MEMORANDUM

Pacific Northwest NATIONAL LABORATORY

Date:	**May 28, 2022**
To:	**Rachel Zakrasek and Rick Dunn, NEEA**
From:	**Katie Cort, PNNL Project Manager, and Edward Louie, PNNL Principal Investigator**
Subject:	**Summary of Field Evaluation of Non-Glass Interior Secondary Window Attachments**

Introduction

This memo describes the findings from field evaluations examining non-glass, interior window attachments to see how these options compare in terms of initial cost, energy savings, noise attenuation, and subjective factors such as optical clarity and aesthetics. This study was undertaken by Pacific Northwest National Laboratory (PNNL) with support from the Northwest Energy Efficiency Alliance (NEEA) to evaluate the effectiveness of non-glass secondary window attachments in improving the window thermal performance of commercial buildings in the Pacific Northwest.

Secondary window attachments save energy by reducing thermal transfers through the window. These window attachments come in two forms: exterior and interior attachments. Interior secondary windows can sometimes have advantages over exterior attachments for certain applications, they can be easier to install in multi-story buildings, tend to require less maintenance because they are not exposed to the elements, and they generally do not affect the exterior façade, which is an important criterion when dealing with historic buildings.

This summary describes the findings from a series of field tests that examine the thermal and acoustic performance of three commercially available non-glass interior secondary window products in two different commercial buildings, one in Seattle and the other in Tacoma, Washington. The products were evaluated from July 2021 through February 2022 over a series of windows of two sizes, 44" wide x 88” height and 105" wide by 80" tall to understand how these products scale to larger windows that are commonly found in commercial buildings. This summary draws from a comprehensive white paper report[1] that provides detailed documentation of scoping process, field-testing protocols, instrumentation specifications and procedures, product screening, baseline conditions, and data collected.

[1] “Field Evaluation of Non-Glass Interior Secondary Window Attachments,” by Edward Louie, Pacific Northwest National Laboratory, Richland, Washington, published on May 2022, PNNL-32832.

Tested Products and Field Site Characteristics

The following three types of commercially available non-glass interior panels were evaluated for this study:

- Frame-mounted acrylic panel with vinyl + weatherstripping perimeter seals (pictured below)
- Frame-mounted acrylic panel with vinyl + magnetic perimeter seals (pictured below)
- Glazing-mounted copolyester panels (pictured below) This is ***Polar****Skin*™

The frame-mounted acrylic panel with vinyl + magnetic perimeter seal product requires the installation of light gauge (~24 gauge) metal L-angle stock or flat metal stock into the window frame first to create a magnetic surface for the magnets in the panel's frame to stick to. The acrylic products hold themselves to the window frame using friction. The glazing-mounted copolyester panel product comes with clear adhesive-backed mushroom snap-together connectors that are installed onto the window glass surface. These mushroom snap-together connectors are like the more commonly known hook-and-loop fasteners; but unlike hook-and-loop fasteners, they have a field of tiny hard plastic mushrooms that allows the product to mate to itself with a fastener.

Figure: Frame-mounted acrylic panel with vinyl + weatherstripping perimeter seals

