MINNEAPOLIS STORM WINDOW PILOT

Evaluating the value of replacing old storm windows with new, modern storm windows.

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EXECUTIVE SUMMARY

Storm windows are relatively ubiquitous in Minnesota, often used over a single-pane window. After several decades or more, these windows tend to leak, which results in reduced benefits and creates an opportunity for storm window upgrades.

This pilot found that replacing old, leaky storm windows with new storm windows provides a significant air sealing benefit, resulting in 10–20% whole-building air leakage reduction. Additionally, new storm windows can include a low emissivity coating (Low-E) that provides even higher insulating power than clear glass storm windows.

This 10–20% air leakage improvement was achieved for both internal and external storm windows, for single-family and multifamily properties, and installs completed by either homeowners or contractors. Modeling results showed that the energy savings from air leakage improvements were larger than the insulative improvements for all four sites. Based on pilot findings, storm window utility programs and Technical Reference Manual (TRM) measures that are not accounting for air-leakage reduction dramatically undervalue the benefits of replacing storm windows.

Because storm windows are significantly less expensive than replacement windows, they provide a more affordable and cost-effective path to significantly improve the building envelope. Based on pilot results, homes with older storm windows would benefit from a utility program for replacing these older storm windows (just as older HVAC equipment is eligible for replacement).

An estimated 10–15% of all Minnesota single-family homes and 30% of affordable multifamily homes have single-pane windows,[1] providing a significant opportunity to improve the thermal performance of these buildings and secure a lower energy burden for Minnesota residents.

STORM WINDOW BACKGROUND

Windows are a critical part of a home's energy use. According to the Storm Window and Insulating Panel (SWIP) playbook,[2] windows contribute to a quarter of home heating and cooling energy use, and 10% of a building's total energy use. Although windows typically only cover about 8% of the building envelope, they make up 45% of the heat transfer through the envelope.

In a previous field study, Pacific Northwest National Lab (PNNL) found that new Low-E storm windows can yield an 11% reduction in the heating load and an 8% reduction in the cooling load compared to a market baseline home. In a DOE field validation study, the installation of Low-E storm windows resulted in up to 30% savings on annual heating and cooling bills and reduced

[1] Discussed in more detail in market size section. Source: https://mn.gov/commerce/energy/industry-government/cip/card-grant-search/card-project-pages/

[2] https://paws.energy/wp-content/uploads/2023/04/SWIP-Utility-Program-Playbook-V3.pdf

whole-building air leakage by 10% or more. These results are consistent with our study's findings.

U-factor is a measure of a window's insulating power (lower is better), and is the inverse of R-value, which is commonly used for insulation products. As an example, a single-pane window with a new Low-E storm window is about an R-value of 3 and a U-factor of 0.33 (1/3 = 0.33, or 1/0.33 = 3).

A single-pane window that is well air sealed (i.e., assuming zero air leakage) has a U-factor of approximately 1, and a well-sealed clear storm window added to that gives an approximate U-factor of 0.5. An old and leaky clear storm window over a single-pane window will have an upper limit of performance of about 0.5 U-factor, but likely will be better than 1.0 (better than a single-pane window alone). The leakier the storm window and primary window, the worse the U-factor will be.

After replacing old storm windows, the U-factor is improved from the previous range of 1.0 and 0.5 to a consistent 0.5 (for clear storm windows) or 0.33 (for Low-E storm windows). The notable improvements to air sealing and thermal properties result in double the insulating power. The expected U-factors before and after are also outlined in Table 1 below.

Table 1. Approximate U-factor of several window glazing combinations

Window type	Before	After (Clear Storm)	After (Low-E Storm)
Single pane, no storm	1.0 U-factor or worse* (<R-1)	0.5 U-factor (R-2)	0.33 U-factor (R-3)
Single pane, clear storm	0.5 U-factor or worse* (<R-2)	0.5 U-factor(R-2)	0.33 U-factor (R-3)

** For the "before" cases above, leakiness will reduce this value so that this maximum is a very conservative upper bound.*

Low-E storm windows have also been used to retrofit historic buildings, in which it's desirable to preserve the aesthetic of a building. Examples include:

- The 1892 Umbrella Works building in Lancaster, PA for adaptive reuse to apartments using interior Low-E storm windows
- Wissahickon Avenue Apartments in Chestnut Hill, PA that used exterior Low-E storm windows
- 1929 French Apartments in New York City, NY that used operable interior Low-E storm windows

Storm windows improve performance and air sealing for historic buildings like these and can also be used to preserve historic features such as stained-glass windows, arched, circular, or other window shapes.

Figure 1. Examples of low-e storm windows on historic multifamily upgrades

1892 Umbrella Works, Lancaster PA - adaptive reuse to apartments, interior low-e panels.

Wissahickon Avenue Apartments, Chestnut Hill, PA - exterior low-e storm windows.

1929 French Apartments, New York City, NY - interior operable low-e panels. Photos courtesy of Quanta Panel

PILOT OVERVIEW

This pilot evaluated the value of replacing old storm windows with new, modern storm windows. Five pilot participants were recruited through programs implemented by CEE. Three of the buildings were multifamily affordable housing and two were single-family homes. Pre- and post-measurements were taken in each building, so the air-leakage reduction could be measured, and the overall energy savings could be modeled.

Pilot Recruitment

Single-Family

Homeowners interested in participating in the pilot were identified through a survey. An initial list of qualified sites was selected using survey responses and pictures provided by the homeowners. These homeowners received an energy audit where the energy auditor confirmed the need for new storm windows. Energy auditors completed a blower door test (described below), to test the air leakage of the home, and completed a visual inspection of the windows. Energy auditors were looking for signs of leakage, deterioration of the sealant, and visual gaps. From this data, two single-family homeowners were selected and agreed to participate in the pilot.

Multifamily

The multifamily buildings were recruited through Minneapolis's 4d Affordable Housing Incentive program.[3] CEE reached out to a building owner to see if they were interested in this pilot, and they recommended multiple buildings for this pilot. These buildings had gone through the Minneapolis 4d program, but windows are not included in the program's scope. Similar to the

[3] https://www2.minneapolismn.gov/government/programs-initiatives/housing-development-assistance/rental-property/4d/

single-family homes, CEE completed a blower door test and walkthrough inspection to verify that these buildings needed new storm windows.

Storm Windows

For this pilot, several combinations of storm windows were tested including non-Low-E interior storm panels, non-Low-E exterior storm windows, and Low-E exterior storm windows. Storm window brands assessed include Indow (interior non-operable storm insert), Mon-Ray (exterior operable clear glass product), and Quanta Panel[4] (exterior operable Low-E product). Storm windows were installed by the homeowner for the single-family homes and by a contractor for the multifamily homes.

Pilots Sites

Figure 2. Site 1, "Indow Single-Family," single-family unit with 25 windows, window age estimated 60–120 years. Homeowner-installed product: interior non-Low-E storm window inserts.

Figure 3. Site 2, "Mon-Ray Single Family," single-family unit with 31 windows, window age estimated 60–120 years. Homeowner-installed product: exterior non-Low-E storm windows.

