Performance Comparison of a Low-E Storm Window in a Philadelphia Multifamily Apartment Building

Prepared For:
Quanta Technologies, Inc.
5 Great Valley Parkway, Suite 349
Malvern, PA 19355

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Prepared By:
Home Innovation Research Labs, Inc.
400 Prince George's Boulevard
Upper Marlboro, MD 20774

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Background

Controlling rising energy costs in older multistory, multifamily buildings can take various pathways such as envelope or equipment improvements. Equipment upgrades, such as the use of high efficiency motors or boilers can result in reduced energy costs. However, for older building envelopes with low wall insulation levels and window technologies with high U-factors, the efficiency gains from equipment improvements may be hindered. While the equipment may be more efficient, the discomfort of the occupants in inefficient buildings often leads to increased energy use (e.g., supplemental heaters). Furthermore, the equipment upgrades in older buildings must be sized to service the same loads whereas in more efficient envelopes, the equipment upgrades can be sized smaller thus saving upfront costs as well as ongoing fuel costs.

Envelope upgrades; however, can be very expensive for building owners. Envelope upgrade costs may include not only the installation of new materials, but also include removal and disposal of old materials and displacement of occupants during renovations.

Addressing these concerns for envelope upgrades, an innovative storm replacement window technology has been installed to decrease the window U-factor, add a low-E coating, and reduce air infiltration. The storm window retrofit was performed on two large three-story residential multifamily apartment buildings located in downtown Philadelphia, Pennsylvania on West Girard Avenue (Figure 1). The buildings were constructed in 1962 with 101 apartment units using 4,720 ft^2 of single-pane, metal-framed windows with attached single-pane, triple track, clear glass storm windows. During this retrofit, it was noted that many of the existing storm windows were not functioning properly, broken, or missing.

The purpose of the window upgrade was to reduce operating energy costs, increase the comfort of the occupants, and provide a more uniform interior temperature that does not rely on use of supplemental heating units. The window upgrade technology selected is a new low-E storm window. The storm window retrofits are performed from the exterior; therefore, the occupants are not displaced during the renovation process.

Modern low-E exterior storm windows were provided for the window upgrades by Quanta Technologies Inc. Upgrading the existing metal frame single-pane windows with the low-E storm window; the new combined window system is estimated to have an approximate U-factor of 0.44[1] and a solar heat gain coefficient (SHGC) of 0.48. The original single-pane windows are estimated to have a U-factor of 1.12 and SHGC of 0.61, and a U-factor of approximately 0.58 and a SHGC of 0.56 with the old clear glass exterior storms. As a result, the new low-E storm windows lower the U-factor by 61 percent compared to the single-pane primary window, and 24 percent compared to the single-pane window with the older traditional storm window. In both cases, the storm windows were attached to surrounding wood trim to ensure a thermal break with no direct metal-to-metal contact. Additionally, the new low-E storm windows were expected to reduce air infiltration compared to the older leakier windows. This effect was measured as described below.

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[1] All U-factors are in $Btu/hr{\cdot}°F{\cdot}ft^2$

