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Northern*STAR* 1-½-Story Demonstration House of Cold Climate Solutions for Affordable Housing

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NorthernSTAR Building America Partnership

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The work presented in this report does not represent performance of any product relative to regulated minimum efficiency requirements.

The laboratory and/or field sites used for this work are not certified rating test facilities. The conditions and methods under which products were characterized for this work differ from standard rating conditions, as described.

Because the methods and conditions differ, the reported results are not comparable to rated product performance and should only be used to estimate performance under the measured conditions.

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"Unless otherwise noted, all figures were created by NorthernSTAR Building America Partnership."

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Definitions

ACH50	Air Changes per Hour at 50 Pa
ASHRAE	American Society of Heating, Refrigerating, and Air-Conditioning Engineers
Btu	British thermal unit
ccSPF	Closed-Cell Spray Polyurethane Foam
CEE	Center for Energy and Environment
CFM50	Cubic Feet per Minute at 50 Pa
DHW	Domestic Hot Water
DOE	U.S. Department of Energy
HRV	Heat Recovery Ventilator
HVAC	Heating, Ventilating, and Air Conditioning
MERV	Minimum Efficiency Rating Value
MMBtu	One Million Btu
OSB	Oriented Strand Board
UC2	Urban Construction Company
UHW	Urban Homeworks
XPS	Extruded Polystyrene

Executive Summary

Various groups from the affordable housing industry have consulted with the University of Minnesota's Cold Climate Housing Program to solve persistent energy and health-related problems such as ice dams, high energy bills, and mold/moisture issues—especially in complicated house types such as 1-½-story homes in cold climates. The Northern*STAR* Building America Partnership has completed multiple research projects on high-performance measures applied during renovation of single-family homes that could help the affordable housing industry address performance concerns.

This demonstration project is an example of three high-performance measures applied to one house in Minneapolis, Minnesota. The selected vacant home was completely renovated by Urban Homeworks (UHW), which is a nonprofit housing partner, with the intent of selling the home to a low-income family. The renovation included the addition of the three advanced-performance technologies that were applied to the overall scope of the project.

Single-family homes in urban areas that are available for renovation by nonprofit developers are often in need of repair. Budgeting has historically focused on improving homes to meet basic housing standards. A rising interest in the long-term impact of homeownership has introduced the need to balance basic needs with home performance. The goal of this demonstration project was to help UHW and other nonprofit developers become familiar with three U.S. Department of Energy Building America performance measures—including the installation processes, impacts, and benefits of each. To maximize efficiency of application and to address budget issues, the NorthernS*TAR* team worked with UHW to identify ways to use volunteers and construction training programs to install the measures. An open invitation to visit the job site was provided to other nonprofit developers and support teams to encourage dialog about the systems during live installation.

The three measures installed were:

- "Excavationless" insulation, an exterior foundation insulation
- "Overcoat," an exterior thermal moisture management system for roofs
- "Combi," a combination space and water heating system.

Four blower door tests were performed: pre-construction, post-construction, and two intermediate tests. The final test showed a total air leakage reduction of 73%. BEopt computer modeling predicted source energy savings of 95.4 MMBtu/yr, site energy savings of 81.7 MMBtu/yr, and a cost savings of $625 per year. Actual energy savings could not be compared to the prediction because the home did not have an occupant before the close of the study.

The combi system was installed by a licensed subcontractor. The final cost for the combi system installation met the original budgeted amount. Previous Northern*STAR* research has demonstrated that the cost of a combi system is similar to installing an energy-efficient furnace and energy-efficient water heater, yet the combi yields an overall energy savings of 15% to 20%.

Volunteer workers assisted with the installation of the excavationless foundation insulation system by finishing the above-grade transition from grade to siding and installing new basement windows through the exterior insulation. Students from the Urban Construction Company contractor training program installed the roof overcoat system. Excavationless and overcoat systems can cost significantly more than other measures that are typically used to manage energy, ice dam, and comfort issues. In this application, the higher costs of the three measures were agreed upon; some additional funding came from outside sources and some costs were paid by UHW. The expectation was that performance benefits would add value. The additional benefits realized included elimination of ice dams, energy reduction, comfort, and an expandable living space in the basement.