[4] The Quanta products selected are listed on both the Attachments Energy Rating Council (AERC) database as well as on the storm window ENERGY STAR Product Finder due to their performance levels

Figure 4. Site 3, “Quanta Multifamily #1,” four-plex multifamily with 55 windows, window age estimated 60–100 years. Contractor-installed product: exterior Low-E storm windows.

Figure 5. Site 4, “Quanta Multifamily #2,” duplex multifamily with 29 windows, window age estimated 60–120 years. Contractor-installed product: exterior Low-E storm windows.

Figure 6. Site 5, “Quanta Multifamily #3,” five-plex multifamily with 30 windows, window age estimated 60–120 years. Contractor-installed product: exterior Low-E storm windows.

Figure 7. Example of a blower door test.

Air-leakage testing

To test air leakage, a blower door test was performed, in which a membrane is placed into an exterior doorway with a large pressure fan that depressurizes the home to 50 Pascals. By measuring how fast the fan runs at this static pressure, the leakiness of the home can be calculated. This is measured in CFM50, or cubic feet per minute pulled out of the home at 50 pascals.

The blower door test was completed prior to the storm windows being installed (pre CFM50), and again after the new storm windows were installed (post CFM50). Homeowners agreed not to complete any other house upgrades or renovations between these blower door tests.

PILOT RESULTS

For the homes assessed in the pilot, significant air leakage reductions were realized, at 10% and 19% for resident self-install sites, and ranging from 16–19% for contractor-installed storm windows. Sites ranged from one to five units, with between 25 and 55 windows per site. Based on modeling from Lawrence Berkeley National Laboratory (LBNL), air leakage improvements account for more than half of the overall energy savings (compared to thermal/insulative improvements). Further details are outlined in the Modeled Energy Savings Results section below. Presently, many storm window measures account for thermal improvements, such as adding a Low-E coating, but not for air leakage improvements.

Table 2. Pilot results table highlighting improvement (charts in appendix).[5]

	Indow Single-Family	Mon-Ray Single-Family	Quanta Multifamily #1	Quanta Multifamily #2
Storm Type	**Interior Storm (Single-Fam.)**	**Exterior Storm 1 (Single-Fam.)**	**Low-E Exterior Storm 2 (MF1)**	**Low-E Exterior Storm 2 (MF2)**
Install Type	Homeowner	Homeowner	Contractor	Contractor
Home Sq. Ft.	3792	3238	4290*	1877*
Window Count	25	31	55	29
Glazed sq. ft.	340.7	268.2	602.2	258.8
Lineal ft. Window Perimeter.	396.5	365.3	762.7	350.9
Pre CFM50	5162	3356	7857	4405
Post CFM50	4200	3026	6373	3692
CFM50 Improvement	962	330	1484	713
Percentage Reduction	**18.6%**	**9.8%**	**18.9%**	**16.2%**
CFM50 per Window	38	11	27	25
CFM50 per sq. ft. glazed area	**2.8**	**1.2**	**2.5**	**2.8**
CFM50 / glazed lineal ft.	2.4	0.9	1.9	2.0

** Multifamily square footage does not include basement area, which is unconditioned.*

[5] There are no results for the 3rd multi-family site, because window air-conditioning units were installed between the pre- and post-blower door test, which significantly skewed results.

Storm Window Cost

The cost per storm window ranged from $200–400. Of the products assessed in this trial, Quanta offered the lowest cost product at an average of $200/window. Product price averages are outlined in Table 3. For multifamily sites, the installing contractor charged $75 per storm window installed, including removal of the old window, installation of the new product, and disposal of the old product, with an additional flat fee added for one site with higher second story windows.

From a previous study (Culp, 2015[6]), it was found that the cost of upgrading from a clear storm window to a Low-E storm window is typically $2/sq. ft. of glass area. Therefore, the incremental cost is small for the respective U-factor gains, and Low-E storm windows should be preferred where possible (e.g., ~$15 extra per window to go from clear to Low-E storm windows, but 50% higher insulating power, going from ~R-2 to ~R-3 for the storm product).

Table 3. Average cost per window for each of the assessed sites with parts and labor separated

Cost Per Window		Indow	Mon-Ray	Quanta (avg)	Quanta 1	Quanta 2	Quanta 3
$/window	Materials	$388	$402	$203	$184	$197	$227
$/window	Labor (measurement + install)	H.O. install	H.O. install	$75	$75	$75	$75
$/window	Mats+Labor	$388	$402	$278	$259	$273	$301
$/CFM50 improvement	Materials	$10.21	$36.57	$7.37	$6.83	$7.91	TBD
$/CFM50 improvement	Mats+Labor	N/A	N/A	$10.26	$9.61	$10.91	TBD

Participant Survey Results

As a part of the pilot, qualitative feedback was collected from the contractor, residents, and a multifamily building owner to understand how they experienced the new storm windows. Statements are outlined in the following, along with averaged survey results from homeowners that included ratings of indoor and outdoor aesthetics, thermal comfort, sound transfer, etc.

Homeowner

Homeowners provided the following statements about their experience in the pilot project:

[6] https://www.pnnl.gov/main/publications/external/technical_reports/PNNL-24826.pdf

"Overall, I'm very pleased with the Indow windows. Although it did take me some time to get all of them installed, the installation itself was relatively easy. My heating bill has decreased, and I can actually feel a difference temperature-wise when comparing the old windows to the same windows with the Indow inserts. As far as I'm concerned, the only drawback will be having to remove and store in the inserts when I want to open the windows to let some fresh air in. That is a relatively minor inconvenience, though, compared to the cost savings."

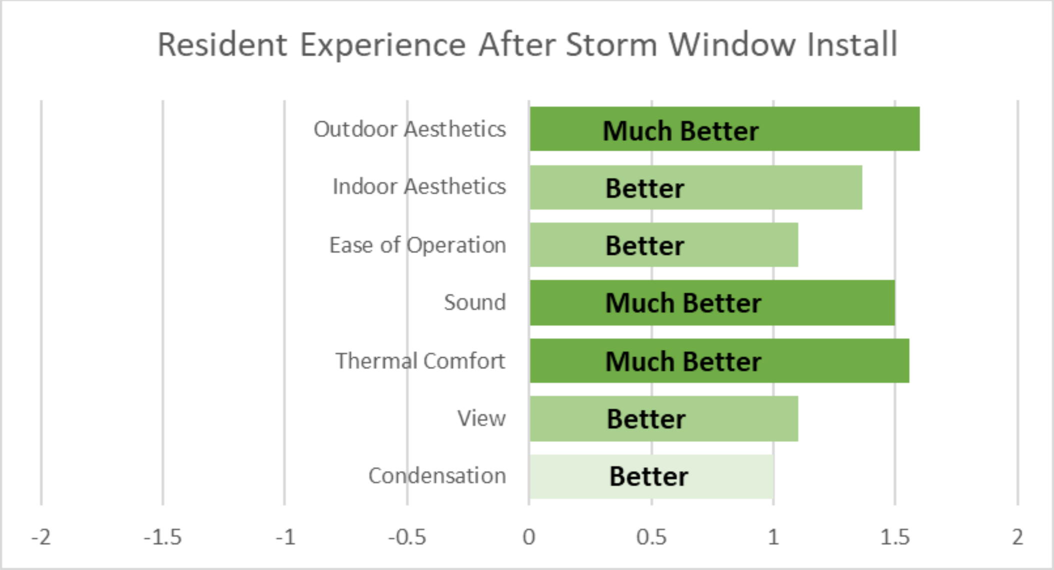
– Indow Site Homeowner

"We have over 30 original single-pane windows in our home. It felt wasteful and too expensive to replace them all. Though they are drafty, they function as they should. We opted for these new energy efficient storm windows in hopes that we could minimize our environmental impact through heat loss in the winter. So far, they seem to be helping. I'm interested in the data. I doubt that our old windows and new storms are as airtight as new high efficiency windows, but at a fraction of the cost the new storm windows felt like a good value and step forward in our efforts to minimize natural gas usage and impact on the environment."

