Affordable Window Retrofit Solutions for Multi-Family Buildings

Allegra Steenson, Pacific Northwest National Laboratory
Katherine A. Cort, Pacific Northwest National Laboratory
Christian R. Valoria, Pacific Northwest National Laboratory
Steven Sylvestre, Center for Energy and Environment
Isaac Smith, Center for Energy and Environment
Thomas D. Culp, Birch Point Consulting
Mike Radack, D+R Intl/Attachments Energy Rating Council

ABSTRACT

Multi-family buildings represent a pivotal opportunity to advance energy efficiency and decarbonization while reaching underserved communities such as low-income households and renters. In this aging and inefficient building stock, improving the building envelope can improve comfort, enable more efficient decarbonization, reduce energy burden, and provide a better overall experience for the occupant. With single-pane windows comprising 40% of existing windows in multi-family buildings, focusing on upgrading windows holds immense potential. Improving windows can have vast energy efficiency benefits, including air leakage reduction, HVAC load reduction, and equipment downsizing, utility bill savings, and peak demand reduction; however, non-energy benefits such as improvements in indoor thermal comfort, acoustics, and passive resilience can be a game changer for tenants. Unfortunately, window replacement is often disregarded due to high first costs, lack of financing options, and concerns about tenant disruption. Consequently, tenants are left with high utility bills and an uncomfortable home – which can escalate into life-threatening scenarios during extreme weather events.

Introduction

The majority of a building's heating, ventilation, and air conditioning (HVAC) loads are attributed to thermal transfer and air leakage through the building's envelope. Despite windows taking up only 7% of the building envelope, they are responsible for 48% of envelope heat transfer (conduction + radiation) and 25% HVAC energy use (Harris 2022; Hart et al. 2019). Reducing heat transfer and decreasing air leakage by improving the insulation, solar heat gain, and infiltration characteristics of a window can significantly improve the building's overall thermal performance and energy efficiency. In the U.S., approximately 40% of all existing multi-family units still have poor-performing, single-pane clear windows, and approximately 80% of multi-family units have never replaced their original windows (EIA 2020). Seventy-five percent of multi-family units were built prior to the year 2000, before higher-performing double-pane, low-e windows became popular (EIA 2020; Harris 2022), creating a huge opportunity to improve the old, inefficient windows of the multi-family building stock.

Looking to the future, the multi-family housing sector presents a unique potential for decarbonization. Multi-family buildings account for 60% of the U.S. rental market (JCHS 2022), and the sector has been particularly slow to implement energy efficiency upgrades compared to other building sectors, presenting the opportunity to leverage unrealized energy savings through deep energy retrofits. In addition to energy savings, efficiency upgrades help to improve affordability for residents, leading to reduced operating costs and ultimately the long-term preservation of affordable housing.

While full window replacement may be the standard for improving window performance, window attachments provide an effective alternative, improving energy efficiency at a fraction of the cost. Energy-efficient window attachments are products that can be installed on either the exterior or interior of the existing window to improve thermal performance. This product category includes storm windows, window inserts, insulating cellular shades, roller shades, and solar screens. Window attachment products, particularly interior attachments, have traditionally been thought of as decorative features; however, these products offer a variety of benefits to building occupants, including energy savings, improved comfort, noise reduction, and improved aesthetics.

Standards and product energy ratings help drive consumer awareness and market dynamics, increasing market adoption of energy-efficient technologies. In 2014, the U.S. Department of Energy (DOE) helped launch the Attachment Energy Rating Council (AERC), an independent, nonprofit rating council, to remedy the lack of energy ratings and standards for window attachment technologies. AERC offers a comprehensive program for energy-rating, certifying, and labeling window attachment technologies, providing the public with accurate and credible performance data. During the certification process, window attachments are simulated in both warm and cool climates to deliver independent ratings tailored to each climate type. A summary of commercially available window attachments is available on the AERC website, and as of 2024, AERC has energy ratings available for both interior and exterior storm windows (aka insulated window panels or secondary glazing), as well as cellular and roller shades, solar screens, blinds, Roman and pleated shades, and awnings. Figure 1 shows four AERC-rated window attachment retrofit solutions that can be applied to multi-family buildings.

Figure 1. Window attachment retrofits (from left to right) interior operable storm window, exterior low-e storm window, insulating cellular shades, and exterior shades. *Source:* PNNL, AERC.

This paper explores affordable window retrofit technologies and strategies, which promise substantial improvements, lower costs, and less tenant disruption. It includes findings from multiple lab and field validation studies, including recent results of the Twin Cities (MN) Multi-Family Storm Windows Replacement Pilot. Readers will learn about applications for various energy-efficient window attachments in multi-family buildings and understand how affordable window retrofit solutions can be used as a tool to enable equitable transition to a decarbonized multi-family sector.