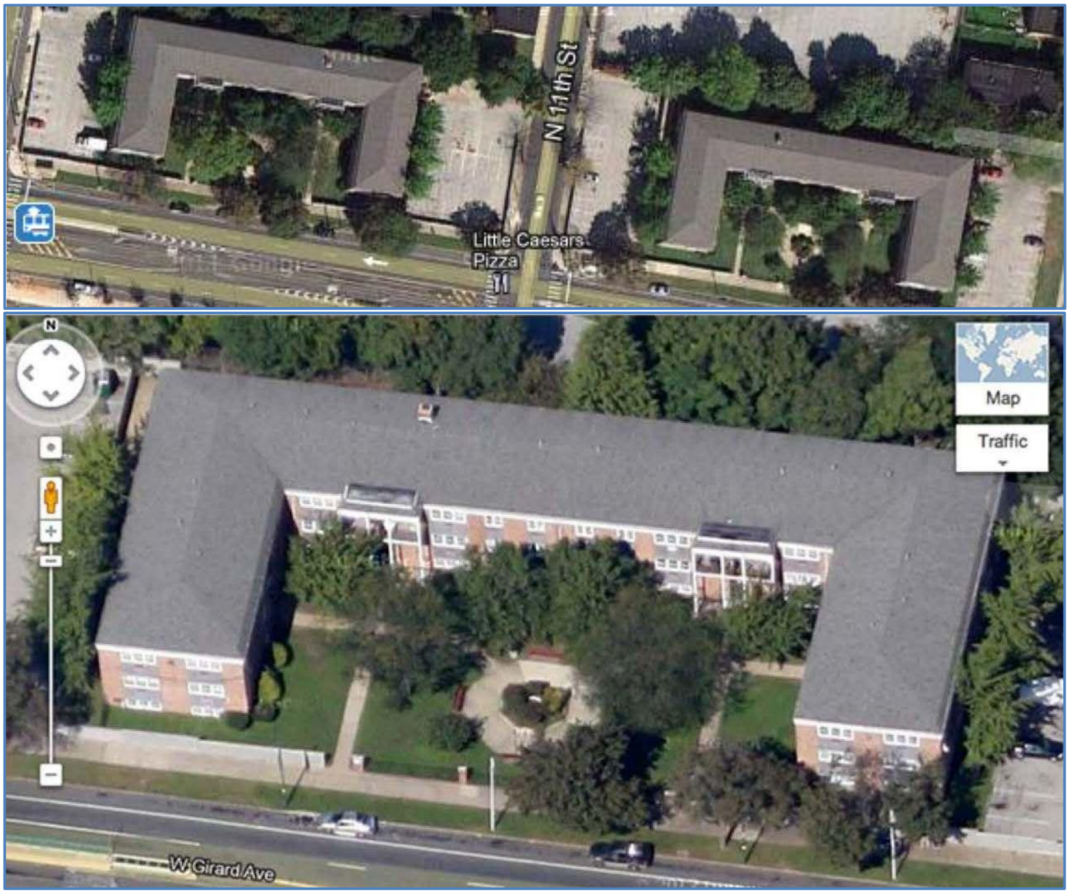

Figure 1. Multifamily Apartment Buildings Upgraded with Low-E Window Retrofit Panels

Test and Analysis Methodology

Improvements in the energy performance were assessed in two ways: blower door tests on representative apartment units to measure air infiltration reductions; and analysis of the utility bills for one of the two buildings.

For the blower door tests, 15 percent of the dwelling units were chosen for the study (15 units). For the best diversification they were located on any of the three floors, and also included studio, one, and two bedroom layouts.

Each of the units was tested for infiltration leakage with the existing storms both open and closed. After the new storms were installed, the infiltration tests were performed again to quantify the leakage reduction attributed to the new low-E storm windows. The testing was performed at 50 Pa air pressure difference.

To better approximate the whole building performance, the building's utility bills for the preceding year and the year following the window retrofit were analyzed to calculate actual savings. However, the analysis is limited by changing building occupancy and weather patterns from year to year and thus serves only as a marker of energy savings. The benefit of the utility bill analysis is to generally confirm the savings based on the test study and to generally estimate a magnitude of the savings that can be realistically expected from the window retrofits.

Monitoring Results

Infiltration Testing

Infiltration testing on individual apartments was performed at multiple points in the project. Perhaps surprisingly, initial infiltration data indicates that the reduction in air leakage from the existing storms was not measurable – the older triple-track storm windows showed no significant improvement in air leakage between when they were closed and open. Following the installation of the new low-E storm windows, infiltration measurements were again taken with the storm windows open and with the storm windows closed. The main windows were closed and latched in both cases (where latching was feasible). Figure 2 compares the result of the infiltration testing for each unit. The infiltration testing was performed at 50 Pa of pressure difference from the apartment to the outside using a depressurization methodology. The test metric is cubic feet per minute at the test pressure (CFM50) and is the total leakage from the apartment.[2]