– Mon-Ray Site Homeowner

For all sites, residents were surveyed on their experience of the storm windows (average of 11 surveys, "-2" is much worse, "0" is about the same, "+2" is much better)

Figure 8. Survey results of single- and multi-family sites, average of 11 surveys.



Building Owner

The building owner for the multifamily sites provided the following statement:

> *"I'm born and raised in Minneapolis. I have worked with several programs in conjunction with the city and the Green Cost Share initiative….*
>
> *I was the recipient of storm windows through a CEE pilot program in Minneapolis and had an exceptional experience. The tenants mostly of modest means saw a noise reduction and a (sic) increase of natural light and saw significant saving on utility bills. The buildings themselves saw an enhanced curb appeal and were more efficient as a result. So,*
>
> *I can say without a doubt that this was a success and I'm glad I participated in the Pilot program and look forward to more."*
>
> *– Multifamily Building Owner*

MARKET INFO

Market Size

According to a 2014 CARD study,[7] 30% of MN low-income housing have single-pane windows (with or without storm windows) and 86% of single-family homes have double-pane windows. This indicates an opportunity for storm-window replacements in the 10–15% of single-family homes that likely have single-pane windows, but there is a larger opportunity for storm windows in low-income and multifamily buildings. These opportunities likely skew toward an older housing stock, before double-pane windows became prominent.[8] Still, these figures show a sizable opportunity for storm-window replacements in MN, many of which may not be functioning well.

Manufacturers

A large manufacturer of storm windows, Larson, recently pulled out of this market because of a company acquisition. This created a void in the storm window market, but there are still national manufacturers that produce storm windows, including: Alpen, Andersen Corp, Indow, Mon-Ray, ProVia, Quanta panel, and several others.

Quanta was a key contributor to this pilot and recently added a nationwide local partner list lookup tool,[9] for which they distribute products to local hardware stores and customers can look up local retailers by area code. In total, forty-five stores located throughout all six

[7] https://mn.gov/commerce/energy/industry-government/cip/card-grant-search/card-project-pages/

[8] Double-pane windows became common in new construction in the 1980s (Reference: CARD Study)

[9] https://www.quantapanel.com/find-a-contractor/

Minnesota regions sell Quanta panel windows. Quanta has stated that they are currently ramping up production to meet the growing demand for storm windows.

Installers

This pilot identified a gap in the market for installers, because storm window installation is currently a niche service/market. Luckily the installation is simple, requiring only basic hand tools. For external storm windows, some caulking, and several screws are used to affix the panel. For internal storm window inserts, installation is often tool-free due to a closely measured gasketed press fit. Because little-to-no training is required, installation can be completed by a variety of people including local handymen, insulation contractors, siding contractors, energy audit staff, multifamily building maintenance workers, or building owners. Currently, the network needed to track those capable of installation is not readily available. SWIP has made it a goal to build this network in regions of the country that have active programs.

The contractor used for this pilot had never installed storm windows before, but delivered significant air infiltration improvements from the storm window replacement. The installing contractor provided the following statement on their experience in the pilot project:

> ***"Working with CEE and Quanta panel on the installation of their 500 series windows was a seamless experience. The staff at Quanta panel were knowledgeable and attentive when instructing how to measure and what styles to order. The windows arrived packaged very securely yet easy to unpack. The storm windows themselves are very well built yet light enough for one worker to install. Quanta panel would be my first recommendation to any of my customers looking for new storm windows."***

The installing contractor produced great results (16–19% air leakage reduction) without any formal installation training. We assume that homeowners who self-install their storm windows may not be able to achieve the same install quality as a general contractor with more construction experience. This may be why a lower air leakage improvement was observed on the homeowner-installed Mon-Ray site with a 10% air leakage improvement. However, more information is needed to draw conclusive results, because of confounding variables that include different installers, different products and manufacturers, and different home styles (single-family vs. multifamily homes).

MODELED ENERGY SAVINGS RESULTS

To estimate year-round heating and cooling use and savings from the application of storm windows in multiple Minnesota climate zones, Lawrence Berkeley National Lab (LBNL) modeled energy savings results for two single-family homes and two of three multifamily homes in this pilot, and for a representative model home in four major MN cities (spread over two climate zones). Modeling was performed using EnergyPlus modeling software. Additionally, Xcel Energy provided calculations using equations from air sealing and weatherization measures to estimate the benefit of upgrading storm windows based on the results from this pilot.

For the site-specific LBNL modeling, HVAC heating and cooling savings ranged from 5–15%, whole-site electric savings ranged from 3–4% and whole-site gas savings ranged from 4–14%. Peak gas and electric savings (maximum usage on the most extreme weather days) ranged from 6–13% for the pilot homes. Note that fan energy savings are larger than what is typically accounted for within HVAC savings calculations via SEER number, as these fan savings also capture reduced fan runtime in the heating season. This data is outlined for each site in Tables 4 and 5 below.

Table 4. Modeled gas, electric, and peak heating and cooling savings by site (percent).

Site	HVAC Cooling savings	HVAC Heating savings	Site Elec. Savings	Site Gas Savings	Peak Heating Savings*	Peak Cooling Savings*	Peak Fan Savings*
Indow	10%	13%	4%	11%	12%	12%	11%
Mon-Ray	8%	5%	3%	4%	6%	8%	7%
Quanta #1	10%	15%	4%	14%	13%	13%	11%
Quanta #2	8%	13%	3%	11%	12%	11%	9%

** Note that peak electric cooling savings occurs in July whereas fan and heat savings peak in January.*

Table 5. Modeled gas, electric, and peak heating and cooling savings by site (values).

Site	HVAC Cooling savings per window (kWh)	HVAC Fan savings per window (kWh)	HVAC Heating savings per window (therms)	Peak Gas Savings per window (BTU/h)*	Peak Cooling Savings per window (W)*	Peak Fan Savings per window (W)*
Indow	16	10	10	455	22	3
Mon-Ray	9	4	2	143	9	2
Quanta #1	11	8	7	316	16	2
Quanta #2	9	6	7	325	14	2

** Note that peak electric cooling savings occurs in July whereas fan and heat savings peak in January.*

Peak Energy Use Savings

As outlined above, peak cooling (electric) savings of 8–13% and peak heating (gas) savings of 6–13% are modeled for the pilot sites. Peak savings from homeowner-installed windows ranged from 6–12% and peak savings from contractor-installed windows ranged from 11–13%. These peak savings can be significant for existing building stock, particularly for affordable and multifamily housing. These are generally a lower-performing building stock due to capital constraints to upgrade, and split incentives between occupants and building owners for multifamily housing.

