

Insulated Siding as Home Insulation



Insulated Siding Energy Performance Study



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About the Authors

This research project was conducted by Newport Ventures of Schenectady, New York. Newport Ventures performs technical, regulatory and market research and analysis related to the built environment, with a specific focus on the energy performance of buildings and building systems.

Executive Summary

Traditionally, insulation for wall assemblies has been installed either within wall cavities or between the structural components of a wall (e.g., framing/sheathing) and the exterior cladding. Insulated siding, which combines the functionality of siding with the thermal properties of insulation in one integrated assembly, has emerged as a complementary product to traditional insulation for above-grade wall assemblies.

Insulated siding is a vinyl cladding with manufacturer-installed rigid foam plastic insulation that is laminated or otherwise permanently attached to the cladding product.

The thermal resistance rating, or R-value, of insulated siding is developed through a standard test that is specified by the Federal Trade Commission (FTC) in the *Code of Federal Regulations* (16 C.F.R. 460). The test¹ specified by FTC, and referenced in ASTM D7793, *Standard Specification for Insulated Vinyl Siding*, is intended to simulate the performance of insulated siding under real-world conditions, and to provide consumers with realistic R-values for the product. While an R-value is a useful metric for comparing thermal performance across insulation products (with higher R-values representing greater energy savings), more analysis is required to evaluate the effects of an individual product on the energy performance of a home.

This study was conducted to determine insulated siding's effect on the energy performance of existing single-family homes under real-world conditions, with a focus on building air tightness and heating energy use as a function of outdoor temperatures.

Within this study, five insulated siding products from several different manufacturers were installed on five single-family detached homes in five cities spanning three climate zones. For each home, the existing siding was first removed, a water-resistive barrier was installed, and finally the new insulated siding was installed. The five insulated siding products installed had R-values that ranged from R-2.0 to R-2.7.

Building Air Tightness Improvements

Prior to the installation of the insulated siding, energy audits were conducted on each home to identify values for key energy performance metrics (e.g., airtightness testing, insulation levels, size, equipment efficiency, etc.). Air tightness testing was conducted three times for each home to identify the homes' air tightness: prior to the remodel; after the existing siding was removed and the water-resistive barrier was installed; and then after the insulated siding was installed. Results showed an average air tightness improvement of 11 percent across the five homes after the insulated siding was installed.

¹ ASTM C1363, *Standard Test Method for the Thermal Performance of Building Materials and Envelope Assemblies*.

Infrared Imagery

Pre-insulated siding and post-insulated siding infrared images of the above-grade walls on four of the homes were also taken to gauge the qualitative effect of the insulated siding on reducing the thermal bridging of the wood framing within the walls. The infrared images for two of these sites were disregarded because the outdoor ambient temperature happened to be higher while the post-insulated siding images were taken. Higher outdoor temperatures result in less accentuation of the thermal bridging effect, which could be misconstrued as a benefit of the insulated siding. Of the two homes that had lower outdoor temperatures during the post-insulated siding image collection, both visually appeared to have a slight reduction in the thermal bridging after the insulated siding was installed.

Heating Energy Analysis

The impact of insulated siding on heating energy use was evaluated. Utility bills for two years prior and two years following the installation of insulated siding on the five homes were collected and analyzed for differences in heating energy use. Occupancy remained the same during pre- and post-retrofit periods, and homeowners were asked to maintain thermostat settings as they had been prior to the retrofit. Utility bill data were normalized and reported on a Therms-per-heating-degree-day basis in order to account for temperature differences from year to year. Average monthly temperature for each billing period was used for each particular site.

Analysis of pre- and post-retrofit utility bill data showed energy savings at all five sites. Savings ranged from 1 percent in Indiana to 11 percent in Colorado.² Average savings were 5.5 percent. In addition to actual energy and dollar savings, some of the homeowners commented on the fact that their homes felt more comfortable. Areas that had been cool or drafty prior to the retrofit were no longer uncomfortable.

² Although energy savings were observed in all five homes in the study, the results for only one of the homes were statistically significant (the Colorado home that showed 11 percent savings).

Introduction

With escalations and instability in energy prices, and concerns about the environmental impact of energy use, increasingly greater emphasis has been placed on the energy performance of residential buildings. Whether by policymakers, builders, contractors, or homeowners, demand for innovative, energy-efficient buildings and products is increasing, and insulated siding is one such product.

Insulated siding is a siding material that is engineered to incorporate a substantial thickness of insulation. More specifically, insulated vinyl siding is a vinyl cladding with manufacturer-installed rigid foam plastic insulation that is laminated or otherwise permanently attached to the cladding product. Although insulated siding has been commercially available since 1997, product developments have increased its recognition as a premium residential cladding that improves a building's thermal performance.³

Due to its ability to reduce thermal bridging, insulated siding has been recognized by the U.S. Environmental Protection Agency as a building product that can help qualify homes under ENERGY STAR® Qualified Homes Version 3.⁴ The International Code Council has also recognized insulated siding among the building materials that can be used outside of the building framing to provide the required total wall R-value for buildings in cold climate zones, according to the 2012 *International Energy Conservation Code (IECC)*.⁵ In 2012, ASTM D7793 *Standard Specification for Insulated Vinyl Siding* was released to provide standardized guidance for material and thermal properties of insulated vinyl siding. While insulated siding is being increasingly recognized for its insulating benefits in new residential construction, less is known about its performance in existing construction.

The objective of this study was to provide a real-world performance evaluation of insulated siding when retrofitting existing homes. Particular attention was given to quantifying building air tightness and heating energy use as a function of outdoor temperatures, before and after the installation of the insulated siding. The study covered the installation of five insulated siding products from several manufacturers on five single-family detached homes in five cities spanning three climate zones. For each home, the existing siding was first removed, a water-resistive barrier was installed, and finally the new insulated siding was installed. The five insulated siding products installed had R-values that varied from R-2.0 to R-2.7, as shown in Table 2.

HERS Index calculations were based on building energy simulations, on-site audits and diagnostic testing (including building leakage measurements), product R-value ratings, and

³ Vinyl Siding Institute, *Insulated Siding as Home Insulation: Guide for Users and Energy Raters*, January 2011.

⁴ U.S. Environmental Protection Agency, *ENERGY STAR Qualified Homes Version 3 (Rev. 03) Inspection Checklists for National Program Requirements*, March 25, 2011.

⁵ International Code Council, *2012 International Energy Conservation Code*, 2011.

thermal imagery. Utility bill data were also collected to compare heating season natural gas energy use between the pre-retrofit and post-retrofit cases.

Selecting the Homes

At the outset, four homes were chosen to retrofit with insulated siding for the study. One year later, a fifth home was added when funding became available under the U.S. Department of Energy's (DOE's) Building America Program. Homes were selected to be fairly representative of existing wood-framed, single-family detached construction containing some level of insulation (e.g., cavity insulation of R-11 to R-19 with continuous foam board insulation of R-2.5 to R-3.0 at two sites). All sites were selected to provide a wide geographic distribution across cold climate zones (IECC climate zones 4, 5, and 6 in Colorado, Indiana, and Maryland and two sites in New York). Four homes employed natural gas-fired furnaces for heating; one home used a propane-fired hot water boiler. In order to facilitate the analysis of utility bill data, homes were screened to exclude those with large natural gas loads that were in addition to heating and water heating (e.g., no homes with gas-fired pool or hot tub heaters were included). Homes that used wood fireplaces more than occasionally were also excluded from the study.