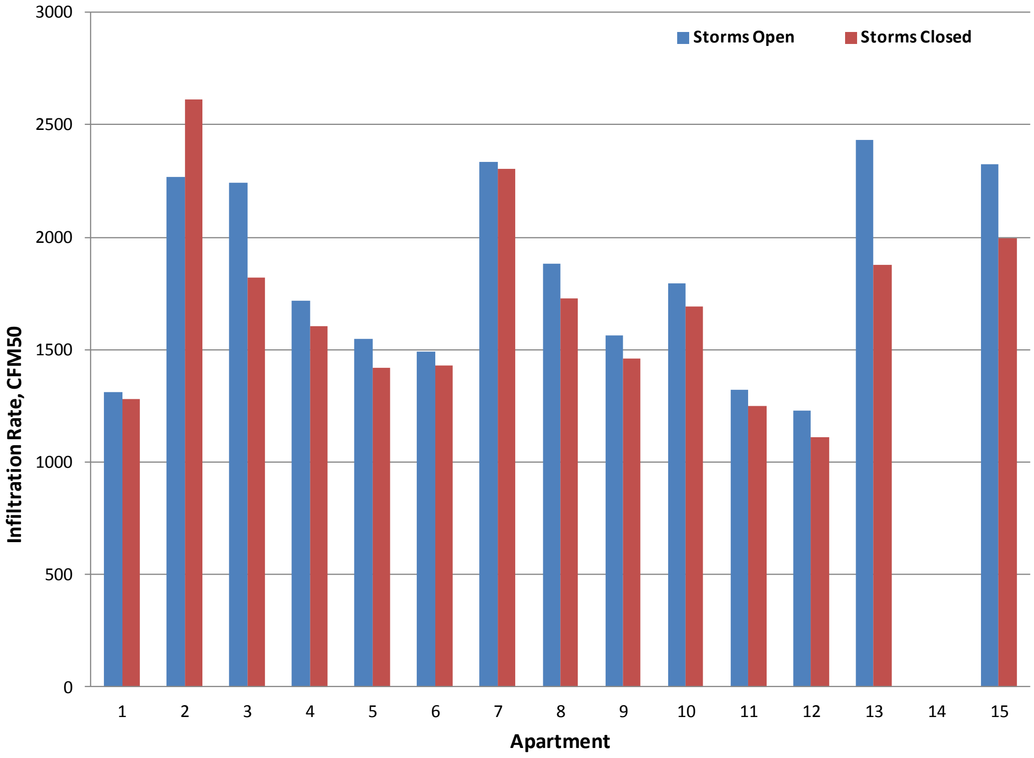

Figure 2. Post Retrofit Air Leakage Measurements with Low-E Storms Opened and Closed

When evaluating the change in the air exchange rate and the change resulting from the installation of the storm windows, unit 2 data is excluded due to the anomaly of an increasing level with the storms closed.[3] Unit 14 is also excluded as it was not available for testing on the appointed test date. The remaining units show a 10 percent reduction overall in the overall apartment air infiltration rate with a range of 1 percent to 23 percent reduction across all units. This is an average reduction of 3.2 CFM50 per square foot of window area. It is important to note that this 10 percent reduction in air infiltration for the overall apartment test units was solely from adding the new low-E storm windows; no other air sealing measures were applied.

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[2] Total leakage includes leakage to the outside and to adjacent units. Isolation of one apartment to determine solely leakage from the unit to the exterior was not feasible in the occupied building.

[3] It is unknown at this time the cause of the anomalous result for unit #2.

Whole Building Gas Utility Usage

The primary metric to quantify the benefit of the retrofit storm windows is energy consumption. Analysis of the monthly utility bills for fuel use for pre- and post-retrofit conditions assumes that the window upgrades are the primary change in the building operation that accounts for the energy consumption differences across the two heating seasons. Changes in outdoor temperature, the primary driver for heating energy use, are accounted for through a normalization of the consumption data of the heating degree days for the same month period. Temperature set points, occupancy levels, and window operation during heating periods are important factors but are not available in sufficient detail to qualify the summary results.

Heating energy was estimated for a period from October through April. The heating period was selected where there would be the least crossover between heating and window use or cooling system operation. Figure 3 shows the total monthly estimated gas use for heating plotted with the heating degree days for the month.