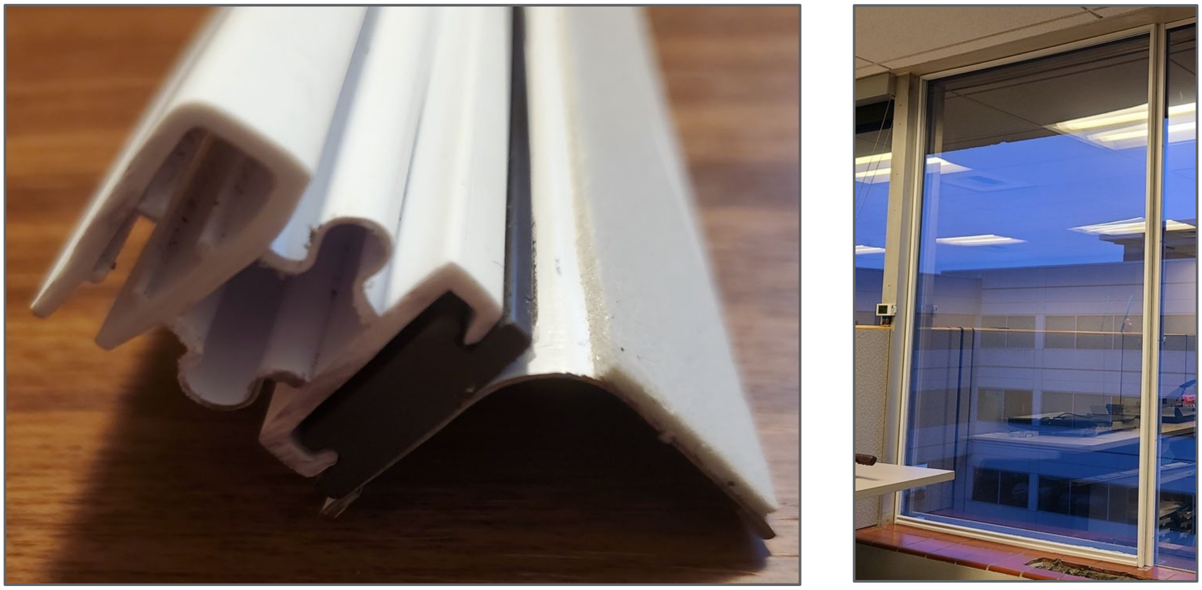

Figure: Frame-mounted acrylic panel with vinyl + magnetic perimeter seals

Figure: Glazing-Mounted Copolyester Panels

The non-glass window attachments were tested in three unique spaces located within two commercial buildings: Site 1 was a commercial administrative office building located in Tacoma, Washington, with large single-glazed windows, and Site 2 was a historic commercial office building in Seattle, Washington, with relatively smaller operable windows constructed with multiple glass lites held together by wood muntins in wood sashes in a wood frame windows. The Site 1 windows feature a single sheet of glass without mullions and surround an open plan office with cubicles. Although occupancy was low due to COVID-19 restrictions, the Site 1 office would normally house several occupants serving a customer service call center. Two spaces within Site 2 were used for testing, where one space was occupied by office staff and the other space was a common area (e.g., conference room) and was intermittently occupied. Occupancy at Site 2 was also lower than normal during the testing due to COVID-19 onsite work restrictions. Both sites are located within International Energy Conservation Code (IECC) Climate Zone 4C.

Figure: Photo of Site 1 Window from Interior of Building in Tacoma, WA

Figure: Photo of Site 2 Historic Building in Seattle, WA

Summary of Findings

The three non-glass products were evaluated in terms of installation requirements and features, thermal performance, air leakage reduction, noise reduction, aesthetics, and installed cost. Installations features and characteristics were gathered during the installation process and included observations from building facilities staff.

Thermal comfort characteristics were determined by measuring the surface temperature of the interior panel before and after installation using both thermocouple sensors and infrared (IR) imaging. The air-leakage reduction for each window attachment was measured before and after the application of the panels using a modified duct leakage tester, which measured air leakage around the window (see figure below). Noise reduction to the inside of the building from the application of the attachments was measured using a speaker placed outside the window; pure tones at different frequencies were played at decibels (dB) high enough to be the main source of outside noise. The sound meter inside the building was used to measure the sound infiltration at different frequencies. Observations related to the aesthetic appeal and clarity of the attachments as well as changes related to glare were gathered from building occupants sitting near the windows; however, these observations were limited to three occupants at each location due to the COVID-19 occupancy restrictions. The initial cost of the products was based on acquisition costs at the time of the testing. Installation costs were based on the time it took to install the products.