Technology Overview

With a thermal conductance of approximately 0.0243 BTU/(h ft °F), glass is a poor insulator. Clear glass also transmits between approximately 70 and 90 percent of light/heat at all wavelengths, including infrared (IR) radiation (LBNL 2023). In recent decades, new window attachment retrofit technologies have been developed that can be customized to address home energy-efficiency needs and climate conditions to decrease solar heat gain, increase the reflectance of the window in the IR wavelengths, lower emissivity, and decrease the amount of thermal conduction and convection between indoor spaces and the outdoors. Although replacing old existing windows with new high-performance windows (e.g., ENERGY STAR certified triple panes) is a time-tested retrofit that will provide energy savings as well as improve occupant comfort and increase property values, window replacements are rarely completed in the multi-family sector due to the high upfront expense and tenant disruption. Window attachments, such as secondary windows and window shading systems, are a less invasive and more affordable retrofit solution that can increase the frequency of window upgrades in multi-family buildings. The following provides a summary of window attachment technologies that have been energy-rated and field tested in residential applications and would be applicable to low- to mid-rise multi-family buildings, where primary window assemblies are typically residential-style windows commonly used in single-family home construction.

Storm Windows and Insulating Panels

Storm windows, sometimes referred to as window inserts or insulating panels, are typically made of a single pane of glass or plastic in a wood or aluminum frame and are installed on the interior or exterior of an existing primary window. This technology improves the thermal performance of the window by reducing air leakage and creating a dead air space to reduce both convective and conductive heat losses through the window. Storm windows can also include a durable low-emissivity (low-e) coating, which reduces the U-factor of the glass and acts as a heat mirror, reflecting heat inwards in the winter and outwards in the summer, as seen in Figure 2.

Over the past 10 years, DOE has sponsored multiple field demonstrations for both interior and exterior storm windows over single- and double-pane windows in single-family and multi-family homes in both cold (e.g., Minnesota, Pennsylvania) and mixed (Georgia) climate zones, where year-round air-sealing and thermal performance improvements have been realized in all cases (see Table 1). In a comprehensive modeling study that examined the energy savings and cost effectiveness of installing low-e storm windows over existing single- and double-pane clear glass windows in prototypical residential homes across 22 different cities in all eight International Energy Conservation Code (IECC) climate zones, the energy savings provided by low-e storm window attachments provided a savings-to-investment ratio greater than 1 for all prototype homes and window types in IECC climate zones 3-8 (Culp and Cort 2015).

Modern storm windows can be installed as a permanent year-round measure while allowing for full window operability, making them a good fit for multi-family buildings where window egress is required. The benefits of storm windows have been validated in both low- and mid-rise multi-family applications (see Table 1) and have included both energy and non-energy benefits including improved occupant comfort and aesthetics, reduced condensation on the interior window surface, and improved sound insulation (less outdoor noise) – all benefits that are highly valued by multi-family occupants and building owners.

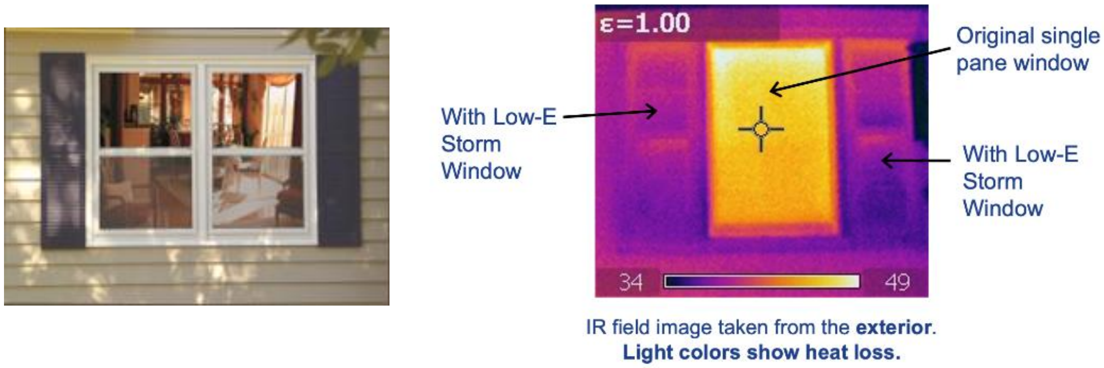

Figure 2. Exterior low-e storm window installation (left), and infrared image of a 3 single-pane windows with low-e storm window attached to outer windows. *Source:* Larson, QuantaPanel.