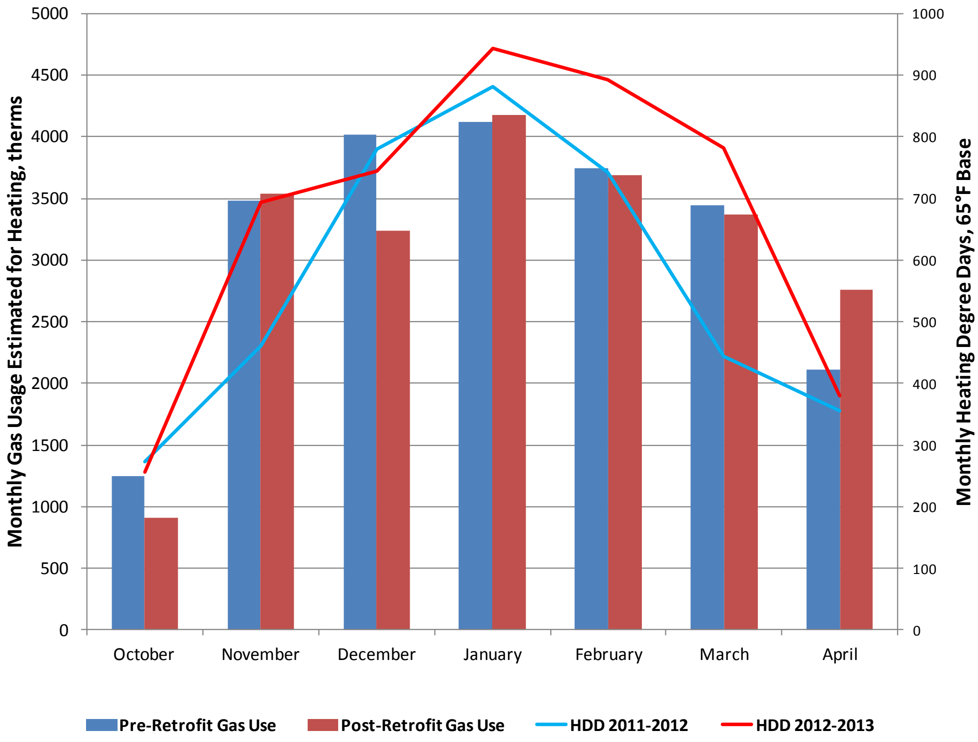

Figure 3. Monthly Estimated Heating Gas Use and Heating Degree Days

The heating energy was estimated by subtracting the estimated gas use for water heating from the June and September monthly billing periods. These periods were selected based on the few heating degree days and the slightly cooler incoming water temperatures that may better represent the energy used for water heating.

Based on the estimated fuel use for heating and the heating degree days, the fuel use is normalized to the heating degree days. This approach is considered valid if the interior temperature is assumed fairly consistent for each apartment over the analysis period. Figure 4 shows the normalized use for comparison of the pre- to post-retrofit heating periods.