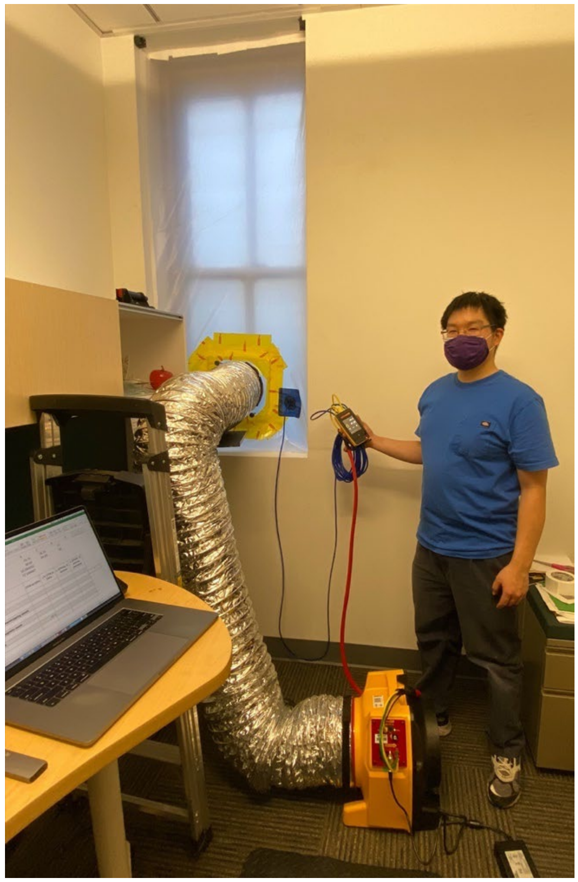

Figure: Test Setup for Measuring the Air Leakage of an Individual Window

Across all non-glass products tested, it would appear that there would be some distinct installation advantages relative to full replacement or their secondary window glass counterparts. These advantages include the lighter weight and flexibility of these non-glass panels. The copolyester panels, in particular, were very light, flexible, and extremely easy to install and were acquired for the lowest cost. Thermal comfort benefits were measured for all three panels, with the copolyester panel yielding the greatest change in temperature to the interior panel. Significant air leakage and sound reductions were measured for both acrylic panels. The aesthetics, glare, and clarity features of the interior panels were generally viewed favorably by the building occupants. These findings are summarized in the table below.

Table: Summary of Findings for Non-Glass Secondary Panels Evaluated

Characteristic Evaluated	Acrylic panel with weatherstripping seals	Acrylic panel with magnetic seals	Glazing mounted copolyester panels *PolarSkin*	WexEnergy Notes
Installation Features				
• Measuring/Ordering (complication level)	Moderate	Moderate	Easy	
• Weight (Lb./ft^2)	1.4	1.4	0.2	*Featherweight = lower shipping costs*
• Flexibility	Flexible	Flexible	Very Flexible	*Easy to maneuver around furniture.*
• Size Availability	Most Sizes	Most Sizes	Limited[a]	*Max dimensions: 46" X 60" (as of Q2-'22)*
• Time Required for Installation	Moderate	High	Moderate[b]	*See note (b).*
• Ease of Installation	Moderate-Difficult	Moderate-Difficult	Easy (limited application)	*See note (f).*
Thermal Comfort				
• Surface Temperature (change)[c]	2-5 °F	2-5 °F	5-10 °F	
• IR Images (temperature change)	7.5 °F	7.5 °F	10 °F	
Air Leakage Reduction (CFM/ ft^2 change)[d]	-2.9	-2.9	0	*PolarSkin moves with the glazing to preserve window operability. It was not designed to reduce air leakage at frame or noise transfer.*
Noise Reduction (average dB reduction)	17	17	2	
Aesthetics	Favorable	Favorable	Okay	*Aesthetics impacted by atypical install: 6 skins p/ pane.*
Glare/Clarity	Better	Better	Slightly Better	
Cost				
• Material Costs ($/ft^2 at scale[e])	$21	$25	$10	
• Labor Costs (time/installation)	.3-.7 hrs	.8-1.2 hrs	.4 hrs	*See note (b).*

[a] Size availability is extendable via tiling coupled with added muntins or mullions adhered to the glazing to create artificially divided lites. This project did not evaluate this approach.
[b] Time required for windows with 6 lites, windows with only 1 or 2 lites would be short. *Typical install time for 2 PolarSkins is 6 minutes.= .1 hour.*
[c] Measured when outdoor temperatures were 50s to 60s °F and the nighttime lows were in the 40s °F with indoor temperature at 74 °F.
[d] Tested on a window with a baseline air leakage of 3.1 CFM/ft^2.
[e] Cost reflects study period pricing 2021-2022 and are not necessarily reflective of current retail rates. Windows with high United Inches (Width + Height) relative to their square foot can result in additional costs.

(f) WexEnergy opted out of Site 1 due to concern of possible damage to the site's recently installed window film and potential for damage of the film upon removal of the ***Polar****Skin*. This site would have been approved for a ***Window****Skin* installation had this study been designed as a long term installation.

