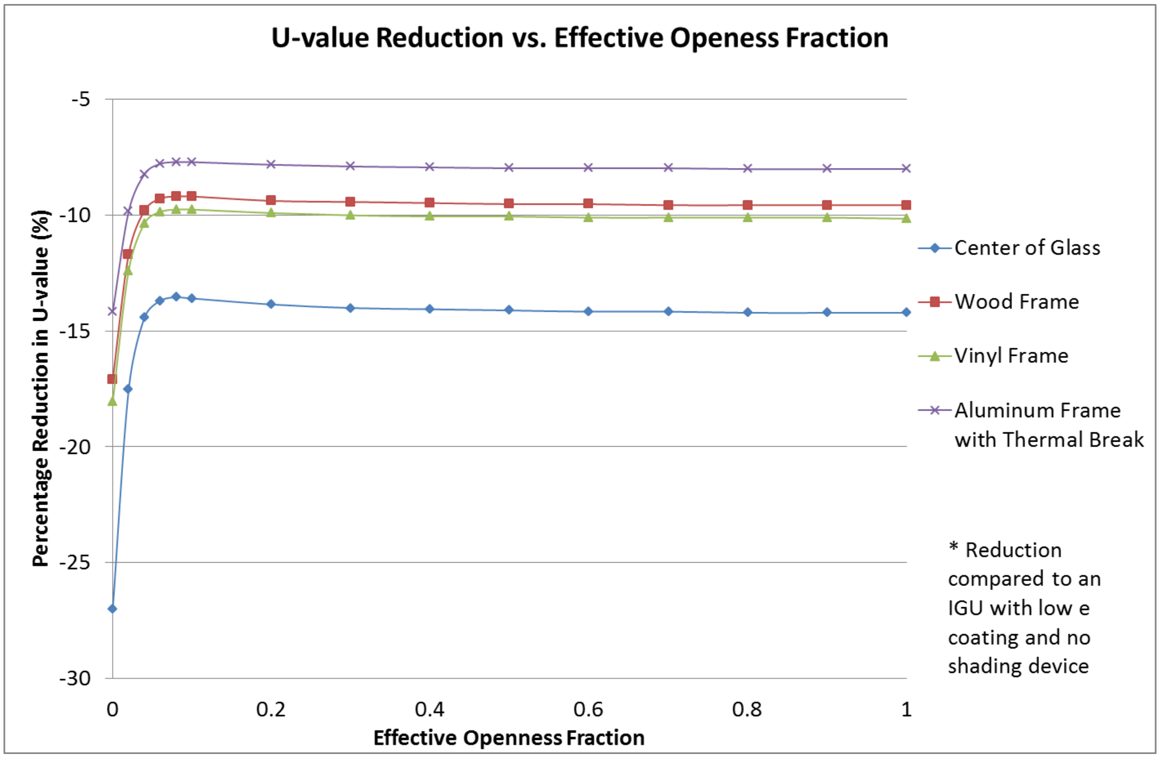

Figure 9: Reductions in U-value as a function of effective openness.

The effect of slat thickness was next investigated. For this analysis, it was assumed that the blinds are in the completely closed position, with a 16 mm (0.63 inches) slat width, a 12 mm (0.47 inches) spacing, and a 0 mm rise. It was assumed that the slats would be in the fully closed condition, as is appropriate for nighttime use when improvement in U-value is most critical. For the initial portion of this analysis, a material conductivity of 160 W/mK was used. The results of this study are shown graphically in Figure 10.

