

Methods to Analyze the Energy Performance of Window Attachments

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ABSTRACT

Window attachments, such as blinds, shades, shutters, awnings, and storm windows, represent an enormous existing market. With roughly 2/3 of U.S. homes having inefficient windows, the savings opportunity is significant, especially with studies showing energy savings of up to 30% after installing more efficient attachment technologies. A window attachment energy rating program launched in 2018 through the Attachments Energy Rating Council (AERC) is changing the way people think about residential and commercial window attachments by providing reliable, easy-to-understand energy performance information to consumers.

Through AERC, window attachment products are rated based on their Annual Energy Performance (AEP). The AEP metric is an easy-to-understand comparative metric, which creates a new energy savings measure for utilities and efficiency programs to incentivize energy efficient window attachment products. To accelerate utility adoption of these technologies as an energy savings measure, AERC has submitted window attachments for consideration into state Technical Reference Manuals (TRMs).

This paper will present an overview of the energy savings potential of window attachments, and summarize simulation, field, and evaluation studies assessing the real-world energy performance of window attachment technologies. Additionally, it will outline AERC's methodology for developing TRM work papers for low-e storm windows that were accepted in states across the country, including key differences in the baseline assumptions, and lessons learned that can be applied to measure development methodologies for other window attachment products.

Introduction

Residential buildings in the United States currently require 8 quadrillion Btu/yr of energy for heating and cooling – that accounts for more than 40% of primary residential energy use (EIA 2015). Net thermal transfer through residential windows accounts for approximately 10% of a building's energy use (Hart et al. 2019). Over the past 20 years, window attachment retrofit technologies have been developed that significantly increase the options available to home builders, homeowners, and utilities when considering upgrades to overall window performance. The paper details AERC's methodology for calculating key energy performance metrics which can include annual energy savings, peak demand and lifecycle savings, incremental measure cost, and sources for baseline assumptions. The paper also presents a new approach for

developing deemed savings values for other window attachment products including manual and automated cellular and roller shades.

Window attachments are interior and exterior products that are installed over windows, doors, or skylights in both residential and commercial buildings. Interior products often are referred to as window treatments, window attachments, or window fashions, and include blinds, shades, drapes, shutters, and films. Exterior products include roller shades, roller shutters, window quilts, and awnings. Attachments also include both interior and exterior storm windows. Window attachment products, particularly interior attachments, have traditionally been thought of as decorative features; however, these products offer a variety of benefits to homeowners, including energy savings.

Standards and ratings can help inform consumers and drive the market for energy-efficient products. To address the lack of energy-related ratings or standards for window attachments, Department of Energy (DOE) helped launch the Attachment Energy Rating Council (AERC) in 2014. AERC is an independent, non-profit, rating council that has developed a comprehensive energy-rating, labeling, and certification program for window attachments, which provides accurate and credible information about the energy performance of rated products to the public. A summary of commercially available window attachments is provided on the AERC website¹, and photos of window attachments that have recently been tested in the field by PNNL, ORNL, and LBNL are provided in Figure 1. As of 2020, AERC has energy ratings available for both interior and exterior storm windows (aka insulated window panels or secondary glazing), blinds, cellular shades, roller shades, pleated shades, and solar screens, with plans to develop energy ratings for other window attachment categories in the future.



Figure 1. High Performance Window Attachments include (from left to right) exterior low-e storm windows, insulated cellular shades, exterior shades, and awnings. *Sources: PNNL, AERC*

Previous Field Testing, Modeling, and Case Studies

Window attachment technologies can improve the thermal and optical properties of the window via coatings (e.g., storm windows with low-emissivity coatings) or coverings (e.g., blinds or shades) that decrease solar heat gain, increase the reflectance of the window in thermal infrared (IR) wavelengths, and decrease the amount of thermal conduction or convection between indoor spaces and the outdoors. With automation or scheduled manual operation, operable shades and blinds can add a dynamic performance element to conventional windows, allowing solar gains

¹ More information on the range of window attachments available and slated for energy ratings can be found at the AERC website: <https://aercenergyrating.org/>.

when beneficial during the winter and reducing solar gains in the summer. For more details see DOE (2022) and visit <https://windows.lbl.gov/windows-videos> for educational videos.