Because utility bills were to be collected two years prior to and two years following the insulated siding installation, candidate homes were rejected if they had any significant energy efficiency upgrades in the two years prior to the installation of insulated siding. This screen was employed to facilitate a more consistent home heating energy use profile, which should provide a higher correlation between heating energy use and outdoor ambient temperature over time. Because different occupants can have different energy usage patterns, homes were also screened to ensure that they were owner-occupied for two or more years and that occupants were likely to stay in the home for two years after the installation of the insulated siding. Primary characteristics of the five homes prior to the installation of insulated siding are provided below.

Table 1 Characteristics of the Five Study Homes

| Characteristic | Fort Collins, Colorado | New Palestine, Indiana | Severna Park, Maryland | Burnt Hills, New York | New Paltz, New York |
|--|---------------------------|---------------------------|---------------------------|--------------------------|------------------------|
| Climate zone | 5 | 5 | 4 | 5 | 6 |
| Construction era | 1990s | 1980s | 1970s | 1980s | 1960's |
| Type | Single-family detached | | | | |
| Above-grade/conditioned area (square feet) | 2660 / 3830 | 2589 / 2589 | 3158 / 4598 | 2640 / 3960 | 1144 / 1452 |
| Siding (existing) | Wood composite | Wood | Vinyl | Wood | Aluminum |
| Structure | Wood 2x4 | Wood 2x4 | Wood 2x4 | Wood 2x6 | Wood 2x4 |

| | | | | | |
|--|--|---------------|---------------------|---------------------|--|
| Wall insulation, existing (cavity + continuous) | R-13+3 | R-13+2.5 | R-11 | R-19 | R-11 |
| Occupancy | Owner-occupied for two or more years | | | | Owner and renter- occupied for two or more years |
| Primary heating | Natural gas furnace with ducted distribution | | | | Propane boiler with baseboard distribution |
| Energy upgrades in last two years? | No | No | No | Minor | No |
| Wood fireplaces | No | Yes, not used | Yes, rarely used | Yes, rarely used | No |
| Heated hot tub or pool | No | No | No | No | No |

Installing the Siding

The R-value of insulated siding determined through ASTM C1363 is based on its tested performance when installed over a sheathing product with a flat profile. Therefore, to enable the in-situ thermal performance to track as closely as possible to the expected performance, the homes' existing siding was first removed to expose a substrate with a flat profile. In speaking with installation contractors, several noted that removal of the existing siding prior to installing insulated siding was not typical practice, in that it was more expensive and time-intensive to execute than simply residing over existing siding. Installing insulated siding over existing siding may improve the thermal performance of the wall assembly, but this benefit is unclear based on substrate profiles that could reduce the air tightness of the assembly. Other questions that are raised by such an installation include its impact on moisture management, installation durability, and any challenges associated with finishing around penetrations. While beyond the scope of this study, further research is recommended to understand how insulated siding performs when installed over existing siding.

When the existing siding was removed, it was revealed that none of the homes had a water-resistive barrier under the existing siding. In keeping with the requirements of the International Residential Code, a water-resistive barrier was installed over the existing sheathing. Though not all sites used the same manufacturer for their water-resistive barriers, all used a polyethylene fiber product that was installed according to the manufacturer's installation instructions with seams lapped and taped.

The homeowners were permitted to select their insulated siding from among all available products. Five different insulated siding products were selected by the homeowners, sourced from several different manufacturers, and installed by five different contractors. At four of the sites, all deconstruction and installation work was subcontracted to contractors certified through the *Vinyl Siding Institute (VSI) Certified Installer Program*. At the New York Climate Zone 6 site, the contractor was not a VSI Certified Installer, but carried strong references from both previous customers and the local siding retailer. Specifications for work included installation of all materials according to manufacturer instructions.

Pre- and post-retrofit photos of all five homes are located in Appendix B.

Wall U-factors

While R-values represent the thermal resistance of an individual product, U-factors are used to represent the thermal conductivity of an assembly of products within a wall, including the thermal properties of exterior and interior air films. By knowing the individual R-values of the products within an assembly, its U-factor can be easily derived. Walls with lower U-factors have a lower thermal conductivity and are more resistant to heat transfer.

For each site, U-factors were calculated prior to and following the installation of insulated siding. The calculation methodology used was the same as employed by the *IECC*, as well as REScheck, DOE's software for demonstrating energy code compliance for residential buildings.⁶ R-values of the existing siding, R-values of the replacement insulated siding, and pre- and post-retrofit U-factors are provided in Table 2. The percent improvement in the whole wall U-factors across the five sites ranged from 10 percent to 17 percent.

Variation in the percent improvement in wall U-factors across the homes occurred for several reasons. Not only was there a slight variation in the tested R-values of the insulated siding materials themselves (R-2.2 to R-2.7), but wall configuration varied as well. Four of the five homes had 2"x4" wall construction with either nominal R-11 or R-13 fiberglass insulation installed. The New York home in Climate Zone 5 was framed with 2"x6" studs, and R-19 insulation was compressed into the wall cavity, thereby degrading its insulating value to R-18. The Colorado home had a half inch of rigid polyisocyanurate insulation installed on the exterior, boosting its R-value by approximately 3.0. The Indiana home had a half inch of extruded polystyrene insulation (R-2.5) on the exterior. Finally, the existing siding materials also had slightly different insulating values, with wood siding being somewhat higher than aluminum or vinyl. Because of these different characteristics of the exterior wall profiles, percentage improvement in insulating value also differed.

⁶ Pacific Northwest National Laboratory, *Methodology for Developing the REScheck™ Software through Version 3.7*, October 2005, PNNL-14864-1-2.

Table 2 Properties of the Existing and Post-insulated Siding Installation Walls

| Location | Siding R-value | | Whole Wall U-factor | | |
|----------------------------|-------------------|------------------|----------------------|-----------------------|---------------------|
| | Existing Siding | Insulated Siding | Pre-Insulated Siding | Post-Insulated Siding | Percent Improvement |
| Colorado Climate Zone 5 | Hardboard, R-0.67 | R-2.0 | 0.077 | 0.069 | 11% |
| Indiana Climate Zone 4 | Wood, R-0.81 | R-2.2 | 0.072 | 0.065 | 10% |
| Maryland Climate Zone 5 | Vinyl, R-0.62 | R-2.7 | 0.091 | 0.076 | 17% |
| New York Climate Zone 5 | Wood, R-0.81 | R-2.6 | 0.061 | 0.054 | 11% |
| New York Climate Zone 6 | Aluminum, R-0.62 | R2.7 | 0.091 | 0.076 | 17% |

Building Air Tightness Tests

Previous studies have identified air tightness benefits for the installation of water-resistive barriers when installed to function as an air barrier. An example of a water-resistive barrier installed to function as an air barrier is polyethylene fiber housewrap with joints taped and sealed per manufacturer instructions. A 2006 literature review of in-situ building tightness tests conducted on existing homes that were retrofitted with water-resistive air barriers found that the air tightness of these homes was improved by 11.8 to 35 percent.⁷ Similar improvements were expected for the five homes in this study.

To enable the homes to achieve similar air tightness improvements, the installation contractors were required to install the water-resistive barrier and insulated siding in accordance with manufacturer installation instructions. Where manufacturer instructions provided specific details for installing the water-resistive barrier “as an air barrier,” those details were specified. Where manufacturer installation instructions were vague or permitted multiple options for attachment, the more stringent options were specified. For example, not only were all seams, joints and penetrations taped, but the termination of the water-resistive air barrier at the bottom of the wall was also taped or sealed with caulk. Capped nails were used to attach the water-resistive barrier to the wall on all five homes.