Reducing the peak power demands of a house is a significant benefit to homeowners, utilities, and society in general. Homeowners will experience reduced costs particularly if they're utilizing a time of use/time of day plan. For example, Xcel Energy's time of day pricing states an off-peak power price of $0.05/kWh, whereas on-peak power prices are $0.26/kWh in the heating season and $0.21/kWh in the cooling season. Based on these example costs, on-peak power savings could be approximately four to five times more valuable than off-peak savings (although the time-of-day pricing is not currently a highly utilized rate structure in MN).

For utilities, notable cost and effort is expended to meet the small number of hours of peak demand annually. This reserve capacity to meet peak demand is typically disproportionately expensive versus base load power due to its inherently intermittent use. Utilities are highly aware of the added cost of peak power and target numerous programs specifically for minimizing peak power demand.

Reducing peak power additionally provides a societal benefit in both price and performance. By reducing peak demand, costs should be reduced (by lowering demand on the grid for the disproportionately expensive reserve capacity, which is four to five times higher in the example above). Reducing peak power demand may also improve grid stability in extreme weather events because a lower collective peak load is more easily balanced than a higher peak load.

Model Home

LBNL also provided modeling based on the pilot results extrapolated out to a representative single-family example home in four different Minnesota cities: Minneapolis (Climate Zone 6a), Rochester (6a), Duluth (7), and Bemidji (7). This representative home was assumed to be approximately 2400 sq. ft. and two stories, with insulation levels typical to the region: R-19 attic insulation, R-11 wall insulation, and R-11 exterior floor insulation.

Cooling, heating, fan, and peak power reductions were modeled for five different assumed air leakage improvement levels ranging from 5–25% (based on the measured range of values in the pilot) and for three different HVAC regimes:

- "eFAF": Electric resistive heating with traditional A/C
- "Gas + AC": Gas furnace with traditional A/C
- "HP + clg": Heat pump with heating and cooling capabilities

Based on the air leakage improvements measured in this pilot from 10–20%, the modeled results for the mean value of 15% air leakage reduction are reported in Tables 6, 7, and 8 below.

Table 6. Modeled home results for climate zone 6A

	Climate Zone	HVAC Regime	HVAC Cooling Savings	HVAC Heating Savings	Site Elec. Savings	Site Gas Savings	Peak Elec. Savings	Peak Gas Savings
Minneapolis, MN	6A	eFAF	13%	9%	8%	N/A	10-11%	N/A
		Gas + AC	13%	10%	5%	8%	14%	10%
		HP + clg	13%	9%	7%	N/A	11%	N/A
Rochester, MN	6A	eFAF	14%	10%	8%	N/A	10-11%	N/A
		Gas + AC	13%	10%	5%	9%	14%	10%
		HP + clg	14%	10%	8%	N/A	11%	N/A
Average	**6A**		**13%**	**10%**	**7%**	**9%**	**12%**	**10%**

For a modeled home representative of climate zone 6A, HVAC heating and cooling energy savings ranged from 9–14%, sitewide energy savings ranged from 5–9%, and peak power demand savings ranged from 10–14%.

Table 7. Modeled home results for climate zone 7

	Climate Zone	HVAC Regime	HVAC Cooling Savings	HVAC Heating Savings	Site Elec. Savings	Site Gas Savings	Peak Elec. Savings	Peak Gas Saving
Duluth, MN	7	eFAF	16%	10%	8%	N/A	12%	N/A
		Gas + AC	15%	10%	4%	9%	13%	12%
		HP + clg	16%	9%	7%	N/A	11%	N/A
Bemidji, MN	7	eFAF	15%	9%	8%	N/A	12%	N/A
		Gas + AC	14%	10%	4%	8%	13%	12%
		HP + clg	15%	9%	7%	N/A	12%	N/A
Average	**7**		**15%**	**10%**	**6%**	**9%**	**16%**	**12%**

For modeled homes representative of climate zone 7, HVAC heating and cooling energy savings ranged from 9–16%, sitewide energy savings ranged from 4–9%, and peak power demand savings ranged from 11–13%.

Table 8. Modeled results summary for climate zones 6A and 7

Climate Zone	HVAC Cooling Savings	HVAC Heating Savings	Site Elec. Savings	Site Gas Savings	Peak Elec. Savings	Peak Gas Saving
6A, Avg.	13%	10%	7%	9%	12%	10%
7, Avg	15%	10%	6%	9%	16%	12%

Xcel Energy – Measure savings results

Xcel Energy provided estimates of savings in parallel to the modeling done by LBNL. An estimate of energy saved per site, split by infiltration versus thermal improvements, was assembled using the measured air leakage improvements for each of the four modeled pilot sites. Deemed savings equations were used for window insulating power improvements and air infiltration improvements (repurposed from a non-window-specific air infiltration insulation measures).

Values are outlined in Table 9 below. Note that for the Mon-Ray site, there are no modeled U-factor savings, as the old clear glass storm window was replaced with a new storm window that also used clear glass. It is important to note that while no U-factor savings are modeled, due to the extent of leakiness from the old storm window, there is likely to be a notable in-practice U-factor improvement (although this is nontrivial to quantify). For all four sites, the energy savings from air infiltration improvements were larger than the modeled savings from thermal improvements. ***This means that a utility or TRM storm window measure that does not account for air infiltration improvements may be undervaluing the benefit of replacing the storm windows by more than half.***

Table 9. Xcel Energy modeled savings results for a storm window measure

	Indow	Mon-Ray	Quanta 1	Quanta 2
Infiltration – kWh Savings	91	31	140	67
Infiltration – Dth* Savings	27	9	41	20
U-value – kWh Savings	77	0.0	137	59

U-value – Dth* Savings	16	0.0	28	12
Customer kWh Savings	168	31	277	126
Customer kW Savings	0.43	0.08	0.60	0.27
Customer kW Savings	0.23	0.08	0.30	0.15
Customer Dth* Savings	42	9	68	32
% Savings from Infiltration	**58%**	**100%**	**55%**	**58%**

**Note that "Dth," "Dekatherm," or "Decatherm" is equal to 10 therms or 1,000,000 BTU.*

Comparison of Modeling Results

The modeled gas and electric savings for both the LBNL and Xcel estimates are summarized in Table 10.