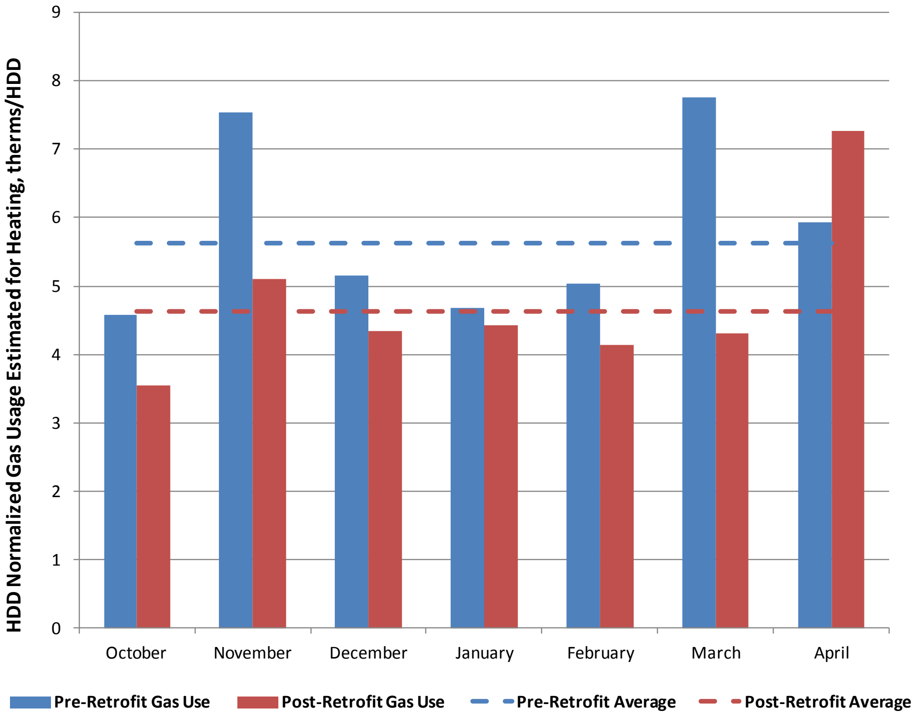

Figure 4. Monthly Normalized Heating Gas Use for Low-E Storm Window Pre- and Post-Retrofit

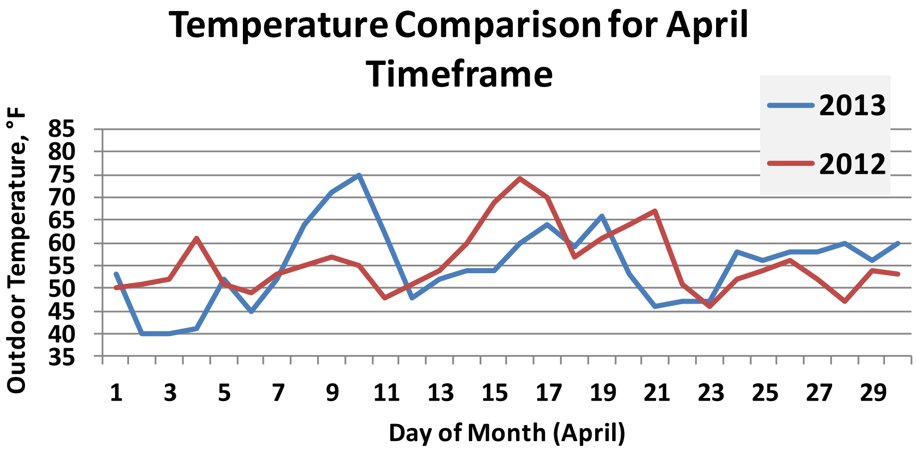

Figure 5. Temperature Comparison for April

Heating energy was reduced by about 1 therm per heating degree day over the seven-month period, or about an 18 percent reduction. If a narrower window for heating is used from November through March, then the energy use is reduced by about 1.25 therms per heating degree day or approximately 22 percent energy savings. It is not specifically known the cause of the April energy use to be higher after the storm windows were installed; however, one indicator is that a warm spell occurred earlier in the month 2013 (see Figure 5) where many residents may have opened the windows (including the storms) and then left the storms opened when the weather turned colder later in the month.

The gas use for heating is affected by both the imprecise temperature control for each apartment and the occupant operation of the windows. It is expected that with changing outdoor temperatures and an imprecise control over the heating supply to the apartment, that the windows might be used to help control large temperature extremes. If this is the case, then the full benefit of the storm windows may be dampened. Table 1 shows the overall energy use and estimated savings based solely on utility bill data.

Table 1. Energy Use Comparison Based on Monthly Utility Billing

Heating	October 2011 to April 2012 [A]	October 2012 to April 2013 [B]
Heating Degree-Days, HDD	3,938	4,693
Heating Gas Use [C], therms	22,167	21,692
Normalized Gas Use, therms/HDD	5.63	4.62
Heating Savings Over Base		18%
Heating	**November 2011 to March 2012 [A]**	**November 2012 to March 2013 [B]**
Heating Degree-Days, HDD	3,309	4,058
Heating Gas Use [C], therms	18,808	18,023
Normalized Gas Use, therms/HDD	5.68	4.44
Heating Savings Over Base		22%

[A] Pre-window retrofit
[B] Post-window retrofit.
[C] Heating Gas Use estimated by subtracting estimated hot water gas use in non-heating swing months.

