BIRCH POINT
Consulting

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Dear Doug:

In earlier comments on the proposed new Energy Star® program for exterior and interior storm windows and panels, the question was asked how much the frame material of the storm window affects the overall performance. The framework document and referenced papers note that differences in performance between storm window products are dominated by the glazing type (low-e or not) and air leakage reduction, and therefore suggested using emissivity, solar transmittance, and air leakage as the primary metrics for the program. Unlike primary windows, differences in frame material should have minimal impact because even for aluminum framed storm windows (which are the vast majority due to structural, durability, and design benefits), the storm window panel is attached to nonmetal components like wood brick mold, wood blind stops, inside drywall, or wood trim that act as a thermal break. But to address this question, I have included some additional analysis here that you might find useful and confirms this conclusion.

<u>Part 1 – WINDOW / THERM analysis</u>

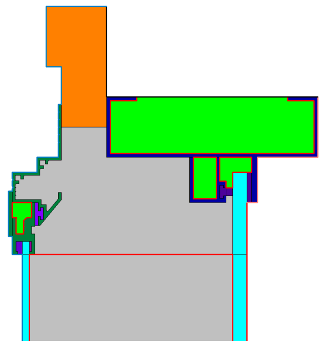
First, to directly test this question, I started with the same WINDOW/THERM models that were used in the Pacific Northwest National Laboratory paper "Thermal and Optical Properties of Low-E Storm Windows and Panels" (PNNL-24444, July 2015) to determine U-factor, SHGC, and VT properties of different storm windows and panels over different types of primary windows. I then simply changed the storm window frame material in the THERM models from painted aluminum to rigid PVC, and reran the simulations to determine the change in performance.

The results are shown in Table 1 for two primary windows bracketing the end points: a single glazed metal-framed window and a double glazed wood window. Despite the fact that the thermal conductivity of aluminum is 941 times higher than that of rigid PVC (92.45 vs. 0.0982 Btu/hr-ft-F), ***the effect of storm panel frame material on overall U-factor is only 1.9-2.6%***. The U-factor of the overall assembly only changed 0.005-0.011, which is barely relevant. The thermal conductivity of the panel frame material alone is not a relevant parameter because it is the combined attributes of the panel, wood stop / thermal barrier, and primary window that matter.

In contrast, as shown in Table 2, ***the effect of glazing type (low-e vs. clear) has a 10 times larger impact, reducing the U-factor of these windows by 21-24%***. This clearly supports the use of glazing-only properties for the program criteria, in addition to air leakage. I can also provide you the results using the other primary windows shown in PNNL-24444, which show similar impact.

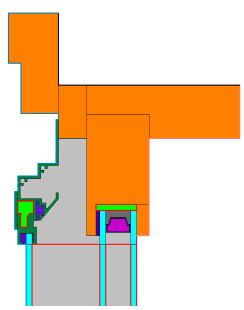
Table 1

Exterior Low-E Storm Window over Fixed Single Pane Aluminum Window



	Aluminum framed panel	Vinyl framed panel	Difference	
U-factor (Btu/hr-ft^2-F)	0.419	0.408	**0.011**	**2.6%**
SHGC	0.521	0.521	0.000	0%
VT	0.590	0.590	0.000	0%

Exterior Low-E Storm Window over Fixed Double Pane Clear Wood Window



	Aluminum framed panel	Vinyl framed panel	Difference	
U-factor (Btu/hr-ft^2-F)	0.266	0.261	**0.005**	**1.9%**
SHGC	0.460	0.460	0.000	0%
VT	0.524	0.524	0.000	0%

Table 2

Low-E vs. Clear Exterior Storm Window over Fixed Single Pane Aluminum Window				
	Clear glass	**Low-E glass**	**Difference**	
U-factor (Btu/hr-ft^2-F)	0.552	0.419	**0.133**	**24%**
SHGC	0.611	0.521	0.090	15%
VT	0.649	0.590	0.059	9%
Low-E vs. Clear Exterior Storm Window over Fixed Double Pane Clear Wood Window				
	Clear glass	**Low-E glass**	**Difference**	
U-factor (Btu/hr-ft^2-F)	0.323	0.266	**0.057**	**21%**
SHGC	0.535	0.460	0.075	16%
VT	0.574	0.524	0.050	10%

Part 2 – Annual Energy Performance analysis

Second, as part of the development work for an AERC annual energy performance rating for window attachments, LBNL has conducted a sensitivity analysis examining the impact of different variables on the annual energy savings associated with the use of different fenestration attachment types in a single family home. Using EnergyPlus, two energy performance indices are calculated: EP_C for cooling and EP_H for heating, which are defined as the ratio of annual HVAC cooling/heating energy saving resulting from the addition of a window attachment to the annual energy use caused by the window in the home without the attachment, multiplied by 100. An EP less than zero means the attachment has a negative impact on the energy performance of the window. An EP between 0 and 100 means the attachment has a positive impact on the energy performance of the window, with higher EP indicating higher energy savings. An EP greater than 100 means the attachment and window system is a net-energy producer compared to an adiabatic window. Houston TX is used for calculating EP_C for cooling, and Minneapolis MN is used for EP_H. Details on the calculation from LBNL are provided in Attachment A.