Interior Shading

In 2013, DOE sponsored a comprehensive energy modeling study led by LBNL that focused on a range of window attachments, including products such as shades, blinds, storm window panels, and surface-applied films simulated in four types of "typical" houses located in 12 characteristic climate zones. The simulations captured the optical and thermal complexities of these products (Curcija et al. 2013) and also considered typical operation and usage patterns based on a separate study that focused on user behavior with respect to operable window attachments (Bickel et al. 2013). The study found that interior insulating shades can yield significant year-round energy savings when installed over windows; however, the degree of savings depends on the thermal properties of the material, baseline window conditions, seasonal and climate factors, and how the attachment is operated. Insulating cellular shades are made of multiple layers of fabric that create cellular pockets. They can be made with single or multiple layers of cells, and work to insulate the primary window and increase the R-value of the window assembly by creating a layer of trapped air between the cells to reduce heat transfer.

To further evaluate the performance of cellular shades in multiple seasons, climate zones, and with varied baseline conditions and operation scenarios, DOE and the Bonneville Power Administration sponsored a series of field validation studies performed by ORNL and PNNL researchers (Kunwar et al. 2022; Cort et. al. 2018; Petersen et. al. 2016), as shown in Table 1. Although shade settings and operation (i.e. user behavior) affect the overall level of savings for all shading technologies, the ORNL and PNNL research teams found that cellular shades out-performed the most common window coverings in the market (vinyl blinds) during both the heating and cooling seasons under all operation scenarios examined. Furthermore, cellular shades yielded HVAC savings ranging from 5-15% when operated in a "typical use" manner, based on user behavioral studies (Bickel et al. 2013), suggesting that persistent year-round HVAC savings and occupant comfort benefits could be realized by upgrading interior window coverings with higher-performing insulating products, such as cellular shades. Automated shading systems will offer even larger savings and persistence as demonstrated in the PNNL Lab Homes with an optimized operation schedule (Petersen et al. 2016).

Exterior Shading

Exterior shades are window attachments that are applied to the exterior of the existing window and include fixed solar screens, roller shades (shown in Figure 1), and awnings. Exterior shades block solar heat before it reaches the building envelope, which effectively reduces heat gain transfers through the window during the cooling season. Exterior shades also help to reduce glare and improve comfort in the home while maintaining views to the outdoors. Field studies conducted in PNNL's Lab Homes and in single-family field sites in Richland, Washington, have demonstrated whole home cooling HVAC savings up to 20% when applied to south- and west-facing windows depending on operation schedule. In a side-by-side home comparison, the application of exterior shades on just 3 west- and south-facing windows achieved 10% whole home cooling HVAC savings when compared to an identical home with interior vinyl blinds covering the same windows (Hunt and Cort 2020). Exterior shades regularly include a manual crank, motor, or rod that allows the resident to operate them from indoors, but many newer models utilize a remote-controlled motor to raise and lower the shade. Although exterior shading is not commonly employed in U.S. multi-family buildings, these shading window attachments are more common in Europe and Asia where field studies have demonstrated significant cooling savings and comfort benefits for both single-family and apartment-dwellers, particularly in apartments with south- and west-facing window orientations (Alwetaishi et al. 2021; Ho et. al 2023).

Table 1. Summary of Selected Window Attachment Retrofit Field Study Findings

Technology	Study	Baseline Description	Findings
Secondary Window Panels (e.g., storm windows, interior window panels)			
Exterior Low-e Storm Windows	10 older single-family homes in Atlanta, Georgia (EERE 2015)	Single-pane windows	• 17% (3.7 cfm50) reduction in home air leakage • Heating savings average: 17% • Cooling savings range: 2-30%
Exterior Low-e Storm Windows	Multi-family (100 units) storm window retrofit in Philadelphia, PA, measured field study (EERE 2015)	Single-pane, wood-frame windows with old clear-glass storm windows	Low-e storm windows showed: • 18% reduction in overall home heating load • 10% reduction in overall home air infiltration
Interior Low-e Secondary Window Attachments	Air-sealing multi-family 80-unit apartment building in Bronx, New York (Steven Winters, 2013)	Single-pane metal frame windows with panels for air-conditioning units	Application of interior low-e panels windows nearly eliminated window air leakage and a 30% reduction of whole building air infiltration was estimated based on window improvements.
Interior Non-Glass Secondary Window Attachments	Historic commercial building application, field testing in Seattle, Washington (PNNL 2022)	Single pane wood-framed historic facade	• Frame-attached interior panels nearly eliminated (i.e., >90% reduction) air leakage and reduced outdoor noise by 17dB on tested window • >50% improvement U-value of window with all attachments
Interior Shades			