Individual Unit Electric Utility Usage

Many of the apartments have through the wall air conditioning units. It is not known how often the units are employed or the interior set point temperature for the A/C units. Given the uncertainty of the data, an estimate of cooling energy use is made by comparing the summertime energy use with a swing season electricity energy use. This methodology assumes that the electric energy use for lighting, appliances, and miscellaneous use in the summer months is no more than that in the swing seasons. Figure 6 charts the average electricity use for the test apartments and the estimate for cooling energy for the pre- and post-retrofit low-E storm windows. It appears that with a similar cooling demand (based on cooling degree days) for each year, there is a distinct reduction in electricity use (the darker bars represents the total electricity use and the lighter shaded overlay column is the estimated electricity used for cooling).

Normalizing the cooling electricity to cooling degree days attempts to adjust the electricity use for air conditioning based on the weather conditions. Figure 7 graphically shows this analysis.

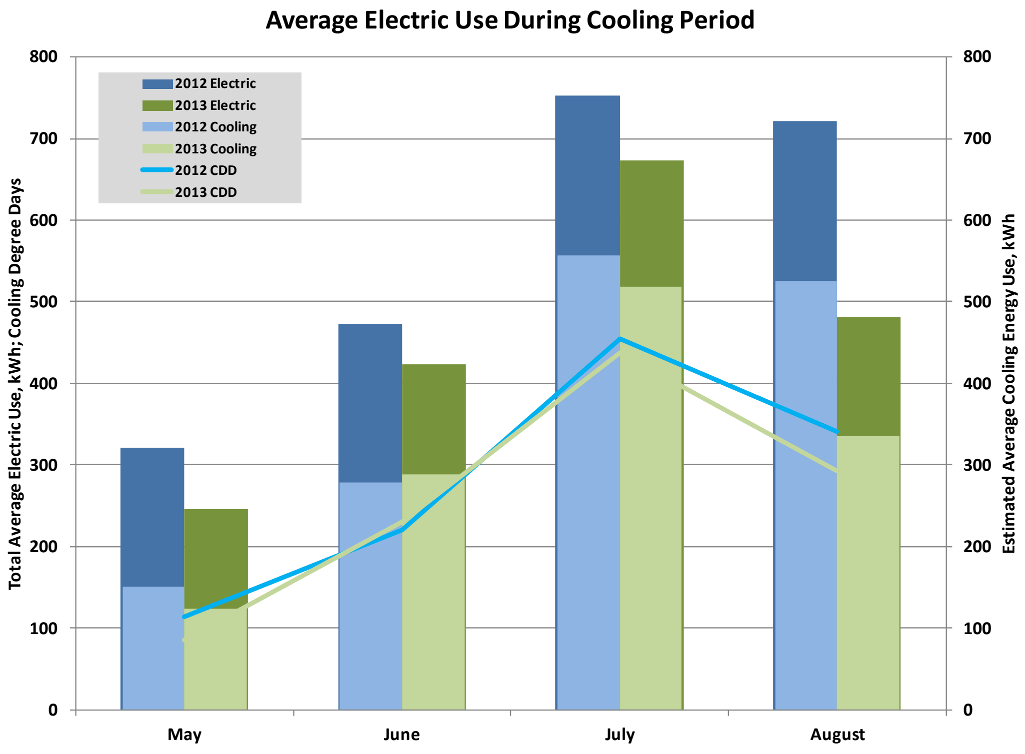

Figure 6. Average Unit Electricity and Estimated Cooling Electricity Use for Summer Months