Using a blower door, air tightness testing was conducted three times for each home to identify the home’s air tightness in its existing state, after the existing siding was removed and the water-resistive air barrier was installed, and after the insulated siding was installed. The blower

⁷ Weston, T. *A Review of Housewrap Performance and Its Implications for Energy Savings*, 2006. Presented at the 2006 ACEEE Summer Study on Energy Efficiency in Buildings.

door tests conducted were single-point depressurization tests conducted at a 50 Pascals pressure differential across the building envelope. Single-point tests were administered because they have been shown to provide similar results to multi-point tests and are commonly used for new and existing construction.⁸ Results were provided using the metric of air changes per hour at 50 Pascals (ACH 50), which represents the number of times that the air volume of the home is exchanged with outdoor air in one hour at a pressure differential across the building envelope of 50 Pascals.

Four of the five homes showed air tightness improvements after the existing siding was removed and the water-resistive air barrier was installed. All five homes demonstrated improvements in air tightness between the existing condition and post-installation of the insulated siding. Overall, an average 11 percent improvement in air tightness was observed across the five homes after the insulated siding was installed. Three of the five homes were fairly tight in their existing condition (ACH 50 below 7.5). Two homes were extremely leaky. Results provided in Table 3 demonstrate that installation of both the water-resistive air barrier and the insulated siding contributed to the air tightness of the homes.

It should be noted that no other air sealing improvements were made other than those to the above-grade walls as part of the siding retrofit work. For instance, electrical and plumbing penetrations through the walls were sealed and the perimeter of windows and doors were caulked. No air sealing was done in the attic or basement; nor was any done on the interior. In the case of the Climate Zone 6 home, there were several very large leakage pathways into the attic that were not addressed in order to better isolate the improvements due to the siding retrofit alone. The large leakage areas into the attic dominated the blower door test results. Yet, even so, a 10 percent reduction in air leakage due to the siding retrofit was a significant improvement.

⁸ Wilcox, B. et al. *2013 Building Energy Efficiency Standards Staff Workshop Residential Infiltration and Testing*, May 31, 2011. Presented to the California Energy Commission through research funded by the California Statewide Utilities Codes and Standards Program's Codes and Standards Enhancement Study.

Table 3 Building Air Tightness Test Results

| Location | Existing Leakage (ACH 50) | Post-Water-Resistive Air Barrier Installation Leakage (ACH 50) | Post-Insulated Siding Installation Leakage (ACH 50) | Overall Percent Improvement |
|-------------------------|---------------------------|--|---|-----------------------------|
| Colorado | 4.9 | 5.2 | 4.7 | 3% |
| Indiana | 19.9 | 19.2 | 18.1 | 9% |
| Maryland | 6.3 | 5.8 | 5.6 | 11% |
| New York Climate Zone 5 | 7.2 | 6.3 | 5.5 | 24% |
| New York Climate Zone 6 | 15.1 | 14.5 | 13.7 | 9.5% |

Building Energy Simulations

Simulations of pre-insulated siding and post-insulated siding conditions were conducted to calculate the Home Energy Rating System (HERS) Index for each of the homes, for both their existing condition and their condition after the installation of insulated siding. The HERS Index is a home energy performance rating system developed by the Residential Energy Services Network (RESNET) that is widely used in industry to compare an existing or new home to a reference home built to the 2006 IECC. The reference home receives a HERS Index of 100. Homes that achieve a HERS Index below 100 are expected to use less energy than the reference home, and homes with a HERS Index above 100 are expected to use more energy than the reference home. The HERS Index is structured so that each point below 100 is expected to represent about 1 percent less energy use than the reference home.

Energy audits were conducted on the five homes to identify the pre-insulated siding conditions, with data collected on insulation levels, existing siding material type, geometry, orientation, window area, building air tightness, and equipment age. Where labels were not provided for the thermal performance of building envelope components, their thermal performance rating was estimated using industry-accepted reference materials (e.g., 2009 ASHRAE *Fundamentals* from the American Society of Heating, Refrigeration and Air-Conditioning Engineers). A list of building components and simulation inputs is provided in Appendix A.

Simulations were conducted using EnergyGauge USA software, developed by Florida Solar Energy Corporation or REM/Rate. EnergyGauge USA uses the DOE 2.1E engine. Both software programs are recognized as accredited building energy rating software by RESNET. Simulations included both the R-value impact of the insulated siding, as well as the airtightness improvement, which was measured for each individual home. Based on the building energy simulation results, each home experienced an improvement (i.e., a reduction) in its HERS Index of between two and eight points through the installation of a water-resistive air barrier and insulated siding. Results are presented in Table 4.

Table 4 Building Energy Simulation Results from Installation of Water-Resistive Air Barrier plus Insulated Siding

| Location | Existing HERS Index | Post-Insulated Siding HERS Index | HERS Index Improvement (Points) |
|-------------------------|---------------------|----------------------------------|---------------------------------|
| Colorado | 93 | 91 | 2 |
| Indiana | 169 | 161 | 8 |
| Maryland | 93 | 91 | 2 |
| New York Climate Zone 5 | 122 | 116 | 6 |
| New York Climate Zone 6 | 120 | 114 | 6 |

Infrared Imagery

Infrared (IR) thermography is now a widely used tool in residential building energy performance diagnostics. Current IR technology can provide surface temperatures and even calculate whole-wall R-values and U-factors of assemblies under controlled conditions. This tool is especially useful in identifying areas of low thermal resistivity (also known as thermal bridges) in the building envelope.

IR imagery was used on four of the homes in this study to supplement other data gathered on insulated siding's expected impact on wall performance (i.e., building airtightness and R-value improvements, heating energy savings projections, and utility bill analysis). IR images were taken of four homes before and after the installation of insulated siding to enable a comparison of the walls' thermal bridging effects in each case. Because the homes were all occupied, pre-sunrise access to the interior was difficult to coordinate, and interior walls that were free of coverings were difficult to access. For these reasons, all images were taken from the exterior. Images were taken before sunrise, to approximate steady state wall conditions and to remove any interference that would be observed from incident solar radiation. Images were also taken during the winter, when temperature differentials across the building envelope were sufficiently high to allow the observation of thermal bridging.

After the images were taken, they were post-processed to set the temperature scale corresponding to a range of 10° Fahrenheit for all sites. This was done to enable reasonable comparisons across pictures and ensure that differences in the images were not unduly exaggerated. Additionally, the sets of images were screened to remove any that may have led the observer to make false conclusions. For example, the New York Climate Zone 5 home's images were discarded because the "after" pictures were taken at a smaller temperature differential across the building envelope than the "before" pictures. Because smaller temperature differentials deemphasize thermal bridging, an observer could potentially falsely

attribute an observed reduction in thermal bridging to the insulated siding when it could have equally been impacted by differences in temperature differential. The Colorado home's images were also discarded, due to poor image quality.

The images that were retained (those for Indiana and Maryland) appear to demonstrate a slight reduction in thermal bridging after the installation of the insulated siding, even with a greater temperature differential across the building envelope. The dampened thermal bridging effect was observed based on a reduction in the visual prominence of the wood framing behind the insulated siding. Taken together with the other data collected in this study, the images are supportive of the benefits of insulated siding in reducing thermal bridging. Examples of the images are provided in Figures 1 and 2. A reduction of thermal bridging can be observed in the post-insulated siding images in both figures.