Insulating Cellular Shades (double- and triple-cell)	PNNL Matched Lab Homes comparisons; multiple operation scenarios (Cort et al. 2018; Petersen et al. 2016)	Clear glass windows with and without vinyl blinds (all windows and orientations)	Multiple scenarios comparing home with cellular shades with baseline home with unshaded windows or windows covered in identical manner with vinyl blinds (varied shade settings) • Cooling HVAC = 10-25% savings • Heating HVAC – 5-18% savings
Insulating Cellular Shades	Side-by-side Room Comparisons in ORNL 2-Story Test Home (Kunwar et al. 2022)	Double-pane low-e windows with southeast orientation.	24% heating savings achieved with application of cellular shades
Exterior Shades			
Exterior Shades	PNNL Lab Homes side-by-side testing and single-family field sites (Hunt and Cort 2020)	Multiple double-pane windows with and without interior blinds	• 10% cooling savings when compared to interior vinyl blinds • 20% cooling savings when compared to home with no shading on same windows
IGU = insulated glazing unit; LBNL = Lawrence Berkeley National Laboratory; ORNL = Oak Ridge National Laboratory; PNNL = Pacific Northwest National Laboratory			

Previous Field Testing and Case Studies

Table 1 summarizes some of the key findings from selected field studies examining window attachments that could provide minimally disruptive, scalable and cost-effective retrofit solutions to minimize air leakage and improve the insulation and solar heat gain characteristics of multi-family windows. Secondary storm window attachments, in particular, have been proven to provide cost-effective air-sealing and insulating measure to improve multi-family window performance as demonstrated in multi-family buildings in Brooklyn and Philadelphia (see Table 1). Because infiltration is a major contributor to multi-family heating loads (Huang et al 1999), the air-sealing capabilities of modern storm windows (as revealed with blower-door testing), make this technology a particularly attractive retrofit option for multi-family applications. In addition, when sound infiltration testing has been performed, modern storm windows have demonstrated substantial sound infiltration benefits, reducing outside noise up to 17dB through the window (see Seattle historic building field site, Table 1), which can be a particularly valued benefit in urban settings when multi-family buildings are located on noisy streets.

Multi-Family Low-e Storm Window Field Study

In 2013, DOE and Home Innovation Research Labs examined the effects of replacing old existing storm windows with modern, low-e storms in two large, three-story multi-family apartment buildings in Philadelphia, Pennsylvania, as seen in Figure 5. Constructed in 1962, the apartment buildings had 101 units and 4,720 ft^2 of single-pane, clear glass storm windows installed over the existing single-pane, metal-framed windows. The old storm windows were replaced with low-e storm windows[1], improving the overall performance of the window

[1] Original single-pane windows without clear glass storm windows were estimated to have a SHGC of 0.61 and a U-factor of 1.12, and an SHGC of 0.56 and U-factor of 0.58 with clear glass storm windows. The upgraded assembly after installation of low-e storm windows provided a new U-factor of 0.44 and a SHGC of 0.48.

assemblies by lowering the estimated U-factor by 61% compared to the bare primary window and 24% compared to the single-pane window with the clear-glass storm window.

Figure 3. Philadelphia multi-family apartment building with installed low-e storm windows. *Source*: EERE 2013.

Improvements in energy performance were analyzed using a combination of blower door tests and utility bill analysis. A sample of 15% of units from any of the three floors and bedroom layouts were selected to undergo blower door tests, and air leakage was tested at 50Pa with the existing storm windows in both open and closed positions; this test was then repeated after the old storm windows were replaced with new, low-e versions. While the old storm windows did not show significant improvement in air infiltration when open or closed, the application of modern low-e storm windows achieved a 10% reduction in air leakage of the overall apartment unit and an average reduction of 3.2 CFM50 per ft^2 of glazing, demonstrating the potential for low-e storm windows to significantly improve energy efficiency through improved air tightness as well as reduced U-factor.

Whole building gas utility usage was examined to determine energy consumption and savings during the heating season, and individual unit electric utility usage was used to determine energy savings during the cooling season. As a result of replacing old storm windows with the new low-e storm windows, whole-building gas usage was found to be reduced by 18% during the heating season, and electricity usage due to cooling was reduced by approximately 9% when normalized to the cooling degree days for the testing period (EERE 2013).