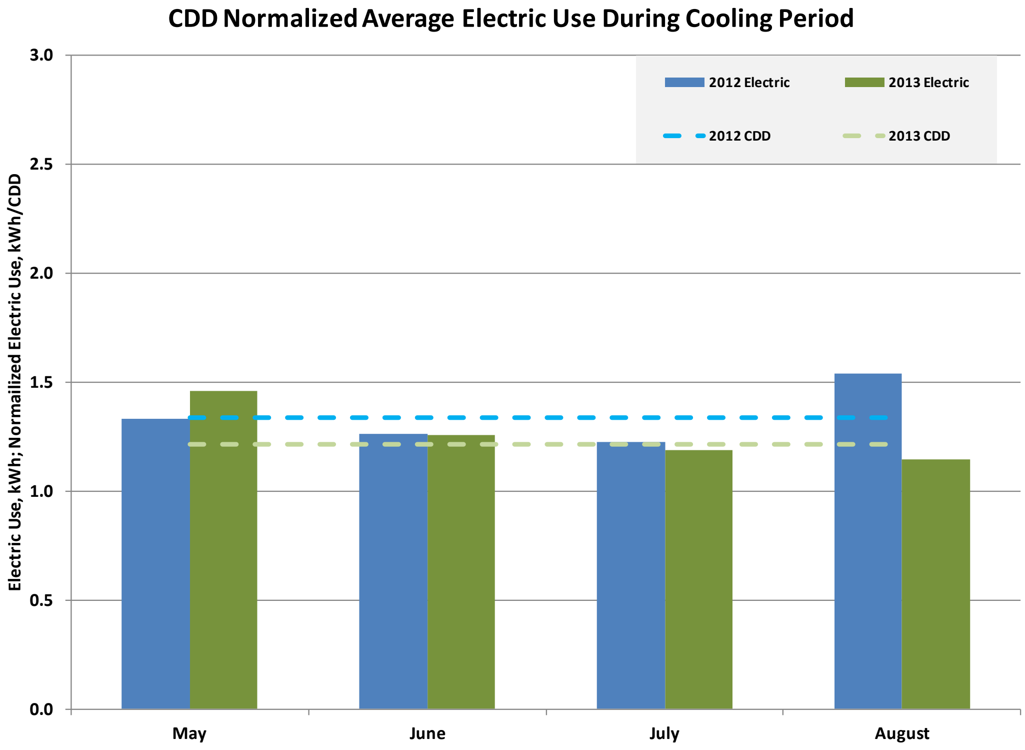

Figure 7. CDD Normalized Estimated Average Cooling Electricity Use

Summarized in tabular form (Table 2), the summertime electricity use for four cooling months shows just over 9 percent electricity savings on average.

Table 2. Cooling Electricity Use Estimates

Cooling Month	Apartment Average Electric Use[A], kWh		Estimated Cooling Electric Use, kWh		CDD[B] Normalized, kWh/CDD		Post- to Pre-Retrofit Savings[C]
	2012	2013	2012	2013	2012	2013	
May	322	245	151	124	1.33	1.09	18.0%
June	474	424	278	289	2.45	2.54	-3.8%
July	752	673	557	519	4.90	4.57	6.7%
August	721	482	526	335	4.63	2.95	36.3%
Month Average Total	2,269	1,824	1,512	1,267	1.34	1.21	9.3%

[A] Only non-zero meter values (occupied apartments) included.
[B] CDD = Cooling Degree Days, 65°F base.
[C] Savings based on normalized energy use.

Whole Building Simulation Estimates

An initial software analysis was used to translate the performance results of upgrading the storm windows in 10 to 15 apartments to the larger building complex of 100 units. Due to the relatively minimal amount of information available for each of the apartments, the analysis utilized a software tool that is commonly applied to existing homes, including multifamily buildings, that has internal defaults for energy use of non-space conditioning loads. The software, REM/Rate version 14.2[4], was used to model the whole building using an average size for all of the apartments.

The software analysis focused on two improvements afforded by the upgrade to the low-E storm windows. One is the reduced infiltration outlined above, and the second is the improved (lower) U-factor and lower solar heat gain coefficient based on estimated values (refer to the Background section above). The purpose of the analysis is to estimate the annual energy savings resulting from using the upgraded storm windows.

