Optimized Strategy for Scaling Up Deep Energy Retrofit

Final Report

Prepared for

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Notice

Abstract

We attempted to develop a cost-effective approach for exterior wall retrofits using polyisocyanurate board insulation. After optimizing our approach using time and motion studies, we retrofitted four houses, documenting costs, improvements in airtightness and R-values, and pre-and post-retrofit energy use.

Recommendations from the time and motion studies include:

1. Use of specialized foam-cutting tools to reduce labor and improve tolerances.
2. Preferred fasteners and fastening schedules for wood-frame and concrete walls.
3. Dispensers to speed the application of construction tape while reducing waste.

The proposed wall system produced R-25+ wall assemblies. As part of a comprehensive retrofit, the treatment produced 56-77% air leakage reduction. In three houses for which pre- and post-retrofit utility bills were available, heating energy was reduced by 47-60%. In all three cases, building models over-predicted savings. Project costs ranged from $46,434 to $138,346. The incremental cost associated with adding exterior insulation was just under $10/sf. Payback periods ranged from 47 to 100 years. We conclude that, while deep energy retrofits do not represent a rapidly scalable approach for emissions reductions, optimized techniques for cutting and attaching foam developed during this study may reduce costs in new construction and conventional home performance retrofits.

Keywords: deep energy retrofit, exterior insulation, polyisocyanurate, home performance

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Executive Summary

In this research project for the New York State Energy Research and Development Authority (NYSERDA), Optimized Strategy for Scaling Up Deep Energy Retrofits, the Taitem - Snug Planet – Dow Building Solutions team attempted to develop a simple, scalable, durable system for wall retrofits. Our approach used high-density cellulose cavity insulation, Dow Thermax polyisocyanurate sheathing, and the Dow Weathermate flashing system. Through an initial series of time and motion studies in controlled settings, we evaluated strategies to optimize this system and reduce labor and materials costs. We then field-tested our system on four houses, documenting costs, improvements in airtightness and R values, and pre-and post-retrofit energy use.

Time and motion studies evaluated techniques for cutting, fastening, and taping Thermax sheathing, and for building and flashing window bucks. Major findings include:

1. Use of a specialized foam-cutting tool, the Accu-Cutter, significantly reduces cutting time and improved tolerances for lengthwise (rip) cuts.
2. Common hand tools are preferred for detail cuts: PVC saws for cross cuts, keyhole saws for hole cuts.
3. For wood-frame walls, pre-assembled washer screws produce higher quality attachment at similar cost compared to washer nails.
4. The number of washer screws per sheet of sheathing can be significantly reduced from manufacturer's recommendations while still providing secure attachment.
5. Tape dispensers speed the application of Dow Weathermate tape while reducing waste.
6. Powder-driven fasteners provide the quickest and most secure attachment of foam board to concrete walls.

These findings were employed with good success on all four retrofits. A recommended procedure for framing and flashing window bucks was also developed during the time and motion studies but could not be applied consistently due to differences in window style, contractor preferences, and construction sequence among the four houses.

The proposed wall system was used to achieve R-25+ wall assemblies in all four houses. As part of a comprehensive retrofit that included attic and basement insulation, air sealing and targeted window and door replacements, the treatments produced 56-77% reduction in total air leakage,

achieving the air tightness target of <0.25 CFM50/ square foot shell in three of the four houses. Heating, hot water, and mechanical ventilation upgrades were installed as necessary to bring houses into compliance with BPI health and safety standards.

Pre- and post-retrofit energy use was available for three of the four houses. Measured reduction in heating energy use ranged from 47-60%. In all three cases, building models over-predicted savings (predicted range 50-69%). For the fourth house, unoccupied and in poor condition prior to the retrofit, models predicted 72% savings.

Total project costs ranged from $46,434 to $138,346. The lowest-cost installation already had modern, low-e windows and existing siding that could be re-used. The most expensive house was the largest and most geometrically complex. Comparing costs of wall treatments between different houses was made more challenging by differences in existing conditions and contractor price breakdowns. Our best estimate for the average cost for exterior wall retrofit, including insulation, air sealing, and flashing but excluding windows, doors, siding, and trim, is $9.72/square foot, just under the project target of $10/sf.

Despite many good discoveries and significant reductions in total and per-square foot costs compared to previous deep energy retrofits (DER) such as the Utica pilot project, the economics of DERs remain daunting. Simple payback periods for the houses in our study ranged from 47 to 100 years. DER wall insulation may be more cost-effective if considered as an add-on to an already-planned exterior remodel, but at this point does not represent a rapidly scalable approach for emissions reductions. Optimized techniques for cutting and attaching foam developed during this study may be relevant in other situations, including new construction and conventional home performance retrofits.

Executive Summary in Photos

Figure 1: West Hill Photo Summary

Figure 2: Hawthorne Photo Summary

Figure 3: Ellis Hollow Photo Summary

Figure 4: Cayuga Heights Photo Summary

Path to Market

The objective of our study was to develop a simple, affordable approach to Deep Energy Retrofits that could be brought to scale. Through a careful design process and time and motion studies, we developed a set of techniques that allowed us to significantly reduce costs (both per-building and per-square foot) compared to the prior Utica pilot study[1], done by others. Our team was able to meet target cost and performance objectives in two of the four study houses and to come close in the other two.

Despite many good discoveries and real cost reductions, the price of deep energy retrofits will remain an insurmountable barrier to widespread adoption for most homeowners, unless further cost-reduction strategies can be identified. We found that we were able to simplify and standardize several aspects of the DER process and to identify tools and best practices which reduce installation labor and materials waste. However, many aspects of the work remain labor-intensive. Even among the simple houses chosen for this study, attempts to standardize were limited by variation in house construction, pre-existing conditions, and homeowner preferences.

Low heating fuel prices (especially for natural gas-heated homes) result in very long payback periods for deep energy retrofits. Simple payback periods based on measured energy savings for the four houses in our study ranged from 47 to 100 years. As Martin Holladay[1,2] has noted, reductions in the cost of photovoltaic (PV) panels have made rooftop solar a far more attractive investment. Payback periods for PV systems are typically under 30 years (quicker when incentives and tax credits are taken into account). Because of PV's modular nature and easily measured output, widespread deployment of rooftop solar also represents a more rapidly scalable and verifiable path to emissions reduction. Installation of a rooftop solar system is also quicker and less invasive than a deep energy retrofit. PV can offset not just space heating and cooling but base load use, which is an increasingly important component of household energy consumption. PV, paired with an air-source or ground-source heat pump (and possibly a more conventional insulation and air sealing retrofit) now represents a viable path to net-zero housing.

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[1] http://www.greenbuildingadvisor.com/blogs/dept/musings/high-cost-deep-energy-retrofits
[2] http://www.greenbuildingadvisor.com/blogs/dept/musings/deep-energy-retrofits-are-often-misguided

Rather than attempt to plot a path to market that includes a massive scale up of deep energy retrofits, we believe it makes sense to ask, under what scenario would a deep energy retrofit make sense to homeowners? The most likely scenario is one in which the homeowner is already planning a major exterior remodel that includes siding replacement, and possibly window and roof replacement. In this scenario, upwards of 50% of the cost of the project will typically be incurred whether or not energy improvements take place; these expenditures produce little or no energy savings. However, in many cases, homeowners may expect to recover 50-70% of the cost of this work in increased resale value[3].

In this scenario, the incremental cost of upgrading from a conventional remodel to a Deep Energy Retrofit represents less than 50% of the cost of the full project. The payback on the energy measures may drop to 25-50 years, possibly less, particularly for delivered fuels like oil and propane, which cost more today, on a per-Btu basis, that natural gas. If so, it may represent a reasonable investment, particularly if non-energy benefits such as comfort improvements, footprint reduction, and passive survivability are valued by the homeowner.

The opportunity to make exterior wall retrofits at least somewhat cost-effective occurs only when the siding is replaced; if the opportunity is missed, it may not arise again for 40-100 years. Energy efficiency programs, home performance professionals, and insulation manufacturers can work to make remodelers and homeowners aware of this “once-in-a-lifetime” window of opportunity, while also promoting other pathways to energy use and emissions reductions.

Many of the lessons learned in retrofitting the four homes in this study can be readily transferred to improve the quality and cost-effectiveness of conventional retrofits and energy-efficient new construction. While retrofitting foam sheathing onto above-grade walls remains prohibitively expensive in most cases, attics and basements can be retrofitted to DER standards at a cost only slightly more than that of conventional retrofits. For new construction, the 2012 IECC requires foam sheathing on 2 x 4 and 2 x 6 walls to meet minimum R value requirements. The techniques for cutting, fastening, and sealing developed in our time and motion studies may help builders get better results at lower cost, and so be of use to new construction projects. An important next step in spreading these findings to a larger audience will be to write up our results for publication.

[3] http://www.remodeling.hw.net/cost-vs-value/2015/middle-atlantic/

Scopes of Work

The four deep energy retrofit houses were completed over a period of 1-1/2 years, spanning two winter seasons, as shown in the timeline in Figure 5.

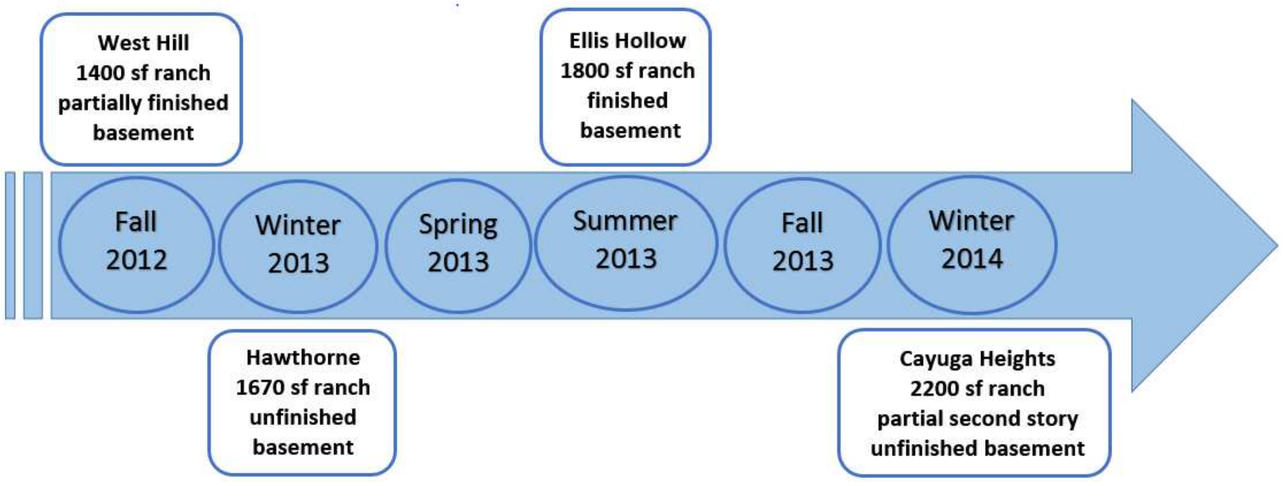


Figure 5: Timeline of DER Houses

West Hill

The first house in the deep energy retrofit project was performed at West Hill during the fall of 2012. The West Hill House is a 1400 sf. ranch built in 1955 with a partially finished basement. The scope of work for this DER included:

- Attic: Removed existing fiberglass insulation. Thoroughly air sealed all penetrations of attic plane. Installed vent chutes and soffit blocking. Insulated to R-60 with cellulose insulation.
- Walls: Removed existing vinyl and wood siding. Removed degraded fiberglass where present. Dense packed walls with cellulose insulation. Installed window bucks, flashing and trim. Installed 2.5” Thermax. Reinstalled existing vinyl siding.
- Basement walls: Installed 2.5” Thermax on exposed basement walls. Removed sheetrock on approximately 130 s.f. of finished basement wall and insulated with 3” closed cell foam. The basement band joist was insulated with 2” closed cell foam.
- Windows and doors: Main floor windows were new double pane low-e vinyl windows and were kept and flashed/sealed. One basement window and three doors were replaced.
- Mechanicals: A new, sealed combustion natural gas boiler was installed. Pipe insulation was installed. Energy Star compliant ventilation (Panasonic Whispercomfort ERV and Whisperlite bath fan) was installed.

Hawthorne

The second DER house was performed at Hawthorne during the fall/winter of 2012-2013. The Hawthorne house is a 1670 sf. ranch built circa 1950 with an unfinished basement. The scope of work for this DER included:

- Attic: Removed existing fiberglass and cellulose insulation. Thoroughly air sealed all penetrations of attic plane. Installed vent chutes and soffit blocking. Insulated to R-60 with cellulose insulation.
- Walls: Removed existing wood siding. Extended eaves on selected portions of roofline. Performed targeted insulation with high-density cellulose to fill voids in wall cavities. Installed window bucks, flashing and trim. Installed 2.5" Thermax. Installed furring strips and fiber-cement siding.
- Basement and crawlspace walls: Installed 2.5" Thermax on basement and crawlspace walls. Installed 2" polyurethane foam on rim joists. Installed ¾" EPS insulation and vapor barrier on crawlspace floors.
- Windows and doors: Older single pane windows with aluminum storms were replaced with new, double pane, low-e vinyl windows. One older wood door was replaced with a new insulated steel door. Air sealing was performed around both new and existing windows.
- Mechanicals: A new, sealed combustion natural gas furnace and a water heater were installed. Energy Star compliant ventilation (Panasonic Whisperlite bath fan) was installed.

Ellis Hollow

The third DER house was performed at Ellis Hollow during the summer of 2013. The Ellis Hollow house is a 1950s-era 1800sf house with a finished basement. The scope of work for this DER included:

- Roof
    - Extend roof at east and west gable ends by 24"+/-.
    - For carpentry details, including brackets, rake, and soffits, see drawings and bid document.
    - Install underlayment and standing seam metal roof.
- Siding/sheathing removal and replacement
    - Remove existing siding, trim, and sheathing down to studs.

- Install new 5/16 OSB sheathing.
- Install window and door bucks as needed to bring new window flanges in plane with siding.
- Install furring strips over foam insulation to provide vented rain screen. Use approved fasteners. Use Cor-a-vent at top and bottom as insect screen.
- Install new factory-primed Hardie Board siding (5/16" with a 4" reveal) and trim (5/4).

- Windows and doors
  - Removed 31 windows, and replaced 29 windows with Marvin Integrity Energy Star qualified units. One door sidelight was removed, and one kitchen window was changed into a door.
  - Install windows, including all exterior caulking and flashing. Interior trim is not included.
  - Replace front door with Marvin Integrity clad wood door.
  - Replace two entry doors with insulated fiberglass doors.
  - Install Marvin Integrity French door in place of two existing double hung windows in kitchen.
  - Install insulated garage door
- Exterior first and second floor walls insulation:
  - Dense-pack walls with cellulose insulation. This will be done after removal of old siding, sheathing, and insulation and installation of new sheathing. Fill all wall cavities with all-borate cellulose to a density of 3.5# per cubic foot, verifying coverage with an infrared scanner. Drill through the sheathing and install foam plugs in the holes. If the pressure of the cellulose is causing sheetrock nails to pop, homeowner will be responsible for installing additional screws to support the sheetrock and for any associated sheetrock finishing and painting.
  - For a few wall sections (denoted in red of drawings), closed cell foam will be installed instead of cellulose to allow for R-21+ where Thermax cannot be installed.
  - Air-seal band joist and other critical framing transitions prior to installation of Thermax. Use caulk or sealant (Prosoco R-Guard or similar).
  - Add 2.5" Dow Thermax polyiso board insulation. This will cover the entire wood-frame wall and band joist assembly, except as shown on drawings. The

foam will be notched to extend between the rafter tails and provide wind blocking for the attic insulation, making contact with the underside of the vent chutes. On the gable ends it will go up to the peak to maintain an even surface for the siding. Tape seams and corners.

- Garage:
  - Insulate wood-frame walls between house and garage with high-density cellulose and 2” Tuff-R insulation.
  - Block floor cavities from soffits using 2 x 10 material to prevent blown insulation from spilling into soffits. This applies to the soffits adjoining interior walls but not to a short section of soffit on the exterior side wall of the garage.
  - Insulate exterior block wall with 2.5” Thermax insulation.
  - Insulate soffits with 2.5” Thermax insulation. Seal joints with tape and foam.
  - Dense pack ceiling with cellulose insulation. Please use 5/8” sheetrock and adhesive on the joists to minimize nail pops.
  - Seal all penetrations at tops of walls.

Cayuga Heights

The fourth DER was performed at Cayuga Heights during the winter and spring of 2014. The Cayuga Heights house is a 2184 sf. ranch built circa 1950. It has a partial second story and unfinished basement. The scope of work for this DER included:

- Attic: Removed existing fiberglass insulation. Thoroughly air sealed penetrations of attic plane. Installed vent chutes and soffit blocking. Insulated to R-60 with cellulose insulation.
- Roof slopes: Upgraded insulation on open and enclosed roof slopes using closed cell foam and high-density cellulose.
- Walls: Removed existing wood and vinyl siding. Extended eaves on selected portions of roofline. Performed targeted insulation with high-density cellulose to fill voids in wall cavities. Installed window bucks, flashing and trim. Installed 2.5” Thermax. Installed furring strips and fiber-cement siding.
- Basement walls: Installed 2.5” Thermax on basement walls. Installed 2.5” Thermax blocking in rim joists.

- Windows and doors: Older single pane windows with aluminum storms were replaced with double pane, low-e wood and vinyl windows. Air sealing was performed around both new and existing windows.
- Mechanicals: A new, power vented water heater was installed. Energy Star compliant ventilation (Panasonic Whisperlite bath fan) was installed.

The demonstration project objectives were attained in full for two of the houses, and nearly satisfied for the other two houses. The results for air leakage improvement, wall insulation improvement, and costs for implemented wall strategies are shown in Table 1.

Program Objectives	Goal	West Hill	Hawthorne	Ellis Hollow	Cayuga Heights
Total envelope air leakage	< 0.25 CFM50/ssf	0.14	0.23	0.19	0.32
Above grade wall insulation	> R-25	R-29	R-30	R-25	R-28 to R-35
Wall labor and material costs	< $10/ssf	$9.55	$6.01	$16.88	$10.67

Table 1: Program Objectives

Energy Analysis

The energy analysis of the four project houses identifies achieved energy savings quantitatively as a result of their deep energy retrofit (DER) renovations.

Methodology

A TREAT energy model was created for each house. TREAT stands for Targeted Retrofit Energy Analysis Tool. The energy models were built using the known building size, building materials, lighting, heating and domestic hot water equipment, orientation and home location, and miscellaneous usages, as well as energy rates. The tool calculates the predicted energy usage and costs based on these inputs. Adjusted or "trued up" actual energy usage is calculated in TREAT, and then, it is compared to the predicted usage. Pre-improvement consumptions are regarded as the baseline.

Once the baseline is completed, the recommended energy conservation measures are added to the model to predict energy savings. TREAT can predict the possible energy savings for individual measures, and/or as a total package of measures that also takes into account the interactive effects between the recommended measures.

In this project, TREAT was used to compare the home pre-improvement energy usage (the baseline) to the post-improvement home usage. This was accomplished by adding actual post-improvement energy usage into the tool.

Actual energy usage from utility billing data was applied to a regression analysis to determine a correlation to outdoor temperature. This regression analysis was conducted on natural gas or propane usage for the pre-retrofit period and the post-retrofit period, separately. According to this, the energy usage listed on each billing statement is split into heating-related usage and base-load usage. The heating-related usage is then adjusted by a ratio of the actual weather conditions during the statement's days-of-service and typical weather conditions for the same calendar days in Binghamton, New York. To be able to compare the buildings in this study, heating usage intensity is calculated by a normalized comparison by dividing the heating usage per square foot by an identical Typical Meteorological Year version 2 Heating Degree Days (TMY2 HDD) per year at a 65F reference temperature for all buildings.

West Hill Summary of Findings

As a result of the deep energy retrofit, natural gas consumption for heating has been reduced by approximately 615 therms per year, at a cost of $1.20/therm. This will result in annual gas cost savings of $738 per year. Baseload has also been reduced by 41 therms creating a cost savings of $49 per year. Electric usage has increased by 1,807 kWh/yr, at $.10/kWh, this will result in a cost increase of $181 per year. This and other energy usage is summarized below in Table 2. Table 3 shows percentage of savings for the model compared to actual savings.

		Heating (Therms)	Heating Slope (Btu/ft2/HDD)	Baseload (DHW + etc)	Electric (kWh)
Pre-Improvement	Model	917	N/A	256	N/A
	Actual	1,046	5.2	178	5,335
Post-Improvement	Model	286	N/A	190	N/A
	Actual	431	2.1	137	7,142

Table 2: West Hill Energy Summary

Explanation of Corrected Actual Savings Percentage

The TREAT model predicted a heating savings of 69% compared to the actual usage from the utility bills which showed a 59% heating reduction. Possible explanations for some of the differences have been identified.

- The homeowners had a baby in spring, 2011, after the pre-retrofit heating period. As a result, they are keeping their house warmer during the year of the post-improvement data, decreasing energy savings. The occupied temperature set point was 63F for pre-improvement and 68F for post-improvement in the TREAT model. After reviewing data collected at the home from data loggers, it has been determined that the home was heated to an average of 70F during the actual post-improvement heating months. In the post-improvement, that would consequently result in a decreased savings percentage. According to our calculations, this would reflect in a 2% savings penalty for the post-retrofit.
- Billing analysis of the post-improvement period electric utility bills reflect an increase of 34% in electric usage. This could also be a result of the new child in the home, reflecting an increase of hours of lighting usage, laundry and dishwasher usage. On the other hand, the heat from the appliances and lighting in the home could add to internal heat gains, reducing the amount of heating needed. In the post-improvement, that would consequently result in increased savings percentage. According to our calculations, this would reflect about a 1% savings credit for the post-improvement.