This home was renovated using three high-performance measures to address energy, durability, and comfort problems; however, actual performance measures applied to other homes would be chosen based on specific need, performance benefits, budget, subsidy requirements, and volunteer/student training options. Many housing industry professionals visited the site during construction to observe the installation of the systems and engage in conversation about hurdles and benefits. Photo documentation and video footage followed the project sequence. Three instructional videos will be available online to encourage continued enhancement of homes using these measures.

Acknowledgements

We thank Craig Angell at Angell Aire for donating Aeroseal duct sealing and installation for this project.

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We thank Burnsville Heating & Air Conditioning for donating duct sealing for this project.

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1 Introduction

It is the stated mission of nonprofit housing developers such as Urban Homeworks (UHW) and Habitat for Humanity to stabilize and improve the lives of families struggling with socio-economic issues. Housing is a primary means for accomplishing this. While an affordable mortgage or rent has been a primary goal in the past, there is a growing effort to also consider energy efficiency, health, and durability. Reducing the costs associated with long-term expenditures like utility bills, repairs, and medical intervention has become important. There are 1 million to 2 million vacant houses across the country (Kresin 2012) that could be renovated or rebuilt for the purpose of supplying affordable housing. If these homes are not remodeled in a way that reduces or eliminates long-term expenses, they can leave occupants at risk of unmanageable expenses. Houses not remodeled to attend to health considerations such as mold and allergens can also be harmful to vulnerable populations such as infants, children, and the elderly.

With the availability of large numbers of vacant homes in urban areas around the country, city officials and neighbors want these houses either demolished or returned to occupancy. The cost to the community is high if homes are left empty (National Vacant Properties Campaign 2005). After conversations with affordable housing developers we learned many vacant homes are located in lower-income neighborhoods with generally lower market values, making it difficult for for-profit companies to "flip" a house for profit. The task of renovation is generally in the hands of nonprofit housing groups. In Minneapolis and St. Paul, Minnesota, a typical remodeled house in a low-income neighborhood will sell for $130,000 to $160,000. Costs to renovate homes, however, range from $180,000 to $210,000. This does not include acquisition costs as they are not typically included in the final price: A city or county often donates the house to the nonprofit. The nonprofit developer must find funds to subsidize the difference. These subsidies come from a number of local, state, and federal programs as well as from private sources. Adding solutions such as advanced energy upgrades can be difficult due to the perceived higher costs and lack of understanding on how to specify the measure, add it to the budget, and manage the installation.

To stretch the subsidy dollar, nonprofits use volunteers or minority/youth training programs to do much of the work. They also use area subcontractors, but can be limited in options when they are required to hire minority-owned contractors. The process of figuring out how to meet all the funding requirements as well as budget constraints while developing a scope of work can be difficult. Adding energy, health, and durability measures increases the complexity.

One of the first things to sort out when deciding what measures or upgrades should be included in a scope of work is what is needed and appropriate for a particular house. The first priority is what must be done for livability, safety, or to meet code, such as a new roof, siding, foundation repair, kitchen, furnace, and so on. Then there should be questions about what will make the family more comfortable and healthy and reduce their maintenance costs. What will bring value? Make the house more sellable? While asking these questions, one must also consider the budget.

The Northern*STAR* Building America Partnership team has worked with a number of affordable housing groups on projects over the last few years. The team has also been conducting field and laboratory research on advanced energy-efficiency solutions for homes in cold climates. This demonstration project is a culmination of the Northern*STAR* team's research work on three individual energy saving technologies applied to one affordable housing project. The three technologies include roof "overcoat" with an external air barrier, thermal barrier, and ventilation system; "combi" combination water and space heating system with integrated ventilation; and "excavationless" exterior foundation insulation system.[1] All of the solutions are market ready and use products, tools, and systems currently available and in use.