A number of research efforts, field studies, and experiments have demonstrated the energy-saving capabilities of various window attachments. Window attachments can save energy across product types, window types, and climate zones. Table 1 shows the range of energy savings from field demonstrations and modeled estimates of energy savings for various attachment types over single-pane and double-pane clear windows in a variety of climate zones. The savings potential is based on a range of field, lab, and modeling studies, and is focused on heating, ventilation, and air-conditioning (HVAC) savings. More detail on these studies is provided in Table 2 and discussed below.

Table 1. Savings Potential and Application of Windows Technologies Reviewed

Technology	Application	Energy Savings Range
Low-e Storm Windows	Over single-pane or double-pane clear glass windows in all climate zones.	10-33% (annual HVAC savings)
Insulated Cellular Shades	Applicable with all types of new or existing windows in all climate zones.	3-34% (annual HVAC savings)
Exterior Shades	Best applications include unshaded south- and west-facing windows in cooling season (all climate zones).	12-25% (Cooling HVAC savings)

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 many of the window attachments examined can yield significant energy savings when installed over windows; however, the degree of savings depends on the attachment type, baseline window conditions, seasonal and climate factors, and when applicable, how the attachment is operated. Nevertheless, the study concluded that in heating-dominated climates, particularly in the north-central climate zones, low-e storm windows and insulated cellular shades are two of the most effective window attachments at reducing HVAC usage.

PNNL conducted whole-home experiments for some of the more high-efficiency products identified in LBNL’s initial 2013 study, including low-e storm panels, cellular shades, and exterior shades. The PNNL Lab Homes are two side-by-side test homes located on the PNNL campus in Richland, Washington (Petersen et al 2016; Petersen et al 2015; Knox and Widder 2014; Cort; Hunt and Cort 2020) These experiments measured the energy savings of window attachment products within different operational schedules in an experimental home compared to a baseline home equipped with standard double-pane, clear-glass windows with aluminum frames and sliding clear-glass patio doors. The results of the experiments are provided in Table 2.

In addition to research focused on window attachments, a number of research institutions, energy-efficiency programs, and utilities have completed characterization and meta-analyses (Ariosto et al. 2013) and energy simulation analyses (CEE 2014; Garber-Slaght and Craven 2011; Zirnheld et al. 2015) that validate energy savings from cellular shades and other window attachments (Table 2).

Table 2. Summary of selected case studies focused on high-R windows and window attachments

Study	Description and Findings
Field Studies	
<i>Chicago Low-e Storm Window Single-Family Field Study</i> (Drumheller et al. 2007) DOE, HUD, NAHB Research Center, LBNL	A retrofit field study compared single-pane wood-framed windows with and without low-e exterior storm windows in six low-income homes. • 21% reduction in overall home heating load • 7% reduction in overall home air infiltration • Simple payback of 4 to 5 years
<i>Philadelphia Low-e Storm Window Multifamily Case Study</i> (EERE 2013) DOE, Quanta, Larson, NAHB, AGC Flat Glass, NSG-Pilkington	A retrofit field study compared old clear-glass storm windows with low-e storm windows over single-pane, metal-framed windows in two large multifamily buildings. • 18%–22% reduction in heating energy use • 9% reduction in cooling energy use • 10% reduction in overall apartment air leakage
<i>Atlanta Low-E Storm Case Study</i> (2-year study) (EERE 2013) DOE, Quanta, Larson	A retrofit field study compared single-pane wood-framed windows with and without low-e storm windows in ten occupied homes. • ~15% heating energy reduction • ~2% to 30% cooling reduction (highly variable) • 17% reduction in overall home air infiltration
<i>Exterior Roller Shades, 1% Openness Factor</i> (Hunt and Cort 2020) DOE and multiple manufacturers	Exterior shades over west- and south-facing double-pane low-e windows (2 new homes and 1 existing home) 1.0°F to 4.0°F temperature reduction when rooms were shaded
Modeling & Analysis	
<i>Pennsylvania weatherization technical support: Low-e Storm Windows</i> (Zalis et al. 2010) DOE, Birch Point Consulting	An energy simulation modeling study compared 37 homes with range of window types in 7 climate zones. 12%–33% overall HVAC savings
<i>LBNL Modeled Energy Savings from Window Attachments</i> (Curcija et al. 2013), DOE	An energy simulation modeling study examining five cellular shade product types over single-pane and double-pane windows in 12 climate zones. • Savings vary by product types, climate zones, and baseline, but annual energy dollar savings ranged from \$280 to \$470 for cellular shades