Table 10. Comparison of Xcel Energy and Berkeley Lab modeled savings values

	Xcel	LBNL	Xcel	LBNL
	kWh Savings	**kWh Savings**	**Dth* Savings**	**Dth* Savings**
Indow	168	655	42	24
Mon-Ray	31	411	9	7
Quanta #1	277	1032	68	40
Quanta #2	126	431	32	20

**Note that "Dth," "Dekatherm," or "Decatherm" is equal to 10 therms or 1,000,000 BTU.*

The LBNL model yielded a larger annual kWh savings than the Xcel Energy modeling. This discrepancy is due in part to several differences in modeling inputs:

- Xcel Energy utilizes a heating degree day (HDD) and heating hour estimate framework and LBNL utilizes weather data with a building model.
- The LBNL model accounted for changes to window Solar Heat Gain Coefficient (SHGC) performance due to the addition of Low-E coatings, resulting in greater modeled savings in the cooling season and lower winter therms used.

- Xcel Energy assumed a higher assumed higher coefficient of performance (COP) of 3.93 for cooling equipment whereas LBNL used a value of 3.00 (i.e., the Xcel Energy model presumes less energy used for the same level of cooling delivered).
- The Xcel Energy model accounts for fan use reductions in the cooling season via the SEER value (i.e., fan savings in cooling season only). LBNL modeling additionally factored in potential improvements to fan use in the heating season resulting from less heating demand that yielded less furnace runtime (i.e., year-round fan savings).

TECHNICAL REFERENCE MANUALS (TRMs)

As this pilot demonstrated, upgrading old and leaky storm windows can improve the U-value of the window and reduce the air-leakage of the home. Unfortunately, the air-sealing benefit is not typically accounted for in TRM and utility measures for storm windows. This is even the case for utilities that already have a storm window measure and incentives in place, such as CenterPoint Energy's storm window rebate that does not include an air-leakage improvement component.

The MN Technical Reference Manual (TRM) has a storm window measure, but air sealing improvements are not included in this measure. Based on modeled energy savings for both the pilot homes and the modeled homes, the air sealing benefit is notable and accounts for half or more of the overall modeled energy savings, as outlined in the Modeled Energy Savings Results section.

Based on the pilot findings and similar nationwide pilots, these are the recommended inputs for a utility or TRM storm window measure:

1) **Deemed CFM50 improvement per glazed square foot: 2.5**
    a. This was the lowest value achieved by a professional installer in the MN trial.
    b. Consistent with other similar pilots: PA field study[10] showed a higher CFM50 / glazed sq. ft. of improvement of 3.2.
2) **Deemed CFM50 improvement per lineal foot window perimeter: 1.9**
    a. Conversion of the value above based on actual window dimensions.
    b. In some cases, a CFM50 improvement per lineal foot of window perimeter may better account for homes with unusually sized windows (windows that are particularly large or small).

Lifetime

The expected service life of storm window panels is long. According to Quanta panel's website,[11] *"A modern low-e storm window, with state-of-the-art technology provides the same level of performance [as a double-pane insulating glass unit], allows one to retain the original windows*

[10] https://www.quantapanel.com/wp-content/uploads/2016/08/10_Performance_Comparison_Zion_11012013_Final.pdf

[11] https://www.quantapanel.com/storm-window-faqs/

(architecturally desirable), and should have a significantly longer lifespan [than an typical double-pane insulating glass unit].”

There are many examples of homes in Minnesota and nationally that have the original storm window panels that have been in service for 50+ years. For several homes in this pilot, the original storm windows were estimated to be well over 60 years old, and there are many such homes in Minnesota and nationwide, some with historic features like stained glass windows.

Currently, several state Technical Reference Manuals, including the Minnesota and Illinois TRMs, have a deemed storm window lifespan of 20 years. However, there is a proposed change in consideration to the Minnesota TRM for a 30–40 year measure life for envelope upgrades, including new primary windows and storm windows.

For any utility measure, it is important to have some assurance that the product will stay installed long-term. In practice, storm windows are long-term products. Exterior storm windows in particular have a long track record of service life; there is a notable portion of the Minnesota building stock with storm windows from the 1970s, 40–60 years old or older. Based on this in-practice service life, and commentary from manufacturers, a 20-year deemed measure life is a conservative value.

An important note that is consistent with this study’s findings is that while storm windows have a long *service life*, many old storm windows also are measurably leaky. This suggests that they both have a long in-practice service life, and that they tend to become leakier as the overall window assembly deteriorates over time.

UTILITY PROGRAM OPPORTUNITIES

A significant benefit of storm windows is that they are available at a more accessible price point than replacement windows, typically costing as little as a third to half of the full window replacement cost. Due to the relative affordability of the measure, it provides an alternate path to upgrading windows, which are the weakest link in a building's envelope. This alternate path could be especially applicable to low- and middle-income housing, multifamily housing, and other rental programs. Ameren in Illinois is completing a storm window pilot to assess how the results might scale up into their low-income portfolio.

The cost of storm windows compared to window replacement makes them a good fit for existing programs such as the state Weatherization Assistance Programs (WAP), Low-Income Weatherization (LIW) programs, and multifamily rental programs. Lower-income households have fewer resources to make large purchases like window upgrades, resulting in a lower-performing building stock on average and a higher opportunity for storm window incentives. This is also true of rental properties that suffer from split-incentives between the owner and tenant, which lead to less investment and lower-performing buildings.

At a relatively low implementation cost, utilities can also offer market-rate incentives for those looking to upgrade their old and leaky storms. This could be a simple homeowner rebate application, that would encourage these homeowners to make this investment and help them select the best performing products when they do.

CONCLUSIONS

Opportunities for storm window upgrades exist in Minnesota's older building stock, with an especially strong opportunity in the low-income and rental market. Thirty percent of Minnesota's low-income housing stock still has single-pane windows. As shown in this pilot, homes with existing storm windows over single-pane windows can be leaky and benefit significantly from replacement with modern products. This presents a huge opportunity for a program focused on this underserved market.

Replacing storm windows significantly reduces (10–20%) whole-home air leakage. This pilot verified past research, that showed the air-sealing benefits of adding and replacing storm windows. Further, it provided evidence that air leakage through windows is a major contributor to overall home air leakage in older existing buildings.

Technical Reference Manuals (TRMs) and utility programs need to include air-sealing benefits in their storm window measures. Air-leakage reduction accounts for over half the savings that storm windows deliver (even when replacing old existing storm windows), and this benefit needs to be included when implementing energy efficiency programs.