- The natural gas baseload savings likely was due to using the higher efficiency boiler installed to provide domestic hot water (DHW), reducing the DHW water temperature and adding pipe insulation. The savings may have been offset slightly by additional water usage for dishwashing and laundry.
- Blower door testing was done at different stages during the improvement process which demonstrated the reduction of air infiltration into the home. An energy recovery ventilator (ERV) was installed to provide an additional supply of fresh air to the home to make up for the natural supply of fresh air that was reduced by airsealing. This could also account for additional electric usage.

Consequently, the TREAT model is used for pre-and post-improvement calculations with a 63F thermostat setpoint and 68F for post-improvement. However, the average space temperature that was measured during post-improvement is 70F. If the actual usage for post-improvement is corrected to a 68F setpoint and adjusted for the increased internal gains due to the increased electric usage, the overall actual natural gas savings for heating is calculated to be around 60%, which reflects about a 9% difference from the modeled savings. Table 3 shows the savings percentages for West Hill.

	Heating	Baseload	Electric
Model	69%	30%	N/A
Actual	59%	28%	-34%
Corrected Actual	60%		

Table 3: West Hill Savings Percentage

Analysis Periods

For this report, energy usage is determined by an analysis of monthly billing and meter readings for electricity and natural gas at the West Hill Home.

- The pre-improvement period represents 12 months of energy usage from October 2011 to September 2012. This time period is selected because it covers the last complete heating season prior to the Pre-retrofit.

- The post-improvement period represents 12 months of energy usage from October 2012 to September 2013.

Hawthorne Summary of Findings

Because there was no available pre-improvement actual usage data for the Hawthorne house, the pre-improvement model energy use is taken as actual baseline, and compared to the post-improvement actual results, calculated as described in the methodology section of this report. Based on this simplification, as a result of DER renovations, natural gas consumption for heating has been reduced by approximately 995 therms per year. At a cost of $1.2/therm, this will result in natural gas cost savings of $1,195 per year. Baseload has also been reduced by 103 therms, which creates a cost savings of $124 per year. Since there was no available pre-improvement actual electric usage data for the Hawthorne house, and no electric improvements were calculated in the model, no change is undertaken in the usage. All the energy uses for pre-and post-improvement is summarized in Table 4 as shown below.

		Heating (therms/yr)	Heating Slope (Btu/ft2/HDD)	Baseload, DHW + etc (therms/yr)	Electric (kWh) Includes Cooling and Baseload
Pre-Improvement	Model	1,390	N/A	313	4,266
	Actual*	1,390	N/A	N/A	N/A
Post-Improvement	Model	407	N/A	301	4,266
	Actual	395	3.2	210	4,266

Table 4: Hawthorne Energy Summary

*: Actual energy use for the pre-improvement era is assumed to be same with energy modeling energy use, as there are no actual fuel bills available for that time period.

Explanation of Savings Percentage

The pre-and post-improvement TREAT models predicted a heating savings of 71% by implementing the heating related improvement package. The pre-improvement model compared to post-improvement actual usage from the utility bills showed a 72% heating reduction. Some other highlights in this project:

- Some possible reasons for such a great energy savings are: the initial blower door test conducted showed leakage of 6,759 CFM at CFM50 pre-and 1,434 CFM at CFM50 during post-improvement, which means that the house was very leaky and a great amount of airsealing was done, in addition to the installation of a new high efficiency furnace.
- The occupied temperature set point was kept the same at 60F for the pre-and post-improvement in the TREAT model. There was no data collected at the home from data loggers after the retrofit was completed to make any corrections for actual temperature set points.

- The natural gas baseload savings likely was due to the installation of a higher efficiency domestic hot water (DHW) heater.
- Electric savings likely occurred because of the higher efficiency ECM motor on the new furnace, but it was not presented in here as it was not part of this study.

Because actual pre-improvement energy usage (fuel bills) does not exist, there is no way to precisely compare the modeled and actual heating energy use between the pre-and post-retrofit periods. Therefore, we simplify the analysis by assuming the pre-improvement model energy use represents the actual energy use for that time period. According to this, energy savings for actual and model is very close to each other as shown in Table 5.

	Heating	Baseload	Electric
Model	71%	4%	0%
Actual*	72%	4%	N/A
Corrected Actual	N/A		

Table 5: Hawthorne Savings Percentage
*: Actual energy use for the pre-improvement era is assumed to be same with energy modeling energy use, as there are no actual fuel bills available for that time period.

Analysis Periods

For this report, energy usage is determined by the TREAT calculated energy usage for the pre-improvement period and an analysis of monthly billing for electricity and natural gas at the Hawthorne house for the post-improvement period.

- There was no pre-improvement actual data available. The base model was built using observed conditions at the Hawthorne home. Typically once the model is built; it is adjusted or “trued” to actual billing data.

- The modeled post-improvement period represents 12 months of energy usage predicted, after upgrading the model with post-improvement DER measures. The post-improvement period adjusted to represent 12 months of actual energy usage is July 2014 to May 2015.

Ellis Hollow Summary of Findings

As a result of the deep energy retrofit, propane consumption for heating has been reduced by approximately 526 gallons per year, at a cost of $2.65/gallon. This will result in annual cost savings of $1,395 per year. Baseload propane and electric use has remained the same, so did not result in any cost savings. This and other energy usage is summarized below in Table 6. Table 7 shows percentage of savings for the model compared to actual savings.

		Heating (Gallons)	Heating Slope (Btu/ft2/HDD)	Baseload (Gallons) (DHW + etc)	Electric (kWh)
Pre-Improvement	Model	1,133	N/A	259	7,111
	Actual	1,293	6.3	271	7,874
Post-Improvement	Model	565	N/A	259	7,111
	Actual	767	3.7	271	7,874

Table 6: Ellis Hollow Energy Summary

Explanation of Corrected Actual Savings Percentage

The TREAT model predicted a heating savings of 50% compared to the actual usage from the utility bills which showed a 41% heating reduction. Possible explanations for some of the differences have been identified.

- One of the homeowners works from home and manually adjusts the programmable thermostat according to her comfort needs. The occupied temperature set point was kept the same at 60°F for pre-and post-improvement in the TREAT model. After reviewing data collected at the home from data loggers, it has been determined that the home was heated to an average of 64°F during the actual post-improvement heating months. In the post-improvement, that would consequently result in a decreased savings percentage. According to our calculations, this would reflect into a 6% savings penalty for the post-retrofit. Since there is no evidence in a change in the hours worked at home, this should not create a change but parallel the same usage. Typically, in a home with less air leakage, there would be a reduction of heat called for based on comfort, increasing savings.

Consequently, the TREAT model is used for pre-and post-improvement calculations with a 60°F thermostat set-point, as it was set up at the time of pre-improvement. However, the average space temperature that was measured during post-improvement is approximately 64°F. When the actual usage for post-improvement is corrected to a 60°F setpoint, the overall actual propane savings for heating is calculated to be around 47%, which results in about only 3% difference from the modeled savings. Table 7 shows the savings percentages for Ellis Hollow.

	Heating	Baseload	Electric
Model	50%	0%	N/A
Actual	41%	0%	0%
Corrected Actual	47%		

Table 7: Ellis Hollow Savings Percentage

Analysis Periods

For this report, energy usage is determined by an analysis of monthly billing and meter readings for electricity and propane at the Ellis Hollow home.

- The pre-improvement period represents the energy usage from July 2009 to June 2013. This time period is selected because there is a large (1,000 gallon) propane tank, which leads to intermittent and sometimes partial fills. A long analysis period helps to adjusts for irregularities.

- The post-improvement period represents the energy usage from July 2013 to January 2015. This time period, which covers the post improvement data, is selected because there is a large (1,000 gallon) propane tank, which leads to intermittent and sometimes partial fills. A long analysis period helps to adjusts for irregularities. Also, a fill-up was done at the start of the post-improvement period and the most recent propane delivery was also a complete fill-up.

Cayuga Heights Summary of Findings

As a result of the Deep Energy Retrofit, natural gas consumption for heating has been reduced by approximately 556 therms per year, at a cost of $1.20/therm, this will result in annual gas cost savings of $667 per year. Baseload has increased by 31 therms creating a cost increase of $37 per year. Electric usage has decreased by 1,269 kWh/yr, at $.10/kWh, this will result in a cost savings of $127 per year. This energy usage is summarized below in Table 8.

		Heating (Therms)	Heating Slope (Btu/ft2/HDD)	Baseload (DHW + etc)	Electric (kWh) Includes Cooling and Baseload
Pre-Improvement	Model	1,347	N/A	230	9,545
	Actual	1,341*	N/A	229	8,899
Post-Improvement	Model	551	N/A	204	9,417
	Actual	785*	4.5	260	7,630

Table 8: Cayuga Heights Energy Summary

*The actual fuel data for the pre-improvement was not useable for the regression analysis; therefore, TREAT model "true-up" is presented in the table. Post-improvement actual energy is based on regression analysis.

Explanation of Corrected Actual Savings Percentage

The TREAT model predicted a heating savings of 59% compared to the actual usage from the utility bills which showed a 41% heating reduction. Possible explanations for some of the differences have been identified.

- A programmable thermostat was installed in the Cayuga Heights home as part of the DER implementation to control the occupied and unoccupied temperatures in their home. They have also decided to increase their home temperatures after the pre-retrofit heating period. As a result, they are keeping their house warmer during the year of the post-improvement data, decreasing energy savings. The temperature setpoints in the TREAT model were kept at 62F for both occupied and unoccupied temperatures in the pre-improvement and at 65F for occupied temperature and 63F for unoccupied temperatures (for 8 hours per day) in the post-improvement. After reviewing data collected at the home from data loggers, it has been determined that the home was heated to an average of 70F during the actual post-improvement heating months for the first and second floors. According to our calculations, that would consequently result in a 9% savings penalty in the post-improvement performance.
- The original model was based on heating a 2,321 sqft home. During the retro-fit process an un-conditioned 144 sqft sunporch was converted to conditioned space. TREAT does not allow for adding additional space. The heating load would have been increased if the

additional space was part of the baseline model, so this results in additional 3% savings penalty for the post-improvement energy use.

Consequently, when we correct the actual post-improvement use, after the regression analysis, with average setpoint temperature as 64F instead of the measured 70F, and when the base model square footage is corrected to include the additional conditioned space, the combined savings penalty would be around 12%. The overall actual natural gas savings for heating is calculated to be around 53% as shown in Table 9, which shows percentage of savings for the model compared to actual savings.

	Heating	Baseload	Electric
Model	59%	11%	1%
Actual	41%	-14%	14%
Corrected Actual	53%		

Table 9: Cayuga Heights Savings Percentage

Billing analysis of the post-improvement period electric utility bills reflects a decrease of 14% in electric usage. This could be a result of the owner's change in habits, or a result of the mostly estimated billing data available. Separately, the natural gas baseload increased by 14% likely in the same period likely due to the same reasons, while the natural gas baseload reduction was expected because of the installation of a higher efficiency domestic hot water heater and a water temperature reduction from 140F to 120F in the post-improvement.

Analysis Periods

For this report, energy usage is determined by an analysis of monthly billing and meter readings for electricity and natural gas at the Cayuga Heights home.

- The model analyses is for the pre-improvement period of 12 months of energy usage from January 2011 through December 2011. This time period is selected because it covers a year including a complete heating season prior to the beginning of the post-improvement period. The energy usage for the pre-improvement period is an approximation based on data provided by the utility company which included at least 90% estimated readings for both natural gas and electric.

- The post-improvement period for natural gas represents 12 months of energy usage, based on scaled usage from June 2014 to April 2015 from actual data. The post-improvement period for electric represents 12 months of electric usage from May 2014 to May 2015. This usage was determined from actual meter readings.

Areas of Air Leakage Reduction

There were four main areas of air leakage requiring significant attention during the deep energy retrofits in the four project houses. Additionally, there were opportunities for air sealing in locations unique to each home. All air sealing was checked using the blower door in depressurization. Attic air sealing was checked by a combination of visual inspection and blower door diagnostics.

Attic Plane

The attic plane was a major source of air leakage, as shown in Figures 6 through 17. A thorough clean-out of the attic involved the removal of fiberglass batts by hand, followed by vacuuming of debris with a gas-powered insulation removal vacuum.

Figure 6: West Hill - Attic insulation removal in progress

Figure 7: West Hill - Using the insulation vac to remove the last of attic debris

Figure 8: Hawthorne - Attic prior to start of work

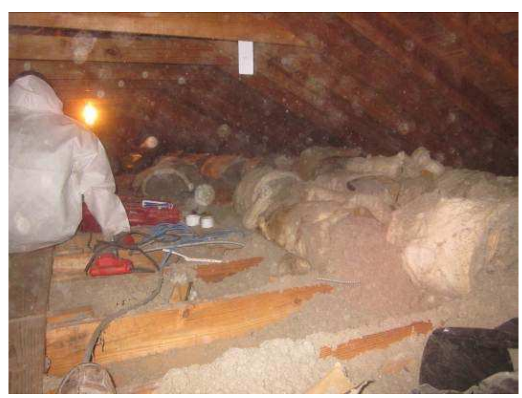


Figure 9: Hawthorne - Attic cleanout in progress

This restored the attic to a very clean condition, and it allowed complete inspection and sealing of air leaks in accordance with best practices for new construction. Attic air sealing was checked by a combination of visual inspection, blower door (including zone pressure diagnostics) and infrared inspection.

The attic planes in the houses had numerous air leaks, found at these locations: small linear gaps between top plates and sheet rock, wiring penetrations, plumbing stacks, electrical boxes for lights and smoke alarms, and bath fans. In Ellis Hollow, an old recessed light fixture, not rated for insulation contact, was replaced by a surface-mounted fixture. All attic access hatches were insulated and weatherstripped. At West Hill, a range hood vent, which passed through a roughly cut hole in the sheetrock, was airsealed.

Interior and exterior top plates were sealed with a coat of 2-part polyurethane foam. This sealed sheetrock/top plate junctions and wiring penetrations. On the exterior bearing walls, the top plates were sealed to the exterior foam sheathing, which extended between the rafter tails up to the vent chutes to form a wind block.

Figure 10: West Hill - Spray foam used to seal top plates and electrical penetrations

Figure 11: West Hill - Plumbing vent with air leaks

Figure 12: West Hill - The plumbing vent is now sealed

At West Hill, a very large chase around the CMU chimney, which housed both the fireplace flue and the old boiler flue was airsealed. This chase, while originally covered with faced fiberglass, connected directly to grilles in the first floor wall on either side of the fireplace. Additional framing was installed to support a Thermax air barrier at ceiling level, which was sealed with two-part foam. Sheet metal and high-temperature caulk were used within 2” of the chimney itself.

Figure 13: West Hill - A giant air leak around the chimney

Figure 14: West Hill - Chimney air sealed; a metal dam provides 2" clearance between cellulose and chimney

At Ellis Hollow, removal of the old attic floor decking and fiberglass batts revealed significant air leakage pathways. The two largest breaks in the attic plane were above the stairs to the basement and above the main floor fireplace. Additional framing was installed to allow attachment of foam board over the stairs, in line with the rest of the attic plane. The areas adjoining the chimney were sealed with foil-faced ductboard and high-temperature caulk.

Figure 15: Ellis Hollow - The chimney chase was sealed with foil-faced ductboard and high temperature caulk

At Hawthorne, a CMU chimney was present at the beginning of the project, extending from the basement to above the roof line. This was demolished down to the basement, and the holes in the ceiling plane were patched with sheetrock. Also at Hawthrone, general repairs to holes in sheetrock were performed by the general contractor. An older recessed light was removed, the sheetrock patched, and a surface-mounted fixture installed.

Figure 16: Hawthorne - Holes were patched and repaired

Figure 17: Hawthorne - The ceiling plane contained some obvious air sealing opportunities

Main Floor Walls

In the project houses, the main floor walls were an opportunity for air leakage reductions, as shown in Figures 18 and 19.

At West Hill, with the exception of the garage wall, which contained some perlite and fiberglass, and the wall behind the kitchen sink, which contained a few pieces of fiberglass, the main floor wall cavities were empty. A large bypass was discovered behind a bath tub on an exterior wall. After blocking the bypass with fiberglass to prevent blow-by into the interior of the house, the cavity was packed with high-density cellulose insulation.

Figure 18: West Hill - The 2 x 4 wall cavities on exterior walls were completely empty

Figure 19: West Hill - Dense-packing the wall cavities

Smaller leaks were associated with gaps in the sheathing, electrical penetrations, etc. Visible holes in the sheathing, such as those from stray hammer strikes, were sealed with one-part foam. Wall cavities were packed with high-density cellulose insulation. Complete coverage was verified with an infrared scanner. Additional air sealing was provided by the Thermax sheathing, which was sealed at top and bottom by a bead of one-part foam; seams were taped with Weathermate construction tape.

At Hawthorne, a large bypass was also discovered behind a bath tub on an exterior wall. A new one-piece tub was installed as part of the bathroom remodel. Sheathing was removed so that the tub could be installed from the exterior. The wall cavity was enclosed with new plywood on the interior and exterior surfaces, and the cavity was dense packed. Wall cavities were mostly full of old urea formaldehyde foam insulation, which had shrunk and cracked, leaving voids toward the tops of many wall cavities. Voids were estimated at ~8% of total wall area. Voids were identified with infrared scanner and dense-packed with cellulose insulation. Additional air sealing was provided by the Thermax sheathing, which was sealed at top and bottom by a bead of one-part foam; seams were taped with Weathermate construction tape.

At Ellis Hollow, most wood-frame walls were completely empty of insulation at the start of the project, containing only an aluminized paper with minimal R value and little resistance to air flow. A few bedroom walls contained cellulose blown in by the homeowner at low density using a rented machine. The aluminized paper and cellulose insulation were removed when the old fiberboard sheathing was replaced. Air leakage through the wall cavities was addressed by packing the cavities with high-density cellulose. In addition, the new OSB sheathing was caulked at tops, bottoms, and joints, and the rigid foam board installed over the OSB was taped using DOW Weathermate construction tape. Electrical penetrations and a kitchen vent were sealed at the outer surface of the Thermax using caulk, foam, and construction tape.

At Cayuga Heights, the first floor walls were empty 2 x 4 walls. These walls were dense-packed from the exterior with cellulose insulation, except the front of the house, where there is a brick façade. The walls on the front of the house were insulated from the interior using Johns Manville Spyder blown fiberglass insulation. One brick façade wall in the kitchen was blocked by kitchen cabinets; this wall section was not insulated because it was determined that it would be too disruptive to the occupants.

Windows and Doors

At West Hill, first floor windows and one window in the basement media room were newer double pane vinyl windows. These were determined to be in good condition, with almost no detectable leakage around the fixed or moving parts of the window assembly. Tests with an electronic window coating detector indicated that the main floor windows had low-e coatings. Sealing the window exteriors with Dow straight flashing provided a small air sealing benefit. The original wood doors were leaky, and they were replaced by new, tightly sealing fiberglass and steel doors. Adjustable thresholds were raised to seal visible gaps at the bottoms of the doors. Door frames were sealed with one-part foam. One single-pane, steel-framed basement window was replaced with a new, double-pane low-e vinyl slider. Other basement windows had been caulked shut and covered over with XPS by the previous homeowner.

At Hawthorne, the conditioned main floor of the house contained a mix of old, single pane windows with aluminum storms and newer, double-pane replacement windows. The older windows were replaced with new, double-pane vinyl replacement windows; windows were sealed with one-part foam and caulk. For the double pane windows than were not replaced, interior trim was removed, and gaps between the window jambs and rough framing were sealed with foam and caulk. The original wood back door was leaky and was replaced by a new, tightly sealing steel door. The solid wood front door was kept and will have a new threshold and weatherstripping installed toward the end of the interior finish work.

At Ellis Hollow, the existing windows were mostly original single-pane windows with storms; doors were older wood doors with single-pane glass. The windows themselves, and the gaps between the rough openings and the window units, represented a significant source of air leakage. Older windows were upgraded to Marvin Integrity double pane windows with low-e glass. Doors are new fiberglass doors. Gaps between the new window/door units and the rough framing were sealed with caulk and foam.

At Cayuga Heights, older windows and doors on the first floor did not operate well or close completely. Several of these were upgraded as part of the retrofit.

<u>Basement Sill Plate and Band Joist</u>

At West Hill, the basement band joist/sill plate assembly consisted of 2 x 8s on a CMU foundation. Small leaks were detected around the entire perimeter at points of wood/wood contact. Larger leaks were found at places where power, telecommunications, and radon utilities passed through the band joist. The band joist was sealed and insulated with 2” closed cell foam. The sill plate was left exposed to allow drying to the inside; however, the wood/CMU joint was sealed with one-part foam.

At Hawthorne, the basement band joist/sill plate assembly consisted of wood on a CMU foundation. Small leaks were detected around the entire perimeter at points of wood/wood contact. Larger leaks were found at places where wiring and other utilities passed through the band joist. The band joist was sealed and insulated with 2” closed cell foam. The sill plate was left exposed to allow drying to the inside.

At Ellis Hollow, leaks at the band joist assembly between the basement and main floor were typical of wood-frame construction. Because the basement was finished and occupied, band joist leaks were sealed from the exterior by caulking seams in the OSB sheathing and sealing penetrations such as a hose bib and dryer vent with caulk and one-component foam. Taping and sealing foam sheathing also reduced air leakage at band joist level, especially in areas where the basement was wood-framed and continuous exterior insulation could be installed to span the band joist between basement and main floor walls.