Study	Description and Findings
<i>Window Retrofit Solutions</i> (Ariosto and Memari 2013) PHRC	An energy simulation modeling study that examined multiple window attachments, including cellular shades • Reduction in U-factor of 38% for cellular shades
<i>Modeling Cellular Shades in multiple climate zones</i> (Metzger et al. 2017) Silicon Valley Power, APPA	An energy simulation modeling study estimated savings from cellular shades covering multiple window types in 13 climate zones. • 10-34% HVAC savings for small existing homes with large window area • 3-29% HVAC savings for larger homes with large window area • Savings similar for double- and triple-cell cellular shades
Lab Home Experiments	
<i>Exterior Low-e Storm Windows</i> (Knox and Widder 2014) PNNL, DOE and Larson	Measured HVAC savings when attached over clear glass, metal-framed, double-pane windows. 10.1% ±1.4, annual HVAC savings
<i>Interior Low-e Insulating Panels</i> (Peterson et al. 2015) PNNL, DOE, Quanta, and NEEA	Measured HVAC savings when attached over 74% of window area (clear glass double-pane windows). • 7.8% ±1.5, annual HVAC savings
<i>Cellular Shades (Double/Triple Cell)</i> (Cort et al. 2018)/ (Peterson et al. 2016) PNNL, DOE, Hunter Douglas, and NEEA	Cellular shades over clear glass double-pane windows compared to uncovered windows and/or windows similarly covered with vinyl venetian style blinds (varied shade settings/operations): • Cooling HVAC = 10-25% savings • Heating HVAC = 7-18% savings
<i>ORNL Cellular Shades Exterior Roller Shades, 1% Openness Factor</i> (Hunt and Cort 2020) PNNL, DOE and Springs Fashion	Exterior shades over west- and south-facing clear glass double-pane windows compared to uncovered windows and windows covered with venetian style horizontal slatted blinds. 10% cooling HVAC reduction when compared to home with vinyl blinds 20% cooling HVAC reduction when compared to home with no coverings
BPA = Bonneville Power Administration; LBNL = Lawrence Berkeley National Laboratory; CEC = California Energy Commission; IR = infrared; HUD = U.S. Department of Housing and Urban Development; Larson = Larson Manufacturing Company; NAHB = National Association of Home Builders; NEEA = Northwest Energy Efficiency Alliance; ORNL = Oak Ridge National Laboratory; Quanta = Quanta Technologies, Inc.; Larson = Larson Manufacturing Company; RMI = Rocky Mountain Institute; APPA = American Public Power Association; PHRC = Pennsylvania Housing Research Center	

Low-e Storm Windows

As shown in Table 2, both the exterior and interior configurations of low-e storm windows have significant energy saving potential as a retrofit application in climate zones across the U.S., providing both thermal and air-leakage benefits. Unlike traditional versions of seasonal

storm windows, which consisted of a single piece of clear glass (or plastic) fixed in place in a wood or aluminum frame, modern versions of storm windows are commonly intended for permanent year-round use with improved seals and operable configurations (e.g., slider, single-hung, etc.) Modern storm windows can also include low-e storm glass, which lowers the emissivity of the glass for certain wavelengths, effectively reducing heat transmission through the storm window, reflecting the radiative heat back to the inside during the winter, while the reverse transfer of heat occurs during the summer (Culp et al. 2015). 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 across all eight International Energy Conservation Code (IECC) climate zones, the incremental cost for using low-e glass versus clear glass (roughly a 10% price premium) was found to be cost effective in all climate zones over all windows types with an average payback period of 2 to 5 years (Culp and Cort 2014).

Insulating Cellular Shades

Insulating cellular shade performance have also demonstrated significant year-round energy savings in the PNNL and ORNL test homes. PNNL Lab Homes studies demonstrated up to 25% cooling HVAC savings in comparison to a home that does not cover its windows and 13% cooling savings when compared to same home with lower-performance vinyl blinds. Heating savings from the application of cellular shades in the Lab Homes averaged around 9% when compared to a home with vinyl blinds under multiple operating scenarios (Cort et al. 2018). ORNL also found that cellular shades saved up to 15% heating and cooling HVAC compared to home without any shades. When cellular shades have sidetracks, they effectively block air movement between the room and space between the window and cellular shade creating even better insulating system. However, care needs to be taken when there is strong incident solar radiation, since the space between the shade and window can become very hot and potentially damage IGU seal in glazing. In that case, it is recommended to leave cellular shade open or partially open.