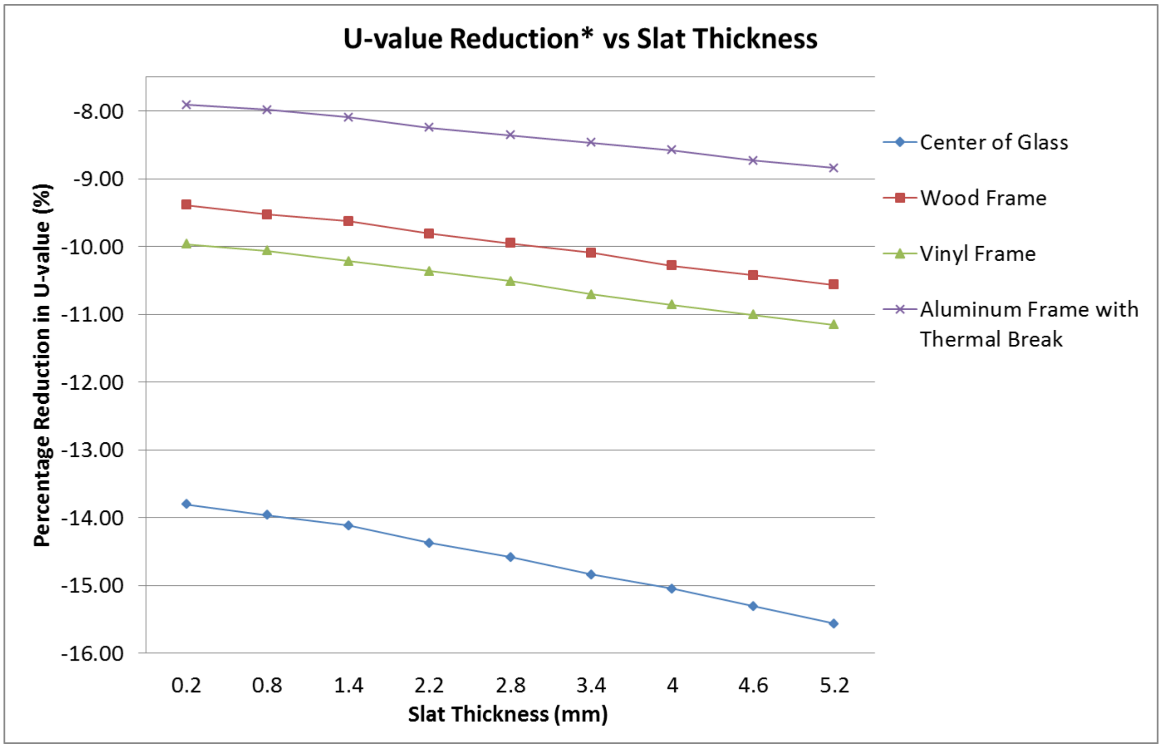

Figure 10: U-value reduction achieved using venetian blinds of various slat thicknesses.

As can be seen in Figure 10, the blind performance improves as the thickness of the slats increases. Over the range of thicknesses examined, the center-of-glass U-value improvement will range of ~13-15% as compared to an IGU with no shading device. The type of window frame present in the system will have a large effect on the performance of the shade. More thermally conductive frames will dominate the performance of the glazing system, allowing the shade to have only a small impact on the improvement of the system. Regardless of the impact of the frame material, variations in the thickness of the slats will only result in a 1-2% variation in shading performance. Therefore, it can be concluded that slat thickness will not be a primary factor affecting shade performance.

In order to determine exactly what role conductance plays in the performance of venetian blinds, the analysis was repeated for conductivities of 200 W/(mK) and 120 W/(mK). For this particular analysis, only center-of-glass U-values were considered. The results of this analysis are shown in Figure 11. This analysis showed that the conductance of the material used for the slats has no effect on the performance of the shade system, as all variations coincide. This makes sense, as thermal performance of the slats is based on reducing radiative and convective heat flow. Since the blinds are such a thin, highly conductive feature of the system, it makes sense that conductance will not be a driving feature of their performance.