At Cayuga Heights, the band joist and sill areas in the main basement were sealed with Thermax blocks and polyurethane foam. The ceiling of a small crawlspace over a bathroom addition was sealed and insulated with Thermax; short pony walls in a sun room addition were sealed with closed-cell foam.

Figure 20: West Hill - Spray foam in basement rim joist. In this photo, Thermax has not yet been installed on the walls, and the sill plate has not yet been sealed to the block foundation

Figure 21: Cayuga Heights - Basement rim joist with spray foam and Thermax

Other Areas of Air Leakage Reduction

At West Hill, an old boiler flue was an opportunity for air leakage reduction. The original boiler was an atmospheric boiler with 6” flue. Although it had a motorized vent damper, leakage was still detected through the draft hood. After a sidewall-vented, sealed combustion boiler was installed, the flue was capped at the chimney top, the thimble plugged and caulked, and the cast-iron cleanout caulked shut.

The chase surrounding the wood fireplace at West Hill was a large source of air leakage, as discussed in attic plane. In addition, the flue itself was found to be a major source of leakage, despite the presence of glass fireplace doors. A Lock-Top damper was installed over the open terra cotta flue, resulting in a 150-200 CFM50 reduction.

Also at West Hill, the range hood was targeted. After the penetration of the range hood ductwork through the ceiling plane was sealed, leakage was still detected through the range hood itself. A spring-loaded metal damper was installed in the ductwork below the depth of the attic insulation.

At Hawthorne, the extremely leaky crawlspace access panel was temporarily replaced by a piece of 2.5” Thermax and was replaced by a tight-fitting, weatherstripped wood access panel. Each of the two crawlspaces contained metal crawlspace vents. These were replaced by CMU blocks, mortared in place.

Figure 22: Hawthorne - Metal crawlspace vents were replaced with CMU blocks

At Ellis Hollow, the most complicated air leaks were associated with the tuck-under garage. The wall between the garage and the adjacent mechanical room had a large gap at the top, allowing air movement over the wall top plate between the exposed floor joists. This connection between the garage and the living space represented a potential indoor air quality problem; vehicle exhaust, gasoline fumes, and other pollutants could be drawn from the garage into the house. Complicating the solution was extensive heat piping and potable and drain plumbing running through the garage below the floor joists. This plumbing had to be protected from freezing while still allowing access (to shut-off valves, traps, check valves, etc.) for future plumbing repairs. The majority of the garage ceiling was sheetrocked and dense-packed. Vulnerable piping was enclosed in wood-framed soffits, which were insulated with 2.5" Thermax. Removable access panels were provided around key plumbing fittings.

At Cayuga Heights, the ends of the second floor have kneewall closets. These areas are similar to Cape Cod-style construction, with all the typical air leakage issues. The fiberglass on the slopes and gable triangles was removed. The enclosed slopes and small "devil's triangle" were dense-packed with cellulose. The open slopes were sprayed with closed cell foam and coated with intumescent paint.

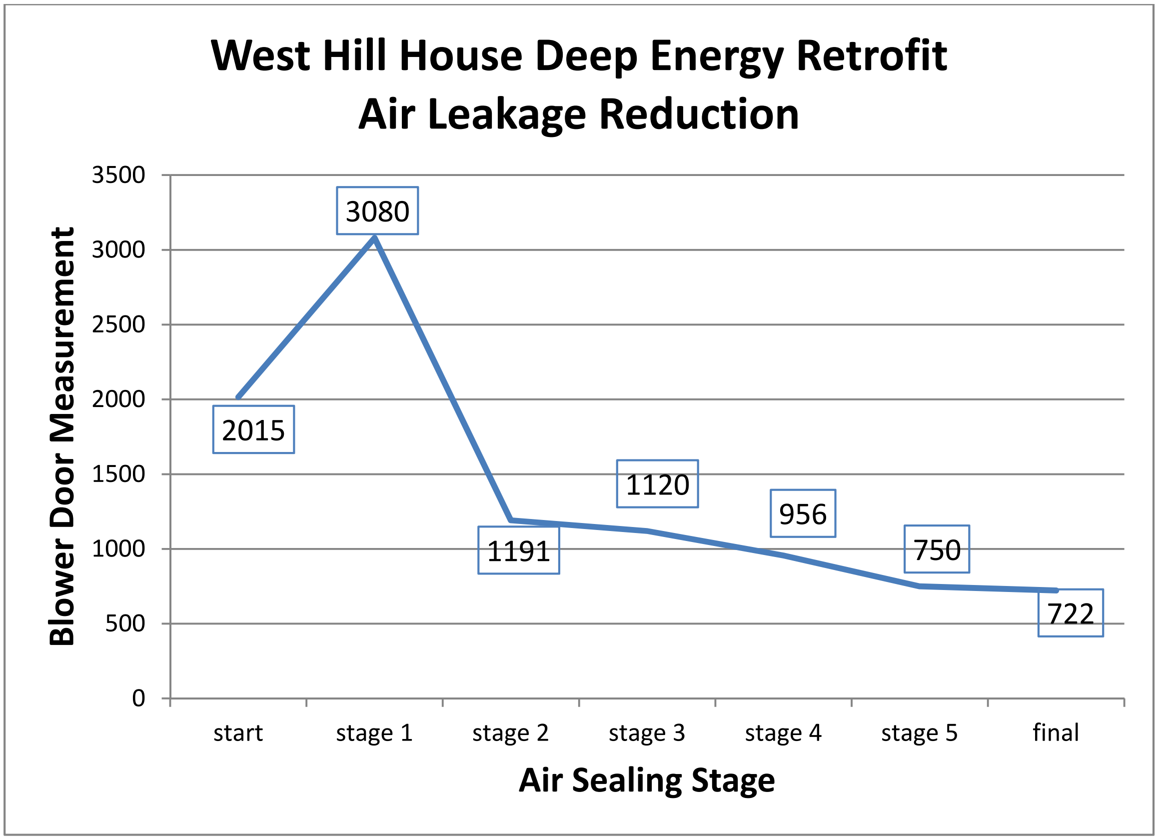
One aspect of the Cayuga Height's construction created an unusual and significant air leakage pathway. The house was originally a one-story ranch; a partial second story was added in the 1980s. The original one-story roof line persists as a vented overhang, which allowed air to intrude between the first and second floors. This area was carefully sealed in line with the exterior walls using Thermax blocks and polyurethane foam.

Figure 23: Cayuga Heights - Air sealing at vented overhang

At Cayuga Heights, the atmospheric water heater was replaced with a power-vented water heater, allowing the sealing of one flue. The presence of a fireplace insert made the installation of a lock-top damper impossible, but air leaks around fireplace cleanouts were sealed.

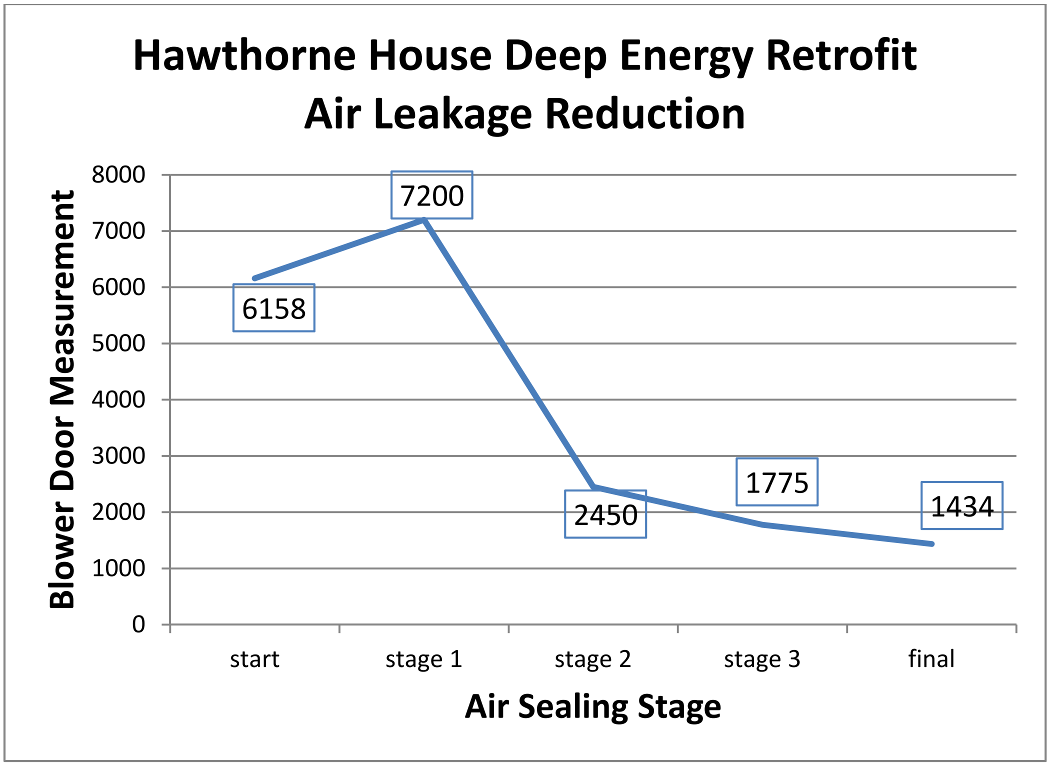
Blower Door Measurements

Blower door measurements were taken at several stages during the air leakage reduction process at each house. The graphs that follow show the measurement at each stage, followed by a table listing the work completed during the stage.



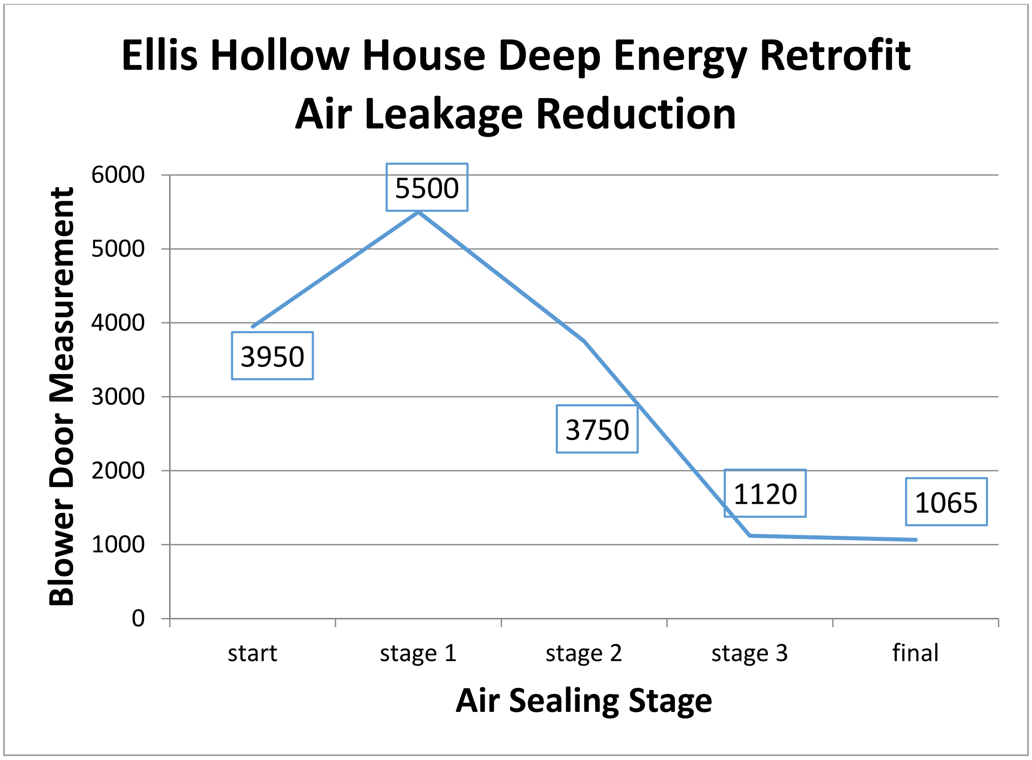
Air Sealing Stage	CFM50	Work completed
Start	2015	
Stage 1	3080	• vinyl siding & old foam sheathing removed • walls dense packed • attic fiberglass removed
Stage 2	1191	• attic airsealed • band joists spray foamed
Stage 3	1120	• wall foam installed
Stage 4	956	• sealed fan ducts and exterior top plates
Stage 5	750	• Lock top damper, window flashing
Final	722	• Final round of blower door guided air sealing, mostly basement sill and band joist

Table 10: West Hill Blower Door Measurements



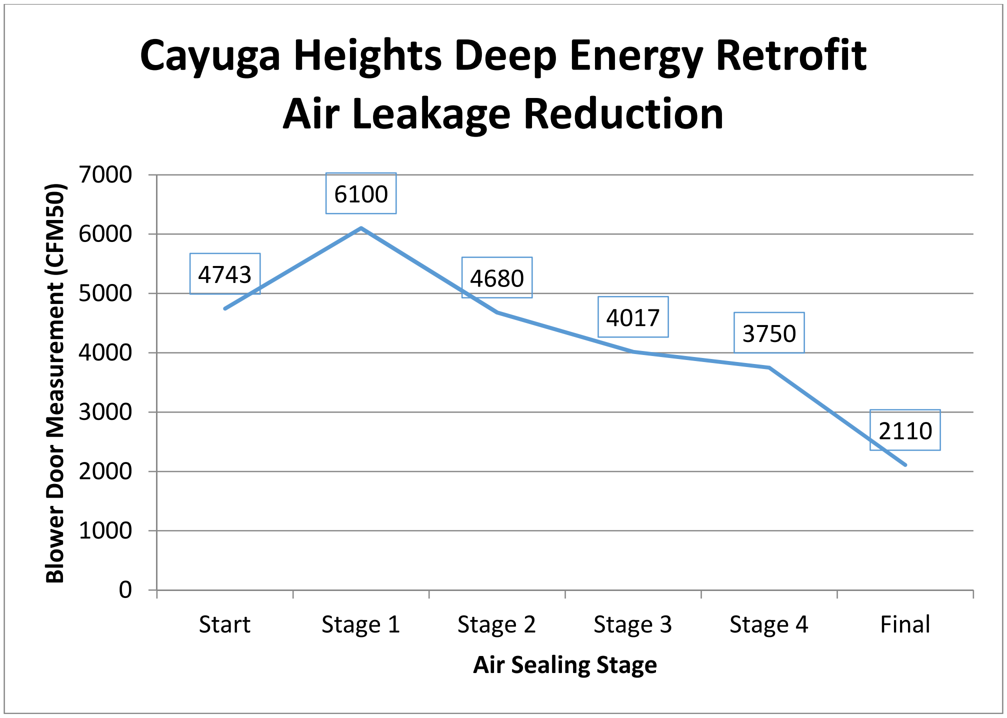
Air Sealing Stage	CFM50	Work completed
Start	6158	
Stage 1	7200	• Attic insulation removed • Siding removed
Stage 2	2450	• Windows and back door replaced • Above grade walls dense packed and foam board attached • Crawlspace vents sealed • Crawlspace and basement walls insulated • Band joist insulated • Damaged sheetrock repaired.
Stage 3	1775	• Attic air sealing (top plates, etc.)
Final	1434	• Blower door/infrared guided air sealing, mainly of window and door openings

Table 11: Hawthorne Blower Door Measurements



Air Sealing Stage	CFM50	Work completed
Start	3950	
Stage 1	5500	• Attic insulation removed • Siding and window trim removed
Stage 2	3750	• Window and door replacement in progress • Walls dense-packed • Attic air-sealed • Foam sheathing installed
Stage 3	1120	• Window and door installation complete • Windows air-sealed • Garage insulation and air sealing complete • Lock-top dampers installed
Final	1065	• Touch-up blower door-guided air sealing

Table 12: Ellis Hollow Blower Door Measurements



Air sealing stage	**CFM50**	**Work completed**
Start	4743	
Stage 1	6100	Attic insulation removed; siding removed
Stage 2	4680	Attic and basement rim joist air sealed
Stage 3	4017	Walls dense-packed
Stage 4	3750	Rim joist between first and second floor sealed
Final	2110	Kneewalls insulated and air-sealed; foam sheathing; new windows; blower-door guided air sealing

Table 13: Cayuga Heights Blower Door Measurements

Insulation Values

Insulation was increased in the attic, basement, walls, and windows during the deep energy retrofit according to the schedule below.

Surface	House	Pre-DER	Post-DER
Attic	West Hill	Nominal R-19 faced fiberglass: effective R-11 to R-15	Cellulose: R-60
Attic	Hawthorne	3” fiberglass batts, 2” cellulose: R-18	Cellulose: R-60
Attic—unfloored section	Ellis Hollow	5.5” fiberglass batts over most of attic (nominal R-19); approx. 200 ft^2 had 5.5” + 6” batts (nominal R-38)	Cellulose: R-60 over most of area. Closed cell foam (tapering to R-36) used within 18” horizontal distance of raftertails.
Attic—floored section	Ellis Hollow	5.5” fiberglass batts (nom. R-19)	5.5” cellulose + 2.5” Thermax (R-37)
Second floor attic	Cayuga Heights	10” fiberglass batts, fair to poor installation: R-15	Cellulose: R-60
Basement walls: Unfinished	West Hill	Uninsulated block: R-2	2.5" Thermax + block: R-18
Basement walls: Finished	West Hill	Uninsulated block, 2 x 4 wall, sheetrock: R-4	3" closed cell foam + block: R-20
Basement walls	Hawthorne	Uninsulated block: R-2	2.5" Thermax + block: R-18
Crawlspace walls	Hawthorne	Uninsulated block: R-2	2.5" Thermax + block: R-18
Finished basement concrete block walls	Ellis Hollow	Block plus 1.5-2” EPS; total R value R-8 to R-10	No change
Basement walls	Cayuga Heights	Uninsulated block: R-2	2.5" Thermax + block: R-18
Basement band joist	West Hill	Uninsulated band joist: R-3	2" closed cell foam + 2.5" Thermax: R-31
Basement crawlspace band joist	Hawthorne	Uninsulated band joist: R-3	2" closed cell foam + 2.5" Thermax: R-31
Band joist	Ellis Hollow	Uninsulated band joist: R-3	2.5” Thermax (R-19 total assembly)
Basement band joist	Cayuga Heights	Uninsulated band joist: R-3	2.5” thermax (interior) + 2.5" Thermax (exterior): R-34
Crawlspace floor	Hawthorne	Dirt floor with 6 mil vapor barrier: R-0	¾” EPS, 20 mil vapor barrier: R-3
Slab floor	Ellis Hollow	Uninsulated concrete, no perimeter insulation	2” XPS (R-10) on exposed slab perimeter.

First floor bathroom floor (cantilevered into garage)	Cayuga Heights	Fiberglass, R~11	Fiberglass + 2.5” Thermax: R-27
Sunroom floor	Cayuga Heights	4” concrete slab: R-0	4” slab + 2” XPS: R-10
Above-grade walls: Most walls	West Hill	Uninsulated 2 x 4 cavity, wood siding, 1/2" polyiso, vinyl siding: R-8	Cellulose in wall cavity + 2.5" Thermax: R-29
Above-grade walls: West facing gable	West Hill	Uninsulated 2 x 4 cavity, wood siding, 1/2" polyiso, vinyl siding: R-8	Cellulose in wall cavity + 1.5" Thermax: R-22.5
Above-grade walls: South-facing gable and north-facing porch wall	West Hill	Uninsulated 2 x 4 cavity, wood siding, 1/2" polyiso, vinyl siding: R-8	Cellulose in wall cavity + 1" Thermax: R-18.5
Above-grade walls: Garage wall	West Hill	2 x 4 cavity with fiberglass and perlite: R-10	Cellulose in wall cavity + 2.5" Thermax: R-29
Above-grade walls: Most walls	Hawthorne	2 x 4 wall, Urea formaldehyde insulation with ~8% voids: R-12	Voids in UFFI filled with cellulose; exterior sheathing of 2.5" Thermax: R-30
Wood frame walls: Most walls	Ellis Hollow	2 x 4 walls; empty cavity (R-5) or loose-fill cellulose (R-12)	2 x 4 cavities; dense-packed cellulose; 2.0”-2.5” Thermax (R-25 to R-28)
Wood frame wall where clearance to door was too small to allow foam sheathing	Ellis Hollow	2 x 4 walls, empty cavity (R-5)	2 x 4 walls; closed-cell foam (R-20)
Above-grade walls: Vinyl cladding, first floor	Cayuga Heights	2 x 4 wall, empty cavity: R-5	Dense-pack cellulose plus 2.5” Thermax: R-28.
Above-grade walls: Brick cladding, first floor	Cayuga Heights	2 x 4 wall, empty cavity: R-5	Dense-pack fiberglass: R-13 (except kitchen)
Above grade walls: Second floor	Cayuga Heights	2 x 6 wall, 5.5” fiberglass: R-19	2 x 6 wall, 5.5” fiberglass plus 2.5” Thermax: R-35
Above-grade walls: Sunroom	Cayuga Heights	2 x 4 wall, empty cavity: R-5	2 x 4 wall, 3” closed cell foam, 2.5” thermax: R-33.
Shed roof	Ellis Hollow	6” fiberglass batts (nom. R-19)	5” Thermax (R-33)
Slopes (open)	Cayuga Heights	5.5” fiberglass, poor: R-11	5” closed cell foam: R-30
Slopes (enclosed)	Cayuga Heights	5.5 fiberglass, poor: R-11	5.5” cellulose: R-20
Windows: First floor and finished basement windows	West Hill	Vinyl, double pane, low-e glass: R-3 (R-2 clear glass on finished basement window)	No change

Windows: Single pane basement window	West Hill	Single pane, steel frame: R-1	Vinyl, double pane, low-e glass: R-3
Windows: Existing double pane windows	Hawthorne	Vinyl, double pane, low-e glass: R-3	No change
Windows: Single pane windows on first floor	Hawthorne	Single pane clear glass, wood frames with aluminum storm windows: R-2	Vinyl, double pane, low-e glass: R-3
Windows: Single pane basement window	Hawthorne	Single pane, steel frame: R-1	No change
Windows: Most main floor and basement windows; door sidelights	Ellis Hollow	Single pane windows (most with storms) or double pane clear glass.	Double pane/low-e/argon, R-3.9
Windows: Existing vinyl windows	Ellis Hollow	Vinyl, glass block (R-2) or double pane low-e (R-3)	No change
Windows: Existing double pane windows	Cayuga Heights	Wood double pane windows (1980s vintage): R-2	No change
Windows: Single pane windows on first floor	Cayuga Heights	Single pane clear glass, wood frames with aluminum storm windows: R-2	Wood, double pane, low-e glass: R-3
Windows: Single pane basement window	Cayuga Heights	Single pane, wood frame, with storm panels: R-2	No change
Doors	West Hill	Wood: R-2 to R-3	Insulated steel/fiberglass: R-5
Back door	Hawthorne	Wood: R-2 to R-3	Insulated steel/fiberglass: R-5
Front door	Hawthorne	Wood: R-2 to R-3	No change
Doors	Ellis Hollow	Wood: R-2 to R-3	Insulated steel/fiberglass: R-5
Doors	Cayuga Heights	Wood/steel: R-2 to R-4	No change

Table 14: Insulation Values

Material List

The materials used during the Deep Energy Retrofit were primarily Dow Building Solutions products. Dow is a partner with Snug Planet and Taitem Engineering on this series of four Deep Energy Retrofit houses for NYSERDA.