Exterior Shades

Exterior shades can come in various forms, including louvered shutters and roller shades. Exterior shades can protect existing windows from weather and provide solar heat gain control in the summer months (i.e., cooling season). When compared to interior vinyl blinds, the most common type of window coverings sold in the U.S., exterior shades demonstrated daily HVAC energy savings from 1.0 to 3.2 kWh, as a function of the outdoor conditions, which equated to approximate 10% cooling savings. When compared to the Lab Home that had no shading on the same west- and south-facing windows, the application of exterior shades yielded an average HVAC savings of 20% (Hunt and Cort 2020).

Demand Response and Peak Savings

All of the window technologies examined in the PNNL Lab Homes produced savings that were commensurate with the peak demand period during the day, particularly during the summer months. Many types of blinds and shades have automated operation and can be set to open and close via predefined schedules for optimized management of solar gains throughout the year. With automated integrated controls, high-efficiency shades could be coupled with thermostat

setbacks to enhance residential comfort and energy savings. For example, the PNNL cellular shade study included a demand response experiment that demonstrated that pulling down the cellular shades in addition to 4°F thermostat increase (set up) during the hottest period of the day not only produced overall HVAC savings (~17%) but also reduced the average maximum peak demand by an additional 700 Watts when compared to a home that did not deploy shades and only setup the thermostat (Cort et al. 2018).

Window Attachment Energy Ratings

Annual Energy Performance Rating

Early in the development of the program, AERC decided to create one overarching energy performance metric consumers could use to make purchasing decisions that would encapsulate the effects of other fenestration performance metrics and how people operate their window attachments in a home. This Energy Performance (EP) metric would address the concern that consumers had very limited knowledge of the existing metrics, while also allowing consumers to compare product performance.

The EP metric, developed by LBNL, is a ratio that represents the annual HVAC energy savings generated by adding a window attachment to a standardized baseline window. The higher the EP, the greater the energy savings and performance of the window attachment. To understand the energy impact of adding a window attachment, LBNL modeled the total energy use of a “typical house” and analyzed the change that occurred when adding a window attachment. Defining a typical home required a number of assumptions regarding the characteristics and existing properties of the house.

Baseline Assumptions

The EP metric is built on a number of assumptions including the house type and size, heating and cooling systems, and geographic location, window area and distribution, and the window attachment product and its operation. The assumptions used to calculate the EP are a joint result of work done by the AERC Technical Committee and LBNL.

Because the building stock varies greatly in each city and climate zone of the United States, AERC first had to make assumptions based on geographic location. The committee accounted for the diverse climates in the country while maintaining simplicity for consumer comprehension, and ultimately decided to divide the country into two climate zones.

The EP ratings for these two climate zones are referred to as EP_H (heating), which characterizes a product’s performance in a heating-dominated (cooler weather) climate, and EP_C (cooling), which characterizes a product’s performance in a cooling-dominated (warmer weather) climate. LBNL conducted analysis of weather, energy consumption, housing stock, and the installed base of windows across the country in order to select a “representative” city for each climate zone. Based on the results, the committee selected Minneapolis, MN as the representative city for the cool climate, and Houston, TX as the representative city for the warm climate.

The Technical Committee developed model home assumptions based on the single-family, residential housing stock of each representative city, taking into account previous versions of the IECC. The committee decided to model the homes based primarily on IECC 1998, which was considered to be more widely representative of the U.S. housing stock. AERC reviewed multiple existing residential building models, including ones employed by PNNL, DOE, the Environmental Protection Agency, the National Fenestration Rating Council, and the American Society of

Heating, Refrigerating and Air-Conditioning Engineers. The Technical Committee opted to move forward with the PNNL model houses, because they had already developed residential house models for the selected representative cities for each climate zone. Each PNNL residential building model combined several building vintages into a single “typical” house for the representative city.

The committee then reviewed and evaluated all of the parameters used in IECC 1998 and the PNNL residential building models. Some parameters such as square footage needed to be representative of the entire U.S. housing stock, while still taking differences in housing stock based on climate zone into account. The key assumptions resulting from the housing stock are summarized in Table 3.