Related to the issue here, one of the variables included in the sensitivity study for window panel attachments was thermal conductivity, bracketing a very wide range from 0.05 to 160 W/mK. (For reference, the thermal conductivity of aluminum is 160, glass is 1, wood is 0.14, rigid PVC is 0.17, and polyurethane foam is 0.05 W/mK.) This tests the extremes, because the analysis used this as the thermal conductivity for the *entire* attachment, whereas a real product may have 80-90% glass, 10-20% framing.

Figures 1-2 show EP_H and EP_C results from LBNL's analysis for different exterior panels as a function of thermal conductivity.

Data is shown for both panels with high solar transmittance (0.8), and panels with low solar transmittance (0.1). Note that these are *hypothetical* end points chosen to test sensitivity over a broad range, and do not represent actual specific products. The high 0.8 solar transmittance end point is reasonably representative of real clear glass (Tsol ~ 0.8) and "traditional" low-e storm panel products (Tsol ~ 0.7-0.75), but the low 0.1 solar transmittance is very low, much lower than real products. It is still useful for testing sensitivity over a large range and could be thought of as a very tinted glass with or without low-e, but real durable solar control low-e products used in this application are more typically in the range of Tsol ~ 0.4-0.55. One real solar control low-e product used in exterior storm panels is shown, but is only an interpolated estimate.

Figure 1: Energy Performance Indices for Exterior Panels with High Solar Transmittance

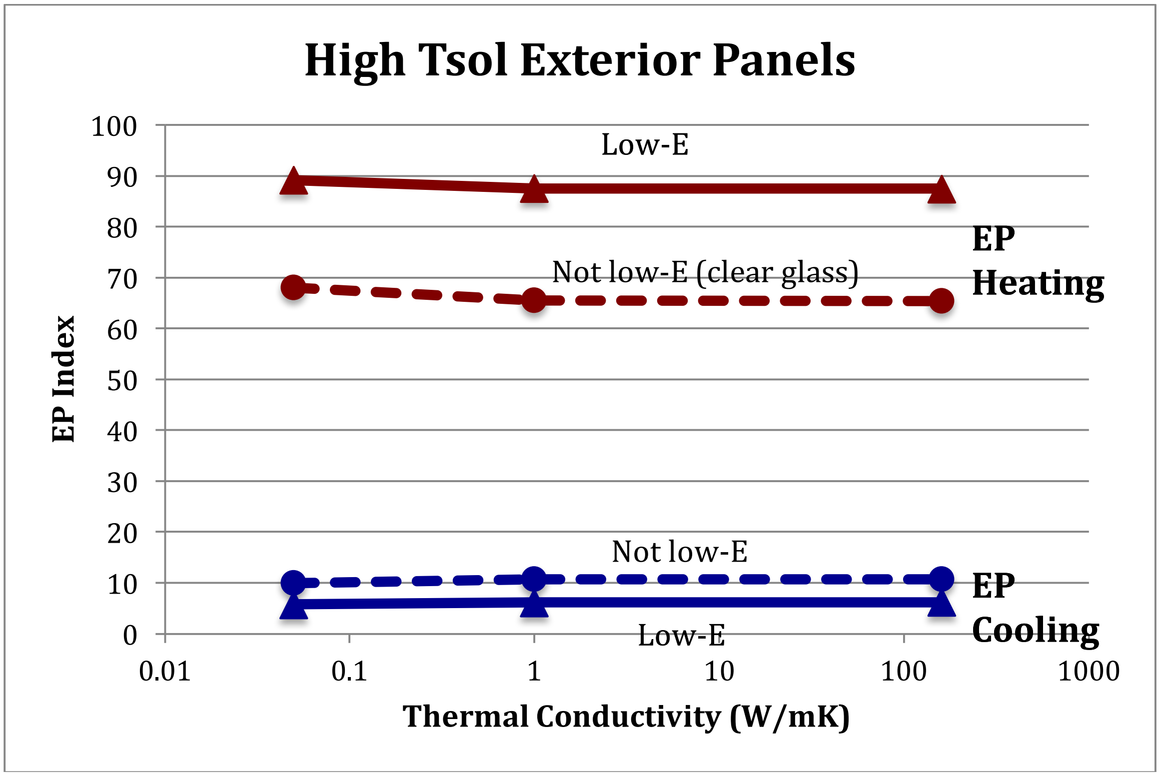
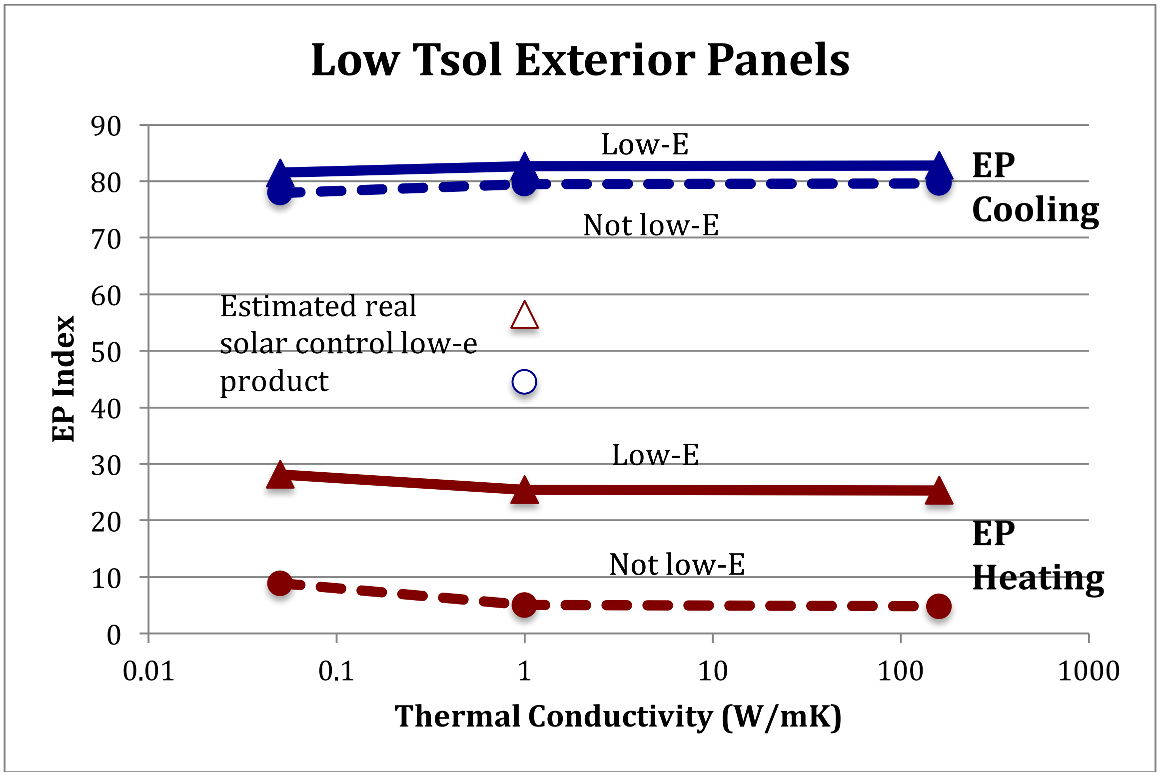