The demonstration project applied all three technologies to a single house in Minneapolis, Minnesota, in which a low-income family will ultimately live. The chosen house style was a 1-½-story bungalow as there are many in the region with aging furnaces that also lack adequate attic and foundation insulation. The demonstration home would provide a means to showcase robust solutions for this complicated housing type.

The United States also faces the challenge of limiting carbon emissions from all sources. As existing homes use 21% of the nation's energy, addressing carbon emissions from this sector is an important step. Affordable housing developers can contribute to this reduction by applying home upgrades that conserve energy.

The goal of the demonstration project was to gain insight into the value of and hurdles to applying three advanced energy solutions in affordable housing in order to reduce energy use and provide healthy living situations for occupants.

The ability to work with an affordable housing developer from the onset of the design, budgeting, and construction process provided further insight into ways to integrate advanced solutions into affordable housing projects. Applying all three technologies to one home, though optimal, may not be cost-effective or necessary. Understanding these advanced solutions and their benefits will help developers chose one solution or a combination that best solves the problems of an individual home.

The project partner, UHW, is a nonprofit developer that builds and remodels affordable housing. They use a variety of means for completing a project including hiring skilled contractors, advancing students through skills training programs, and using unskilled volunteers. UHW chose to hire skilled contractors for the combi and excavationless system installations. Their construction training program, Urban Construction Company (UC2), was guided by the Northern*STAR* team on the installation of overcoat with the goal of reducing labor costs. During the installation of the overcoat and excavationless systems, the home was made available to developers, contractors, and the community to visit and learn.

[1] See NorthernSTAR Building America Research Publications available at http://bbe.umn.edu/publications.

2 Measures Applied to the Demonstration House

The demonstration house shown in Figure 1 was built in 1947. It was chosen by UHW for this project as it had positive features such as a solid framework, hardwood floors, and a good-sized living area in the upper ½ story. The concrete masonry unit foundation around the entire perimeter was sound. The basement had 7-ft-5-in. ceilings over a concrete slab floor. There were no constructed walls in the basement, which provides flexibility to the future homeowner to remodel the space as needed.

Figure 1. Demonstration home in Minneapolis, Minnesota

On the downside, the house had been vacant for about 1 year and was in extreme disrepair. Various openings in the roof and walls led to bulk water intrusion that caused rot in walls and ceilings and water stains in the basement. Three of the four corners in the basement leaked water due to improper landscaping and a sidewalk found to be sloping toward the foundation. Many items were unsalvageable. Garbage and rodent nests were found throughout.

The blower door pre-test indicated that the home was experiencing a large volume of air leakage. This made the home a good match for the three Northern*STAR*-researched energy measures. Insulation, air sealing, and ventilation of the roof would be completed using the overcoat application to eliminate disturbance of the finished ½ story. Excavationless exterior foundation insulation would be used to insulate as well as air seal the foundation while reducing water intrusion through the walls. Combi would eliminate the need for two mechanical systems and reduce the number of penetrations through the building envelope.

2.1 Excavationless Exterior Foundation Insulation

The first energy saving measure selected for this house was an exterior foundation insulation retrofit referred to as "excavationless" (Mosiman et al. 2013). This measure solves several hygrothermal and durability problems commonly encountered when insulating existing basements from the interior. It also solves problems unique to insulating from the outside of the foundation: Few people attempt to insulate basements from the exterior because traditional backhoe excavation to access the foundation wall destroys the yard and potential structures such as sidewalks and porches.

The excavationless system shown in Figure 2 uses hydro-vac technology combining high pressure water and a large vacuum truck to create minimal-width trenches. Developed for the utility industry, it enables relatively precise trenching around a foundation to remove soil from a space 3- to 4-in. wide by 8-ft deep. The flexibility of the system enables tunneling under obstacles and around utilities without removal of the obstacles and with little damage to landscapes. The narrow trench can be filled with a combination of liquid/rigid insulating foam to insulate and air seal the foundation wall and rim (Schirber et al. 2014). This method works best for rough foundation surfaces or rubble foundations. For poured concrete and other smooth foundation walls, water and air seal can be accomplished by draping a membrane sheet (or liquid applied) waterproofing against the concrete wall and then inserting the appropriate thickness of rigid extruded polystyrene (XPS) foam and backfilling with dirt.