Energy Savings

Although the total building heating and cooling savings from the secondary window panel applications could not be measured for this limited application field test, the U-value improvements from the three products tested have been modeled using Lawrence Berkeley

National Laboratory's (LBNL's) WINDOW software to calculate the change in center-of-glass (COG) performance[2]. Considering that the U-values reflect the overall thermal performance of the secondary panel, all panels tested should reduce thermal transfers through the window to a certain degree. The likely ranges of COG U-values for each class of products, over single-pane clear glass wood frames are described in the below table. Based on these data, the overall COG U-values of the glazing systems are reduced by over 50% from application of the window attachments evaluated in this study -- a significant thermal insulating performance improvement. These modeled characteristics could be used to estimate overall building savings and payback for full-scale building retrofits.

Table: Glazing System Modeling Characteristics with and without Attachments

Baseline Window Characteristics	Before COG U-Value (Btu/h·ft^2·F)	Attachment Type	After COG U-Value (Btu/h·ft^2·F)	% Difference in U-Value
Single-Pane Clear Glass Wood Frame	1.041	Copolyester[(a)] panel ~3/8"-5/8" from glass	.516-.496	50-52%
		Acrylic (1/4" thick) ~1/2" from glass	.459	56%
		Acrylic (1/4" thick) ~1-4" from glass	.468	55%

[(a)]Polycarbonate with 0.039" thickness (ID 140) was used as a proxy material for copolyester.

Commercial buildings exhibit large variations in window-to-wall ratios, surface area-to-volume ratios, area-to-height ratios, and internal heat load-to-external heat loss ratio; these aspects all significantly affect the energy savings of a window retrofit relative to the building's total energy use. The starting condition of the primary window also affects the energy savings of a window retrofit project; for example, retrofitting single-pane windows will result in greater energy savings than retrofitting double-pane windows. Retrofitting clear glass windows will result in greater savings than retrofitting windows that have a low-E coated surface(s). For windows that leak a significant amount of air, the envelope air leakage savings from a window retrofit that reduced air leakage should be factored into an energy savings model. Note that modeled energy savings based on changes in COG U-values would not capture the savings from air-leakage reductions from the application of air-sealing attachments, such as the two acrylic attachments evaluated in this study.

Conclusions

Commercial office buildings often have high glazing-to-wall ratios, which means improving the thermal performance of the window could potentially net more significant savings compared to residential applications. However, replacing the primary windows in a commercial building is

[2] Building specific window energy savings can be modeled using LBNL's suite of window modeling software https://windows.lbl.gov/software

often cost-prohibitive and challenging logistically (e.g., requiring sidewalk and/or road closures, deployment of lifts and scaffolding, and occupant disruption). Secondary glazing systems, including non-glass interior window panels, can often be installed for a fraction of the price of full window replacements and provide significant thermal performance and comfort benefits to the building occupants.

Each product and product category has advantages and limitations depending on the baseline conditions and configurations of the primary window and building. The glazing mounted copolyster panel product could be a good choice for windows that need to remain operable, windows with sashes or glass lites divided by muntin bars that have adequate weatherstripping and do not have significant air leakage or noise issues to combat. Where outside noise reduction is a high priority, the acrylic panel products are impressive in their ability to reduce outside noise levels. In addition, both acrylic panels that were tested reduced the air leakage of the primary window by over 90%. The acrylic panel products also occupy a more mature product category, so there are many brands to choose from compared to the glazing mounted plastic panel category.

Maintaining window function is critical to maintaining compliance with building code.

In order to reap the greatest benefits from these products, building owners should select among the available options based on factors and features that are most important for their use case and location. The Attachment Energy Rating Council (AERC) Certified Product Database[3] and Efficient Window Coverings website[4] are useful resources that provide unbiased energy ratings and guidance to help consumers select the best window attachments for their climate, specific needs, and baseline conditions of the building and window.

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[3] See https://aercenergyrating.org/product-search/commercial-product-search/ for more information.
[4] The Efficient Window Coverings & Attachments website was developed by Lawrence Berkeley National Laboratory (LBNL) in partnership with BuildingGreen, Inc with funding support from DOE. See https://efficientwindowcoverings.org/ for more information.