Product Description	Manufacturer	Pricing
2.5" Thermax (reflective)	Dow Building Solutions	$1.63/sf
2.5" Thermax (white facing)	Dow Building Solutions	$1.88/sf
1.5" Thermax (reflective)	Dow Building Solutions	$1.35/sf
1" Thermax	Dow Building Solutions	$0.95/sf
Powder-driven insulation fasteners	Hilti	$0.99/ea
Wind Devil 2 screws	Wind-Lock	$0.20/ea
Closed cell foam (low pressure)	Dow Building Solutions	$0.75/board foot
Closed cell foam (high pressure)	LaPolla Industries	$0.53/board foot
Weathermate construction tape	Dow Building Solutions	$0.13/linear foot
Foil tape	Venture Tape	$0.09/linear foot
Weathermate straight flashing 9"	Dow Building Solutions	$0.81/linear foot
Cellulose insulation	National Fiber	$11.24/25# bag
Rafter chutes	Owens Corning	$0.60/ea
One-part foam sealant	Pur-Fill	$14.50/750 ml can
Acrylic-latex caulk	DAP	$2.09/tube
Aluminum coil stock	Genesee Building Products	$0.73/square foot
TerraBlock (crawlspace floor insulation)	Basement Systems	$0.45/sf
CleanSpace crawlspace liner	Basement Systems	$0.33/sf
2" Tuff-R	Dow Building Solutions	$1.24/sf
2" Styrofoam	Dow Building Solutions	$1.00/sf

Table 15: Material List

West Hill Deep Energy Retrofit Costs

The combined material and labor cost involved in the implementing the above-grade wall insulation strategy at the West Hill house is \$9.55/shell square foot (ssf). The cost is separated by location in the summary table below. Note that the basement floor is included in the shell square footage but was not treated. Additional work (window, door, and HVAC) was completed during the Deep Energy Retrofit, and these costs are summarized separately.

Deep Energy Retrofit – Insulation and Air Sealing Costs

		Contract: bid price for the job		Revised price: based on actual time spent	
Location	SSF	\$/ssf	Total	\$/ssf	Total
Attic	1325	\$4.27	\$5,660	\$8.21	\$10,880
Basement walls	1171	\$6.26	\$7,330	\$7.57	\$8,860
Basement band joist	153	\$10.20	\$1,560	\$10.65	\$1,630
Basement floor	1325	\$0	\$0	\$0	\$0
Above grade walls	1360	\$16.86	\$22,931	\$21.74	\$29,569
Total	5334		\$37,481		\$50,939
Average \$/ssf		**\$7.02**		**\$9.55**	

Deep Energy Retrofit – Additional Improvements (actual cost)

Boiler	\$7,155
Window	\$410
Doors	\$3,000
Bath fan and ERV	\$1,409
Interconnected smoke alarms	\$550
Building Permits	\$300
Total	\$12,824

Deep Energy Retrofit – Funding Sources

Homeowner contribution: GJGNY 3.49% loan	\$18,909
Home Performance with Energy Star incentive	\$2,101
DOW product contributions	\$11,311
PON 2254 Project funds	\$17,434
Homeowner out-of-pocket contribution	\$550
Total	\$50,305

Table 16: West Hill DER Costs and Funding

West Hill Wall Costs

Wall work	Contract Amount	Contract amount per SF	Estimate of donated material	Net contract amount
Demolition	$2,700	$1.99	$0	$2,700
Dense pack walls	$4,770	$3.51	$0	$4,770
Foam board, tape, and flashing	$5,756	$4.23	$3,400	$2,356
Window and door trim	$3,715	$2.73	$0	$3,715
Total, no windows, doors or siding	$16,941	$12.46	$0	$13,541
Install siding	$5,990	$4.40	$0	$5,990
Total, no window or doors	$22,931	$16.86	$3,400	$19,531
Window and doors	$3,410	$2.51	$0	$3,410
Total including window and doors	$26,341	$19.37	$3,400	$22,941

Table 17: West Hill Wall Costs

Hawthorne Deep Energy Retrofit Costs

The combined material and labor cost involved in the implementing the above-grade wall insulation strategy at the Hawthorne Circle house is $6.01/shell square foot (ssf). The cost is separated by location in the summary table below. Note that the basement floor is included in the shell square footage but was not treated. Additional work (window, heating, and fan) was completed during the Deep Energy Retrofit, and these costs are summarized separately. With the additional improvements of windows, heating, and fan, the cost was $9.63/ssf.

Deep Energy Retrofit – Insulation and Air Sealing Costs

		Contract price for the job Revised with actual costs	
Location	SSF	$/ssf	Total
Attic	1671	$3.67	$6,140
Basement/crawl walls	812	$6.21	$5,041
Basement band joist	196	$5.26	$1,030
Crawlspace floor	886	$4.00	$3,544
Basement floor	784	$0.00	$0
Above grade walls, including roof extensions	1532	$12.85	$19,681
	5881	$6.01	$35,345

Deep Energy Retrofit – Additional Improvements

Furnace and ductwork	$14,012
Windows and doors	$9,033
Bath fan	$500
Misc. repairs, non-energy related	$53,472
Total, including DER and additional work	$110,116

Total energy related envelope work	$33,099	$5.62/ssf
Total energy work including windows, heating, and fan	$56,645	$9.63/ssf

Deep Energy Retrofit – Funding Sources

Ithaca Neighborhood Housing construction funds	$89,273
DOW product contributions	$5694
PON 2254 Project funds	$15,150
Total	$110,116

Table 18: Hawthorne DER Costs and Funding

Hawthorne Wall Costs

Wall work	Contract Amount	Contract amount per SF	Estimate of donated material	Net contract amount
Demolition	$815	$0.53	$0	$815
Targeted dense-pack	$3,510	$2.29	$0	$3,510
Foam board, tape, and flashing	$3,246	$2.12	$3,246	$0
Total, no windows, doors or siding	$7,571	$4.94	$3,246	$4,325
Install siding	$9,864	$6.44	$0	$9,864
Total, no windows or door	$17,435	$11.38	$3,246	$14,189
Windows and door	$9,033	$5.90	$0	$9,033
Total including windows and door	$26,468	$17.28	$3,246	$23,222

Table 19: Hawthorne Wall Costs

Ellis Hollow Deep Energy Retrofit Costs

The combined material and labor cost involved in the implementing the above-grade wall insulation strategy at the Ellis Hollow house is $16.88/shell square foot (ssf). The cost is separated by location in the summary table below. Additional work (windows and doors, ventilation, electrical work, and roofing upgrades) was completed during the Deep Energy Retrofit, and these costs are summarized separately.

Deep Energy Retrofit – Insulation and Air Sealing Costs

		Contract price for the job Revised with actual costs	
Location	SSF	$/ssf	Total
Attic	1429	$8.70	$12,430
Above grade walls, including roof extensions	2560	$16.88	$43,202
Garage ceiling, including soffits	337	$9.13	$3,080
Garage block walls	88	$10	$880
Misc. air sealing, including Lock-Top dampers	n/a		$4,000
Slab edge insulation (materials only)	320	$2	$320

Deep Energy Retrofit – Additional Improvements

Windows and doors	$23,494
Roof replacement (including soffits)	$7,252
Electrical upgrades	$1,450
Gutters	$650
HRV	$700
Misc.	$1,124

Total, all work	$98,582

Deep Energy Retrofit – Funding Sources

Homeowner funds	$62,892
DOW product contributions	$6,000
PON 2254 Project funds	$26,690
Home Performance with Energy Star incentives	$3,000
Total	$98,582

Table 20: Ellis Hollow DER Costs and Funding

Ellis Hollow Wall Costs

Wall work	Contract Amount	Contract amount per SF	Estimate of donated material	Net contract amount
Demolition	$2,400	$0.94		$2,400
Extend overhangs	$2,847	$1.11		$2,280
Sheathing replacement	$2,280	$0.89		$2,280
Cavity insulation	$10,384	$4.06		$10,384
Foam board, tape, and flashing	$8,350	$3.26	$6,000	$2,350
Window and door bucks	$1,404	$0.55		$1,404
Total, no windows, doors or siding	$27,665	$10.81		$21,098
Install siding	$15,537	$6.07		$15,537
Total, no window or doors	$43,202	$16.88		$36,635
Window and doors	$23,494	$9.18		$23,494
Total including window and doors	$66,696	$26.05		$60,129

Table 21: Ellis Hollow Wall Costs

Cayuga Heights Deep Energy Retrofit Costs

The combined material and labor cost involved in the implementing the above-grade wall insulation strategy at the Cayuga Heights house is $10.67/shell square foot (ssf). The cost is separated by location in the summary table below. Additional work (windows and doors, ventilation, electrical work, and roofing upgrades) was completed during the Deep Energy Retrofit, and these costs are summarized separately.

Deep Energy Retrofit – Insulation and Air Sealing Costs

		Contract price for the job Revised with actual costs	
Location	SSF	$/ssf	Total
Flat attics	871	$8.43	$7347
Sloped ceilings	291	$8.25	$2400
Above grade walls	2212	$26.69	$59,043
Basement walls	1184	$6.40	$7580
Basement band joist	125	$9.60	$1200
Basement floor	1344	$0.00	$0
Miscellaneous insulation and air sealing			$1500
Overall	6027	$13.12	$79,070

Deep Energy Retrofit – Additional Improvements

Windows and doors	$14,000
Roof replacement (including gutters)	$17,000
Electrical upgrades	$1700
Bath fan upgrade	$500
Power vented water heater upgrade	$1656
Sunroom remodel	$24,420

Total, all work	$138,346

Deep Energy Retrofit – Funding Sources

Homeowner funds	$94,000
DOW product contributions	$9175
PON 2254 Project funds	$23,954
Assisted Home Performance with Energy Star incentives (pending)	$5000
Empower NY funding (pending)	$6217
Total	$138,346

Table 22: Cayuga Heights DER Costs and Funding

Cayuga Heights Wall Costs

Wall work	Contract Amount	Contract amount per SF	Estimate of donated material	Net contract amount
Demolition	$3000	$1.36		$3000
Cavity insulation	$4500	$4.50		$4500
Foam board, tape, and flashing	$13,115	$5.92	$9175	$3940
Window and door bucks	$3000	$1.35		$3000
Total, no windows, doors or siding	$23,615	$10.67		$14,440
Install siding	$35,428	$16.01		$35,428
Total, no window or doors	$59,043	$26.69		$49,868
Window and doors	$14,000	$6.32		$14,000
Total including window and doors	$73,043	$33.02		$63,868

Table 23: Cayuga Heights Wall Costs

Good Discoveries

The deep energy retrofits yielded many good discoveries during the process. The following strategies were employed, and they should be considered for reducing the overall cost and increasing the accessibility of any deep energy retrofit.

1. Homeowner cooperation is critical. Progress on one of the projects was slowed significantly by homeowner decisions about window/siding contractor, siding materials, and a porch and sunroom remodel. Work in the garage and basement was also impeded by clutter, which was not addressed by the homeowner on a timely basis. These factors contributed to a higher-than-necessary project cost.

2. Utilize NYSERDA/Home Performance with Energy Star rebates. In addition to funding and materials provided by PON 2254, in one case, the homeowners were able to qualify for a $3000 incentive from the New York Home Performance with Energy Star Program. In another case, $21,010 of the project cost was funded through the program between an incentive and financing.

3. Income-dependent assistance programs can defray the cost of deep energy retrofits. In one case, NYSERDA "Assisted Home Performance with Energy Star" and "Empower NY" subsidies were accessed to defray approximately $11,000 of the project cost.

4. Working with a local building materials salvage organization is a sound strategy. Finger Lakes Re-use did the removal of the siding on the projects.

5. Keeping existing windows can reduce costs. Existing double pane windows in good condition were kept, reducing the overall cost of the projects.

6. Getting the attic clean is critical. A gas-powered vacuum was used to clean the attics prior to air sealing. Blower door, infrared, and zone pressure diagnostics were used to verify an effective air-seal.

7. A single layer of foam reduces costs. Unlike some DERs that used multiple layers of foam, this study utilized a single layer.

8. The Accu-cutter allows the foam sheathing to be cut quickly and with very tight tolerances.

Figure 24: West Hill - Using the Accucutter

9. Foam wall sheathing can be integrated with exterior wall top plate air sealing and attic wind blocking.

Figure 25: Hawthorne - Notching foam sheathing to fit around rafter tails

Figure 26: West Hill - Soffit boards were removed so the Thermax can extend up past the top plates. We notched around the rafter tails and sealed the wall/ceiling junction with spray foam from the attic

10. Utilize creative strategies to avoid moving window and door openings. At Ellis Hollow, one door was located on an interior corner. The existing door opening would have had to move to accommodate even a 1” layer of Thermax sheathing. To avoid the expense of moving the door while still achieving reasonable R values, the wall that could not take

foam sheathing was insulated with closed cell foam rather than cellulose. This allowed a cavity R value of R-21 for this small section of the house.

Figure 27: Ellis Hollow - Due to narrow clearances to a door, the shaded wall area below was not insulated with exterior sheathing. Closed-cell spray foam was installed to provide maximum R value in the wall cavities

11. Lock-top dampers. Lock-top dampers provided an effective air-seal on two large fireplace flues at Ellis Hollow. The homeowners have been cautioned to open a window to provide makeup air whenever the fireplace is in use.

12. Take advantage of DER to upgrade safety, repair problems and/or aesthetics. The exterior aesthetics of the homes were improved dramatically.

13. Sweat equity. The homeowners at Ellis Hollow contributed sweat equity, taking on the labor-intensive job of trenching around the exposed slab and installing extruded polystyrene slab perimeter insulation.

Time and Motion Techniques

During the deep energy retrofits, many techniques that were investigated and recommended during the Time and Motion Study, included in the Appendix, were utilized. Some of the techniques put into practice were further revised.

1. **Fastening to wood-frame walls**
   a) 4” Ci-lock screws were used to attach Thermax sheathing to wood-frame walls.
   b) The number of screws per sheet was reduced from the manufacturer’s recommendation of 28-30 per full sheet to 12 per full sheet. This seemed to provide very secure attachment. In this house, the siding contractor decided to attach ¾” furring strips with 5” Head-lok screws over the Thermax. The Head-lok screws went directly into the studs. This was done in order to provide a vented air space behind the fiber-cement siding. it also provided an extra-secure attachment for the Thermax.
   c) Where possible, a single Ci-lock screw was used to span the joint between two sheets of Thermax.

2. **Fastening to concrete walls**
   a) Despite the lower installed cost of the Christmas tree fasteners, the crew expressed a strong preference for the Hilti fasteners, both because of the tighter connection to the wall and the reduced physical effort of installation. The Hilti fasteners were selected for this project and performed well. Six fasteners were used per full sheet.

3. **Full cuts**
   a) The Accu-Cutter was used for full length cuts. Using two passes for 2.5” Thermax, it produced clean, straight, factory-like cuts, allowing pieces to be butted very tightly against each other. The clean rips also allowed efficient use of scrap material.

4. **Cross cuts and L-cuts**
   a) A PVC saw or a fine-toothed woodworker’s saw were used for cross cuts with good results. These tools were also used to notch around rafter tails.
   b) It was determined on site that the best overall results would be obtained by avoiding L-cuts around windows and doors and instead using the Accu-cutter to create two rectangular pieces joined by a vertical seam.

5. **Hole cuts**
   a) A keyhole saw was used for hole cuts (for example, around furnace vent pipes) with good results.

6. **Taping**
   a) Weathermate construction tape with a roller applicator was used to tape seams in the exterior Thermax. Corners were taped with 9" straight flashing. No problems were reported.

7. **Window bucks and flashing**
   a) At Cayuga Heights, window bucks and sill pans were installed by the window/siding contractor. The bucks were made of flat strips of OSB screwed through strips of Thermax. This approach provided a broad attachment surface for window flanges and siding and in theory reduced thermal bridging relative to solid wood bucks. In practice, the work was poorly done, leaving irregular pieces of Thermax and gaps that had to be sealed with one-part foam. Side and top flashing was done with DOW straight flashing, which adhered excellently to the Thermax and window flanges and allowed defects in the contractor's installation to be remedied.
   b) At Ellis Hollow, the window buck and flashing techniques developed in the time and motion studies were not utilized. An alternative buck design was developed by the homeowner, incorporating a 2x extension of the rough opening and a 5" wide OSB nailed. The flanged, new construction windows were flashed in the rough opening by the window and siding contractor prior to foam sheathing installation. After the foam sheathing was installed, Weathermate straight flashing and construction tape were installed to protect the OSB and provide a continuous drainage plane.

Figure 28: Ellis Hollow - Window buck

c) The buck and flashing approaches tested in the time and motion studies were designed for new, flanged windows. At Hawthorne and West Hill, the windows were a mix of existing wood/vinyl inserts, which were left in place and new, unflanged vinyl windows, which were installed as inserts to match the style of the existing windows. Bucks, including sill extensions, were built of 2x framing lumber. Aluminum coil stock was bent on a brake to provide an impermeable sill flashing. After the foam sheathing was installed, straight flashing was used to span the joints between the foam and the buck, and between the buck and the window. The flashing was covered with fibercement stops and casings. Straight flashing was also used for the side and head flashings, and a piece of Weathermate construction tape was used to protect the head flashing from low-angle shear per Building Science Corp. recommendations. The straight flashing worked well, although the general contractor complained that it was very hard to remove residue if the flashing extended too far onto the vinyl windows and had to be trimmed back after the fiber cement stops were installed.

Figure 29: Hawthorne - Window bucks. Note the aluminum flashing covering the sill

Figure 30: Hawthorne - Installing Weathermate tape to protect the head flashing from low-angle shear

Figure 31: West Hill - Window buck

Figure 32: West Hill - Sill extension detail

Crew Comments

West Hill

The Snug Planet crew thoroughly enjoyed working with the West Hill homeowners during the Deep Energy Retrofit. Their willingness to fully participate in all that a deep energy retrofit entails, along with desirable house features, made this a successful project.

a) The single story house was accessible: access to attic and basement from outside the main living space.

b) Cleaning out the attic by removing old insulation made a significant impact in the quality of the attic work

c) The Thermax went up fast. Four rows of three fasteners, for a total of twelve fasteners per sheet, were used.

d) The Dow tapes were quite sticky and effective. The flexible flashing was very useful on site for a few details such as the areas around the boiler exhaust pipes.

e) The crew was very mindful of all the connections and drainage planes.

f) Next time, a preconstruction meeting will be held with all the contractors prior to starting.

The siding contractor should have allowed more time and people for this job, and putting the re-used siding back on was a more difficult process than expected.

Hawthorne

The Snug Planet crew thought that the deep energy retrofit at Hawthorne went quite well. There were merits to working in a vacant house, such as less daily cleanup was required. Working with a general contractor who was not fully on board with the DER concept resulted in timing and preparation issues. The Hawthorne Circle house proceeded in a more piecemeal schedule than would have been preferred.

The crew enjoyed putting up the Thermax, and they felt it went very smoothly. They feel more confident in their techniques, and they will keep improving. The crew is developing strategic approaches when encountering different types of existing conditions, and these will be applied to the next two deep energy retrofits for this project, as well as their non-DER work.

Figure 33: Hawthorne - A large sign showcases the work in progress

Figure 34: West Hill - Post-attic cleanout

<u>Ellis Hollow</u>

The Snug Planet crew rated the Ellis Hollow deep energy retrofit as one of their best professional experiences, and successfully overcoming challenges during the project featured strongly into this assessment.

Three factors contributed to the great results and good will during the project. First, the high level of engagement by the homeowner created an ideal environment of aligned goals with the objectives of a deep energy retrofit. Second, the contractors on the project shared the same synergy, creating a working relationship with Snug Planet in which the overall outcome was a high quality energy renovation. The third factor draws from the first two: at every challenging situation presented by the house, a resolution was developed and implemented.

The Snug Planet crew is pleased to have achieved their mark especially on such a challenging project. As one crew member said, “With so many unknowns and variables, it is even more spectacular when it all comes together and the results are so good.”