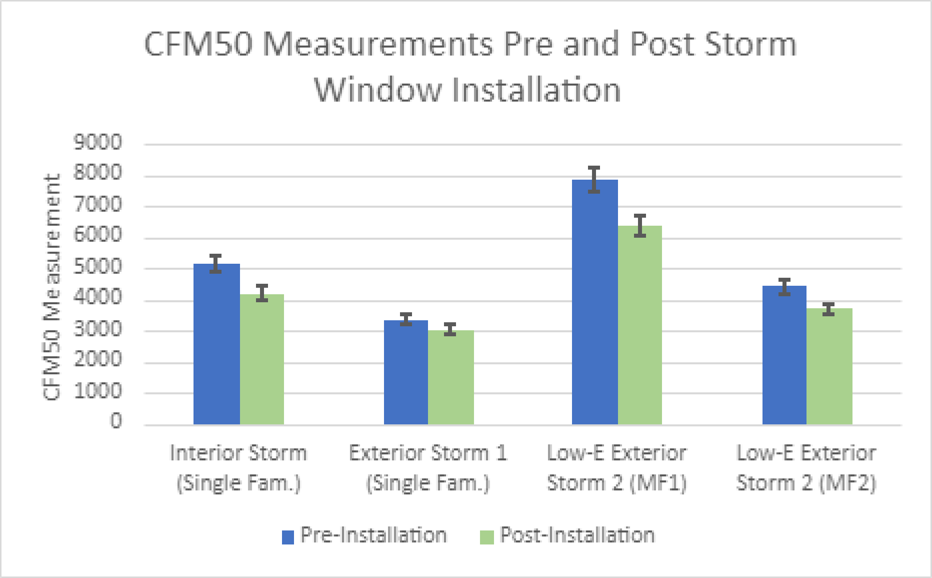
National and regional storm window manufacturers are present in Minnesota and operations are expanding. The void left by a national manufacturer pulling out of this market is starting to be filled by several manufacturers, including Quanta, Indow, and others. A focus of the Department of Energy's SWIP campaign is to continue filling this market gap, and an increase in utility programs will also aid this effort.

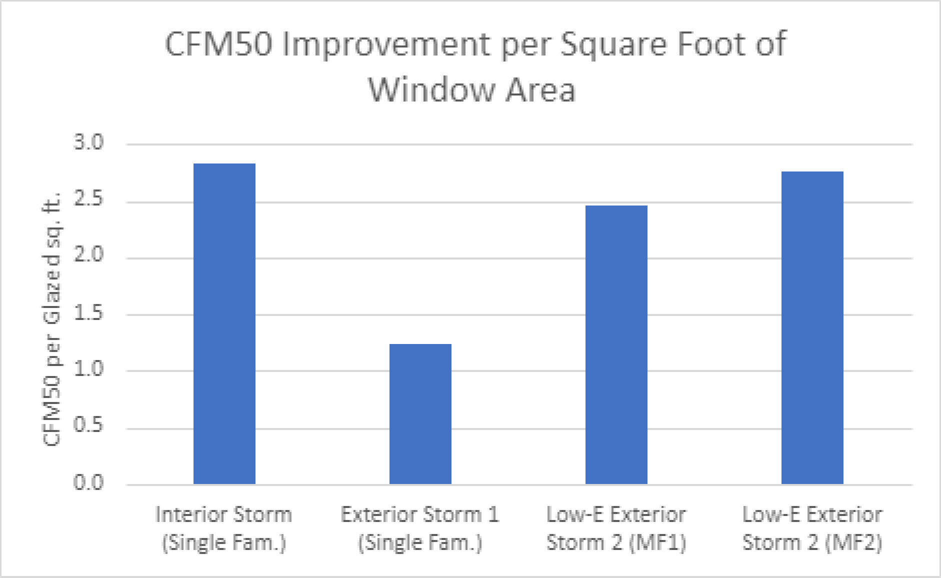
An installer network is needed, but building this network through a utility program would be a light lift. The tools and skills required to install storm windows are relatively ubiquitous among market actors that work on homes. A utility program could leverage current relationships with trade allies, including low-income implementers, insulation contractors, and window installers, to build the network needed for a successful program. The DOE's SWIP campaign is also committed to helping build an installer network in regions that are launching storm window programs.

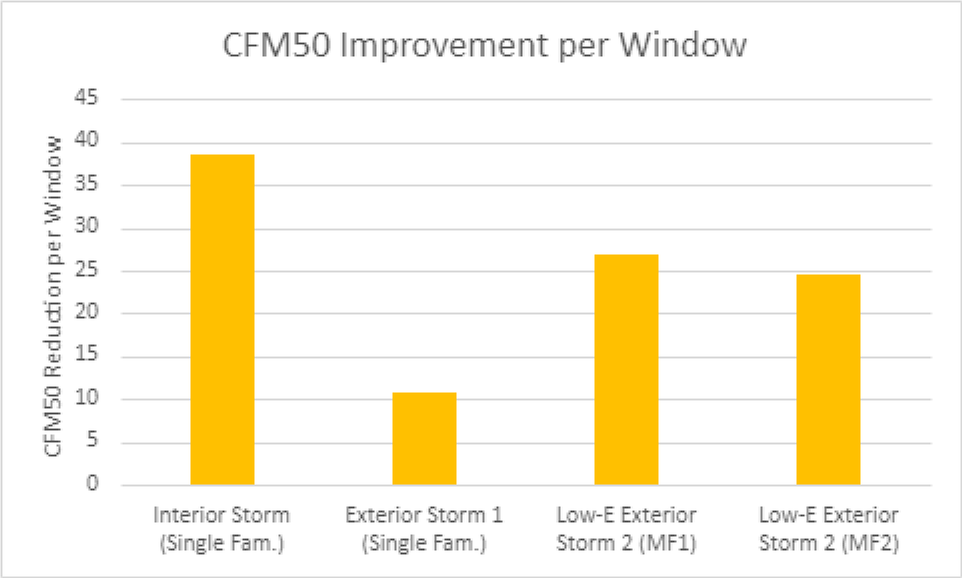
People want updated windows and storm windows provide an affordable option. Many people want to upgrade their windows but can't afford new windows. New, Low-E storm windows provide much of the benefit at a lower cost. They can significantly upgrade an aging and underserved building stock, with a particular focus on older homes, low-income housing, and rentals.

APPENDIX

Result charts from MN pilot. These charts are the graphical counterpart to Table 2.







Storm window pilot case studies

CEE Center for Energy and Environment

Interior Storm Windows as a Cost-effective Window Weatherization Option

Keller Brussow, Isaac Smith, Steve Sylvestre

Project Background

Center for Energy and Environment (CEE) partnered with Xcel Energy and Pacific Northwest National Laboratory (PNNL) to evaluate interior storm windows as an energy savings measure. Funding for this field testing was provided in part by the U.S. Department of Energy's Storm Window and Insulating Panel (SWIP) Campaign to develop cost-effective energy saving technologies. The home was selected through an energy audit as a candidate that could benefit from storm window improvement. New interior storm windows were installed in the home, which had old and leaky exterior storm windows estimated to be 30–50 years old. Unlike traditional window replacements, interior storm windows are custom-designed inserts that press into the room side of existing window frames. Because the inserts do not require additional hardware, they do not damage existing windows.

Benefits

In cold climates like Minnesota, exterior storm windows are commonly installed outside single- or double-pane primary windows. While they offer some insulation benefits, their effectiveness diminishes over time due to quality of installation and the breakdown of seals and gaskets. For many old windows, the energy lost from air leakage significantly surpasses the energy lost from conduction of heat through the window.

The installation of new interior storm windows improves window performance by adding a second air space inside the primary window and increases air tightness through gaskets around the perimeter of the product.

"…my heating bill has decreased, and **I can actually feel a difference** temperature-wise when comparing the old windows to the same windows with the Indow inserts."