Figure 2. Hydro-vac truck and high pressure water nozzle cutting a narrow trench

2.2 Overcoat External Roof Air/Water Barrier, Insulation, and Ventilation System

The Northern*STAR* research report "Project Overcoat—An Exploration of Exterior Insulation Strategies for 1 ½-Story Roof Applications in Cold Climates" (Ojczyk et al. 2013) describes the method of installing an air/water barrier, insulation, and ventilation system on the outside (exterior) of the roof planes and gable walls. Exterior insulation can provide a long-term solution to ice dams by providing three key components: reduced air leakage via a continuous air barrier, reduced heat loss via continuous insulation, and effective roof ventilation. All are difficult to achieve from the inside when attic space has been converted to finished living space, rafter depth for insulation is shallow, and the roofs are complicated with dormers. Additionally, the ventilation of the roof deck is extremely difficult if not impossible from the inside.

The overcoat system, as illustrated in Figure 3, is a combination of rigid XPS foam insulation and an air/water barrier fastened to the existing roof deck with furring strips. New roof sheathing and roofing materials are layered over the furring strips. The air gap created with the furring strips provides proper ventilation to keep the roof deck cool. Overcoat applied to the exterior walls follows a similar process except cladding is used in place of roof sheathing and roofing materials.

The goal of applying overcoat, with its continuous thermal/air/water membrane, to the roof and exterior walls of the ½ story is to correct air leaks and insulate more effectively than an interior approach. Air sealing from the interior requires detailed attention at the knee walls, flat plane of the floor, and the slope planes and flat planes of the ceiling. Overcoat, on the other hand, makes the entire upper level from the second floor joists up to the roof peak perform optimally with continuous air, moisture, and thermal barriers.

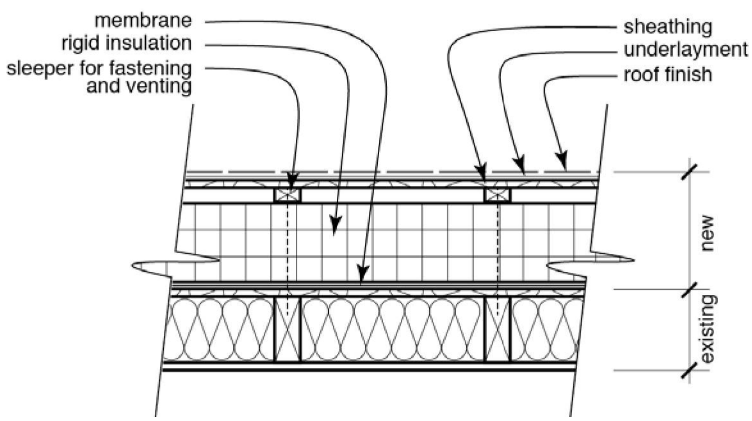

Figure 3. Details for roof overcoat approach

Figure 4 shows the layering of the overcoat materials to create the continuous thermal/air/water barrier and ventilation as applied to the roof of a 1-½-story home.