Table 3. Key housing assumptions

Assumption	Minneapolis	Houston
Floor area	2400 ft ² : 34.64ft (W) x 34.64ft (L) x 8.5ft (H)	
House type	2-story: 1 small core zone and 4 big perimeter zones for each floor	
Wall framing system	Wood	
Bedrooms/ bathrooms	3/ 3	
Foundation	Unheated basement	Slab-on-grade without insulation
Insulation R-values	Ceiling: R-49 Wall: R-21 Floor: R-21 Basement: R-11	Ceiling: R-30 Wall: R-13 Floor: R-11 Slab: R-0
Infiltration	ACH50= 7	ACH50= 10
HVAC system and efficiency (1 zone)	Gas furnace (78% AFUE) and A/C (10 SEER)	Electric heat pump (6.8 HSPF and 10 SEER)
Thermostat setting	70° F	75° F
Baseline window type and performance	Double clear wood frame: VT= 0.639, SHGC= 0.601, U-factor= 0.472 Btu/hr.ft ² .F, AL= 2 cfm/ft ² Adiabatic window: VT= 0, SHGC= 0, U-factor= 0, AL= 0	
Window distribution	8 windows per floor, distributed evenly and centered on the external walls. Each big window was split into two sections.	
Calculation engine	EnergyPlus version 8.5 customized to include window attachment models	

Source: Peng and Curcija 2017.

The committee made adjustments to the assumptions, such as air infiltration levels and temperature set-point, to better represent the characteristics of older housing stock. The same baseline window identified in Table 3 is used in both climates to enable consumers to make apples-to-apples comparisons with the EP metric. All AERC certified products must be rated for EP over this baseline window for comparison purposes, and may be rated for other performance properties over additional optional baseline windows. The characteristics of these baseline windows are

described in technical standard AERC 1 Appendix A. In the future, manufacturers will be able to rate products for EP over additional baseline window types.

EP Calculation

The EP metric represents the simulated annual HVAC energy savings generated by a window attachment in relation to a baseline window in a model house. The difference between the home’s energy use with the window attachment installed compared to the energy performance of the home if the window did not have an energy impact is calculated using a set of software tools. The no-energy-impact window condition is called an adiabatic window, where the window does not allow heat to transfer through its surface (I.e., net energy zero window).

The adiabatic window is modeled as an infinitely insulated opaque surface in place of a window. Schematic representation of the adiabatic, baseline and window with attachment are shown in Figure 2. Formulas used to calculate EP ratings, EP_C and EP_H , are shown in Figure 3:

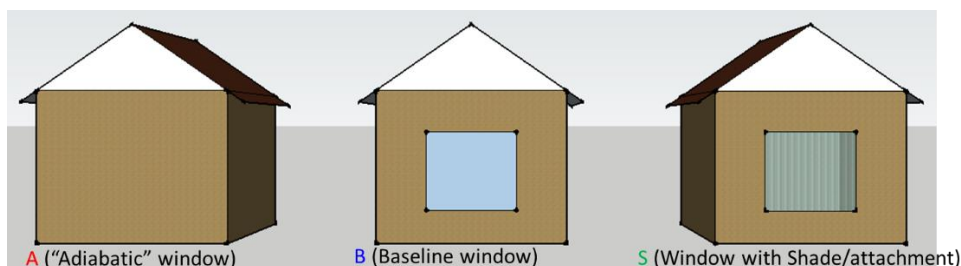


Figure 2. Images of window configurations used to calculate EP.

$$EP_C = \frac{(E_B - E_S)_{Houston}}{(E_B - E_A)_{Houston}} \quad EP_H = \frac{(E_B - E_S)_{Minneapolis}}{(E_B - E_A)_{Minneapolis}}$$

Where:
 E_A : Annual HVAC cooling or heating energy use of the house with “adiabatic” window (A)
 E_B : Annual HVAC cooling or heating energy use of the house with baseline window only (B)
 E_S : Annual HVAC cooling or heating energy use of the house with window attachment (S)

Figure 3. Formulas for EP_C and EP_H .