Figure 1 Infrared Imagery Taken Pre- and Post-installation of Insulated Siding at the Indiana Home

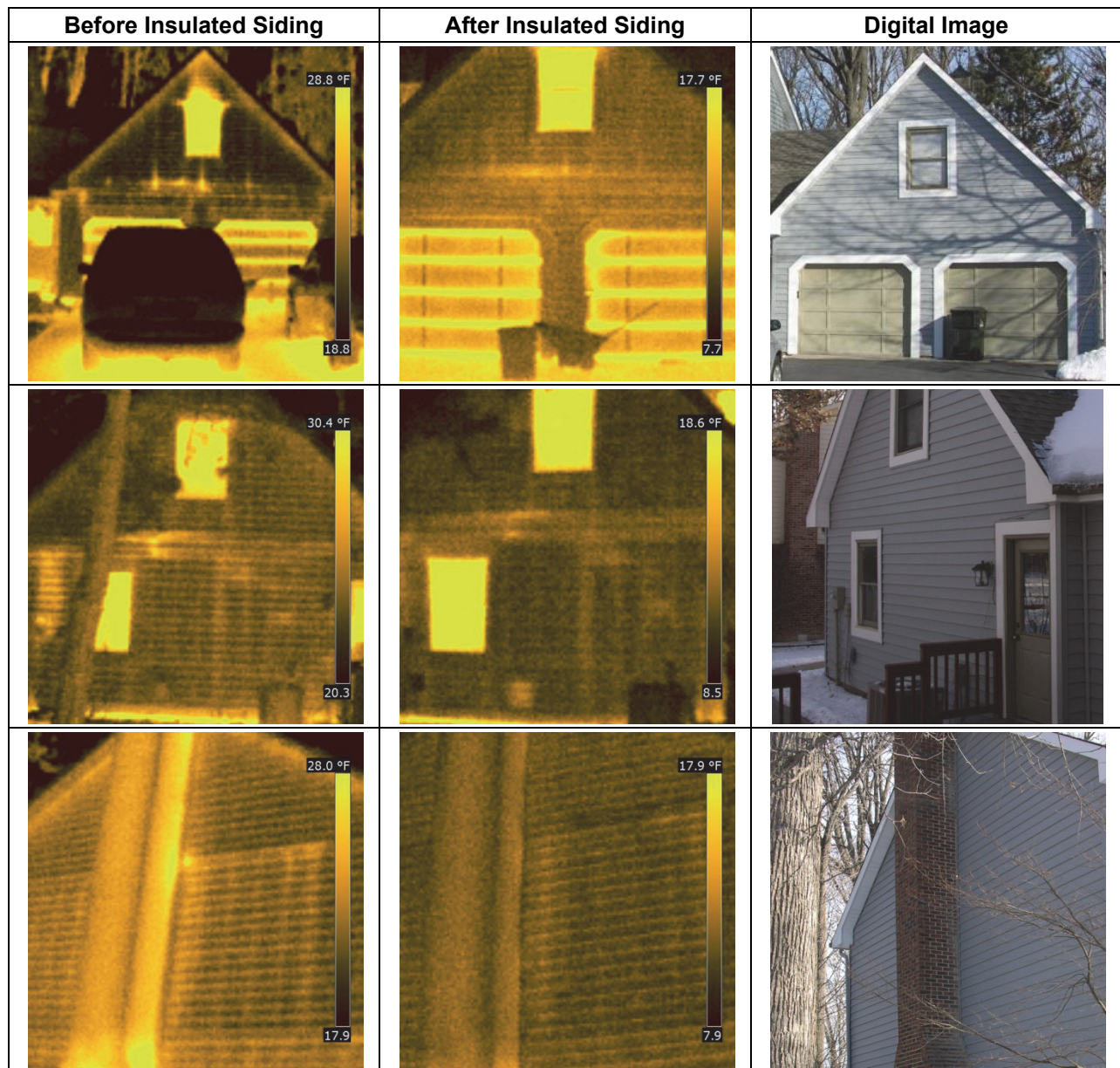
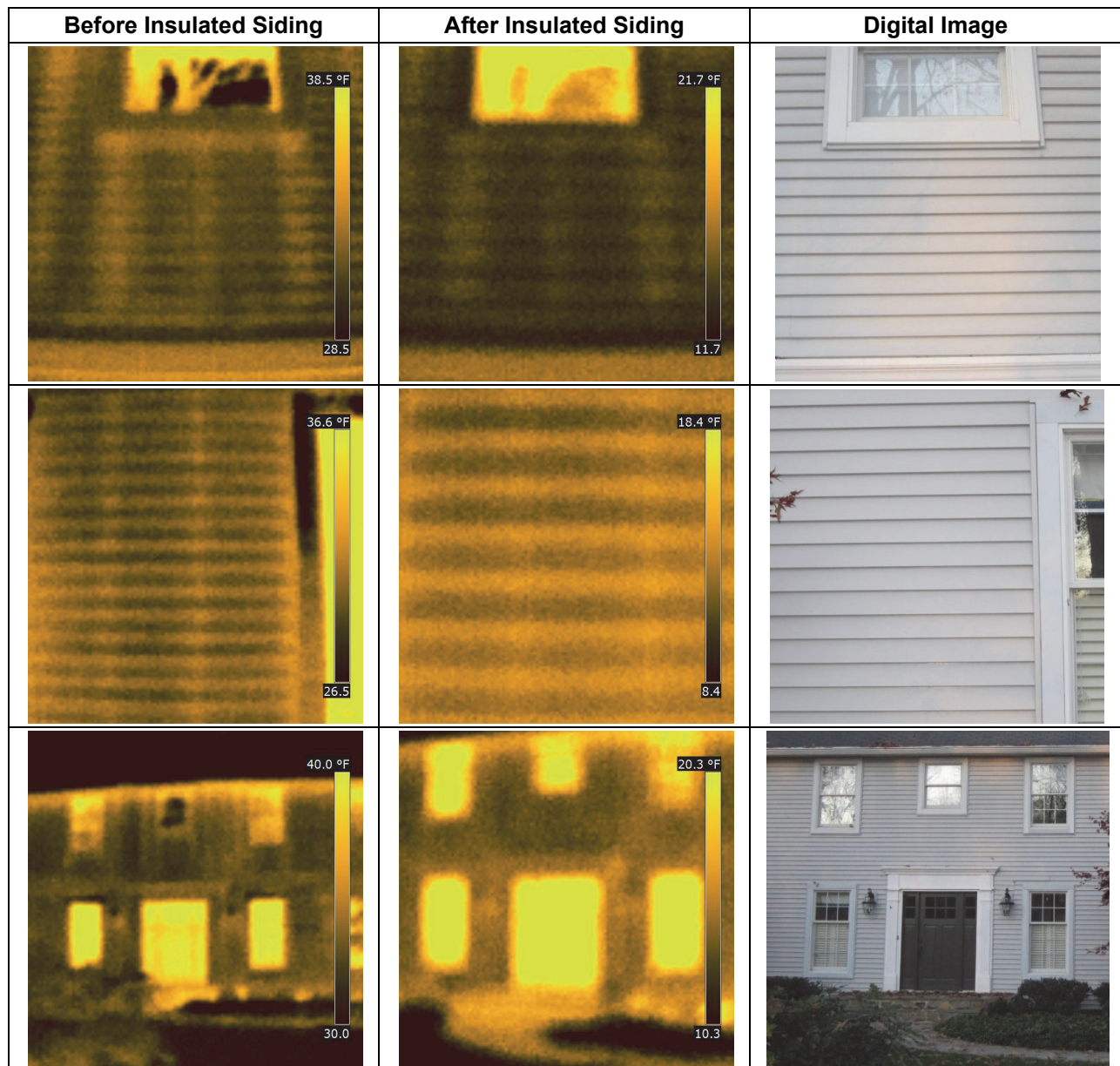


Figure 2 Infrared Imagery Taken Pre- and Post-installation of Insulated Siding at the Maryland Home



Heating Energy Analysis

To examine the impact of insulated siding on the homes' heating energy use, utility bills were collected for two years prior to the installation of insulated siding and for two years following the installation on all of the five homes. In order to minimize the impact of outdoor temperature variations from year to year and across the different geographic locations, as well as the heat content of different fuels, the pre- and post- data were normalized and reported on a Therm-per-heating-degree-day (DDh) per month basis. The number of heating degree days for a 24-hour period is calculated using a base temperature of 65° F. For instance, if the average temperature for a day in January is 35° F, that day has 30 heating degree days. This calculation is performed for each day of the month and then added to find the total number of heating degree days for that month.