Shading Benefits to Multi-Family Occupants

Although DOE has not directly carried out comprehensive shading field studies in multi-family buildings, performance validation studies focused on other residential buildings (see Table 1), modeling analyses (Metzger et al. 2017), and field demonstrations in Europe and Asia (Alwetaishi et al. 2021; Ho et. al 2023) suggest that the application of high-efficiency shading systems would provide multi-family occupants with substantial comfort benefits (thermal comfort and reduced glare), cooling HVAC savings, and improve the comfort and passive resilience of the building during extreme heat events and/or when the building is not equipped with air-conditioning. For example, PNNL conducted a series of field studies examining exterior shade impacts at both the PNNL Lab Homes and three occupied field sites in Richland, WA. In the Lab Homes study, exterior shades were installed in the experimental home on three larger west- and south-facing windows, while the baseline home’s windows were covered with interior vinyl blinds. Compared to the baseline home, the home with exterior shades demonstrated daily HVAC energy savings ranging from 2.4 to 5.2kWh over the 10-day test period, which translated to an average daily cooling savings of 20% during the period in July where mid-day high temperatures exceeded 90°F. The application of exterior shades reduced the overall cooling load of the home and also facilitated a more comfortable indoor environment, where indoor temperatures in the rooms with exterior shades covering the windows were around 3°F (1.67C) cooler than the same rooms in the comparison baseline home. In a no-cooling (i.e., home without air-conditioning) test case, the home with exterior shades was 9°F (5C) cooler than the home covering the same windows with interior vinyl blinds on a sunny day where outdoor mid-day temperatures were around 75°F (23.89C), suggesting that exterior shades could be an effective upgrade measure to control solar gains and improve occupant comfort for homes without mechanical cooling in mild climates, including multi-family dwellings where it is estimated that approximately 20% of U.S. multi-family apartment units are not equipped with central air-conditioning (EIA 2020).

New Window Attachments Pilots, Case Studies, & Programs

Building off of previous field validation studies, a number of utility and energy-efficiency organizations have initiated window attachment pilots and analyses to help inform utility programs and measure adoption processes. Several of these new studies and programs include a focus on weatherization and retrofit measures for multi-family housing.

Minneapolis Storm Window Replacement Pilot

Despite the promising field-testing results of low-e storm windows and their demonstrated effectiveness in multi-family applications, particularly in cold northern climate zones, the research team found that relatively few utility and weatherization programs have adopted this measure into their residential programs. The authors of this paper identified two significant market and policy barriers to broader storm window adoption in energy-efficiency and weatherization programs:

1. The application of new storm windows rarely receive credit for their air-leakage reduction capabilities when considered and evaluated in utility and weatherization programs.
2. If a poorly performing window has a storm window already applied to it, then it is often excluded from any further upgrades, even when the existing storm window is not functioning (e.g., in disrepair, low quality and/or improper installation, at the end of its useful life).

To address these policy barriers, the Center for Energy and Environment (CEE) partnered with Xcel Energy and Pacific Northwest National Laboratory (PNNL) to evaluate the replacement of old, leaky storm windows with new exterior storm windows as an energy savings measure in Minneapolis, MN. The homes were selected through Xcel Energy and CenterPoint Energy’s Home Energy Squad (single-family sites) and multi-family work (including Minneapolis’ 4D program) as part of a pilot program for DOE’s Storm Window and Insulating Panel (SWIP) Campaign which is managed by PNNL. Due to Xcel Energy and PNNL’s interest in assessing storm windows as a measure to address the share of building stock with old and leaky windows, new low-e exterior storm windows, designed to block heat and ultraviolet radiation (UV rays), were installed. During the pilot, exterior storm windows were to be removed and replaced with new low-e storm windows. The pre-installation and post-installation measurements were collected for a thorough analysis of energy savings and cost-effectiveness by Xcel Energy, with the results to be included in a future report.

Pilot sites ranged in size from 1900 to 4300 sq. ft. and 25-55 windows per site. For the single-family interior storm window site, the old exterior storm windows were left in place (monolithic primary windows with both interior and exterior storm windows). For single-family and multi-family exterior storm window sites, the old storm windows were removed and replaced with new low-e storm windows.

In cold climates like Minnesota, storm windows are commonly installed outside of single- or double-pane primary windows. While they offer insulation benefits, their effectiveness diminishes over time due to quality of installation and the breakdown of seals and gaskets. For many old storm windows, the energy lost from air leakage is a significant portion of the energy lost through the window. The installation of new exterior storm windows improves window performance by adding air tightness using gaskets around the perimeter of the product.