The resulting EP is a decimal ratio that is multiplied by 100 to create a whole number rating that provides a comparison of the relative performance of a window attachment to other window attachments within and outside of its product category. Table 4 explains how to interpret EP and from the table it should be clear why this specific form of an equation was chosen (e.g., $E_B - E_S$ denoting energy related to shade only in numerator and $E_B - E_A$ denoting energy related to baseline window only in denominator).

Table 4. Interpreting EP ratings

EP value	Signifies
≤ 0	The window attachment installed over the baseline window causes the house to use more energy on an annual basis than if it had no attachment at all or has no net impact on energy performance of home.

>0 and <100	The window attachment installed over the baseline window improves the net annual energy performance of the home compared to if it had no attachment at all
≥ 100	The window attachment installed over the baseline window provides the annual energy performance equivalent to net zero energy window or the window attachment installed over the baseline window exceeds the energy performance of the net zero energy window (net energy producer).

The deployment schedule for window attachments was developed from the results of a behavioral study (Bickel et al. 2013). Deployment schedule was developed for 3 periods during the day (Morning: 6am-12pm; Afternoon: 12pm-6pm); and Evening: 6 pm-6am), week (weekday and weekend and holidays), and for two seasons (heating and cooling), so the percentage of products that were in one of these three positions at different times of day, week and season were used to post-process energy simulation results by time-weighting results. Detailed description can be found in Certification Standard AERC 200, Appendix A.

EP ratings for a window attachment are generated using a set of software tools developed by LBNL. The Berkeley Lab WINDOW and THERM programs (NFR 2017) can model a number of window attachment types, producing standard indices of performance (U, SHGC, VT) and also producing input file (idf) for EnergyPlus simulation engine. LBNL made further updates to those software tools and created a new software tool, AERCalc (LBNL 2017), to generate EP ratings for the AERC program. AERCalc utilizes EnergyPlus building energy simulation engine to perform annual energy simulations. These software tools are available at <https://windows.lbl.gov/software>. In order to be able to model the large number of different attachment product types, WINDOW software tool produces BSDF (Bi-Directional Scattering Distribution Function) for each attachment and baseline window combination. BSDF files define a discrete set of incident and outgoing angles, which fully describe the optical performance of any system, simple or complex, limited only by the resolution of the angular discretization. In this method each layer, as well as the whole system, is described by a matrix of incident and outgoing angles. BSDF is imported in AERCalc from WINDOW, and, along with the rest of building description, is modeled using EnergyPlus calculation engine and post-processed based on the manual algorithm described above.

Database and Energy Rating Label

The EP metric described above is the centerpiece of the AERC program and the residential consumer label, which will appear on the packaging of certified products in retail locations. The AERC label will list the product's EP_H and EP_C ratings, enabling consumers to quickly understand how that product is likely to perform in their home, depending on the climate where they live. If a consumer does not inherently know their climate, they can reference the AERC climate map, which is available via a QR code on the label. If they are in a cool climate, consumers should look at the cool climate rating on the AERC label and vice versa for a warm climate. Generally, the higher the rating for their climate, the better performance that product can offer. Figure 4 shows an example of the EP rating on the AERC online Certified Product Database and Figure 5 shows an example of the certification label.

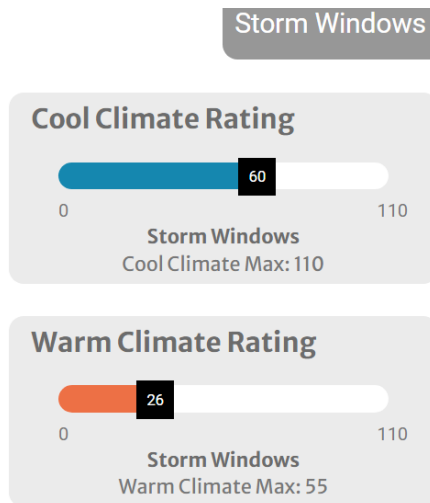


Figure 4. AERC Energy Performance (EP) rating from online Certified Product Database