A reduction in post-siding retrofit energy use per heating degree day was seen in all five of the homes using utility bill data two years prior to the retrofit and, as time allowed, for two years after. The observed percent energy savings ranged from 1 percent in Indiana to 11 percent in the Colorado home. Energy savings across all five homes averaged 5.5 percent and is reported in Table 5 below and shown graphically in the charts that follow. It should be noted that the energy savings analysis includes only the natural gas or propane consumed in the homes; it does not include electrical use. Gas fuel used for space heating was not isolated. The tables below reflect fuel use for water heating and cooking (where applicable), as well as space heating.

Table 5 – Observed Gas/Propane Utility Bill Savings

| Location | Observed Savings | Statistically Significant at 95% Confidence Level? | Other Gas Uses in Home |
|-------------------------|------------------|--|----------------------------|
| Colorado | 11% | Yes | Water heating |
| Indiana | 1% | No | Water heating, range, oven |
| Maryland | 7% | No | Water heating, range |
| New York Climate Zone 5 | 4% | No | Water heating, range, oven |
| New York Climate Zone 6 | 6% | No | Water heating |

Figure 3 Colorado: Pre- and Post-Retrofit Normalized Energy Consumption

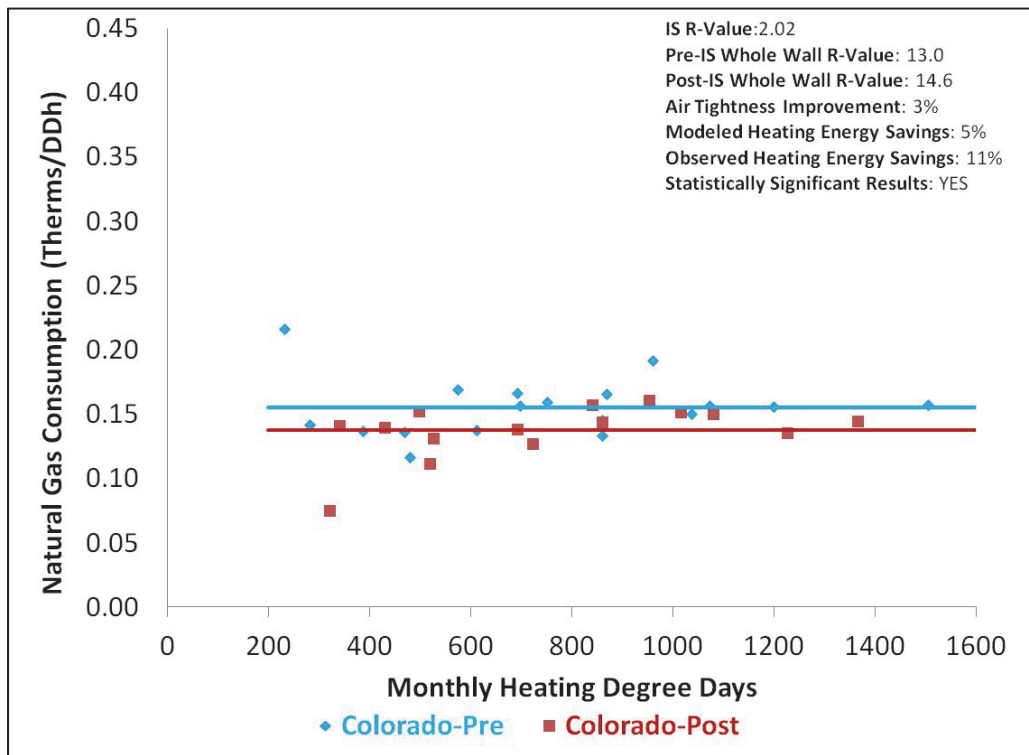


Figure 4 Indiana: Pre- and Post-Retrofit Normalized Energy Consumption

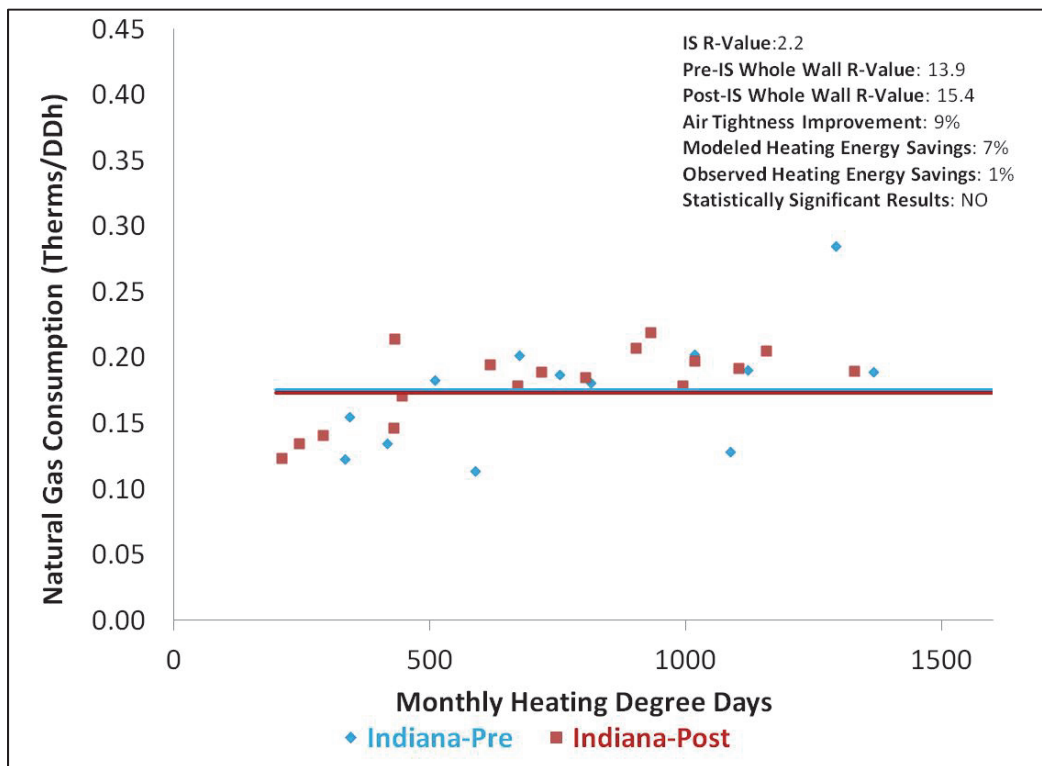


Figure 5 Maryland: Pre- and Post-Retrofit Normalized Energy Consumption

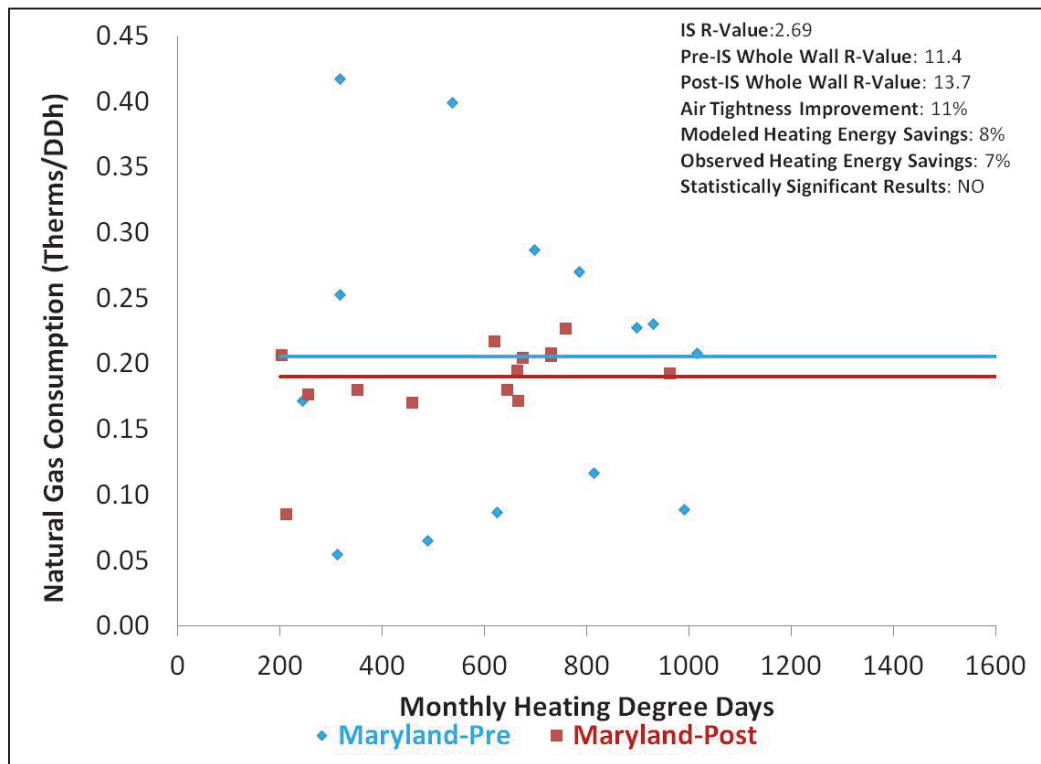


Figure 6 New York Climate Zone 5: Pre- and Post-Retrofit Normalized Energy Consumption

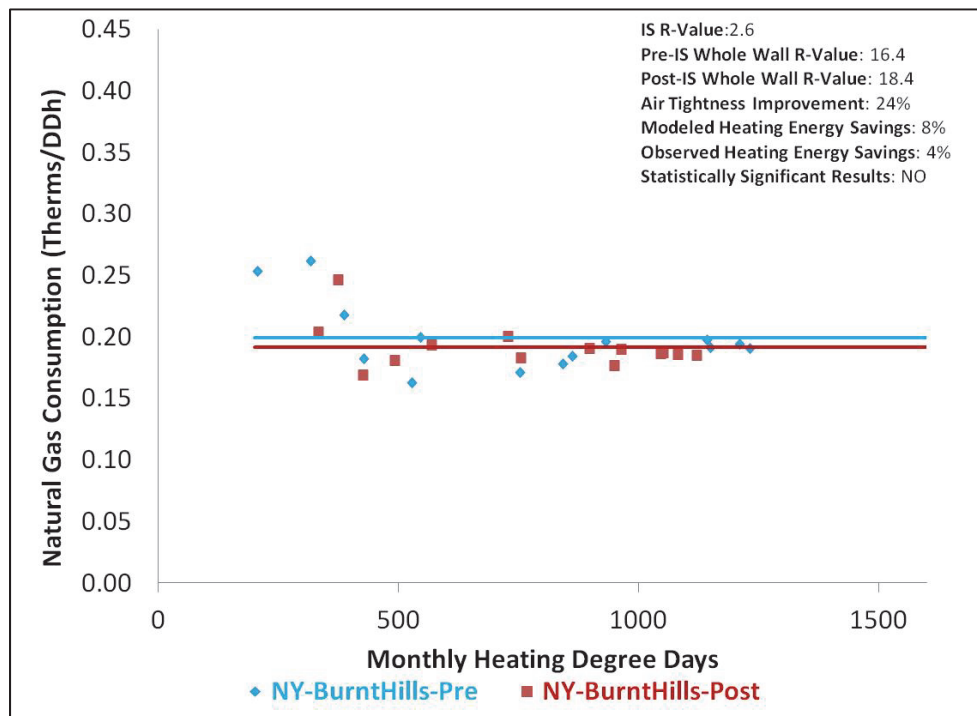
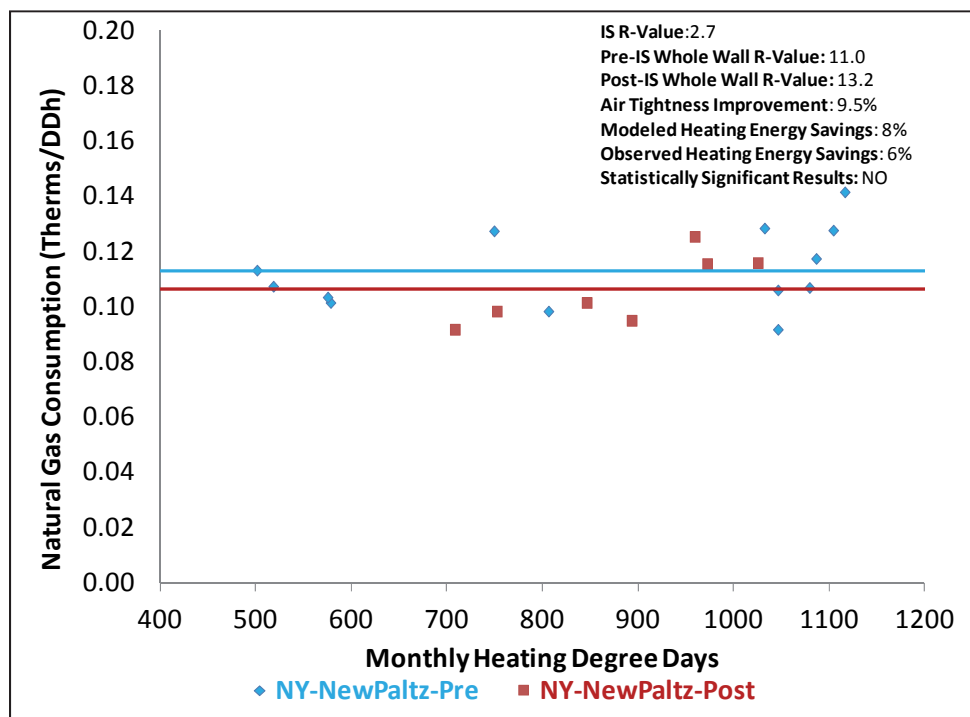


Figure 7 New York Climate Zone 6: Pre- and Post-Retrofit Normalized Energy Consumption