– Bridget, Homeowner

House Details

Street: Polk Street

Manufacturer: Indow (interior storm windows)

Home sq. ft.: 3792

Window Count: 25

Glazed sq. ft.: 341

Pre-CFM50: 5162

Post-CFM50: 4200

CFM50 Reduction: 962

Air Leakage Reduction: **18.6%**

CFM50 Reduction/Window: 38

CFM50 Reduction/Window sq. ft.: **2.8**

Testing and Installation

Interior storm windows are installed inside a house within the frame of the existing window, creating an additional air space between the interior storm window and the existing primary window. For this project, the size of the window frame was precisely measured, and storm windows were installed with a flexible gasket around the entire perimeter. This ensures a snug press fit installation and tight air sealing once installed.

The old exterior storm windows were left in place so that after installing the interior storm windows, the total window construction had three panes, arranged as (from indoors to outdoors):
[new interior storm window – air space – primary window – air space – old exterior storm window]

To measure the change in performance of the house's windows, a blower door test was performed before and after installation of the interior storm windows. In this test, the front doorway is filled with a membrane and a large fan. Air was blown out of the house at a static pressure of 50 pascals, and the airflow volume was measured (CFM50) to calculate the level of whole-house air leakage.

Results

Before installation, the whole house had a relatively high CFM50 of 5162 for a 3792 sq. ft. home. After installation, the CFM50 was reduced by 962 to 4200, or an **18.6% reduction**. For comparison, a house that has professionally retrofitted wall or attic insulation can expect a typical leakage reduction of around 15%.

The homeowner noted a measurement time and installation time of 10–30 minutes per window. Additionally, they noted equivalent aesthetics when viewed from inside or outside, **improved clarity through the windows, improved thermal comfort near the windows, reduced condensation, and significantly reduced noise coming through the windows.** With no major renovation required, the homeowners were able to keep the historic, stained-glass features to preserve the home's style while maximizing comfort and efficiency.

The pilot study demonstrates how adding interior storm windows can be an effective retrofit in homes with poorly air-sealed windows. Following this project, Xcel Energy will conduct a thorough analysis of the energy savings and cost-effectiveness associated with the measure.

Learn more about our work at **rescampaigns.pnnl.gov/campaign/swip**.

Center for Energy and Environment

Exterior Storm Window as a Cost-Effective Window Weatherization Option

Isaac Smith, Steve Sylvestre

Project Background

Center for Energy and Environment (CEE) partnered with Xcel Energy and Pacific Northwest National Laboratory (PNNL) to evaluate replacement of exterior storm windows as an energy savings measure. Funding for this field-testing was provided in part by the U.S. Department of Energy's Storm Window and Insulating Panel (SWIP) Campaign to develop cost-effective energy saving technologies. The home was selected through an energy audit as a candidate that could benefit from storm window improvement. New exterior storm windows were installed in the home, replacing old and leaky exterior storm windows of assorted ages. The primary windows are estimated to be 80–100 years old.

Benefits

In cold climates like Minnesota, exterior storm windows are commonly installed outside single- or double-pane primary windows. While they offer some insulation benefits, their effectiveness typically diminishes over time due to the breakdown of seals and gaskets. For many old storm windows, the energy lost from air leakage is a significant portion of the total energy lost through the window.

The replacement of old storm windows improves window performance by adding air tightness via new gaskets around the perimeter of the product and better sealing for both fixed and operable storm windows. Some storm windows feature Low-E glass that helps control how much heat enters through the window, but the windows assessed in this home did not feature Low-E glass.

"So far, they **seem to be helping**. I'm interested in the data. I doubt that our old windows and new storms are as airtight as new high efficiency windows, but at a fraction of the cost **the new storm windows felt like a good value and step forward in our efforts to minimize natural gas use and impact on the environment.**"

– Steve, Homeowner

House Details

Street: Seymour Ave SE

Manufacturer: Mon-Ray

Home sq. ft.: 3,200

Window Count: 31

Glazed sq. ft.: 268

Pre-CFM50: ~3,350

Post-CFM50: ~3,000

CFM50 Reduction: 330

Air Leakage Reduction: **9.8%**

CFM50 Reduction/Window: 11

CFM50 Reduction/Window sq. ft.: **1.2**

ACH50 reduction: 0.8

CFM50 Reduction/ft. Window Perimeter: 0.9

Testing and Installation

The old storm windows were removed and replaced, but no other changes were made to the primary windows or building.

To measure the change in performance of the house's windows, a blower door test was performed before and after installation of the storm windows. For this test, the front doorway is mounted with a temporary frame built with a powerful fan used to measure the tightness of the house. Air was blown out of the house at a static pressure of 50 pascals, and the airflow volume was measured (CFM50) to calculate the level of whole-house air leakage.

Results

Before installation, the whole house had a relatively high CFM50 of approximately 3350 for a 3200 sq. ft. home. After installation, the CFM50 was reduced by 330 to approximately 3000, or a 9.8% reduction. For comparison, a house with professionally retrofitted wall or attic insulation can expect a typical leakage reduction of around 15%. Although the results are lower than other test sites included in the storm window study, which were closer to 15–20% air leakage reduction, it still demonstrated notable reduction.

The assessed brand of storm windows cost an average of $400 per window and were installed by the homeowner with no associated labor costs.

The homeowner noted it took less than 5 minutes to measure the window and around 10 to 30 minutes to install the insert. Additionally, they noted improved interior and exterior aesthetics, better thermal comfort near the window at night, less sound coming through the windows, and easier use of the new operable storm windows.

The pilot study demonstrates that replacing old, leaky storm windows results in notable air leakage improvements in homes with poorly air-sealed windows. Following this project, Xcel Energy will conduct a thorough analysis of the energy savings and cost-effectiveness associated with the measure.

Learn more about our work at **www.etamn.org/high-performance-windows**.

Exterior Storm Window as a Cost-Effective Multifamily Weatherization Option

Center for Energy and Environment

Improving Multifamily Air Leakage with Exterior Storm Windows

Keller Brussow, Katie LeBlanc, Isaac Smith, Steve Sylvestre
2024-09-10

Project Background

Center for Energy and Environment (CEE) partnered with Xcel Energy and Pacific Northwest National Laboratory (PNNL) to evaluate replacement of exterior storm windows as an energy savings measure. Funding for this field-testing was provided in part by the U.S. Department of Energy's Storm Window and Insulating Panel (SWIP) Campaign to develop cost-effective energy saving technologies. The building was selected through an existing multifamily program as a candidate that could benefit from storm window improvement. New exterior storm windows were installed in the home, replacing old and leaky exterior storm windows of assorted ages. The primary windows are estimated to be 60+ years old.

Benefits

In cold climates like Minnesota, exterior storm windows are commonly installed outside single- or double-pane primary windows. While they offer some insulation benefits, their effectiveness typically diminishes over time due to the breakdown of seals and gaskets. For many old storm windows, the energy lost from air leakage is a significant portion of the total energy lost through the window.

The replacement of old storm windows improves window performance by adding air tightness via new gaskets around the edges of the product and better sealing for both fixed and operable storm windows. Some storm windows, like those used for this multifamily pilot, feature Low-E glass that helps control how much heat enters through the window.