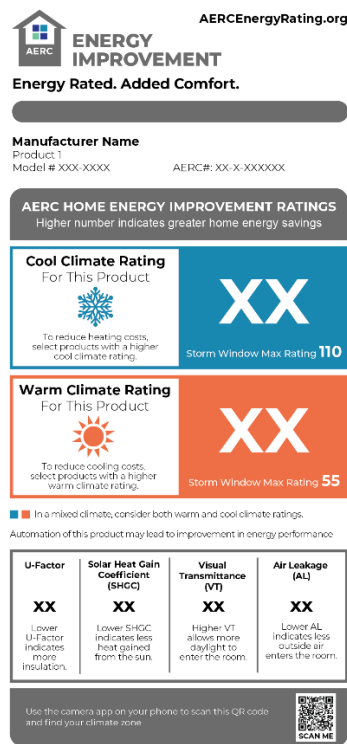


Figure 5. Example of AERC Certification Label

The AERC label also shows the range of performance for products within that window attachment product type so a consumer can understand a product's energy performance compared to others of the same type. In addition, a consumer may compare EP ratings of different options within a product type (e.g., cellular shades) as well as across product types (e.g., cellular shades vs. solar screens).

In addition to the EP metric, the AERC label also lists certified fenestration performance ratings including U-Factor, Solar Heat Gain Coefficient (SHGC), Visual Transmittance (VT), and Air Leakage (AL). The label also refers consumers to the AERC Certified Products Website, where they can access educational resources and search the entire list of AERC certified window attachments along with their ratings and performance metrics.

Automation

Although manually operated window attachments can present challenges to ensure persistent savings, the emergence of motorized operation and automated controls presents opportunities for expanding the market and providing additional energy savings from window attachments. New and emerging integrating platforms can optimize shade control based on weather conditions, thermostat setpoints, and occupancy status. These dynamically controlled high-efficiency shades can provide significant year-round savings. AERC has developed schedule-based automation control algorithms and Automation EP ratings for the standards' heating and cooling climates. The automation schedules (shown in Table 5 below) are based on seasonal deployment patterns that reduce heating and cooling energy use compared to manual operation, while minimizing the number of shade movements. The Automation EP ratings provide a standardized comparison for energy savings potential between automated attachments while allowing innovation from individual manufacturers to utilize their own control parameters in commercial products. Energy analysis for the Minneapolis (heating-dominated) shows up to 10% energy savings for automated shades vs manual operation, while for the Houston (cooling-dominated) the energy savings are up to 15%.

Table 5. AERC Automation Operation Schedules

Heating-Dominant Schedule (Generic Schedule A)

	North	South	East	West
June - August	Closed All Day	Closed All Day	Closed All Day	Closed All Day
September - May	Closed All Day	Open 08:00 - 16:00	Open 08:00 - 12:00	Open 12:00 - 16:00

Cooling-Dominant Schedule (Generic Schedule C)

	North	South	East	West
April - October	Closed All Day	Closed All Day	Closed All Day	Closed All Day
November - March	Open 08:00 - 16:00	Closed All Day	Open 12:00 - 16:00	Open 08:00 - 12:00

Utility Acceptance and ENERGY STAR

Until recently, energy-efficient window attachments have received only modest support in utility energy-efficiency programs; however, that may be changing. Bonneville Power Administration now recognizes the technology on its list of energy-saving measures.² In

² <https://www.bpa.gov/EE/Technology/EE-emerging-technologies/Projects-Reports-Archives/Pages/Low-Emissivity-Storm-Windows.aspx>

addition, Efficiency Vermont³ and Wisconsin's Focus on Energy have both completed successful retail pilot programs focused on low-e storm windows, and Xcel Energy in Colorado has a rebate measure⁴ focused on AERC energy rated cellular shades. In addition, storm windows (i.e., secondary glazing) have been accepted into the TRMs for Minnesota, Wisconsin, Michigan, Vermont, Rhode Island, and New York.

In September 2018, ENERGY STAR added a certification for exterior and interior low-e storm windows.⁵ ENERGY STAR is also evaluating the Attachment Energy Rating Council's proposed automation rating as part of its Smart Home Energy Management System initiative.⁶

Low-E Storm Window Technical Reference Manual Work Papers

Many utilities rely heavily on state Technical Reference Manuals (TRM) to identify and evaluate new measures for program development, and to reference a standardized method to calculate energy savings. Since 2019, AERC has submitted several work papers for residential low-e storm windows to be included in TRMs across the United States. A full list of TRMs that include low-e storm windows are shown in the Table 6 below.