An ANOVA Single-Factor statistical analysis was performed in order to determine the statistical significance of the differences between the average pre- and post-retrofit normalized energy consumption in each of the homes. Such an analysis quantifies the variance between and within two sets of variables to determine the level of confidence at which the averages of the data sets can be distinguished. The results of this analysis showed that the observed energy savings were only statistically significant for the Colorado home. As one can see in the Colorado chart above, there is less scatter in the data than for the other sites. For the Maryland site in particular, the data points do not track the trendlines very closely. Without good correlation between the variables, it is more likely that the results will not have statistical significance. In Indiana, while there is less scatter, the observed energy savings is only one percent. This demonstrates a potential limitation of relying only upon utility bill analysis to determine energy savings. When occupant behavior and energy management may vary widely, it will be more difficult to achieve statistically significant results. This does not refute the fact that actual energy savings were observed for all of the homes, but simply indicates that the observed differences between normalized pre- and post-retrofit energy use based upon utility bill data were not strong enough to make firm predictions regarding potential savings at future sites. Using utility bill data alone does not provide sufficiently controlled conditions to isolate energy consumption for space heating, account for variation in occupant behavior, or identify differences in local weather conditions during pre- and post-retrofit periods that might affect run times of equipment. However, the results of this more cost-effective study do show actual energy and dollar savings and occupant recognition of increased comfort.