> Working with CEE and Qunta Panel on the installation… was a **seamless experience**…. Quanta Panel would be my **first recommendation** to any of my customers looking for new storm windows.
>
> *– Sean, General Contractor*

House Details

Street: 15th Ave S

Manufacturer: Quanta

Home sq. ft.: 4,300

Window Count: 55

Glazed sq. ft.: 600

Pre-CFM50: 7,850

Post-CFM50: 6,375

CFM50 Reduction: 1,484

Air Leakage Reduction: **18.9%**

CFM50 Reduction/Window: 27

CFM50 Reduction/Window sq. ft.: **2.5**

CFM50 Reduction/ft. Window Perimeter: 1.9

Testing and Installation

The old storm windows were removed and replaced, but no other changes were made to the primary windows or building.

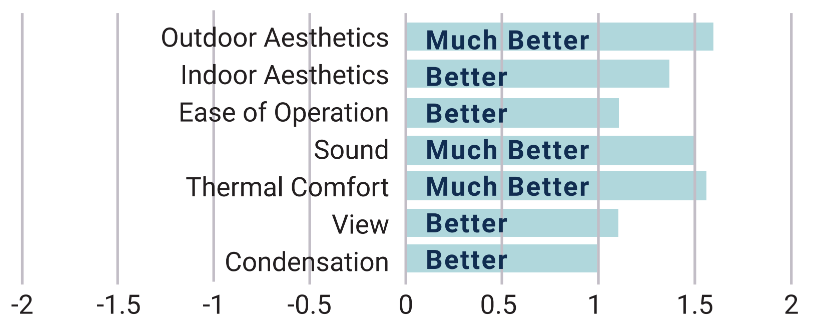
To measure the change in performance of the house's windows, a blower door test was performed before and after installation of the storm windows. For this test, the front doorway is mounted with a temporary frame built with a powerful fan used to measure the tightness of the house. Air was blown out of the house at a static pressure of 50 pascals, and the airflow volume was measured (CFM50) to calculate the level of whole-house air leakage.

Results

Before installation, the whole house had a notable CFM50 measurement of approximately 7850 for a 4300 sq. ft. home. After installation, the CFM50 was reduced by 1484 to approximately 6375, or an 18.9% reduction,the largest result in this study. For comparison, a house with professionally retrofitted wall or attic insulation can expect a typical leakage reduction of around 15%.

The assessed brand of storm windows cost an average of $200 per window and were installed by a contractor at approximately $75 per window. Despite the contractor not having installed storm windows before this project, they delivered a significant level of air sealing improvement. Homeowners that participated in the pilot were surveyed on their experience of the product after installation on a scale from −2 to +2 (much worse to much better).

Resident Experience After Storm Window Install



The pilot study demonstrates that replacing old, leaky storm windows results in notable air leakage improvements in homes with poorly air-sealed windows. Following this project, Xcel Energy will conduct a thorough analysis of the energy savings and cost-effectiveness associated with the measure.

Learn more about our work at **rescampaigns.pnnl.gov/campaign/swip**

Exterior Storm Window as a Cost-Effective Multifamily Weatherization Option

Center for Energy and Environment

Building Owner Perspective—Exterior Storm Windows

Keller Brussow, Katie LeBlanc, Isaac Smith, Steve Sylvestre

2024-09-10

Project Background

Center for Energy and Environment (CEE) partnered with Xcel Energy and Pacific Northwest National Laboratory (PNNL) to evaluate replacement of exterior storm windows as an energy savings measure. Funding for this field-testing was provided in part by the U.S. Department of Energy's Storm Window and Insulating Panel (SWIP) Campaign to develop cost-effective energy saving technologies. The home was selected through an energy audit as a candidate that could benefit from storm window improvement. New exterior storm windows were installed in the home, replacing old and leaky exterior storm windows of assorted ages. The primary windows are estimated to be 60+ years old.

Benefits

In cold climates like Minnesota, exterior storm windows are commonly installed outside single- or double-pane primary windows. While they offer some insulation benefits, their effectiveness typically diminishes over time due to the breakdown of seals and gaskets. For many old storm windows, the energy lost from air leakage surpasses the energy lost from conduction of heat through the window.

The replacement of old storm windows improves window performance by adding air tightness via new gaskets around the edges of the product and better sealing for both fixed and operable storm windows. Some storm windows, like those used for this multifamily pilot, feature Low-E glass that helps control how much heat enters through the window.

"The tenants mostly of modest means saw a noise reduction and a increase of natural light and saw **significant saving on utility bills.** The buildings themselves saw an enhanced curb appeal and were more efficient as a result. So **I can say without a doubt that this was a success** and I'm glad I participated in the pilot program and look forward to more."

–Nate, Multi-family Building Owner

House Details

Street: 34th St E

Manufacturer: Quanta

Home sq. ft.: 1,900

Window Count: 29

Glazed sq. ft.: 259

Pre-CFM50: 4,400

Post-CFM50: 3,700

CFM50 Reduction: 713

Air Leakage Reduction: **16.2%**

CFM50 Reduction/Window: 25

CFM50 Reduction/Window sq. ft.: **2.8**

CFM50 Reduction/ft. Window Perimeter: 2.0

Testing and Installation

The old storm windows were removed and replaced, but no other changes were made to the primary windows or building.

To measure the change in performance of the house's windows, a blower door test was performed before and after installation of the storm windows. For this test, the front doorway is mounted with a temporary frame built with a powerful fan used to measure the tightness of the house. Air was blown out of the house at a static pressure of 50 pascals, and the airflow volume was measured (CFM50) to calculate the level of whole-house air leakage.

Results

Before installation, the whole house had a significant CFM50 of approximately 4400 for a 1900 sq. ft. home. After installation, the CFM50 was reduced by 700 to approximately 3700, or a 16.2% reduction. For comparison, a house with professionally retrofitted wall or attic insulation can expect a typical leakage reduction of around 15%.

The assessed brand of storm windows cost an average of $200 per window and were installed by a contractor at approximately $75 per window. Despite the contractor not having installed storm windows before this project, they delivered a significant level of air sealing improvement.

The building owner provided a quote on their overall experience with the storm windows, saying:

"I'm born and raised in Minneapolis. I have worked with several programs in conjunction with the city and the Green Cost Share initiative.

Recently I have worked with Grant Carlson and Steve [Sylvestre] and both of these gentlemen have been great to work with, and the programs and departments they represent have been excellent. I was the recipient of storm windows through a CEE pilot program in Minneapolis and **had an exceptional experience. The tenants mostly of modest means saw a noise reduction and a increase of natural light and saw significant saving on utility bills.** The buildings themselves saw an enhanced curb appeal and were more efficient as a result. So **I can say without a doubt that this was a success** and I'm glad I participated in the pilot program and look forward to more."

In this pilot study, replacing old, leaky storm windows was a favorable retrofit for the building owner to address air sealing in multifamily buildings with poorly air-sealed windows. Following this project, Xcel Energy will conduct a thorough analysis of the energy savings and cost-effectiveness associated with the measure.

Learn more about our work at **rescampaigns.pnnl.gov/campaign/swip**