<u>Cayuga Heights</u>

The Snug Planet crew experienced significant frustration on the Cayuga Heights project. Although at the point the crew is technically proficient at all aspects of DER insulation/air sealing, progress was slowed by various factors. Work at the house proceeded in a more piecemeal schedule than would have been preferred. The crew enjoyed putting up the Thermax, and they felt it went very smoothly, once the windows/siding contractor prepared the exterior. The crew now feels confident in their techniques, which will be applied in market rate Deep Energy Retrofits, as well as non-DER work.

Appendix: Time and Motion Report

The Time and Motion Report, completed as the first phase of this Deep Energy Retrofit research project, follows. The techniques and strategies learned during the study were used during the installations on the four houses.

Optimized Strategy for Scaling Up Deep Energy Retrofit

Time and Motion Study Results

July 19, 2012

Submitted to:
NYSERDA
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Project Manager Buildings R&D

Prepared by:
Taitem Engineering
Snug Planet

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Executive Summary

Taitem Engineering and Snug Planet conducted a time and motion study to test, analyze, and recommend efficient procedures utilized in deep energy retrofits (DER). The testing occurred over a period of five days. The focus of the study was to optimize strategies involving operations using 2.5-inch Thermax polyisocyanurate rigid foam insulation. The materials used in the study were provided by the manufacturer of Thermax, Dow Building Solutions.

These nine procedures were tested with multiple installers, tools, and methods:

- Fastening Thermax to a wood-frame wall (Fastening to Wood-frame Walls)
- Fastening Thermax to a concrete wall (Fastening to Concrete Walls)
- Cutting full 8-ft lengths of Thermax (Full Cuts)
- Cutting crosswise 4-ft sections of Thermax (Cross Cuts)
- Cutting 16-inch x 18-inch rectangles in Thermax (L Cuts)
- Cutting 4-inch diameter holes in Thermax (Hole Cuts)
- Taping Thermax seams (Taping)
- Flashing window sills with Thermax sheathing (Flashing)
- Creating a window buck for Thermax sheathing (Window Bucks)

The optimal tool and method, accounting for material cost, labor cost, quality, accuracy, damage to Thermax, dust generation, noise, ease, and efficiency, are presented in the following step-by-step guidelines.

These tools and methods will be further tested during the four DER project houses under field conditions.

Recommended Procedure for Fastening to Wood-frame Walls: Ci-lock Screws

Rationale: 2.5” Thermax foam sheathing can be attached to wood-frame walls using either Ci-lock washer screws or framing nails with plastic washers. The Ci-lock screws are recommended for the following reasons:

- Comparable total cost when the time for hand-assembly of nails and washers is taken into account.
- Tighter contact between Thermax and OSB sheathing.
- Less mechanical damage to Thermax caused by stray hammer strikes and over-driving of fasteners.
- Lower noise and less physical exertion, reducing worker fatigue.
- Easier removal of attached Thermax to correct mistakes in placement.

Procedure:

- Use 4” Ci-lock screws to provide 1” penetration into framing through Thermax and plywood/OSB sheathing.
- A cordless screw gun with #2 Phillips bit is recommended. Impact drivers typically cause over-driving and damage to the foam.
- If possible, attach a temporary ledger at the bottom of the wall to be sheathed to support and align the foam during fastening.
- Using a permanent marker, mark locations of stud centers at top and bottom of Thermax.
- Bring Thermax board into position. Butt seams tightly against adjacent boards. Hold Thermax in place with 1-2 Ci-Lock screws at mid-height on board.
- Using a chalk line, snap lines on Thermax to indicate stud positions.
- Drive screws so that the Thermax is pulled tight to the wall assembly but avoid pulling the washer through the foil skin.
- Dow and Ci-lock recommend 28-30 fasteners per sheet (7 per 8’ stud for 16” o.c. framing). Ci-lock fasteners can be used to span seams, reducing the total number of fasteners needed. According the manufacturer, “Perimeter fasteners can be detailed to bridge the gap of abutting board joints due to the 1.75” diameter of the washer used to fasten the board to the studs. This detail can be used to bridge a maximum of two board joints, thus two fasteners should be used at the intersection of three or four boards.”
- Gently push the Thermax in several locations to make sure it is tight to the wall assembly. Visually check that all washers are in full contact with the foam board.


Figure 1. A 4" screw (above) is needed to provide 1" penetration into framing.

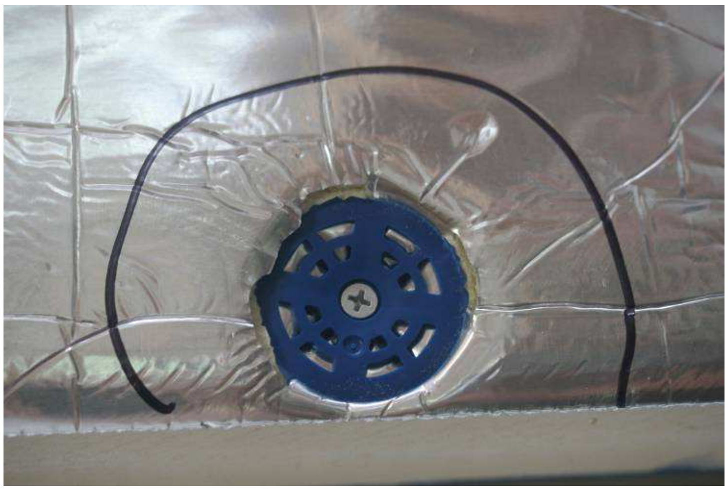


Figure 2. Avoid over-driving the screws and puncturing the foil skin of the Thermax.


Figure 3. Fully attached Thermax with 28 fasteners per 4' x 8' sheet. While not shown here, a single fastener can be used to span a vertical seam, reducing the total number of fasteners needed.

Recommended Procedure for Fastening to Concrete Walls: Christmas Tree Fasteners

Rationale: Several methods are available for attaching foam board to concrete walls such as basement and crawlspace interior walls. In our experience, mechanical fastening (instead of or in addition to attachment with adhesive) is required for long-term durability. We tested two methods of mechanical attachment: Hilti powder-driven insulation fasteners (Hilti X-IE 6-60 PH 52), and 4" "Christmas Tree fasteners," which are barbed plastic anchors that require pre-drilling and are tapped into place. The Hilti fasteners are dramatically faster and easier to install but are also much more expensive. Both styles of fasteners secure the Thermax to the wall in an acceptable manner; overall the Hilti fasteners appear to provide slightly tighter and more consistent contact with the concrete.

When labor and material costs are taken into account, the Christmas tree fasteners are the more cost-effective method and are recommended.

Note: This procedure is recommended for poured concrete and block walls. For stone or rubble foundations, closed cell spray foam is recommended.

Procedure:

- Cut the Thermax to the height of the basement wall. Notch the Thermax around utilities and openings. When measuring and cutting, take into account any required capillary breaks at the bottom of the wall and any insect inspection strips (if required) at the top of the wall.
- If a drainage gap/capillary break is desired at the bottom of the wall, hold the Thermax off the floor temporarily with a scrap 1x board.
- Butt seams tightly against adjacent Thermax boards.
- Holding the Thermax firmly in place, drill a hole through the Thermax and into the concrete with a rotary hammer. Use the masonry bit size recommended by the fastener manufacturer. The hole should be 4 ¼" to 4 ½" deep.
- Gently tap the Christmas tree fastener into the hole. Tap until the Thermax is in full contact with the wall and the head of the fastener is flush with the surface of the Thermax.
- Use a minimum of six fasteners per 4 x 8 sheet.

Figure 4: The Christmas tree fasteners (right), which are tapped into a pilot hole, have a lower installed cost than the Hilti X-IE 6-60 fasteners (left), which are installed using a powder-actuated tool.

Figure 5. Drilling the pilot hole for a Christmas tree fastener using a rotary hammer.

Figure 6. Gently tap the Christmas tree fastener into place. With all fasteners in place, the Thermax should be in full contact with the concrete wall.

Recommended Procedure for Full Cuts: Accucutter

Rationale: We tested three tools for performing full (rip) cuts on 4' x 8' sheets of 2.5" Thermax: A hand saw, a 10" contractors table saw with fine-tooth blade, and the Accucutter (a non-motorized cutting jig). The Accucutter is recommended for the following reasons:

- Clean, very straight cuts, producing near-factory edges.
- Minimal dust generation; low noise.
- Increased worker safety relative to the table saw.
- Time per cut much lower than the hand saw and competitive with the table saw.

Procedure:
- Set up the Accucutter on sturdy saw horses; use C-clamps to secure the Accutter to the saw horses.
- For insulation thicker than 2", two passes through the Accucutter are required. For 2.5" Thermax, set the cutting blade approx. 1" above the table surface.
- Slide the blade assembly horizontally to provide the desired width. Check the distance between the fence and the blade with a tape measure. Tighten the adjustment screw.
- Slide the plastic shims into place to support the Thermax as it slides past the blade.
- Holding the Thermax tightly against the fence, push it through the Accucutter. The first pass will cut slightly more than half way through the Thermax.
- Flip the Thermax end-to-end and repeat the previous step to cut all the way through.

Figure 7. Pushing the Thermax through the Accucutter. A helper (out of picture to right) supports and guides the Thermax, flips it, and hands it back for the second pass.

Recommended Procedure for Cross Cuts: PVC Saw

Rationale: We tested four tools for making cross-cuts on 2.5" Thermax: A 7.25" circular saw with toothless tile blade, the Insul-knife (a smooth-bladed tool similar to a hand saw in shape), a sharpened putty knife, and a carpenter's hand saw.

Among the options tested, the hand saw was the clear winner for the following reasons:

- Lowest time per cut.
- Reduced noise and fine dust generation relative to the table saw.
- Reduced effort relative to the Insul-knife.

The PVC saw was not used in this test but was as quick as the handsaw for L-cuts, with slightly better accuracy. The PVC saw was also favored by installers because its pointed tip allowed them to start the cut in the middle of the sheet and work toward the edge, reducing physical strain. For these reasons, the PVC saw is recommended for cross cuts.

Note: The Accucutter can be used for cross cuts on scraps shorter than 48."

Procedure:

- Set up a pair of saw horses or other work surface.
- Mark the line to be cut with a permanent marker, measuring tape, and straight edge or sheetrocker's square. Check measurements.
- Make the cut with the PVC saw, keeping the blade perpendicular to the surface of the Thermax.

Figure 8. A PVC saw such as the one shown here is the tool of choice for cross cuts and L cuts.

Recommended Procedure for L Cuts: PVC Saw

Rationale: We tested four tools for making L-shaped cuts in Thermax such as those than might be required around a window or door: 7.25" circular saw with toothless tile blade, the Insul-knife, a carpenter's hand saw, and a 12" Lenox PVC saw.

The PVC saw was chosen for the following reasons:

- Lowest time per cut.
- Reduced noise and fine dust generation relative to the table saw.
- Reduced effort relative to the Insul-knife.
- Improved accuracy compared to the carpenter's saw (ascribed to the stiffer blade).

Procedure:

- Set up a working surface such as piece of plywood across sawhorses.
- Mark the lines to be cut with a permanent marker, measuring tape, and straight edge or sheetrocker's square. Check measurements.
- Make the cut with PVC saw, keeping the blade perpendicular to the surface of the Thermax.

Recommended Procedure for Hole Cuts: Keyhole Saw

Rationale: We tested three tools for cutting a circular hole in Thermax such as might be required for a fan duct, dryer duct, or furnace exhaust. The tools tested were: a keyhole (jab) saw; the Accu-knife (a sharp, non-serrated blade that fits into a folding jab saw grip), and an electric meat carving knife.

The keyhole saw is the recommended method, yielding the quickest speed and most accurate cuts. The narrow, sturdy blade was suitable for making curved cuts.

Procedure:

- Carefully mark the hole on Thermax using a permanent marker. If possible, use the item passing through the hole (for example a 4" fan duct) as a template.
- Use a keyhole saw to neatly cut the hole. Keep the blade perpendicular to the surface of the foam to avoid a tapered hole.

Figure 9. The keyhole saw provided the quickest and most accurate hole cuts.

Recommended Procedure for Taping: Construction Tape with Applicator

Rationale: Four methods of taping seams in exterior Thermax sheathing were tested: Dow Weathermate Construction Tape (with and without a tape dispenser), Dow Weathermate Straight flashing, and VentureTape 1520CWNT. Dow Weathermate Construction in conjunction with a tape dispenser is recommended for the following reasons:

- Weathermate Construction tape is recommended by the manufacturer for this application.
- Application time and overall cost (labor plus materials) were the lowest of the four options tested.
- The dispenser eliminated the need for a separate knife to cut the tape and also eliminated time and frustration associated with starting the tape adhered to the roll.

Procedure:

- Fill gaps larger than ¼" between sheets with one-component polyurethane foam. Allow foam to cure and trim excess before taping.
- Apply at temperatures higher than 15F.
- Apply to clean and dry surfaces after evaporation of morning dew. Wipe dust from affected areas with a dry rag.
- Apply tape to seam with dispensers. Tape should be centered over seam with good contact on both sides of seam.
- Apply pressure to the taped area with the palm of your hand to ensure full adhesion.

Figure 10. An installer applies Weathermate construction tape to a vertical seam with a dispenser. With the palm of his other hand, he applies pressure to smooth the tape and ensure good adhesion.

Recommended Procedure for Flashing: Weathermate Straight Flashing

Rationale: Dow recommends three methods for sill flashing in foam sheathed walls: Weathermate Straight Flashing, Weathermate Flexible Flashing, and Weathermate plastic sill pans. Total cost (labor plus materials) was similar for the straight flashing and sill pan methods, and costs for both these methods were considerably lower than for flexible flashing. For walls with 2.5” Thermax sheathing, the straight flashing method is preferred because the 9” wide flashing (which can span the entire assembly from the exterior surface of the foam to the interior edge of the rough sill) provides more complete protection than the 3.75” deep sill pan.

During this test, a tapered sill dam (made for example with wood clapboard) was found to provide a better result than a square edged sill dam. The taped sill dam could be used to cover the exposed cut edge of the foam, providing a surface to which the flashing could be adhered (the flashing adheres well to the foil face of the insulation but does not adhere to the cut edges).

Procedure:

- A sill dam should be installed prior to installation of sill flashing. Cut a tapered clapboard to span the width of the rough opening. Nail or screw it to the sill with the low end flush with the edge of the foam sheathing.
- Cut a piece of 9” straight flashing 6” longer than the sill opening. Remove the release tape and stretch it across the opening with the bottom edge 2-2.5” below the sill and extending horizontally 3” on either side of the opening.
- Make vertical slits at the jambs and fold down the material over the sill dam. Apply pressure with the palm of your hand to ensure good adhesion to the sill dam, foam board, and window jambs.
- Cut 2 pieces of straight flashing 8” long. Make a slit in the middle of each piece 2” deep. Remove the release paper and place these pieces in the corners, folding out the slit portions on the face of the foam board. Smooth these in place by hand.
- Inspect sill flashing assembly for full coverage and adhesion and absence of pockets that could trap water.

Figure 11. Sill flashing using Dow Weathermate Straight Flashing. The complete sill flashing detail includes a long piece spanning the opening and two corner patches.

Figure 12. Close up of corner patch detail.

Recommended Procedure for Installing Flanged Windows in Foam-sheathed walls: Plywood Buck

Rationale: Several methods are available for installing windows in foam sheathed walls. Our approach uses the exterior surface of the foam as the drainage plane. Windows are installed as "outies," with the flanges and head and side flashing outboard of the foam. Washer screws through the window flanges and foam provide secure attachment from the window to the framing, but a wooden buck is still required to allow shimming of the window jambs.

A ½" plywood buck on all four sides of the rough opening is recommended for the following reasons:

- Good thermal performance (low thermal bridging compared to 2x bucks).
- Low installed cost (labor and materials)
- Rigid substrate for shimming
- Compatibility with common interior finishes (wooden extension jambs or drywall returns).

Note: Use of ½" plywood jambs shrinks the rough opening by 1" in each dimension. A tapered sill dam may reduce the vertical opening further. Windows should be sized accordingly.

Procedure:

1. Prior to installation of foam sheathing
    a. Rip strips of ½" CDX plywood on a table saw. Strips of plywood should be the width of the existing wall assembly (studs and sheathing) plus 2.5". For example, for a 2 x 4 wall with ½" sheathing, the bucks should be (3.5" + 0.5" + 2.5" = 6.5").
    b. Screw strips of plywood to 4 sides of rough opening. Use pairs of 1 5/8" or 2" deck screws (one screw or each pair toward the interior of the jamb/sill, one toward the exterior). Screws should be on approx. 16" centers.
    c. If using drywall returns, the plywood buck should be carefully shimmed and squared so that the drywall returns can be screwed directly to the plywood.

2. Following installation of foam sheathing.
    a. Install tapered sill dam. Use appropriately sized clapboard or similar material. Attach to buck with finish or siding nails.
    b. Trial fit the window.
    c. Apply 9" Dow straight flashing to the sill (See Recommended Procedure for Sill Flashing).
    d. Cut two pieces of 9" straight flashing about 1" shorter than the height of the rough opening. Apply the flashing from the top of rough opening down over the top of the sill flashing (shingle style) to protect the seam between the buck and the foam.

e. Install the window plumb and square per manufacturer's instructions. Caulking the top and side flanges (not the bottom) is generally recommended. Use shims between the window frame and plywood buck as needed. Fasten flanges through foam using 4" screws with washers to provide 1" penetration into framing. Follow the window manufacturer's recommendations for fastener spacing.

   Note: It is recommended that the window be elevated above the rough sill/sill dam with a pair of shims to provide a space at the bottom of the window for foam sealant.

f. Check the window for smooth operation and proper latching.
g. Using 4" Dow straight flashing, install side flashing. Flashing should cover the entire side flange and adjacent foam and extend about 1" above the top flanges and 1" below the bottom flanges.
h. Using 4" Dow straight flashing, install head flashing across the top flange. This should extend both above and laterally beyond top of the side flashing.
i. Protect the top of the head flashing using a slightly longer piece of 3" Dow Weathermate construction tape.
j. From the interior, seal the window frame to the buck with one-component foam.

Figure 13. Plywood bucks are cut to match the new wall thickness. They provide a firm substrate for shimming the new window.

Figure 14. After the plywood buck and sill dam are installed and the rough opening is flashed, the window is installed and shimmed, 4" wood screws go through the flanges, foam, and sheathing and into the wall framing.

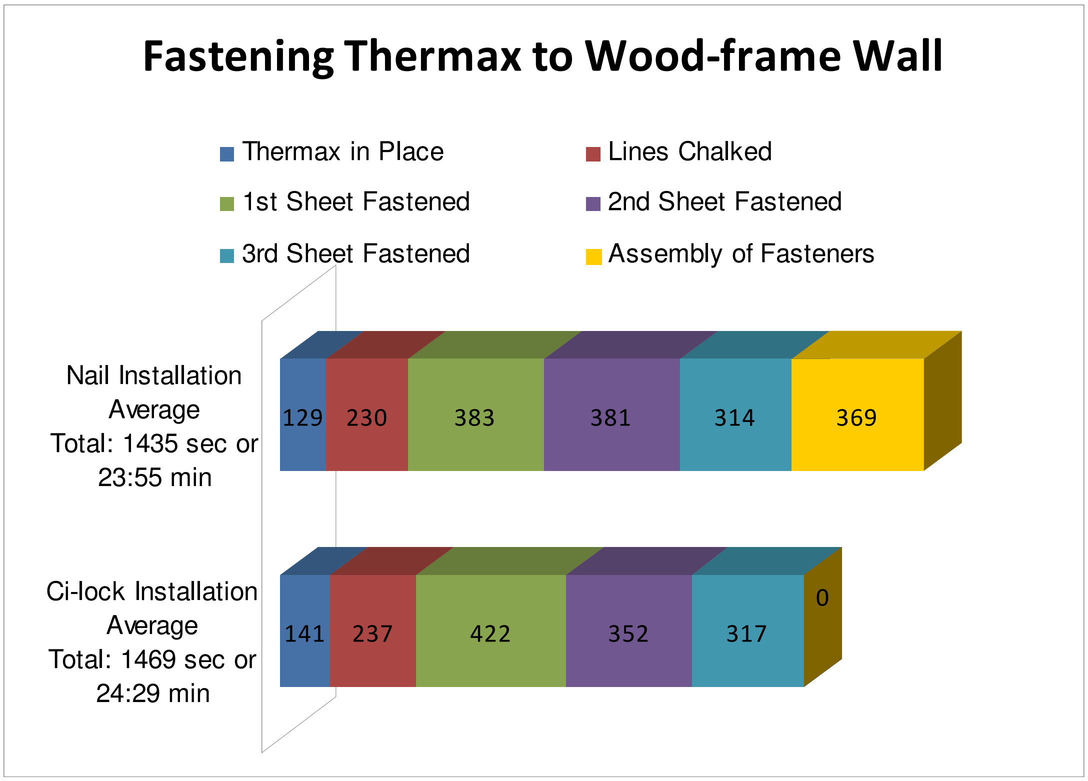
Analysis: Procedure for Fastening Thermax to Wood-frame Wall