To measure the change in performance of the house’s windows, a blower door test was performed before and after installation of the new storm windows. In this test, the front doorway is filled with a membrane and a large fan. Air is blown out of the house to achieve a pressure of 50 pascals (Pa) and then the cubic feet per minute is measured to assess the air-leakage (CFM50).

Before installation, pilot houses were relatively leaky with higher CFM50 air leakage, ranging from 3,400-8,100 (for building square footage ranging from 1900-4300). Air leakage was tested at 50 Pa with the primary and storm windows in the closed position. Installation of the storm windows achieved whole-building air leakage reductions ranging from 10-19% and reductions of 1.2-2.8 CFM50 per ft^2 of glazing. For comparison, a house that has professionally retrofitted wall or attic insulation can expect a typical leakage reduction of around 15%. This shows that using storm windows to address existing windows can provide as significant an improvement in overall building airtightness as other more common housing upgrades. Results for all buildings taking part in this pilot can be found in Table 2.

Table 2. Minneapolis storm window pilot results

Home Type	Single-Family #1	Single-Family #2	Multi-Family #1 (4-plex)	Multi-Family #2 (duplex)
Storm Type	Interior	Exterior mfr A	Exterior mfr B	Exterior mfr B
Home Sq. Ft.	3,800	3,200	4,300	1,900
Window Count	25	31	55	29
Glazed sq. ft.	341	268	602	259
Pre CFM50	5,162	3,356	7,857	4,405
CFM50 Difference	962	330	1484	713
ACH50 Difference	1.9	0.8	2.6	2.8
% Reduction	**19%**	**10%**	**19%**	**16%**
CFM50/Window	38	11	27	25

CFM50/sq. ft. Glazed Area	2.8	1.2	2.5	2.8
CFM50/linear ft. Glazed Perimeter	2.4	0.9	1.9	2.0

After installation, homeowners & installers were surveyed on the install experience. Homeowners & installers mentioned a measurement and installation time of 10-30 minutes per window. Additionally, residents noted equivalent or better aesthetics when viewed from either inside or outside, improved clarity through the windows, improved thermal comfort when near the windows, reduced condensation on the room-side surface of the windows, and significantly reduced external noise coming through the windows. At some sites, and with no major renovation required, the homeowners were able to keep the historic, stained-glass features to preserve the home's style while still maximizing comfort and efficiency.

The pilot study demonstrates that replacing old, leaky storm windows with new low-e exterior storm windows yields notable air leakage improvements, and is an important window measure for homeowners and utilities to consider. Modern storm windows with low-e coatings provide both improved insulating power and better air sealing compared to old, leaky storm windows. These pilot study results also support prior modeling in Culp and Cort 2015 and for the ENERGY STAR™ Program for Storm Windows that showed the importance of considering the air-sealing benefits of storm windows. Air leakage reductions accounted for 23-36% of total modeled home energy cost savings associated with the use of storm windows in colder climates. Therefore, it is important for utility incentive and weatherization programs to consider air tightness benefits in addition to the improved insulating properties of low-e storm windows. Xcel Energy will review the outcomes of the pilot closely to determine the viability of proposing an updated measure for storm windows.

Storm Window Energy Modeling

Partnering with Lawrence Berkeley National Lab (LBNL) and Center for Energy and Environment, PNNL conducted a brief modeling study in 2024 to complement the findings of the Xcel Energy storm window replacement pilot in Minneapolis, Minnesota. Typical model homes were assessed for several major MN cities in climate zones 6A and 7, including Minneapolis and Duluth. The energy performance of low-e storm windows was modeled over a baseline in which the existing windows were already equipped with clear glass storm windows. Energy savings were assessed at several levels of air leakage improvement (ranging from 5-25%). Modeling assumptions include 2 conditioned floors, 2000 conditioned sq. ft., 300 sq. ft. of glazed window area (15% window-to-wall ratio), and several different HVAC fuel types. A typical 15% air leakage improvement resulted in an ~11.5% heating and ~15.5% cooling savings, depending on the fuel type (peak heating and cooling both reduced by 12-14%). An excerpt from this modeling is outlined in Table 3.

Table 3. Modeled energy savings of low-e storm windows in climate zone 6A and 7 buildings, for a typical 15% air leakage improvement scenario.