Conclusion

This study successfully demonstrated that energy savings is realized when existing exterior cladding materials are replaced by a carefully detailed water-resistive barrier and insulated siding in mixed and cold climates. The retrofit not only provides the opportunity to increase the R-value of the exterior walls in a one-step process, but also to seal up air leakage paths at utility penetrations, window and door openings, and other areas where the wall sheathing may have been compromised. In this study, the addition of insulated siding over a water-resistive barrier contributed significantly to the air tightness of all the homes. Across the five homes in this study, air tightness testing showed air leakage improvements between 3 percent and 24 percent. The study also showed reductions in heating season natural gas or propane consumption from 1 percent to 11 percent. Not only did this translate into monthly utility bill dollar savings, but it was also expected to improve comfort for the occupants.

Although energy savings were observed in all five homes in the study, the results for only one of the homes showed statistical significance (the Colorado home that showed 11 percent savings). That is, the amount of savings on future projects cannot be predicted with any large degree of confidence based on this study alone. Primary reasons for lack of statistical significance may be the lack of granularity provided by utility bills alone, variability in occupant behavior, and inconsistency in outdoor weather conditions.

Based on the current effort, other opportunities for further research were identified. Among these are:

- Quality of installation and thermal performance of insulated siding installation over existing siding
- More detailed analysis that would isolate pre- and post-retrofit space heating energy consumption and monitor indoor and outdoor temperatures
- More stringent screening of pre-retrofit utility bills to identify good correlation between energy consumed and average outdoor temperature
- Advanced air sealing techniques while sheathing is exposed
- Cost analysis and comparison to other options that are expected to achieve equivalent thermal performance such as insulated sheathing

Appendix A: Building Components and Simulation Inputs

| Location | New Palestine, IN | Fort Collins, CO | Severna Park, MD | Burnt Hills, NY | New Paltz, NY |
|---|-------------------|------------------|------------------|-----------------|---------------|
| Climate Zone, <i>IECC</i> | 4 | 5 | 5 | 5 | 6 |
| Cooling Employed (Yes=1, No=0) | 1 | 1 | 1 | 1 | 1 |
| House orientation for front of home | South | North | East | NW | SE |
| Predominant width (feet) | 39 | 38 | 64 | 44 | 44 |
| Predominant length (feet) | 28 | 35 | 36 | 30 | 26 |
| Aspect ratio (assumed) | 1.4 | 1.1 | 1.8 | 1.5 | 1.7 |
| Above grade square feet (sq ft) | 2589 | 2660 | 3158 | 2640 | 1144 |
| First floor ceiling height (ft) | 8.0 | 8.0 | 8.0 | 8.0 | 8.0 |
| Second floor ceiling height (ft) | 8.0 | 8.0 | 8.0 | 8.0 | N/A |
| Conditioned area (sq ft) | 2589 | 3830 | 4598 | 3960 | 1452 |
| Conditioned volume cubic feet (cu ft) | 20728 | 30640 | 36784 | 31680 | 11423 |
| Housing type (SFD=single-family detached) | SFD | SFD | SFD | SFD | SFD |
| Number of stories (floors on or above grade) | 2 | 2 | 2 | 2 | 1 |
| Number of bedrooms | 4 | 4 | 4 | 4 | 3 |
| Conditioned floors (including basement where applicable) | 2 | 3 | 3 | 3 | 2 |
| Foundation | | | | | |
| Slab on grade (Yes=1, No=0) | 0 | 0 | 0 | 0 | 0 |
| Crawl (Yes=1, No=0) | 1 | 0 | 0 | 0 | 0 |
| Basement (Yes=1, No=0) | 0 | 1 | 1 | 1 | 1 |
| Conditioned basement (Yes=1, No=0) | 0 | 1 | 1 | 1 | 1 |
| Crawl/frame floor area (sq ft) | 1132 | N/A | N/A | N/A | NA |
| Floor covering, frame floor only | hardwood | N/A | N/A | N/A | N/A |
| Joist spacing, frame floor only inches on center (oc) | 16 | N/A | N/A | N/A | N/A |
| Joist depth, frame floor only inches (in) | 9.5 | N/A | N/A | N/A | N/A |
| First floor R-value in case of unconditioned basement or ventilated crawl | 19 | N/A | N/A | N/A | N/A |
| First floor insulation thickness in case of unconditioned basement or ventilated crawl (in) | 6.5 | N/A | N/A | N/A | N/A |
| Frame floor over garage area (sq ft) | 266.0 | 160.0 | 360.0 | 462.0 | 264.0 |
| Floor covering, frame floor only | carpet | carpet | carpet | carpet | Hardwood |
| Joist spacing, frame floor only (in oc) | 16.0 | 16.0 | 16.0 | 16.0 | N/A |
| Joist depth, frame floor only (in) | 9.5 | 9.5 | 9.5 | 9.5 | N/A |
| Insulation R-value | 19.0 | 19.0 | 19.0 | 19.0 | N/A |
| Insulation thickness | 6.5 | 6.5 | 6.5 | 6.5 | N/A |
| Basement slab area (sq ft) | N/A | 1170 | 1440 | 1320 | 880 |

| Location | New Palestine, IN | Fort Collins, CO | Severna Park, MD | Burnt Hills, NY | New Paltz, NY |
|---|---|------------------|--|-----------------|-------------------------|
| Slab on grade area (sq ft) | 0 | N/A | N/A | N/A | N/A |
| Slab on grade vertical insulation R-value (assumed grade I) | 0 | N/A | N/A | N/A | N/A |
| Slab on grade vertical insulation depth (ft) | 0 | N/A | N/A | N/A | N/A |
| Slab on grade floor covering (carpet/none) | 0 | N/A | N/A | N/A | N/A |
| Foundation full perimeter (ft) | 150.0 | 146.0 | 212.0 | 148.0 | 140 |
| Basement slab or slab on grade total exposed perimeter (ft) | N/A | 146.0 | 152.0 | 148.0 | 35 (adjacent to garage) |
| Basement floor covering | N/A | carpet | carpet | None | None |
| Basement wall R-value (EG=EnergyGauge) | N/A | R-13, finished | R-11 on 3/4 of wall; model as R-5 everywhere due to EG limitations | None | R-11 adjacent to garage |
| Basement blanket insulation height (ft) | N/A | N/A | N/A | N/A | 7 |
| Basement wall average height above grade (ft) | N/A | 2 | 2 | 2 | 2 |
| Basement wall floor to ceiling height (ft) | N/A | 8 | 8 | 8 | 7 |
| Basement wall type (UB=block, uninsulated cores; SC=solid concrete) | N/A | SC | UB | UB | UB |
| Basement slab depth below grade (ft) | N/A | 6 | 6 | 6 | 6 |
| Band joist | | | | | |
| Band joist area (sq ft) conditioned and ambient | No band joist entry option in EG; accounted for in above-grade wall | | | | |
| Cavity insulation R-value (assumed grade I) | | | | | |
| Cavity insulation thickness (in) | | | | | |
| Above-grade wall | | | | | |
| Stud depth and insulation depth (in) | 3.5 | 3.5 | 3.5 | 5.5 | 3.5 |
| Stud spacing (in oc) | 16" o.c. | 16" o.c. | 16" o.c. | 16" o.c. | 16" o.c. |
| Cavity insulation R-value (assumed grade I) | 13 | 13 | 11 | 18 | 11 |
| U-factor to exterior, pre-installation | 0.072 | 0.077 | 0.091 | 0.061 | 0.091 |
| U-factor to exterior, post-installation | 0.065 | 0.069 | 0.076 | 0.054 | 0.076 |
| U-factor to attic | 0.096 | N/A | N/A | N/A | N/A |
| U-factor to garage | 0.091 | 0.091 | 0.091 | 0.069 | 0.091 |
| Exterior wall area (sq ft) | 2582 | 2258 | 2677 | 2036 | 1400 |
| Attic wall area (sq ft) | 324 | 0 | 0 | 0 | 0 |
| Garage wall area (sq ft) | 40 | 224 | 376 | 704 | 245 |
| Color | Med | Med | Med | Med | Light |
| North | 751 | 588 | 482 | - | - |
| South | 751 | 588 | 482 | - | - |