Test plan

1. Overview: Three installers will each install three consecutive full sheets of 2.5” Thermax to the test wall using two different fastening methods.
    a. 3.5” ci-lock screws
    b. 3.5” hand-assembled cap nails
2. Starting conditions
    a. Test wall bare of Thermax, with 2x ledger attached at band joist level
    b. Stud locations marked in sharpie on first and second floor band joists with crows’ feet
    c. Three sheets of Thermax on a saw horse located at office end of wall
    d. 8’ step ladder, opened, at office end of wall
    e. Fasteners in box next to Thermax; minimum 100 fasteners
    f. Installer with tool belt on, tools in hand, standing next to sawhorse
3. Procedure
    a. Timer says “go”
    b. Installer picks up first sheet of Thermax, sets it on ledger (office end of wall), and temporarily tacks it in place with two fasteners at chest height on edges
    c. Installer does the same with second and third sheets of Thermax, butting each sheet tightly against the preceding one
    d. Timer notes “Thermax in place”
    e. Installer moves ladder into place centered on first sheet of Thermax
    f. Installer snaps chalk lines at 16” and 32” on Thermax, clipping chalk line at top and snapping from bottom. Use marks on wall to align chalk lines.
    g. Installer moves ladder and snaps chalk line on second and third sheets
    h. Timer notes “Chalk lines snapped.”
    i. Installer moves ladder back to office end
    j. Installer installs fasteners on each stud on 16” vertical centers (7 fasteners per stud, 28 fasteners per sheet)
    k. Timer notes “First sheet fully fastened”
    l. Timer notes “Second sheet fully fastened”
    m. Timer notes “Third sheet fully fastened”
    n. Number of tests: 6

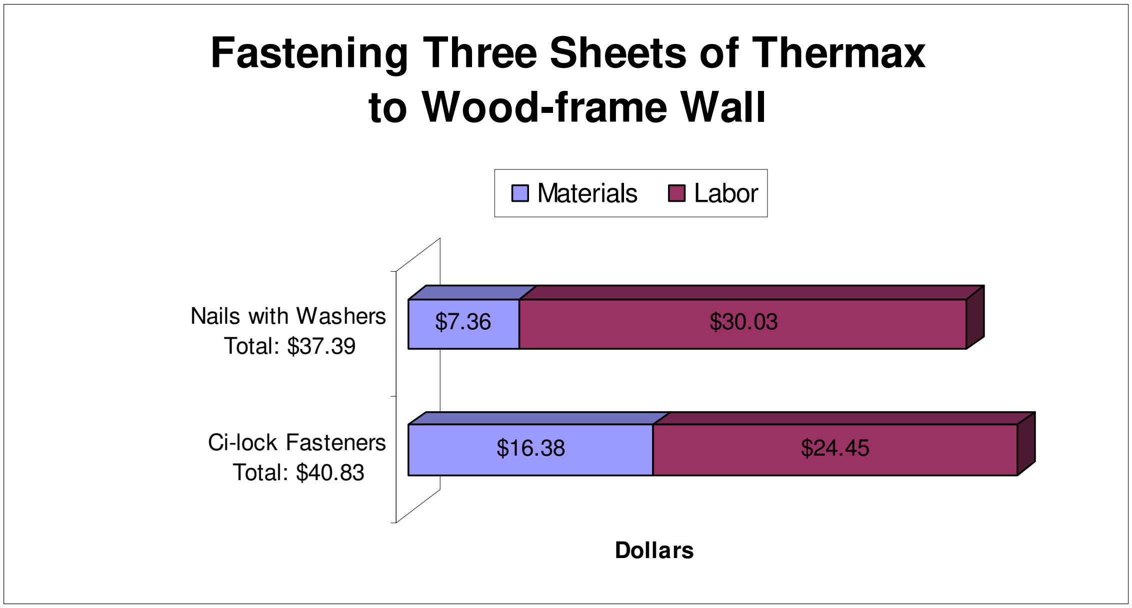
Time Analysis

The time comparison of installation between ci-lock fasteners and hand assembled cap nails is nearly the same. However, this does not include the time for assembly of the washer and nails. This was tested in a batch of 300, and the resultant time for 84 washer and cap nail assemblies, the amount needed for one full test, is about 6 minutes. The ci-lock fasteners take the least time in fastening Thermax to a wood-frame walll.



Cost Analysis

The Ci-lock fasteners were slightly more expensive than the hand assembled cap nails.



Test Notes

Quality

- Ci-lock fasteners pull the Thermax into the plywood more than the nails
- Ci-lock fasteners feel more secure
- With nails, the seams were not consistently tight, possibly due to caution to not damage Thermax
- Hammering nails resulted in more damage to Thermax

Ease and efficiency

- “I’d rather be driving [ci-lock] screws than nails”
- Cap nails and washers fell apart while refilling tool belt
- Hammering was harder and caused more fatigue
- “With nails, if you don’t get a good drive, you’re left with a giant hole.”

Dust or noise generation

- Hammering nails is noisier than driving ci-lock screws; need ear protection
- Dust was not a factor with either method.

Damage to Thermax

- Ci-lock:
    - Washer punctures: 2 on test 1, 0 on test 2, 6 on test 3 (test 3 - due to impact driver)
- Nails:
    - Hammer and washer punctures: 6 on test 4, 5 on test 5, 3 on test 6
    - Hammer marks without puncture: 2 on test 4, 1 on test 5, 1 on test 6
- There was much more damage to Thermax using nails than ci-lock fasteners.

Fastener Schedule Testing

The number of ci-lock fasteners needed secure 2.5” Thermax to a wood frame wall was tested with three fastener spacings. As increasing weight pulled on the center of the 4’x4’ Thermax test board, the amount of deflection was measured.

Fastener Spacing	Test Weight	Deflection
16"	48 lbs	0
32"	48 lbs	0
46"	25 lbs	.3"

The test board with fastener spacing of 46” pulled away from the wall about 0.3” when 25 pounds of force was applied at the center of the Thermax board. However, no deflection was observed with 48 pounds of force applied to the Thermax board with 16” or 32” ci-lock fastener spacing.

We recommend additional testing by Dow to confirm increasing the ci-lock fastener spacing from the standard 16” to our tested 32” for 2.5” Thermax. This would substantially decrease the total number of fasteners need per 4’x8’ sheet of Thermax, from 28 fasteners to 12 fasteners, dramatically reducing both material and labor costs.

Recommendation: Ci-lock screws

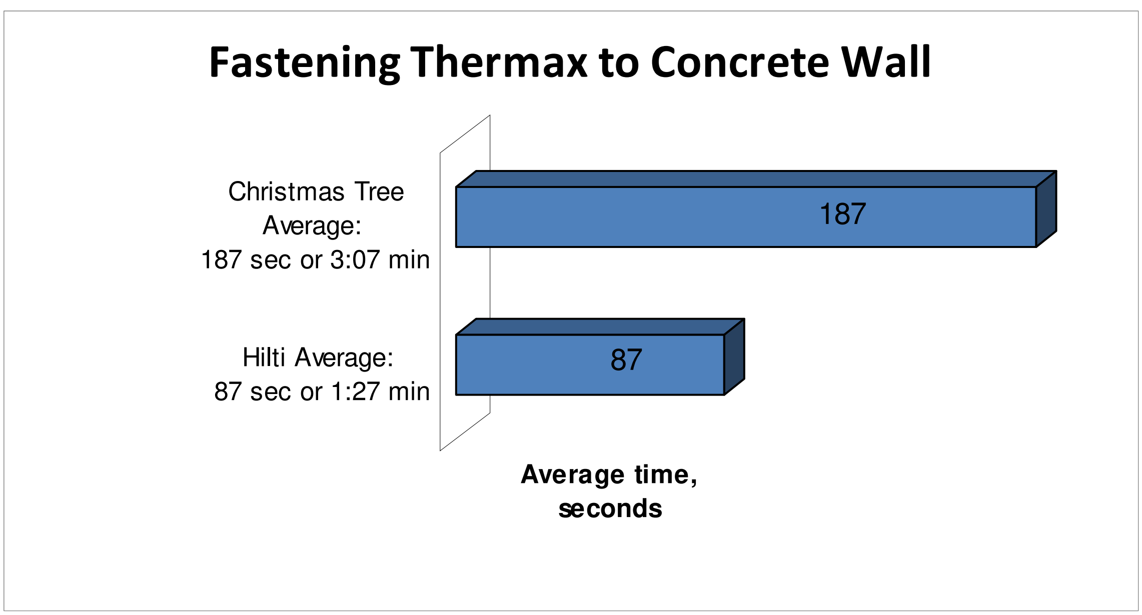
Analysis: Procedure for Fastening Thermax to Concrete

Test plan

1. Overview: Three installers will each install two types of mechanical fasteners:
    a. Hilti X-IE Insulation Fasteners (X-IE 6-60 PH 52) in conjunction with DX 460-F8 Powder-Actuated Tool
    b. Basement Systems 4” Silverglo “Christmas Tree” fasteners, pre-drilled with a Makita rotary hammer and appropriately sized masonry bit
2. Starting conditions
    a. Installers practiced in use of each tool
    b. All pieces of insulation cut to length, notched around windows and other obstacles, and held in place with adhesive
    c. Rotary hammer on floor, plugged in, with bit installed; Christmas tree fasteners in box
    d. Hilti on floor; unloaded; loads and fasteners in boxed on floor
3. Procedure
    a. Timer says “go”
    b. Installer puts in 8 fasteners (4 on each vertical edge of foam). If a fastener breaks or is mis-fired, an additional fastener must be installed.
    c. Timer records “stop”
    d. Number of tests: 12

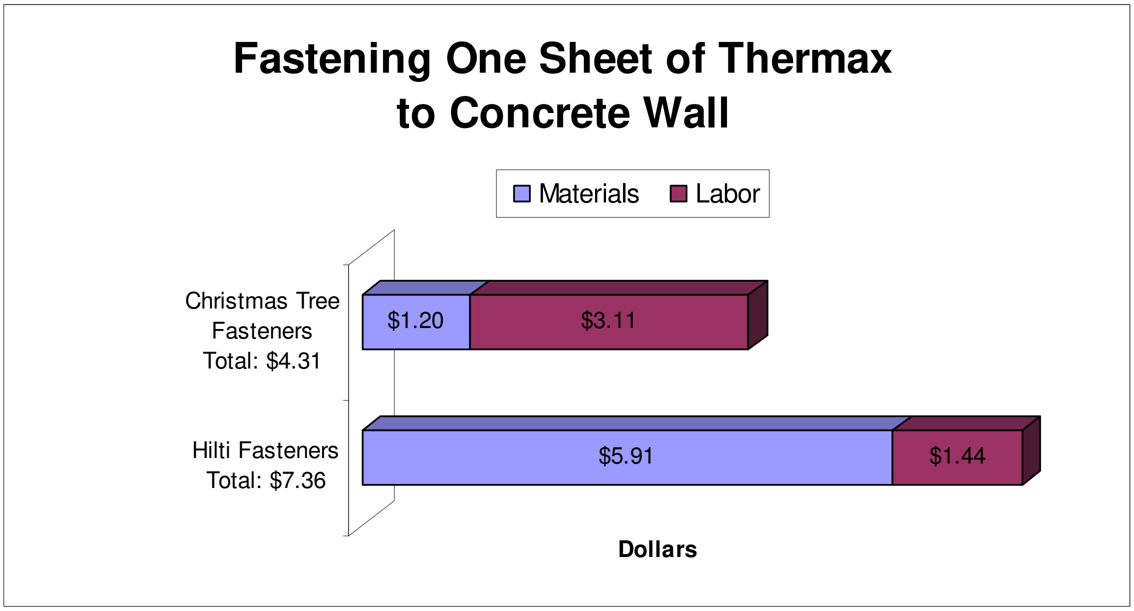
Time Analysis

The Hilti was about twice as fast during the testing.



Cost Analysis

The cost of materials and labor to fasten one sheet of Thermax to a concrete wall was significantly less when using Christmas tree fasteners.



Test Notes

Quality

- Hilti showed superior quality in fastening Thermax to concrete walls; the Hilti fasteners strongly draw the sheet into the wall.
- The Christmas Tree fasteners occasionally broke and were replaced, and their fastening quality was still acceptable.
- In one area of the basement, two Christmas Tree fasteners broke during three installations for a total of six failures. The two Hilti fasteners were installed easily in this difficult concrete area.

Ease and efficiency

- Christmas tree fasteners require predrilling followed by hammering.
- The Hilti is one step.

Dust or noise generation

- Christmas tree fastners requires predrilling, which is noisy, and this step creates dust.
- The Hilti installation was quieter than the drilling and hammering of the Christmas Tree fastener installation.

Damage to Thermax

- Christmas tree washer breakage: 6 broke out of a total of 36 installed
- The Christmas tree fastener installation puts small rips in the Thermax from either the predrilling, the hammering or the washer.

Recommendation: Christmas tree fasteners

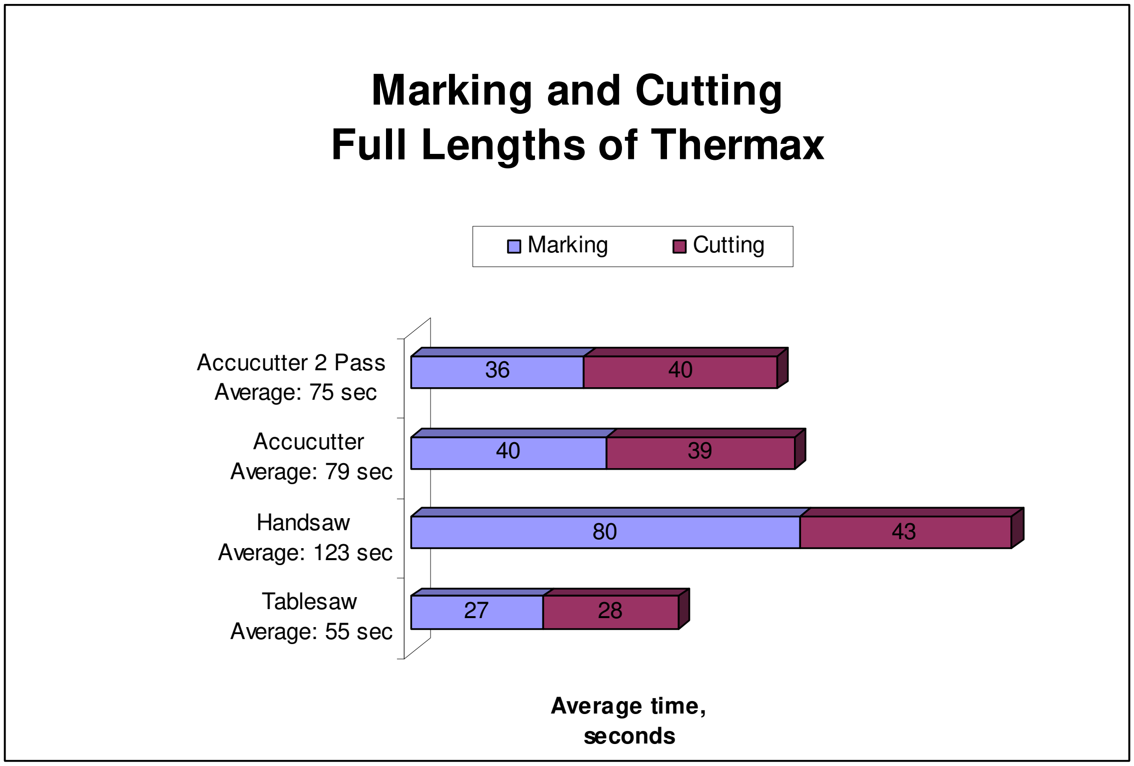
Analysis: Procedure for Full Cuts

Test plan

1. Overview
    a. Installers will test four methods of making lengthwise rips in 4 x 8 sheets of 2.5” Thermax.
        i. 10” table saw with fine tooth plywood blade
        ii. Accucutter
        iii. Hand saw
2. Starting conditions
    a. Single sheet of Thermax on saw horse 15-20’ from work station
    b. Accucutter, table saw, and sawhorse cutting stations set up; fences out of position
    c. Hand tools on ground next to cutting station
    d. Installer and helper with dust masks on standing next to Thermax
3. Procedure
    a. Timer says “Go”
    b. Installer and helper pick up Thermax and move to work station
    c. Marking (hand saw only)
        i. Use straight edge and Sharpie to mark 12” line from factory edge in preparation for cutting a 12” x 96” piece
    d. Cutting
        i. Accucutter and table saw:
            1. Installer feeds sheet through to helper
            2. Helper braces tools and helps hold material flush to fence.
        ii. Helper sets down 12” strip and remaining sheet
        iii. Timer notes time
        iv. Number of tests: 33

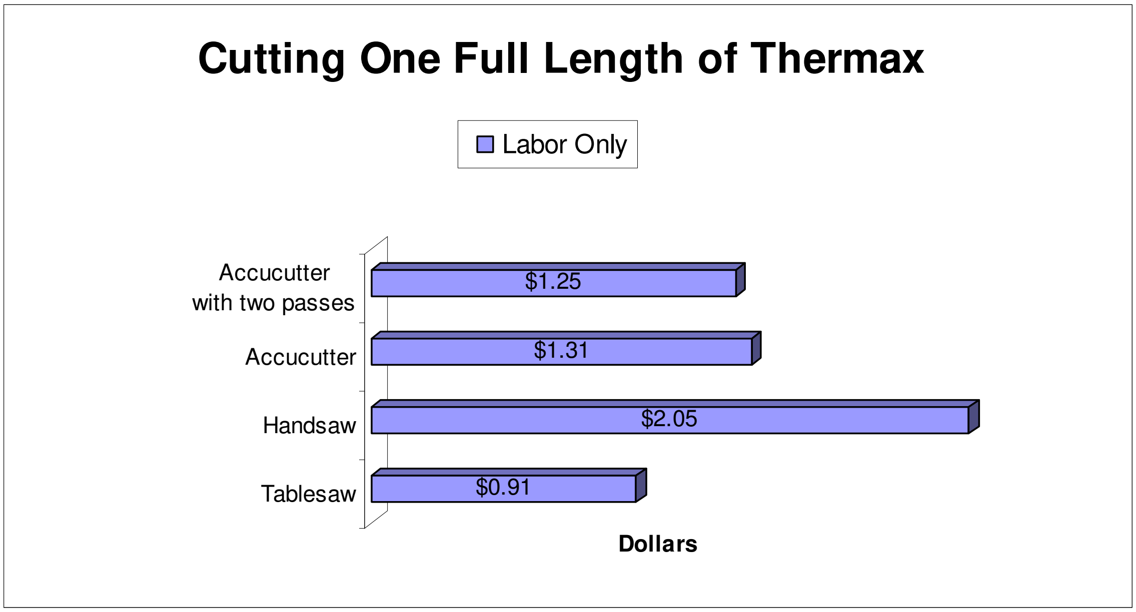
Time Analysis

While the tablesaw took the least amount of time, the performance of the Accucutter was most interesting. It took less time to make two passes with the Accucutter, resulting in a better edge than the one pass test.



Cost Analysis

While the least expensive cutting technique was the tablesaw, the two pass Accucutter method nearly as quick.



Test Notes

Quality

- The two pass Accucutter method had the best edge.
- The tablesaw cut within tolerance and with an acceptable edge.
- The handsaw created the least desirable cuts.

Accuracy

- All methods cut the Thermax within 0.5” on the 12” width and with less than 0.5” taper on the thickness.
- The handsaw created the largest tapers on the width; four out of the nine handsaw tests had tapers of approximately 0.38”.

Ease and efficiency

- Accucutter: the two pass method worked better than the one pass method; less force required, less blade marking
- The handsaw is harder to use when the sheet is no longer 4’ wide.

Dust or noise generation

- Tablesaw: very dusty and noisy
- Handsaw: created larger dust particles, less airborne dust
- Accucutter: makes a squeaky noise, almost no dust

Damage to Thermax

- The handsaw created a chip at the end and a minor burr along the edge.
- The tablesaw created a burr on the foil.