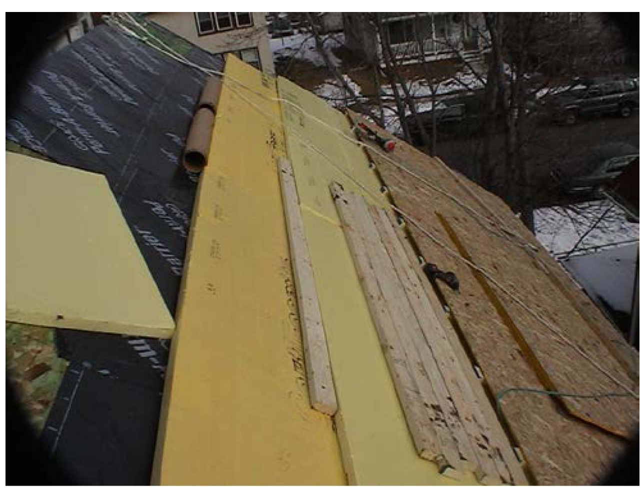

Figure 4. Details for roof overcoat applied to a 1-½-story home

2.3 Combi Space and Water Heating System

Figure 5 is the actual natural gas-fired combi space and water heating system installed in the project house. The combi system is an existing technology tested and studied by the Northern*STAR* team and its research partner Center for Energy and Environment (CEE) (Schoenbauer et al. 2012). Using a large-capacity water heater as the “furnace,” water is heated then pumped through a coil in the air handler box. As a fan blows air over the coil, the heat from the coil is transferred to the air. The fan distributes the heated air throughout the house. During a laboratory study conducted by the team and CEE, nine different products by various manufacturers were tested for 2 years. The performance data was collected and analyzed. The two best systems were then selected for installation in more than 200 affordable homes participating in DOE’s Weatherization Assistance Program. The systems in 19 homes were monitored for 1 year. Overall energy savings of about 20% were achieved as compared to existing space and water heating (Schoenbauer et al. 2014).

Figure 5. Example of the combi space and water heating system

3 Construction Collaboration Process

One of the highlights of the project was the opportunity to work with an affordable housing developer through the design, budgeting, and construction process and weave the three technologies into their typical process. In order to reduce labor costs, UHW identified opportunities to use unskilled volunteers during the excavationless installation, and students from their skilled-crew training program to assist in the installation of the roof overcoat system. The combi system required the use of a qualified heating, ventilating, and air conditioning (HVAC) contractor. Using in-house labor was important to the developer and built confidence within their system that the measures could be applied to future projects.

3.1 Collaborative Partners

The following partners provided construction materials or consulting, design, and/or installation services for the demonstration project.

3.1.1 Urban Homeworks, Minneapolis, Minnesota

UHW, a faith-based Minneapolis nonprofit, is an affordable housing developer that builds and remodels homes for low-income families in low-income neighborhoods in Minneapolis and St. Paul. They also develop community programs that enhance the socio-economic wellbeing of people who live in low-income neighborhoods. The University of Minnesota's Cold Climate Housing program engages UHW in projects where they can learn to build and remodel homes that achieve increased energy efficiency, enhanced health, and long-term durability.

In 2013, UHW launched Urban Construction Company, commonly called UC-Squared or UC2. UC2 is a social venture designed to engage low-income, at-risk youth and young adults who have completed construction training through a partner nonprofit agency, Tree Trust's YouthBuild program. These young people wish to work in the construction trades but lack sufficient job experience to attain full-time employment. UC2 positions are benefited with deliberate job skill development specific to building codes and the following core building competencies: concrete/masonry, general carpentry, and building processes. UC2 program participants are learning in a real-world work environment—not a classroom—while making a living wage. The demonstration house provided an opportunity for the students to combine a full-time field job with deliberate training while helping to lower the labor costs for the overcoat installation. UC2 managers thought it would be a good experience to work on the overcoat installation to develop new skills and learn a cutting edge method of renovating 1-½-story homes.

3.1.2 Cocoon Home Performance Solutions by Kinzler Construction Services, Eden Prairie, Minnesota

Cocoon is an insulation, home performance testing, and radon mitigation contractor that oversaw the installation of the excavationless system and advised on the installation of the overcoat process.

3.1.3 BASF Corporation

BASF is a global chemical company that provided the liquid foam for the excavationless exterior foundation insulation system. They developed pourable foam appropriate for below-grade applications.

3.1.4 Goliath Hydro-Vac Inc., Lakeville, Minnesota

Goliath provides industrial vacuum and hydro-vac excavation services to a variety of clients including utility companies. They provided the hydro-vac truck and professional excavation services.