| Location | New Palestine, IN | Fort Collins, CO | Severna Park, MD | Burnt Hills, NY | New Paltz, NY |
|---|-------------------|------------------|------------------|-----------------|---------------|
| East | 540 | 541 | 857 | - | - |
| West | 540 | 541 | 857 | - | - |
| NW | | | | 605 | 440 |
| SW | | | | 605 | 260 |
| SE | | | | 413 | 440 |
| NE | | | | 413 | 260 |
| Windows | | | | | |
| Skylights U-factor | | | 1.31 | | |
| Skylight Solar Heat Gain Coefficient (SHGC) | | | 0.8 | | |
| Skylight area | | | 16 | | |
| Skylight orientation | | | W | | |
| Window type 1 U-value | 0.49 | 0.36 | 0.90 | 0.49 | 0.675 |
| Window type 1 SHGC | 0.58 | 0.45 | 0.65 | 0.71 | |
| Window type 2 U-value, basement | N/A | 0.87 | | 0.46 | |
| Window type 2 SHGC, basement | N/A | 0.73 | | 0.57 | |
| Window area type 1 (sq ft) | 367.0 | 370.2 | 347.4 | | |
| North | 182.0 | 97.5 | 55.2 | | |
| South | 185.0 | 167.1 | 27.3 | | |
| East | 0.0 | 23.4 | 128.3 | | |
| West | 0.0 | 26.2 | 136.6 | | |
| NW | 0.0 | | | 157.0 | 105 |
| SE | 0.0 | | | 139.0 | 52 |
| NE | 0.0 | | | 59.0 | 6 |
| SW | 0.0 | | | 9.0 | 23 |
| Window area type 2 (sq ft) | | | | | |
| North | | 0.0 | | | |
| South | | 20.0 | | | |
| East | | 20.0 | | | |
| West | | 16.0 | | | |
| NW | | | | 0.0 | |
| SE | | | | 16.0 | |
| NE | | | | 8.0 | |
| SW | | | | 0.0 | |
| Interior shading, winter | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 |
| Interior shading, summer | 0.70 | 0.70 | 0.70 | 0.70 | 0.70 |
| Overhang depth (ft) | 0.0 | 0.0 | 0.0 | 0.0 | 1.0 |
| Overhang to top of window (ft) | 0.0 | 0.0 | 0.0 | 0.0 | 1.0 |
| Overhang to bottom of window (ft) | 0.0 | 0.0 | 0.0 | 0.0 | 3.5 |

| Location | New Palestine, IN | Fort Collins, CO | Severna Park, MD | Burnt Hills, NY | New Paltz, NY |
|---|-------------------|------------------|------------------|-----------------|---------------|
| Doors | | | | | |
| Total area for all doors (sq ft) | 40 | 20 | 47 | 40 | 40 |
| U-factor | 0.46 | 0.46 | 0.46 | 0.46 | 0.66 |
| Attic/ceiling | | | | | |
| Gross area (sq ft) | 1457 | 1490 | 1998 | 1320 | 1144 |
| Ceiling R-value (assumed grade I) | 36 | 34 | 17 | 19 | 22 |
| Roof | | | | | |
| Radiant barrier? (Yes=1, No=0) | 0 | 0 | 0 | 0 | 0 |
| Mechanical Equipment | | | | | |
| ASHP heating season performance factor/seasonal energy efficiency rating (HSPF/SEER)? | N/A | N/A | N/A | N/A | N/A |
| Gas-fired forced air furnace + AC (annual fuel utilization efficiency/SEER)? | 57/10.5 | 67/6.9 | 81/15 | 69/4.8 | |
| Propane boiler (annual fuel utilization efficiency/SEER) | | | | | 80/NA |
| Water heater | | | | | |
| Size (gallons) | 40 | 50 | 40 | 80 | 40 |
| Fuel (NG=natural gas, P=propane) | NG | NG | NG | NG | P |
| Energy factor (EF) | 0.49 | 0.58 | 0.58 | 0.54 | 0.59 |
| Location of space heating and cooling equipment | Garage | Basement | Basement | Basement | Basement |
| Location of water heater | Garage | Basement | Basement | Basement | Basement |
| Heating set point (°F) | 68 | 68 | 68 | 68 | 68 |
| Cooling set point (°F) | 78 | 78 | 78 | 78 | 78 |
| Programmable thermostat | No | Yes | Yes | Yes | Yes |
| Offsets | N/A | N/A | N/A | N/A | N/A |
| Duct system—set areas by EG default | | | | | |
| Supply duct area | 647 | 665 | 790 | 660 | NA |
| Return duct area | 485 | 499 | 592 | 495 | NA |
| Conditioned areas | | | | | |
| Supply duct | 85% | 100% | 100% | 80% | NA |
| Supply duct area (sq ft) | 550 | 665 | 790 | 528 | NA |
| Return duct | 95% | 100% | 100% | 80% | NA |
| Return duct area (sq ft) | 461 | 499 | 592 | 396 | NA |
| Attic | | | | | |
| Supply duct | 10% | 0 | 0 | 20% | NA |
| Supply duct area (sq ft) | 65 | 0 | 0 | 132 | NA |
| Return duct | 0% | 0 | 0 | 20% | NA |
| Return duct area (sq ft) | 0 | 0 | 0 | 99 | NA |

| Location | New Palestine, IN | Fort Collins, CO | Severna Park, MD | Burnt Hills, NY | New Paltz, NY |
|---|-------------------|------------------|------------------|-----------------|---------------|
| Garage | | | | | |
| Supply duct | 5% | 0 | 0 | 0 | NA |
| Supply duct area (sq ft) | 32 | 0 | 0 | 0 | NA |
| Return duct | 5% | 0 | 0 | 0 | NA |
| Return duct area (sq ft) | 24 | 0 | 0 | 0 | NA |
| Leakage: | Default | Default | Default | Default | |
| Duct insulation in unconditioned space | R-4.3 | N/A | N/A | R-6 | |
| Airtightness: cfm 50, pre-installation | 6875 | 2505 | 3845 | 3804 | 2875 |
| Airtightness: cfm 50, post-installation | 6255 | 2425 | 3440 | 2908 | 2752 |
| Mechanical ventilation | | | | | |
| Rate (cfm) | 0 | 0 | 0 | 0 | 0 |
| Daily run time (hours) | 0 | 0 | 0 | 0 | 0 |
| Power draw (Watts) | 0 | 0 | 0 | 0 | 0 |
| Type (supply or exhaust) | 0 | 0 | 0 | 0 | 0 |
| Lighting, percent fluorescent | 45% | 0% | 0% | 0% | 0 |
| Refrigerator (kWh/yr) | 775 | 775 | 775 | 775 | 691 |
| Dishwasher (EF) | 0.46 | 0.46 | 0.46 | 0.46 | 0.46 |
| Ceiling Fan (cfm/Watt) | 0 | 0 | 0 | 0 | 0 |
| Range (cooktop) | NG | Electric | NG | NG | Electric |
| Oven | NG | Electric | Electric | NG | Electric |
| Clothes dryer | Electric | Electric | Electric | Electric | Electric |

Appendix B: Photos of Homes

COLORADO



MARYLAND



NEW PALTZ, NY



BURNT HILLS, NY



INDIANA



Before



After