City (Climate Zone)	Minneapolis, MN (6A)	Duluth, MN (7)

HVAC Type	eFAF (elec. resistance)	Gas + A/C	Heat Pump	eFAF (elec. resistance)	Gas + A/C	Heat Pump
Heating Savings	11%	13%	11%	12%	15%	11%
Cooling Savings	N/A	12%	14%	N/A	12%	18%
Total Site Elec. Savings	9%	4%	9%	9%	4%	9%
Total Site Gas Savings	N/A	10%	N/A	N/A	11%	N/A
Peak HVAC Elec. Savings	12%	14%	13%	12%	13%	12%
Peak HVAC Gas Savings	N/A	12%	N/A	N/A	12%	N/A

Window Attachments in Utility Programs

Technical Reference Manuals (TRM) serve as key resources for utilities in identifying and assessing new energy-efficiency measures to include in their programs. Additionally, TRMs offer a standardized approach to calculating energy savings. Starting in 2019, AERC began submitting workpapers for residential low-e storm windows in TRMs – hoping to raise awareness of window attachment measures and open the door to broader inclusion in utility programs. Although several TRMs include window attachments measures for single-family buildings, only a subset of those measures also apply to multi-family buildings. However, there are ongoing efforts to expand eligibility of window attachments to multi-family buildings in these TRMs. Inclusion in a TRM does not guarantee that a utility will offer the measure, so some additional outreach and awareness building among program administrators may be necessary. A full list of TRMs that include window attachments is shown in Table 4.

Table 4. Technical Reference Manuals with window attachment measures[2]

Technology	Technical Reference Manuals
Storm Windows	**Arkansas**[3], Connecticut[4], **Illinois**[5], Iowa[6], Maine[6], **Michigan**[6], **Minnesota**[5], Missouri[6], **New Hampshire**[6], **New Orleans**[5], **Texas**[5], **Regional Technical Forum**[7] **(Washington**, **Idaho**, **Oregon**, **Montana)**, **Tennessee Valley Authority**[7] **(Tennessee**, **Alabama**, **Mississippi**, **Kentucky**, **Georgia**, **North Carolina**, **Virginia)**

[2] In this table, for TRMs that are bolded, the corresponding window attachment measure is applicable to both single- and multi-family buildings, and un-bolded TRMs are only applicable to single-family.
[3] ENERGY STAR Low-e Storm Windows specified.
[4] Any interior or exterior storm window.
[5] Low-e storm window specified.

Cellular Shades	**Illinois, Minnesota**
Exterior Shades	**Texas,** New Mexico

Several utility programs offer incentives for installing window attachments. According to the Consortium of Energy Efficiency (CEE[6]) in 2022, a small subset of CEE member utilities provided incentives for window attachments, including 6 offering storm window rebates, 1 window insert rebate, 1 window film rebate, 1 cellular shade rebate, and 2 solar screen rebates. Most of these offerings only apply to single-family homes, presenting an opportunity for expansion to multi-family buildings. Historically, the multi-family segment has been underserved by utility energy-efficiency programs (Samarripas and York 2019). This is primarily attributed to split incentives, where tenants are responsible for paying their energy bills and directly benefit from the cost-savings of energy-efficiency improvements, but building owners who don't benefit from the improvements are responsible for paying for and approving the upgrades. This leaves renters with little power to apply energy-efficiency upgrades and thus no agency over decreasing their utility bills and increasing the comfort and resilience of their homes.

Window attachments should be considered for multi-family sector utility programs, even though the current adoption of window attachments in multi-family building programs is sparse. Window attachments require less upfront capital investment from the building owner or manager compared to window replacements, but still offer similar energy efficiency and comfort improvements. Additionally, the installation of window attachments is much less disruptive to tenants than window replacement. For instance, storm windows can be installed on the exterior of the building and may only require a one-time entry into a tenant's space to take measurements. For multi-family buildings with multiple stories where exterior windows aren't easily accessible, interior storm windows could be used instead. Interior window inserts can also be used in this application and both measurement and installation are easy enough that they can be done by the tenant. A building owner may be attracted to these lower-cost, less-invasive options if they are receiving many tenant comfort complaints, or even tenant turnover due to comfort issues.

Building Performance Standards and Historic Building Applications

In addition to efficiency and utility programs, a new driver pushing upgrades in existing buildings are building performance standards (BPS). Building performance standards are established in city or state law to set maximum energy use or carbon emission limits on existing buildings. Building owners must pay financial penalties for exceeding those limits or not complying with reporting requirements, although the intent is not to punish building owners, but to encourage owners to invest in making energy efficient improvements to existing buildings rather than paying a fine to the city. The most famous example of a building performance standard is Local Law 97 in New York City, but these standards are expanding rapidly across the country in places like Boston, St. Louis, Washington D.C., Colorado, and Washington State. Figure 10 shows the locations that have either enacted a building performance standard or

[6] CEE is a consortium of utility efficiency program administrators and other stakeholders from across the United States and Canada with membership representing 38 U.S. states and 4 Canadian provinces.

have committed to develop one as part of the National Buildings Performance Standards Coalition.