3.1.5 Centraire Heating and Air Conditioning, Eden Prairie, Minnesota

Centraire is an HVAC contractor that provided installation services for the combi space and water heating system in the demonstration house.

3.1.6 Center for Energy and Environment, Minneapolis, Minnesota

CEE is a nonprofit energy services provider and Northern*STAR* Building America research partner. They have performed extensive testing and other research on the combi space and water heating system. They provided advice on the design and installation of the combi system in the demonstration house.

3.2 Construction and Installation Processes

The following sections detail the steps taken to install the excavationless, combi, and overcoat systems in the demonstration house.

3.2.1 Excavationless Installation

The first measure installed on the demonstration home was the exterior foundation insulation. To prepare the home for the measure, the original concrete sidewalk located on one side of the house and connected to the foundation was removed as it was sloping toward the house. Two concrete entry stoops on the front and side of the house were left in place, as the hydro-vac process enables tunneling under obstacles. Figure 6 illustrates how high-pressure water delivered through a handheld wand was used by professionals from Goliath Hydro-Vac Inc. to cut into the soil. A large vacuum hose extracted the soil and water as it was loosened. The completed trench, 4-in. wide by 5-½-ft deep to expose the footing, ran along the perimeter of the house.

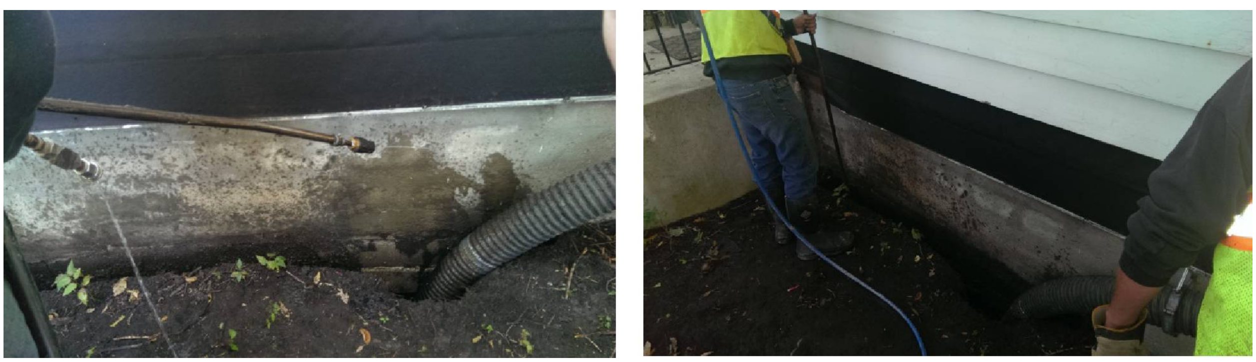

Figure 6. The hydro-vac high-pressure water wand and vacuum used to create the trench

Upon completion of the trench, Cocoon contractors, who had prepared detailed drawings for the system, attached 1-in.-thick furring strips to the rim joist with screws 16 in. on center. Figure 7 shows how the strips were attached flush with the top of the rim and terminated about 1 ft below grade. The left side of the image in Figure 7 also shows how 1-½-in. XPS foam was attached to the furring strips from the top of the rim joist down to the footing.

Figure 7. Furring strips to hold the above-grade rigid form 1 in. from the foundation

The 1-in. cavity created by the furring strip insulation combination provided a closed system into which liquid foam could be "poured" and allowed to expand to fill the rough, imperfect surface of the foundation. The foam was a custom-designed product created by BASF with guidance from the Northern*STAR* team in consideration of climate and soil. After the first few feet of cavity were filled the team determined that the insulation wand was easier to control at shorter depths. Figure 8 shows how the rigid insulation was trimmed just below grade to gain more precise access to the footing while pouring the foam.

Figure 8. Pouring the liquid foam into the 1-in. cavity

Additional XPS foam insulation was attached to the furring strips above grade. A sheet of plywood was attached to the furring strips through the foam to prevent bowing of the rigid XPS foam during expansion of the liquid foam (Figure 9).