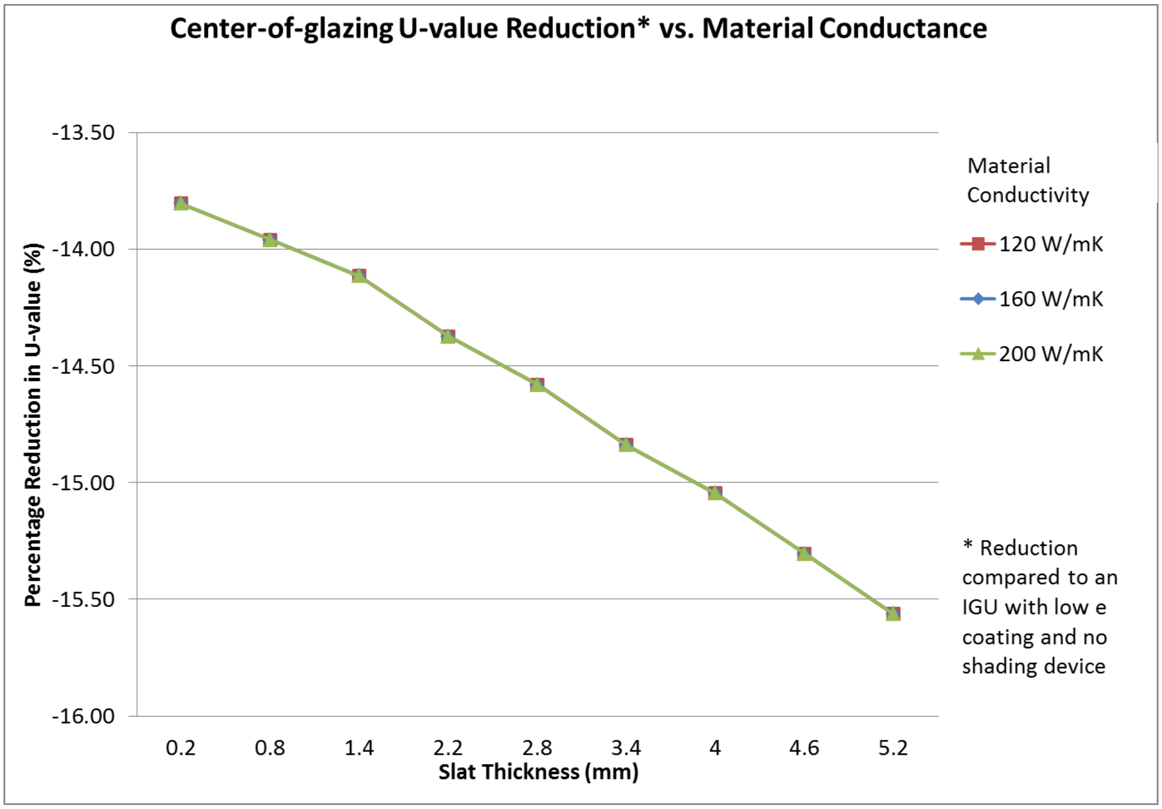

Figure 11: U-value reduction achieved based on the conductance of the shading material used.

From the criteria previously investigated, it can be concluded that the two venetian blind features that are most likely to drive the performance of the system are the openness of the shade and the emissivity of the slat material. A further study was then conducted to evaluate the combined effect of both of these features. The center-of-glass U-values were calculated for systems with openness fractions between 0 and 0.12 and varying emissivity. The results of this study are shown in Figure 12, which seem to indicate that for low-emissivity blinds, with an openness condition of about 2%, approximately 15% to 40% reduction in U-values could be achieved depending on the slat material emissivity. If a 0% openness condition could be reached, this improvement can be increased from 25% to 60%, depending on the slat material emissivity.