Figure 2: Energy Performance Indices for Exterior Panels with Low Solar Transmittance



Several observations can be made:

- The primary application for storm windows has been to reduce heating energy use in cold climates, and this is seen in the high EP_H in Figure 1, with low-e giving a clear and significant benefit. There are still some cooling savings (EP_C is greater than zero) but this part is clearly secondary to the heating savings.
- As expected, low solar transmittance raises the cooling energy performance EP_C for cooling-dominated climates, but lowers the heating energy performance EP_H in heating-dominated climates by blocking beneficial solar heat. Low-e glazing improves upon this and provides higher heating EP. Again, this is using a hypothetical very low solar transmittance, and the estimated performance of a real solar control low-e product shows a good balance with relatively high EP for both heating and cooling – good for mixed climates with both significant heating and cooling.
- The flat lines show that thermal conductivity does not have any significant impact on EP_H and EP_C, even when changing the thermal conductivity by a factor of over 3000. This confirms the conclusion from part 1 that frame material and conductivity of the attachment alone is far less important to overall energy performance of the system than glazing properties (emissivity and solar transmittance).

Overall, both analyses support the conclusion that frame material of the attachment alone does not have a significant impact on overall energy performance, whereas glazing properties have at least 10 times more importance. As the framework document suggested, the program criteria can be based on emissivity, solar transmittance, and air leakage to capture the key variables that differentiate energy efficient products from conventional products. I also agree with the framework document that there is value in providing additional recommendations about proper installation to ensure Energy Star panels are recognized as high-quality products, including guidance on thermal breaks when installed over metal frame primary windows, but that is covered in the installation instruction section.

EPA could also consider transitioning to use AERC ratings for storm windows at a future point once those ratings are well established, but emissivity and solar transmittance are appropriate for the initial Energy Star specification. They are simple, easy to verify, provide consistency with other regional programs, and will not be confused with U-factor and SHGC ratings currently used in the Energy Star program for windows, doors, and skylights.

I continue to be very supportive of the proposed program, and please let me know if you would like any further information or details.

Best regards,

Thomas D. Culp
Birch Point Consulting LLC