Table 6. State Technical Reference Manuals with Low-E Storm Window Measures

Region	States
Midwest	Minnesota, Michigan, Illinois, Iowa, Missouri
Northeast	New York, Rhode Island, Massachusetts (2022 TBD), Vermont
Southeast	Louisiana, Arkansas
Southwest	Texas
West	Colorado
Northwest	Idaho, Montana, Oregon, Washington (in RTF)

In 2021, AERC continued its previous efforts to submit work papers for residential low-e storm windows and expanded its scope to include commercial secondary glazing products. AERC conducted extensive research to collect information on TRM review cycles in order to prioritize work paper development efforts. States were prioritized based on:

1. Timeframe for TRM review cycle
2. Presence of fenestration products in current TRM
3. Climate zone
4. Market potential

AERC staff reviewed and confirmed this prioritization with its Outreach and Utility Committee members. Based on the prioritization criteria listed above, AERC prioritized Arkansas, Texas, Minnesota, New York and New Jersey for 2021. As of October 2021, the

³ <https://www.efficiencyvermont.com/news-blog/whitepapers/low-e-and-behold-low-e-storm-windows-provide-a-new-way-to-solve-the-window-conundrum>

⁴ <https://co.my.xcelenergy.com/s/residential/home-rebates/cellular-shades>

⁵ https://www.energystar.gov/products/storm_windows

⁶ https://www.energystar.gov/products/spec/smart_home_energy_management_systems_pd

Arkansas and Texas TRM workpapers have been submitted for final acceptance, and the other priority state TRMs are still in development or waiting for the new TRM cycle to open.

For each TRM work paper, AERC submitted a method to calculate energy savings, heating and cooling savings, measure installed cost, and measure lifetimes. Submission format and requirements varied based on individual state requirements, but most work papers required similar information. PNNL provided modeling support for each TRM work paper using RESFEN software, developed by LBNL, in order to determine the annual heating and cooling savings associated with the addition of various low-e storm windows installed over a baseline window. Cities chosen for modeling were selected from the RESFEN location database to represent each IECC climate zone present in the target state. Two single-family homes were modeled for both existing and newer construction (based on IECC 2006), a one-story 1700 ft² home and a two-story 2800 ft² home, with window area representing 15% of total floor area. Low-e storm windows were evaluated over single and double pane clear glass, wood frame baseline windows, and heating and cooling savings were calculated based on annual whole house natural gas heating and central air conditioning energy consumption. In the analysis, annual deemed savings for both single and double-pane baselines were calculated in kWh/ft² and weighted by population for each climate zone and glass type using U.S. Census and Residential Energy Consumption (RECS) data.

After submitting the work paper, AERC engaged with the associated TRM advisory committee to present the measure, answer any questions about the work paper, and provide additional information about low-e storm windows. The work papers were revised based on the feedback received during the advisory committee presentation. Examples of revisions include changing the baseline windows to aluminum frame, adding the effects of air infiltration reduction, modeling solar control glass in southern states, and modeling air source heat pump and electric resistance heating savings. Once the work papers are accepted in to the TRM, AERC will work to engage the appropriate contacts at utilities that rely on the TRM to pitch pilot programs.

Conclusions

The research described here highlights the energy savings potential of window attachments and how the AERC energy ratings can help promote the market uptake and optimal use of these high-efficiency products. Considering the energy-savings potential of these products, these findings suggest there is a large market opportunity to move consumers to higher-performance window technologies. For residential customers, the windows technologies highlighted in this paper offer a reduction in HVAC system energy consumption without sacrificing utility or comfort. On a broader scale, high-efficiency window technologies have great potential for reducing energy consumption in the residential and commercial sector and offer a cost-effective incentive option for utilities and state weatherization programs. The field and modeling studies presented in this paper demonstrate significant, measurable, and persistent savings from the application of window attachments, which should help justify the integration of these measures into programs to help achieve energy and carbon reduction goals while enhancing consumer comfort and building resilience.

The addition of energy ratings and labels for window attachment and field-validation research should help consumers, designers, builders, and home performance contractors make

informed decisions about window improvement retrofits. Energy efficiency programs could also reference the new AERC ratings and ENERGY STAR certifications to ensure the highest performing measures are included in energy-efficiency programs. There is also an opportunity to improve efficiency by encouraging “smart” operations of these devices, whether through education or automation. Together these opportunities could help to save some of the vast amounts of energy we lose through windows each year.

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