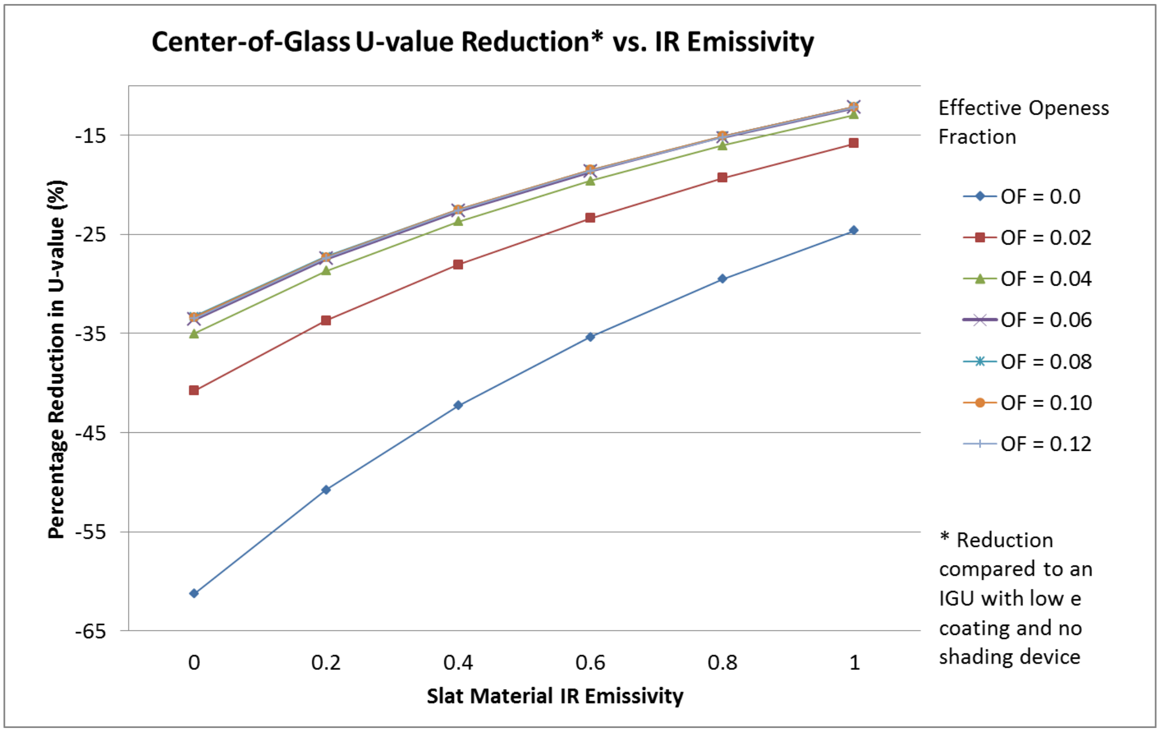

Figure 12: Reductions in center of glass U-value vs. IR emissivity and openness fraction.

The analysis was then repeated to examine the effect of venetian blinds on the exterior side of the glazing. It was found that the venetian blinds reduced the U-value by 20-25% in the center of glass region. The results of this study are shown in Figure 13. Note that the data shown for wood framing was limited to slat angles of -60° to +90°. The data corresponding to slat angles beyond this seemed to be corrupted. The reason for this was not clear, but one possibility seems to be related to internal modeling assumptions.

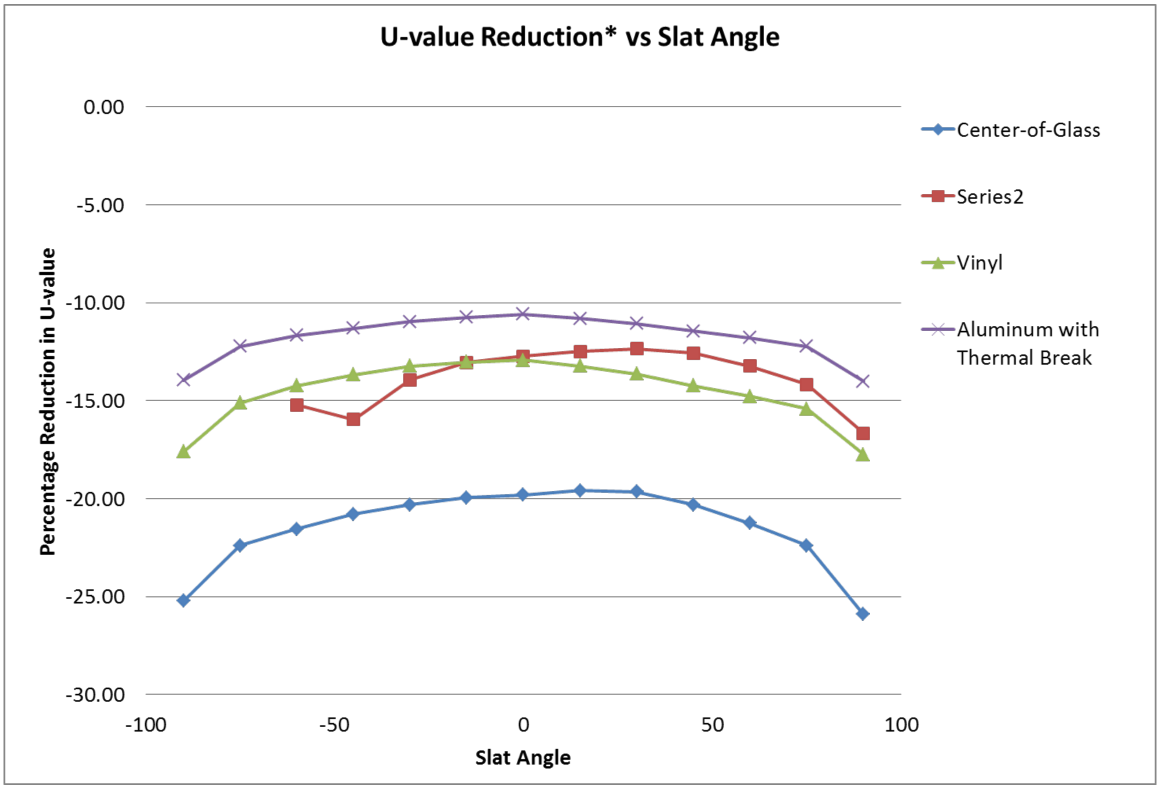

Figure 13: Reductions in U-value vs. slat angle for exterior venetian blinds.

The slat angle had a significant effect on solar heat gain reduction for exterior shades, as is shown in Figure 14. When the slats are in the closed position, the SHGC is reduced by nearly 100%. As the slat angle approaches 0°, however, the reduction decreases. At 0°, there is actually an increase in solar heat gain. This seems to imply that the shades have a magnifying effect at this angle.