Figure 9. Above-grade rigid XPS foam held flat with attached plywood

After the liquid foam hardened, the plywood was removed exposing a smooth, plumb surface for a future stucco finishing layer (Figure 10). The rigid-liquid foam components created a one-piece system with a 2-½-in. layer of insulation fully adhered to the foundation. Two benefits were achieved: using XPS for part of the system reduced the cost compared to an all-liquid foam system, and enabled the contractor to more accurately estimate cost prior to the application.

Figure 10. Smooth, flat surface created by the rigid insulation

The final step required a transition from the top of the foam to the siding. Figure 11 shows how the exposed face of the above-grade foam was covered with a trowel-applied stucco product. A volunteer crew from UHW applied the stucco to the smooth side of the XPS.

Figure 11. Foam system with stucco applied to one side

A metal flashing strip was used to divert water from behind and in front of the siding over the foam. It was fashioned to protrude horizontally over the top of the foam to the outer edge and then vertically downward ¾-in. over the foam. It was attached flat against the house and tucked under the existing building paper and siding. A narrow plank or freeze board painted to match the cedar siding covered the metal flashing. The volunteer crew also cut in the basement window openings and installed windows and wells. Figure 12 shows the finished appearance of the excavationless process with the newly installed sidewalk sloping away from the house and the exterior foundation insulation integrated into the existing siding.

Figure 12. Completed foundation insulation with trim and windows

3.2.2 Combi Installation

Figure 13 shows the finished installation of the combination space and water heating system in the demonstration house. The system was chosen for the project as it was one of the best-performing systems in the aforementioned combi study and would meet the needs of the demonstration house in consideration of the performance upgrades and proposed weatherization. A Polaris water heater serves as both the water heater and furnace with a 100,000 Btu output. Air is delivered through the existing duct system with the help of an Enerzone air handler and hydronic coil, a deep-pleated minimum efficiency rating value (MERV) 13 air filter system to improve comfort and indoor air quality, and an E15 ECM Venmar heat recovery ventilator (HRV).

Figure 13. Combi system installed in the project house, including an HRV

The combi system was installed by a local contractor who had participated in the combi study and gained significant experience with the installation. He understood the importance of a tight building enclosure and took measures to ensure that penetrations through the rim would be air tight upon completion of the excavationless system. Figure 14 shows the exhaust system from both inside and outside the home through a specified sleeve installed prior to installation of the excavationless system, which was made airtight before stucco was applied to the rigid insulation.

Figure 14. Exhaust system sleeve installed prior to application of exterior insulation

The team had the opportunity to seal the ducts in the house to deliver conditioned air more effectively and increase comfort in the home. A donation was provided by Angell Aire, Inc. of Burnsville, Minnesota, an authorized dealer for Aeroseal. They installed the product and effectively reduced leakage on the supply side of the duct system only from 115.4 cubic foot per minute at 50 Pa (CMF50) to 0.0 CFM50.

3.2.3 Overcoat Installation

In an optimal design for a roof overcoat project, the roof planes and gable walls receive a continuous exterior-applied air/water membrane, insulation, and ventilation components. The team proposed that the demonstration house have overcoat applied to the main level walls so that the complete building enclosure could be covered in a continuous exterior air/water/thermal barrier from footing to peak. The budget for the project, however, was not extensive enough to include overcoat on the main level. Additionally, UHW had been awarded a $10,000 grant for lead paint abatement along with installation of new custom double-hung windows for the main floor. The company providing the grant would provide the labor for the lead abatement and the window installation only if UHW would agree to keep the siding intact. Losing the grant would have cost UHW significant budget increases due to the added cost of new insulation, air/water membrane, siding, painting, and new windows. The team decided to leave the exterior cedar siding in place on both the main level and ½-story. The main level walls would remain as is with the original 1-½-in. batt insulation estimated at R-5.