Recommendation: Accucutter with two passes

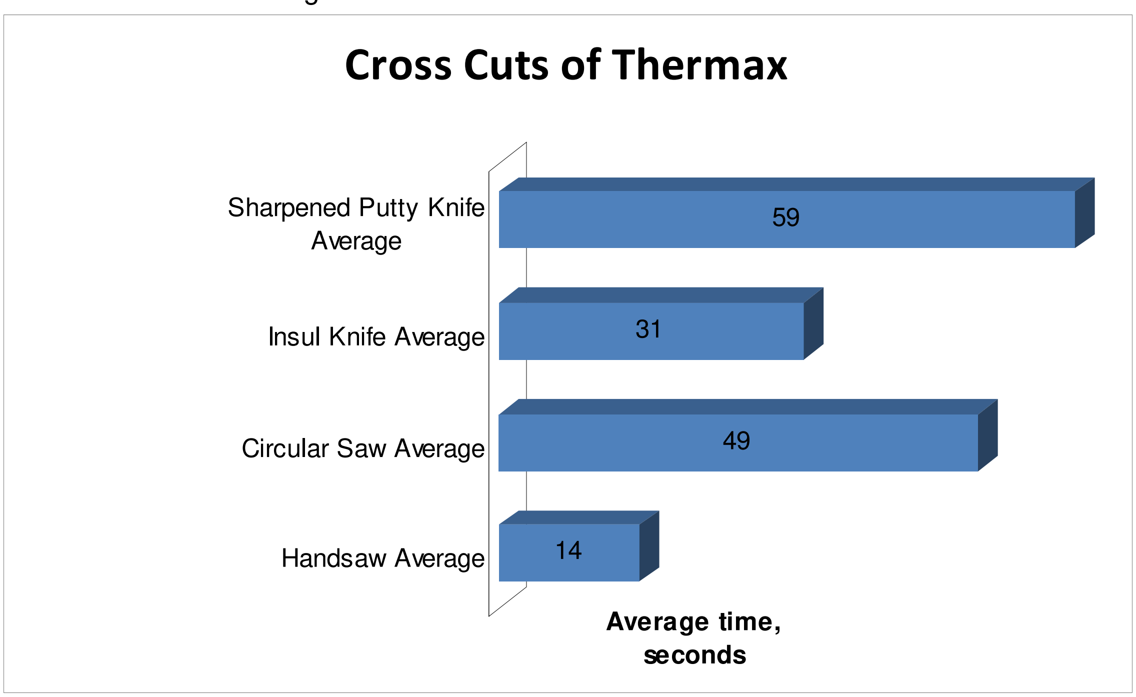
Analysis: Procedure for Cross Cuts

Test plan

1. Overview
   a. Installers will test four methods of making cross cuts in 4 x 8 sheets of 2.5" Thermax.
      i. 7.25 circular saw with toothless blade
      ii. Insul knife
      iii. Handsaw
      iv. Sharpened putty knife
2. Starting conditions
   a. Thermax marked for cutting
   b. Single sheet of Thermax on cutting station
   c. Hand tools on ground next to cutting station
   d. Installer with dust mask on standing next to Thermax
3. Procedure
   a. Timer says "Go"
   b. Installer makes cut
   c. Installer sets down 24" x 48 strip and remaining sheet next to work station
   d. Timer notes time
   e. Number of tests: 30

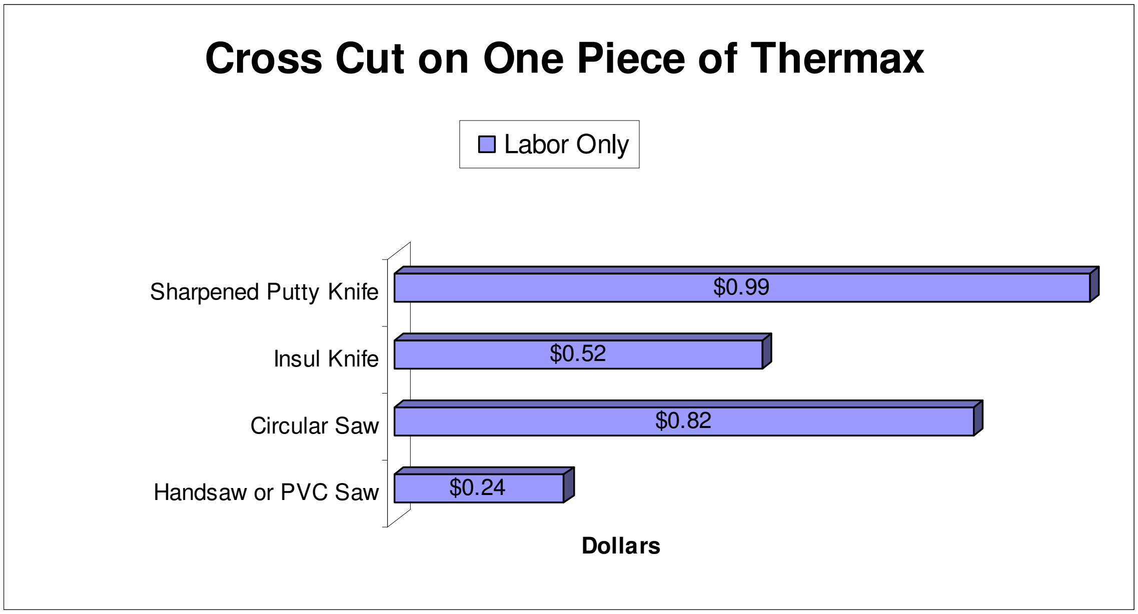
Time Analysis

The handsaw and insul knife were the fastest methods tested for making cross cuts in Thermax. The sharpened putty knife and circular saw did not cut through in one pass, and those tools took longer.



Cost Analysis

The handsaw or PVC saw was by far the fastest method of making cross cuts in Thermax.



Test Notes

Quality

- The quality of the cuts made by all of the tools was acceptable.

Ease and efficiency

- The insul knife required much force to make the cross cuts.
- The handsaw was the easiest tool to use.
- The circular saw was too small to cut through the Thermax in one pass, and it required a second cutting step with a utility knife.

Dust or noise generation

- There was almost no dust with the insul knife.
- There was considerable dust and noise with the circular saw.

Damage to Thermax

- The insul knife made many blade marks in the edge of the Thermax.

Improvements to Tested Procedure

- Perhaps a fence for the handsaw would help.

Recommendation: PVC saw

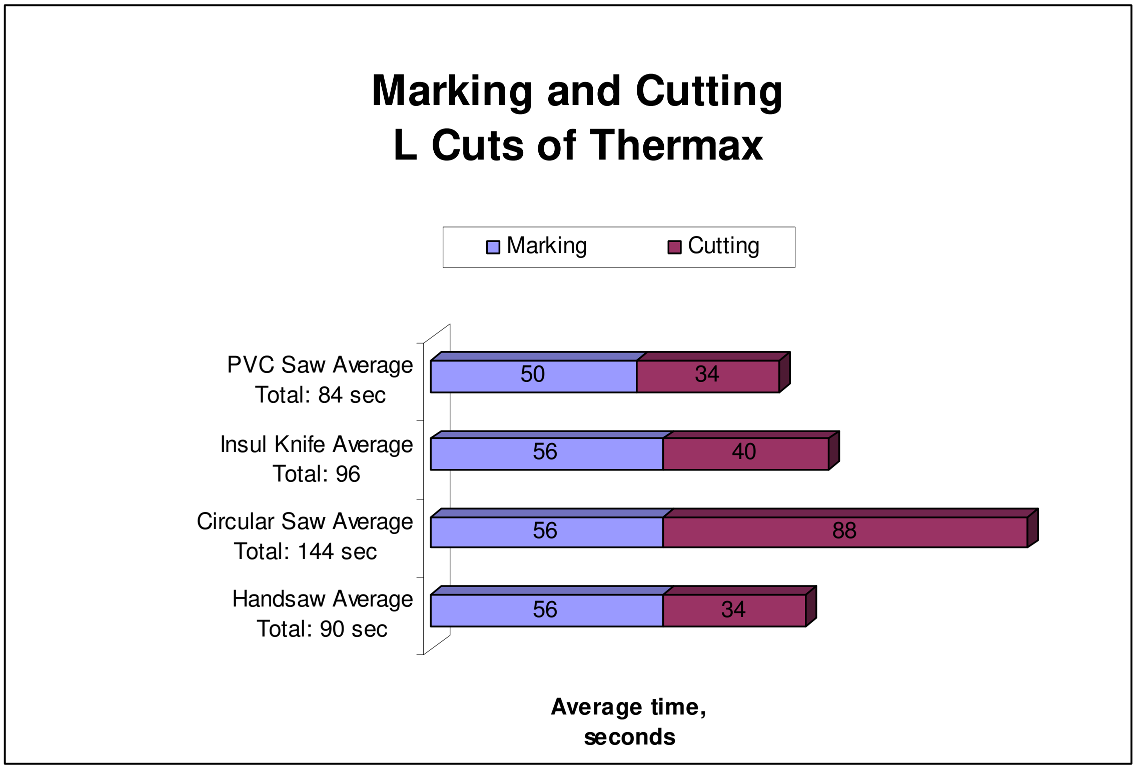
Analysis: Procedure for L Cuts

Test plan

1. Overview
   a. Installers will test four methods of making a 16” x 18” square cut-out from a 24” x 48” piece of 2.5” Thermax.
      i. 7.25 circular saw with toothless blade
      ii. Insul knife
      iii. Handsaw
      iv. PVC saw – 12” Lenox
2. Starting conditions
   a. Single sheet of Thermax on cutting station
   b. Hand tools on ground next to cutting station
   c. Installer with dust mask on standing next to Thermax
3. Procedure
   a. Timer says “Go”
   b. Marking
      i. Installer uses T square and sharpie to mark a 24” line from factory edge in preparation for cutting a 16” x 18” piece
   c. Cutting
      i. Installer makes cut
      ii. Installer sets down cut piece and remaining sheet next to work station
      iii. Timer notes time
      iv. Number of tests: 27

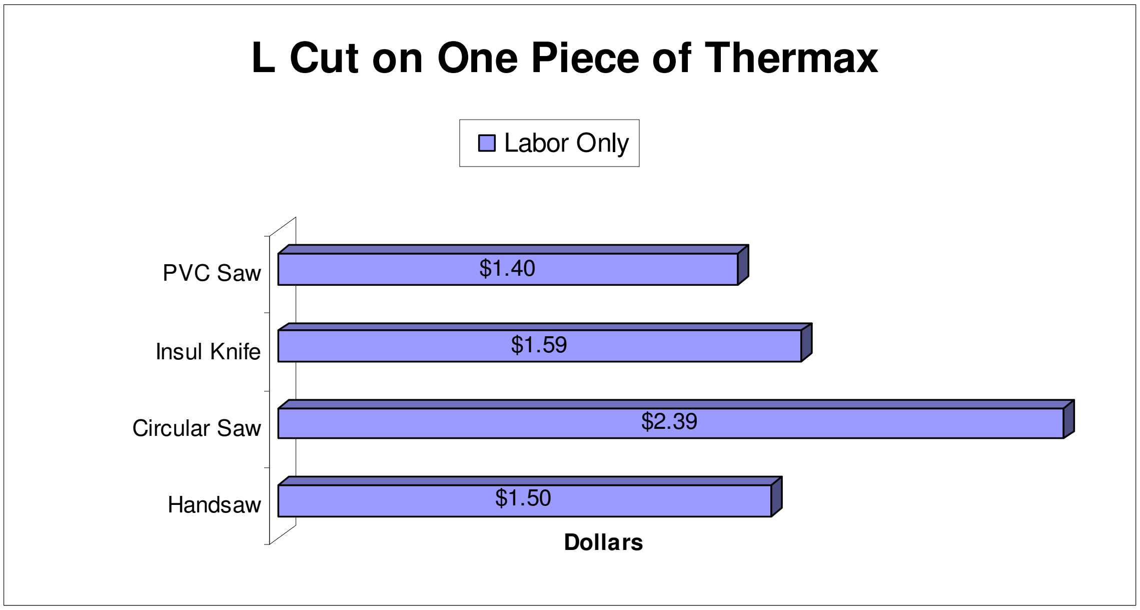
Time Analysis

The circular saw took considerably more time to make the L cuts. The other three tools were nearly identical in time.



Cost Analysis

The PVC saw was the fastest tool in making L cuts in Thermax.



Test Notes

Quality

- The quality of the cuts made by all of the tools was acceptable.

Accuracy

- All methods cut the Thermax within 0.5” on the 16” and 18” dimensions.
- All of the tools experienced some taper on the thickness, which was measured in two places on the 16” side and two places on the 18” side.
    - Handsaw: three occurrences of taper greater than 0.5” and ten occurrences of taper greater than 0.38” but less then 0.5”
    - Insul knife: one occurrence of taper greater than 0.5” and five occurrences of taper greater than 0.38” but less then 0.5”
    - PVC saw: two occurrences of taper greater than 0.5” and two occurrences of taper greater than 0.38” but less then 0.5”
    - Circular saw: one occurrence of taper greater than 0.38” but less then 0.5”
- The circular saw was more accurate than the hand tools.
- The handsaw created the most occurrences of taper on the thickness.

Ease and efficiency

- The insul knife required much force to make the cross cuts, and it required caution to not break of the end of the Thermax board. This tool required starting from the outside edge.
- The handsaw was the easiest tool to use, although it required starting from the outside edge.
- The circular saw was too small to cut through the Thermax in one pass, and it required a second cutting step with a another knife.

- The PVC saw was favored by the installers because of the pointed tip which allowed cutting to start in the middle of the Thermax.

Dust or noise generation

- There was almost no dust with the insul knife.
- The handsaw and PVC saw generated similar amounts of large, crumbly dust.
- There was considerable dust and noise with the circular saw.

Damage to Thermax

- The insul knife made many blade marks in the edge of the Thermax.
- The force required from the insul knife also damaged the Thermax by

Recommendation: PVC saw

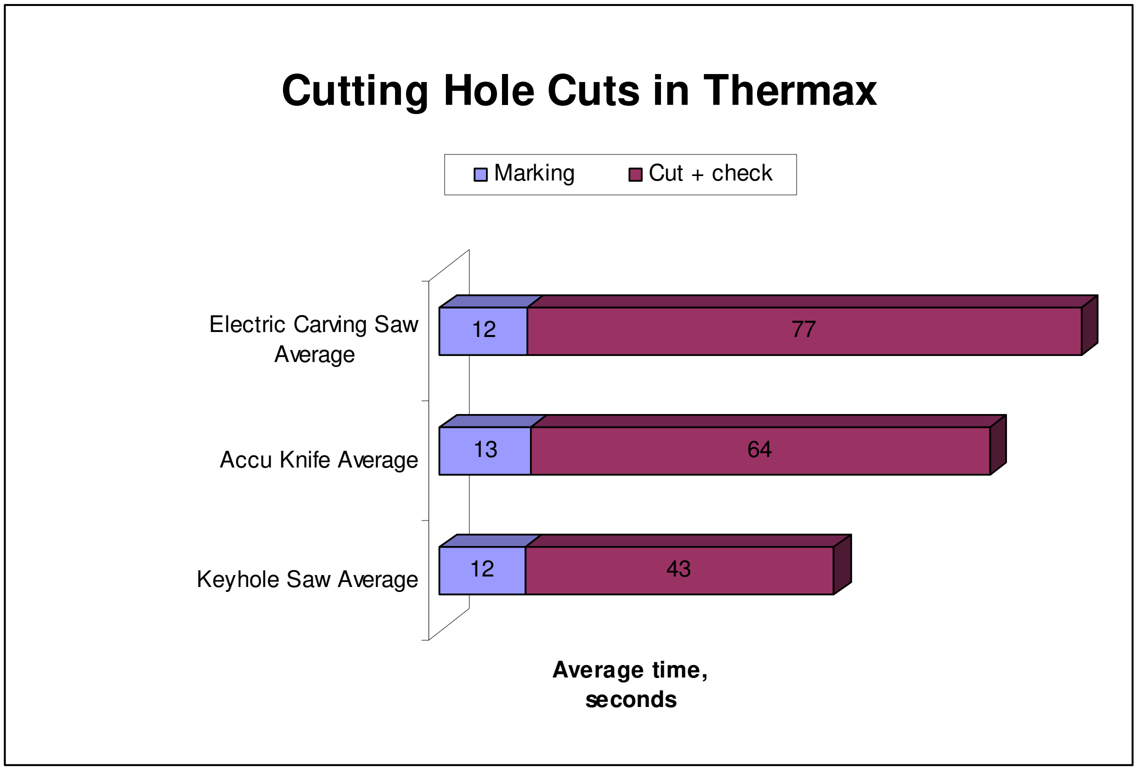
Analysis: Procedure for Hole Cuts

Test plan

1. Overview
   a. Installers will test three methods of making a 4” circular cutout from a 16” x 18” square of 2.5” Thermax
      i. Keyhole saw
      ii. Accu knife
      iii. Electric carving knife
2. Starting conditions
   a. Single sheet of Thermax on cutting station
   b. Hand tools on cutting station
   c. Installer with dust mask on standing next to Thermax
3. Procedure
   a. Timer says “Go”
   b. Marking
      i. Installer uses a circular template and Sharpie to mark a 4” circle on Thermax
   c. Cutting
      i. Installer makes cut
      ii. Installer verifies that 4” round duct will fit through hole, cuts more if necessary
      iii. Installer sets down tools and Thermax
      iv. Timer notes time
      v. Number of tests: 27

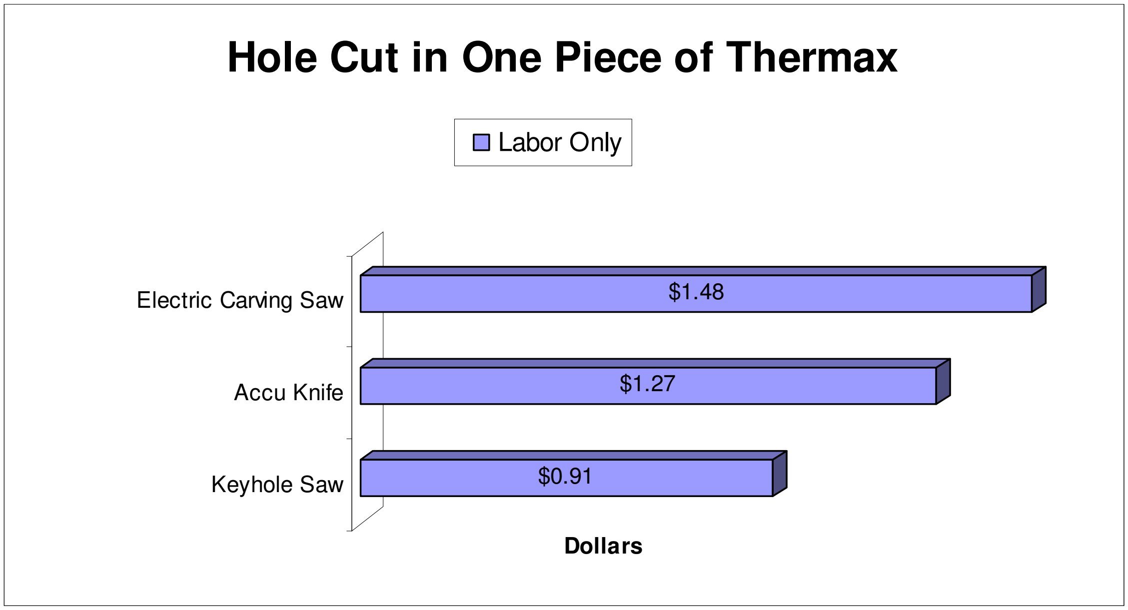
Time Analysis

The keyhole knife was the fastest method for cutting holes in Thermax.



Cost Analysis

The keyhole saw was the fastest method for cutting holes in Thermax.



Test Notes

Quality

- The holes cuts made by all of the tools were acceptable.

Ease and efficiency

- The Accu knife occasionally became disassembled during use. It also seemed too short for the 2.5" Thermax.
- The Accu knife was too flexible to make straight cuts in the Thermax. The flexibility raised concerns about durability and safety of the tool.
- The carving knife was not as easy to hold in position.
- The carving knife required a slower, steady pace. Pushing the carving knife overloaded the motor.
- The keyhole saw was the preferred tool.

Dust or noise generation

- All of the tools created similar amounts of dust and debris.
- The carving knife was noisy.

Damage to Thermax

- The tools did not damage the Thermax.
- Some of the cuts were smoother than others, and this was a factor of skill and number of clean up cuts.

Recommendation: Keyhole saw

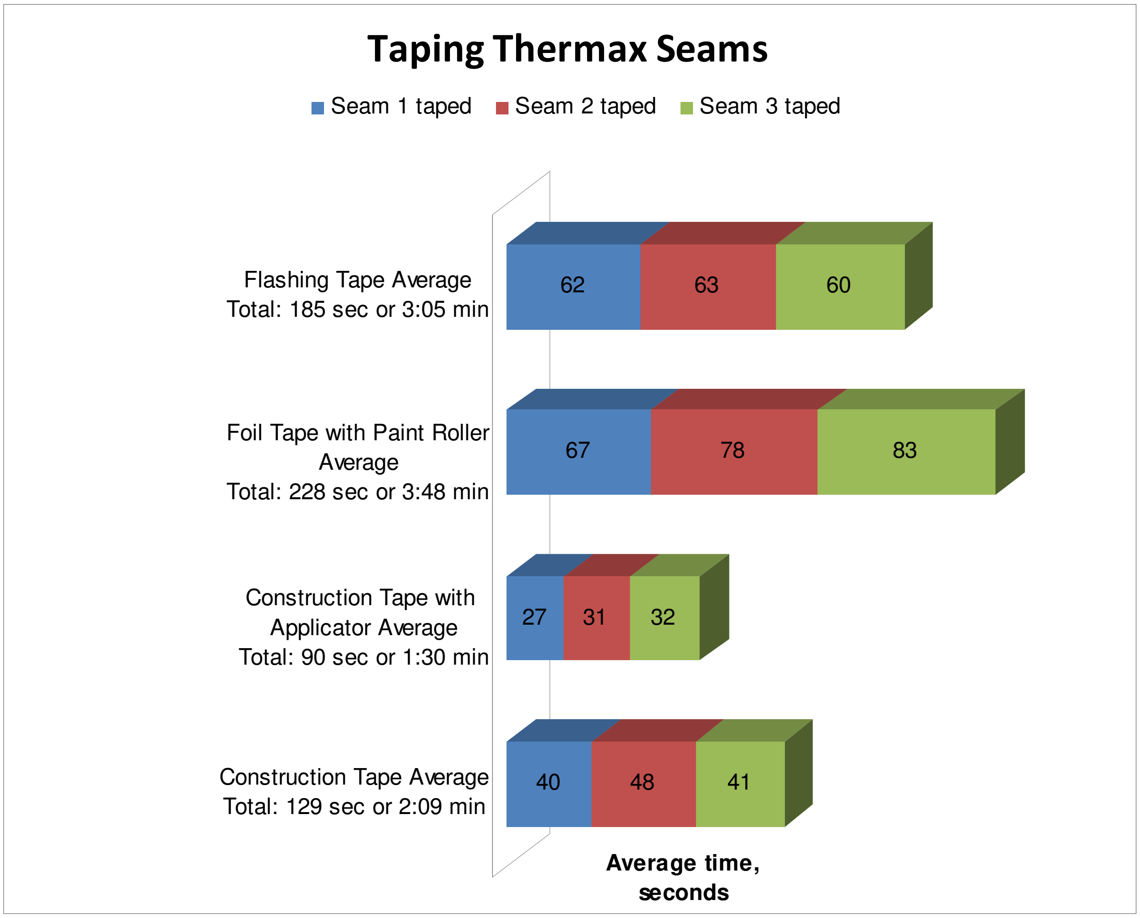
Analysis: Procedure for Taping

Test plan

1. Overview
   a. Installers will test four methods of taping Thermax seams.
      i. 2-7/8” Construction tape without applicator
      ii. 2-7/8” Construction tape with applicator
      iii. 3” Foil tape with plastic roller for smoothing
      iv. 4” Straight flashing tape
2. Starting conditions
   a. Ladder in position at first taping location
   b. Tape and tools on ground
3. Procedure
   a. Timer says “Go”
   b. Installer tapes first seam
   c. Installer moves ladder to second position
   d. Installer tapes second seam
   e. Installer moves ladder to third position
   f. Installer tapes third seam
   g. Timer notes time
   h. Number of tests: 12