Most building performance standards are initially focused on commercial buildings, but many also apply to larger multi-family buildings over 50,000 ft^2. The building owner can only get so far with HVAC and lighting upgrades, so it is important to also address the building envelope. BPS limits are set conservatively to target the worst performing buildings in a jurisdiction, which usually means older buildings with inefficient windows, including single pane windows. This presents a prime opportunity for window attachments such as low-e storm windows, secondary glazing, and automated insulating shades.

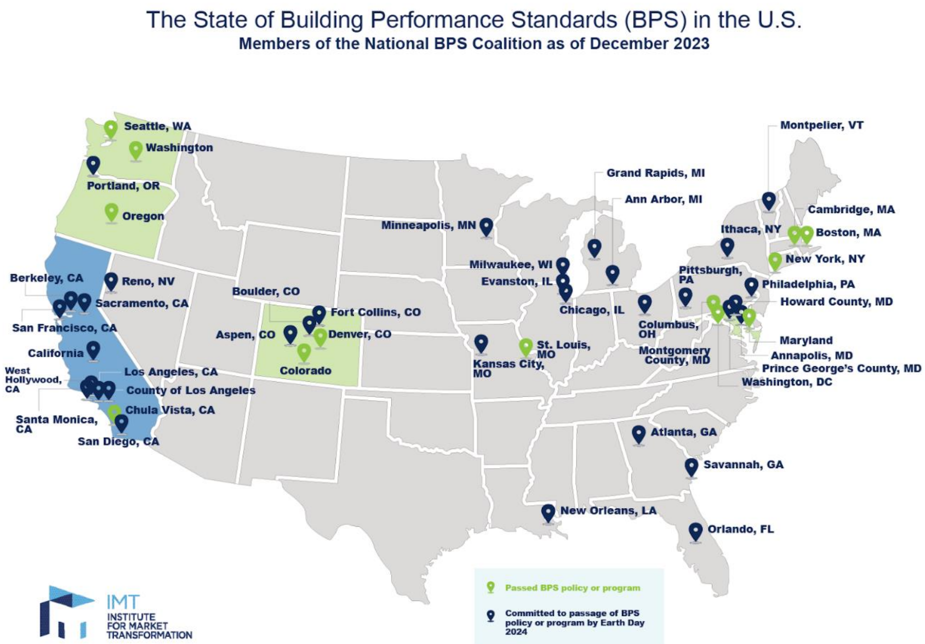

Figure 4: Passed or planned building performance standards in the U.S. as of Dec 2023. *Source*: https://www.imt.org/public-policy/building-performance-standards/

Older buildings may also fall under historic preservation requirements which often restrict window replacement. Low-e storm windows and insulating panels are ideal for upgrading existing windows while maintaining the historic attributes of the existing windows. These products can also be made with custom color framing to match the existing facade. Examples with both exterior and interior low-e storm windows are shown in Figure 11.

(a) (b) (c)

Figure 5. Examples of low-e storm windows on historic multi-family upgrades. (a) 1892 Umbrella Works, Lancaster PA - adaptive reuse to apartments, interior low-e panels. (b) Wissahickon Avenue Apartments, Chestnut Hill, PA - exterior low-e storm windows. (c) 1929 French Apartments, New York City, NY - interior operable low-e panels. Photos courtesy of QuantaPanel.

Conclusion

As existing inefficient residential buildings continue to age, improving the building envelope can improve comfort, enable more efficient decarbonization, and reduce utility bills for tenants or building owners. In particular, multi-family housing presents a unique opportunity for advancing decarbonization while focusing on energy equity in the building sector. The window attachments research and field validation studies described in this paper highlight the relative affordability, energy savings potential, and comfort improvements achievable with window attachments upgrades for residential buildings. While these studies have demonstrated that these benefits can be realized in the multi-family sector, more research is needed to explore their potential in larger multi-family buildings, particularly for shading technologies. Large multi-family buildings also provide a unique opportunity to increase affordability through bulk purchasing and reduced shipping costs. As Building Performance Standards and other regulations and initiatives are adopted to drive existing building energy-efficiency improvements, multi-family building owners will need more affordable and scalable options to improve the thermal performance of the building envelope. The thermal comfort benefits to the occupant combined with the energy savings provided by window attachment retrofits make these technologies an important piece of the decarbonization equation. Utility and tax credit incentives that specify energy-rated window attachments (e.g., AERC ratings and ENERGY STAR specifications) could make these cost-effective solutions even more affordable.

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