As the software analysis relies on a number of estimated factors, the model was calibrated using actual whole building meter data for gas (the only meter data available for this purpose). Following the calibration to within about 4 percent (higher predicted than measured), the air infiltration rate was decreased by 10 percent consistent with the reported average reduction following the storm window installation. The overall window characteristics, including the existing window and the existing storm baseline was 0.64 U-factor and 0.54 solar heat gain coefficient (SHGC). Following the low-E storm window upgrade these values were modified to 0.44 U-factor and 0.48 SHGC.

Assuming that the average energy use of all apartment gas and electric loads is somewhat represented by the software estimates, the heating energy is extracted for comparison since the low-E storm window upgrades will reduce this end load consumption. The results are outlined in Table 3 and are reported to compare the energy savings individually for the change in infiltration rates and window characteristics.

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[4] www.archenergy.com/products/remrate

Table 3. Heating Energy Software Analysis

	Heating Energy, therms	Percent Savings over Base
Baseline	7,990	-
Infiltration Improvement	7,055	11.7%
Low-E Storm Window Improvement	7,296	8.7%
Combined Infiltration and storm window improvements	6,639	20.3%

Given the much larger uncertainty for cooling energy and the lack of interior temperatures during the cooling season, only a rough estimate of the cooling energy savings can be provided based on simulation results. These savings are only representative of general trends and should not be used as firm estimates of cooling energy savings unless it is known that the apartment is fully conditioned for cooling throughout the season. The summary results similar to the heating results are shown in Table 4.

Table 4. Cooling Energy Software Analysis

	Cooling Energy, kWh	Percent Savings over Base
Baseline	157,562	
Infiltration Improvement	158,224	-0.4%
Low-E Storm Window Improvement	130,854	17.0%
Combined Infiltration and storm window improvements	132,084	16.2%

The software simulation results align with the measured heating savings and therefore a reduction in fuel use for heating of at least 20 percent may be expected. However, this result is dependent on the control of the heating supply to individual apartments and the consistent use of the storm windows – both factors that are considered highly variable in this building.

The software results for cooling energy use are less definitive to predict actual energy savings; however, should the storm windows be consistently employed and with a somewhat consistent use of the cooling equipment, electric energy savings of over 15 percent may be expected.

Conclusions

Replacement of the existing storm windows in two large multifamily buildings with 101 units was evaluated for improvements in air leakage and heating gas and electric consumption. The existing clear single-glazed metal windows and clear single-glazed storm windows were upgraded to remove the existing storms and replaced with new low-E storm windows. The improvement in the combined window U-value is estimated to be approximately 0.14 U-factor lower than the original windows (0.58 to 0.44 Btu/hr·ft^2·°F). The solar heat gain coefficient was estimated to be reduced by about 0.08 (0.56 to 0.48).

As a result of the storm window upgrades, the air infiltration analysis shows a 10 percent reduction in overall apartment air infiltration on average across the units. The improved air tightness of the windows along with the low-E glazing is expected to improve the comfort of the occupants, especially near the windows on cold winter days.

An initial utility bill analysis, which includes all units in the building and the common areas, indicates that an 18 percent gas use reduction for the heating season (which includes the transition months of October and April). When evaluating the specific heating period of November through March, the more focused analysis shows a 22 percent reduction in energy use. A software analysis shows an approximate 20 percent heating energy savings over a full typical heating season. It can be expected that based on the first winter following the storm window upgrade, the heating system operation may be further optimized in the swing seasons when the system is being activated or deactivated.

Cooling energy savings was estimated to be approximately 9 percent when normalized to the cooling degree days for each test period. However, the software analysis shows a slightly higher savings of approximately 15 percent over the full cooling season. This difference between the model and real life is expected due to the expected inconsistent use of individual cooling equipment and indoor temperature set points for cooling.

Analysis of ongoing utility costs and a review of the heating (and cooling) equipment operation with building engineers are recommended to fully understand the benefits of the window upgrades.

Further support to the occupants providing direction on the use of the storm windows, the control of the heating supply to the apartment, and for a modified control of the central heating system by the plant manager, would all contribute to further increased energy savings afforded by the low-E storm window replacement.

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