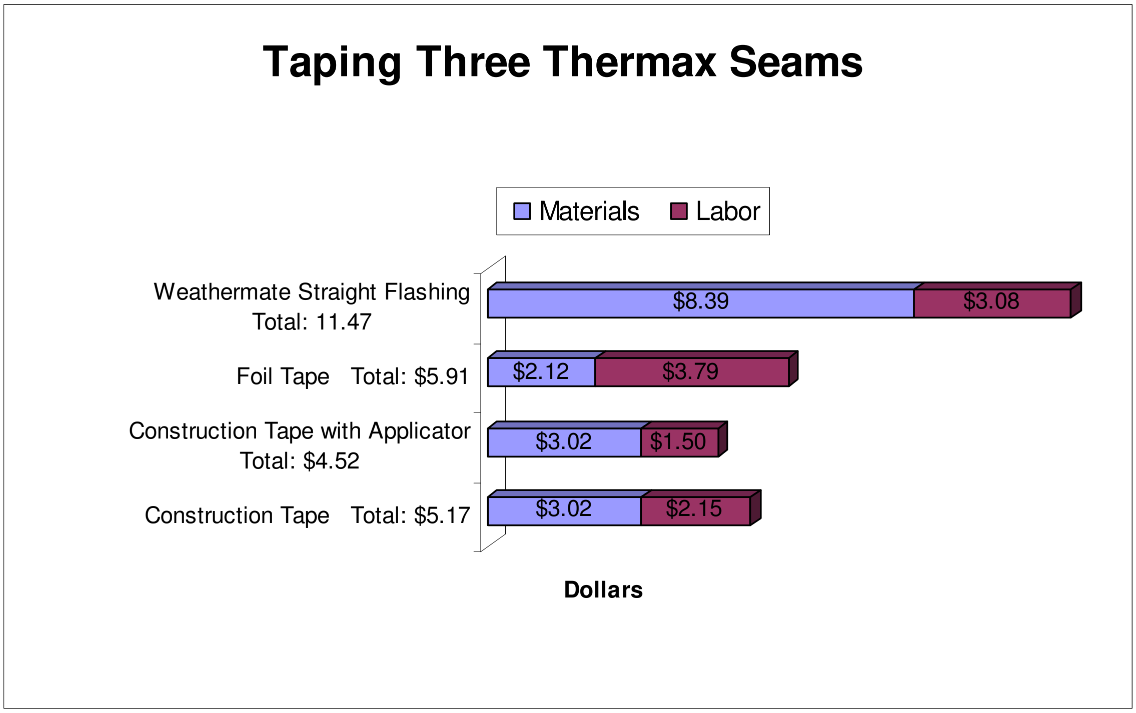
Time Analysis

The seams were sealed most quickly by using construction tape with an applicator. The times listed below do not include the time needed to load the construction tape into the applicator. The time needed for waste disposal of the paper backing from the foil and flashing tapes is not included.



Cost Analysis

Taping seams by using construction tape with an applicator was the fastest method.



Test Notes

Quality

- The quality of the taped seams for all of the tapes and methods were acceptable.

Ease and efficiency

- The tape applicator was easy to use and it kept the tape already started.
- The foil tape cut an installer's hand during application.
- The clear tape was easier to see on the Thermax, and it was difficult to see the foil tape.
- Getting the paper backing started on the foil tape and flashing tape took a little bit of time.

Recommendation: Weathermate construction tape with applicator

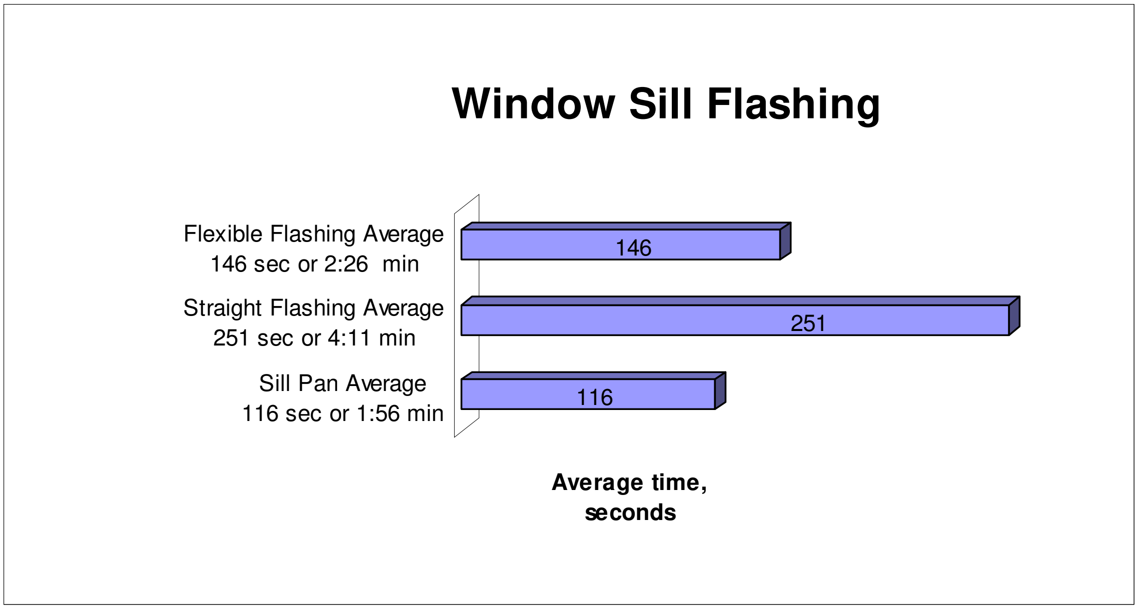
Analysis: Procedure for Flashing

Test plan

1. Overview
   a. Three installers will each install three types of sill pan three times:
      i. Weathermate 9” straight flashing
      ii. Weathermate 9” flexible flashing
      iii. Weathermate plastic sill pan
2. Starting conditions
   a. Installers have watched relevant portion DOW webinar on “Flashing windows in foam sheathed walls,” have familiarized themselves with installation instructions, and have practiced each technique at least once.
   b. Test wall with window opening. 12” x 48” piece of 2.5” Thermax spanning bottom of window, screwed in placed with 4 washer screws. Bottom of Thermax is 3” below rough sill. Thermax is trimmed flush with rough opening. ½” x 3.5” back dam is installed with exterior edge flush with exterior face of rough sill.
   c. Flashing material on ground next to window opening.
   d. Installer with tool belt on, fasteners in tool belt, standing next to window opening.
3. Procedure
   a. Timer says “go”
   b. Straight flashing
      i. Cut a piece of straight flashing 6” longer than the sill opening. Stretch it across the opening with the bottom edge 2-2.5” below the sill.
      ii. Make vertical slits at the edges and fold down the material over the sill.
      iii. Cut 2 pieces of straight flashing 8” long. Make a slit in the middle of each piece 2” deep. Places these pieces in the corners, folding out the slit portions.
      iv. Smooth by hand.
   c. Flexible flashing
      i. Cut to length 12” longer than sill opening (to allow 6” vertical on either side).
      ii. Place flex flashing in sill with inside edge flush with the inside edge of the back dam.
      iii. Remove release paper.
      iv. Form and mold flexible flashing around outside edges as you fold it over the face of the foam.
      v. Smooth by hand.
   d. Sill pan
      i. Put sill pan pieces in place.
      ii. Install 2 Windlock screws in “X”s.
      iii. Tape the seam and edges with clear Weathermate tape. Wrap tape onto foam and onto inside edge of stud/sill.
   e. Timer records “stop”
   f. Number of tests: 27

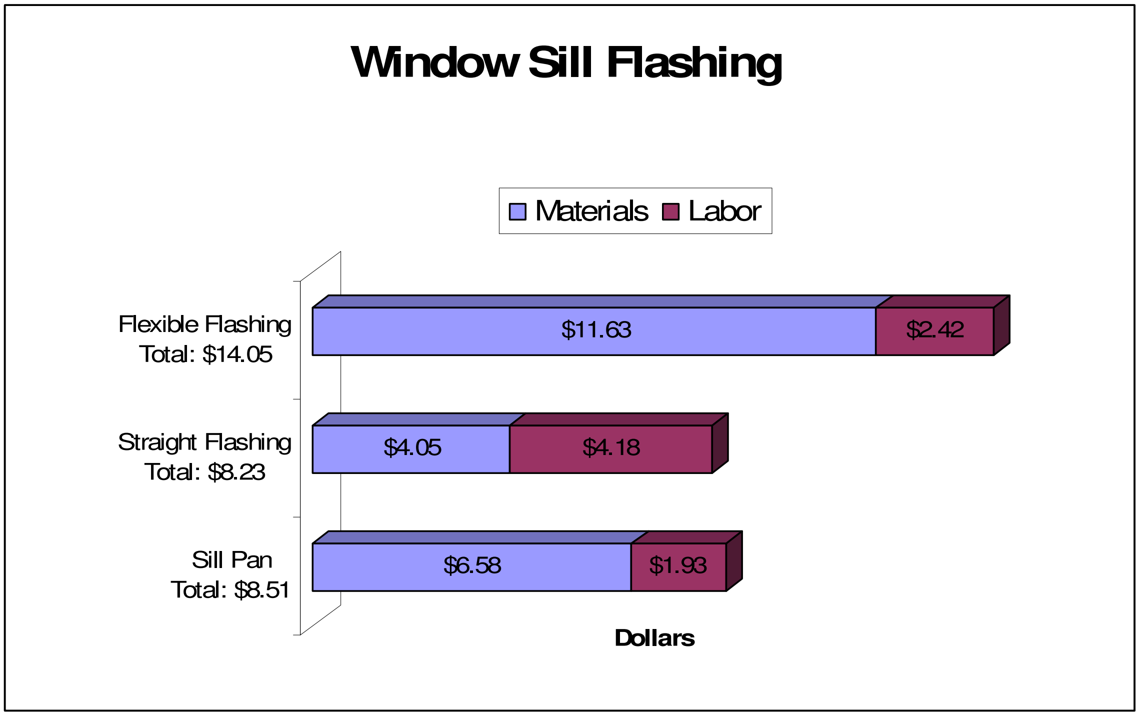
Time Analysis

The straight flashing took a considerably longer amount of time to apply to a window. The times for the sill pan and flexible flashing were close. The times for the flexible and straight flashings do not include time for disposal of the paper backing.



Cost Analysis

Straight flashing and sill pans were very close in costs. The flexible flashing material cost was the greatest, and the method cost the most.



Test Notes

Quality

- All three of the flashing options were acceptable in quality.

Ease and efficiency

- The sill pan was installed the easiest, although there was always a slight warp or bubble in the installed sill pan. The bubble would be removed by the weight of the window.
- The flexible flashing required pulling and smoothing in the corners, and even in the best trials, there were still some ripples. It did not have as much stretch through the width as expected.
- The straight flashing went on smoothly, and it required caution in the corners to ensure they were completely covered.

Improvements to Tested Procedure

- All of the window sill flashing tests performed better when using a piece of clapboard instead of a square edged dam.

Recommendation: Weathermate straight flashing

Analysis: Procedure for Window Bucks

Test plan

1. Overview
   a. Installers will test four methods of creating a window buck
      i. Plywood buck
      ii. 2x buck
      iii. Ledger buck
      iv. Flat buck with foam
2. Starting conditions
   a. Test wall with window opening.
   b. Thermax installed in this manner for tests:
      a. Plywood buck: Thermax installed up edge of rough opening
      b. 2x buck: no Thermax installed
      c. Ledger buck: Thermax on sides and top of window opening only
      d. Flat buck with foam: no Thermax installed
   c. Exact dimensions for bucks taken and provided to installers.
   d. Tools on ground, materials on saw horses near cutting stations.
   e. Two installers ready with tool belts and dust masks on.
3. Procedure
   a. Plywood buck
      i. Rip 6-1/2” plywood from ½” plywood
      ii. Cut to dimensions provided.
      iii. Screw into place with four screws on top and bottom and 6 screws on each side.
      iv. Set window and center in opening. Level with shims. Install two 4” washer screws.
      v. Square up the window and attach both top corners.
      vi. Straighten jambs and install remaining screws.
      vii. Total number of window screws: 14
   b. 2x buck
      i. Rip 2-1/2” 2x material.
      ii. Cut to dimensions provided.
      iii. Screw into place with 4” screws: three screws on top and bottom and 4 on each side.
      iv. Set window and center in opening. Level with shims. Install two screws at bottom.
      v. Square up the window and attached top corners.
      vi. Straighten jambs and install remaining screws.
      viii. Total number of window screws: 14
   c. Ledger buck
      i. Rip 2-1/2 ledgers.
      ii. Cut to dimensions provided.
      iii. Pre-drill and screw into place with 4” screws.
      vii. Set window and center in opening. Level with shims. Install two lath screws at bottom.
      viii. Square up the window and attached top corners with washer screws.
      ix. Straighten jambs and install remaining screws.

ix. Total number of window screws: 14

d. Flat buck with foam

iv. Rip 2x4 material.

v. Cut to dimensions provided.

x. With flat side along wall, screw into place: three screws on top and bottom and 4 on each side.

xi. Cut 1" rigid insulation.

xii. Nail insulation pieces to window buck.

xiii. Set window and center in opening. Level with shims. Install two screws at bottom.

xiv. Square up the window and attached top corners.

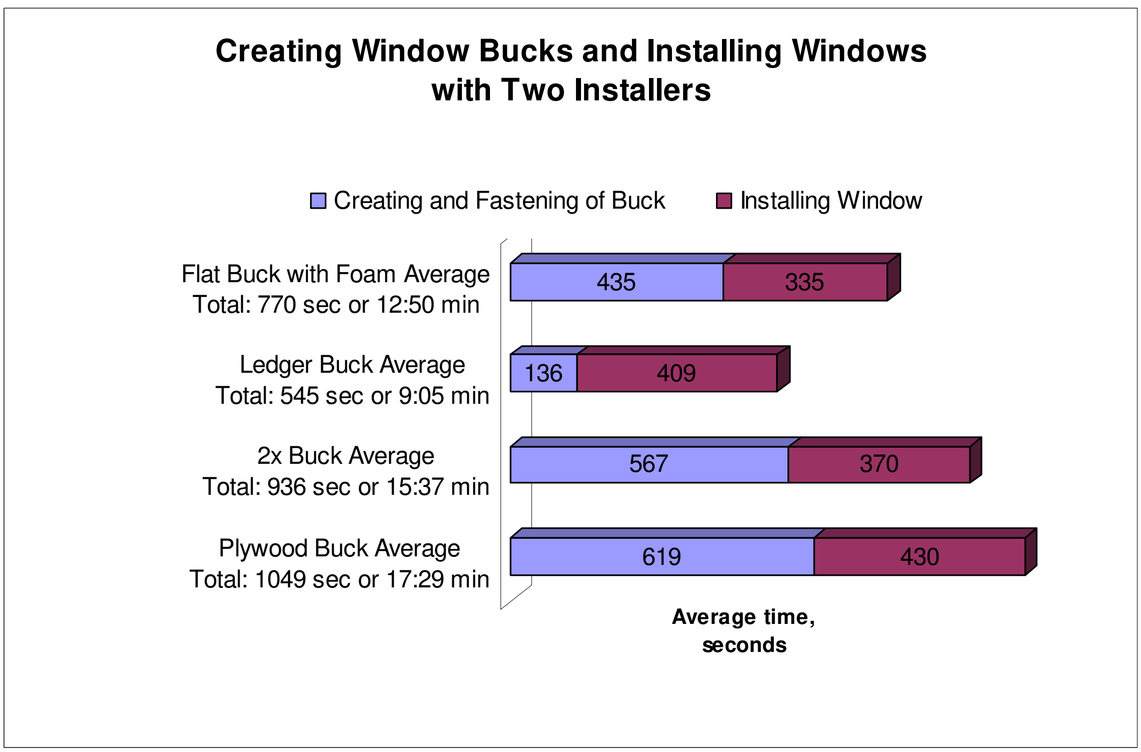
xv. Straighten jambs and install remaining screws.

x. Total number of window screws: 14

xi. Total number of tests: 8

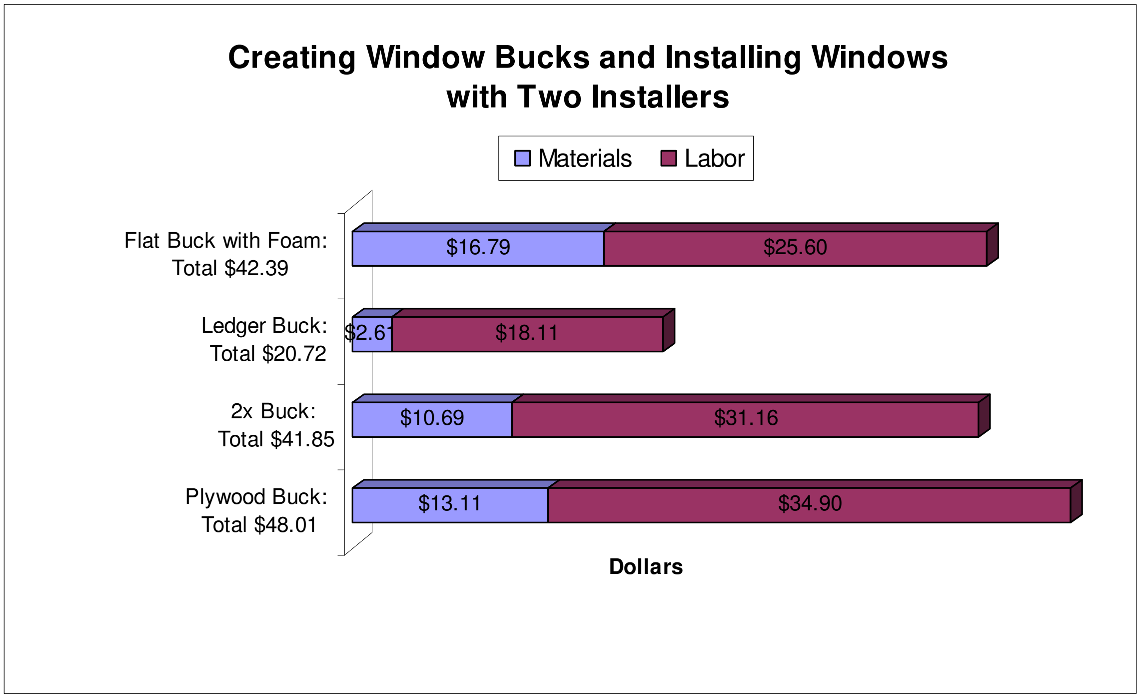
<u>Time Analysis</u>

The ledger buck was the quickest window buck method, followed by the flat buck with foam.



Cost Analysis

The ledger buck was the least expensive to install. The other window buck methods were close in range.



Thermal Analysis

A TREAT thermal analysis was conducted using a modeled building with 20 windows. When compared with the baseline, all options increase the heat loss by less than 1%. The increase in heat loss can be considered negligible. For best structural support and least thermal break, the plywood buck or LVL is recommended.

	Heating (kWh/year)	% Increase from Baseline	Structural Comments
Baseline =	**7,029.60**		NA
Option #1: 2x3 window buck	**7,068.80**	**0.56%**	Here the window is supported on all around the perimeter, which is good. However, screws need to be long enough to penetrated into the wall framing since it is just a single row of fasteners. Disadvantage is that it has a fair amount of thermal bridging.
Option #2: 1/2" x 6.5" plywood window buck	**7,034.50**	**0.07%**	This provides a very good support all the way around the perimeter, creating a box sub-frame. It needs to be fasten properly in order to provide the stiffness & act as a box sub-frame. It has very little area of thermal bridging.
Option #3: 2x3 bottom ledger window buck	**7,036.10**	**0.09%**	Provides the least amount of support since it is only at the bottom. When using this option the bottom buck should be fasten well, since it will provide most of the support. Only a small area of thermal bridging.
Option #4: Same as #1, but use 2x2 with 1.5"x1" poly-iso	**7,048.00**	**0.26%**	Same as option #1, but does not have a lot of thermal bridging.
Option #5: Same as #3, but use 1.5"x1" poly-iso	**7,032.70**	**0.04%**	Same as option #3, but very small thermal bridging.
Option #6: (8) LVL pieces 1.75"thick x 3" wide x 4" long with 3/4" poly-iso	**7,038.20**	**0.12%**	This is an option that provides support at the four corners & has very small thermal bridging.

Test Notes

Quality

- The ledger buck system did not allow for shimming the sides of the window to prevent bowing. This will lead to long term problems with appearance and operation of the windows.
- The flat heads on the lath screws, used on the 2x and ledger bucks, were like little washers and pulled the flanges tight without as much dimpling as the deck screws, used on the flat and plywood bucks.

Ease and efficiency

- All of the methods were easy to install.
- We didn't try too hard to make the plywood bucks perfectly square, and they don't need to be if the finish carpenter is going to be installing extension jambs. However, if the interior finish is going to be a drywall return, it would be worthwhile to spend more time shimming and squaring the buck.

Recommendation: Plywood buck