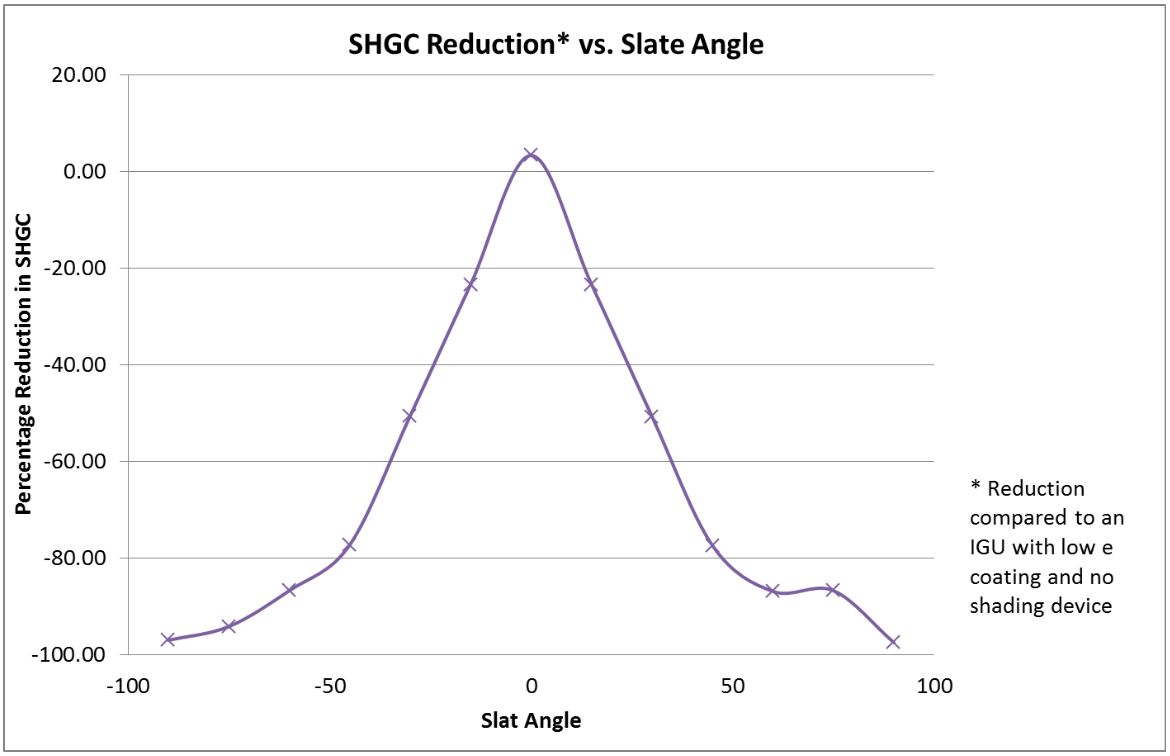

Figure 14: Reductions in SHGC vs. slat angle for exterior venetian blinds.

SUMMARY AND CONCLUSIONS

This study demonstrated that venetian blinds can be an effective retrofit option for reducing the thermal transmittance as well as the solar heat gain coefficient. Numerous criteria were investigated in this portion of the study, including slat angle, the slat width to spacing ratio (w/s), shading cavity thickness, infrared emissivity, openness fraction, slat thickness, and material conductivity. It was found that the least effective criterion was material conductivity, which resulted in no change in performance. The most effective criteria were emissivity of the blinds and the effective openness of the system, which reduced the U-value by as much as 35% and 27.5%, respectively. When these criteria were combined, it was found that up to a 60% reduction in U-value could be achieved.

There were several general conclusions that can be reached from this study.

- Window retrofit solutions generally function by reducing convective and radiative heat loss. Conduction has a small role, if any, in their function.
- Exterior shades are generally more effective at reducing U-value and dramatically more effective at reducing SHGC than those placed on the interior.
- In general, blinds with shiny metallic surfaces will perform better than those matt finishes.
- Blinds should be installed as close to the glazing surface as possible within the frame to limit the flow of convection along the glazing surface.

- Venetian blinds capable of limiting airflow when in the closed (±90°) position have the potential to significantly reduce thermal transmittance of the system.
- Blinds in the 0° position will reduce the U-value without substantially reducing the SHGC. This can be beneficial for passive solar heating.
- Venetian blinds may be particularly useful in mixed climates, wherin the blinds highly adjustable nature will allow the user to selective allow or deny solar heat gain.

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