Because the gable walls of the ½-story could not be insulated from the exterior, insulation was installed on the interior. To do so, the ceiling sheetrock, walls with sheetrock, and wall insulation were removed. The short side walls with tongue and groove pine boards were left in place. Figure 15 shows how Cocoon applied 3 in. of closed-cell spray polyurethane foam (ccSPF) to the interior of the three gable walls between the studs. The entire floor perimeter (including side attic areas behind the knee walls) was also insulated with ccSPF from the top of the floor joists continuous to the top plate of the lower-level wall.

Figure 15. Interior-applied foam on the gable end

To install overcoat to the roof planes, Northern*STAR* provided guidance to the students from UC2. They started by removing the existing roof shingles, underlayment paper, and nails in order to inspect the solid wood (¾-in.) sheathing for damage and prepare it for the overcoat layers. The sheathing was intact and evaluated as sound enough to use as the underlayment deck. The minimal soffit and frieze boards of the gable tops were removed. The 3-in. rafter tails were cut flush to the sheathing. Figure 16 shows the W.R. Grace Perm-A-Barrier peel-and-stick membrane applied to the entire roof and lapped over all the roof edges to above the siding.

Figure 16. The air/water membrane applied to the existing roof deck

Figure 17 below shows how the 5 in. of polyisocyanurate (also referred to as polyiso) rigid foam were attached to the roof deck with all the seams offset to help manage air and water. The 2-in. by 4-in. furring strips were fastened into each rafter with 10-in. GRK lag screws. The rafters were 16 in. on center, and the screws were installed 16-in. vertically apart on the sleeper. Finally, a new roof deck was attached to the furring strips using ½-in. oriented strand board (OSB) sheathing.

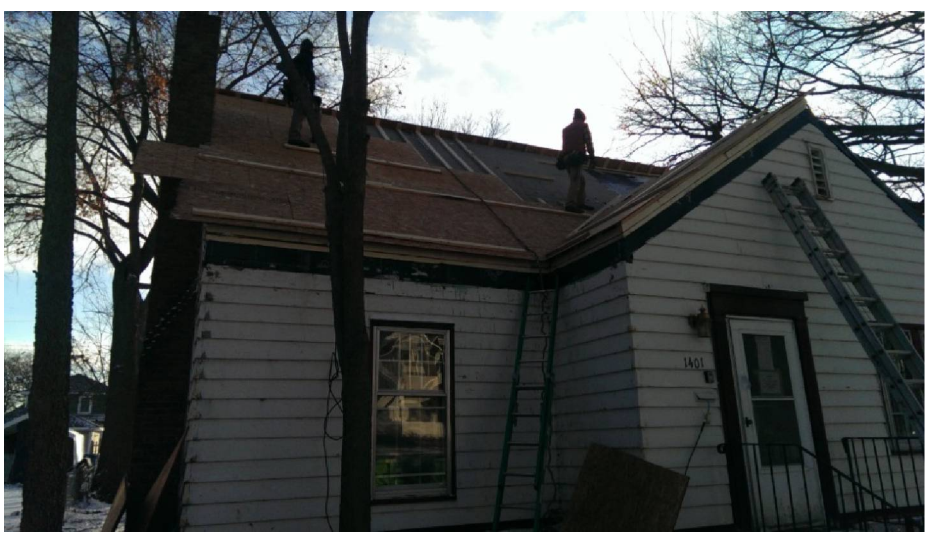

Figure 17. Installation of the insulation, furring strips, and new roof deck

The roof insulation was originally specified to be 6 in. (two 3-in. panels, R-6 per inch) of polyiso. The total thickness, however, was reduced to 5 in. because the rafters below the roof deck already contained R-5 batt insulation. This helped save some money for the roof overcoat component.

When the new roof sheathing was attached to the furring strips, the gap formed an air channel for ventilation (Figure 18).

Figure 18. Furring strips and roof sheathing forming an air channel for ventilation

The minimal overhang of the original roof, however, did not allow for a soffit cavity that would have provided communication of air flow from the soffit to the ridge vent. Figure 19 illustrates part of the solution where a short sleeper, approximately 14-in. tall, was attached to the top of the wall directly below the end of each furring strip.

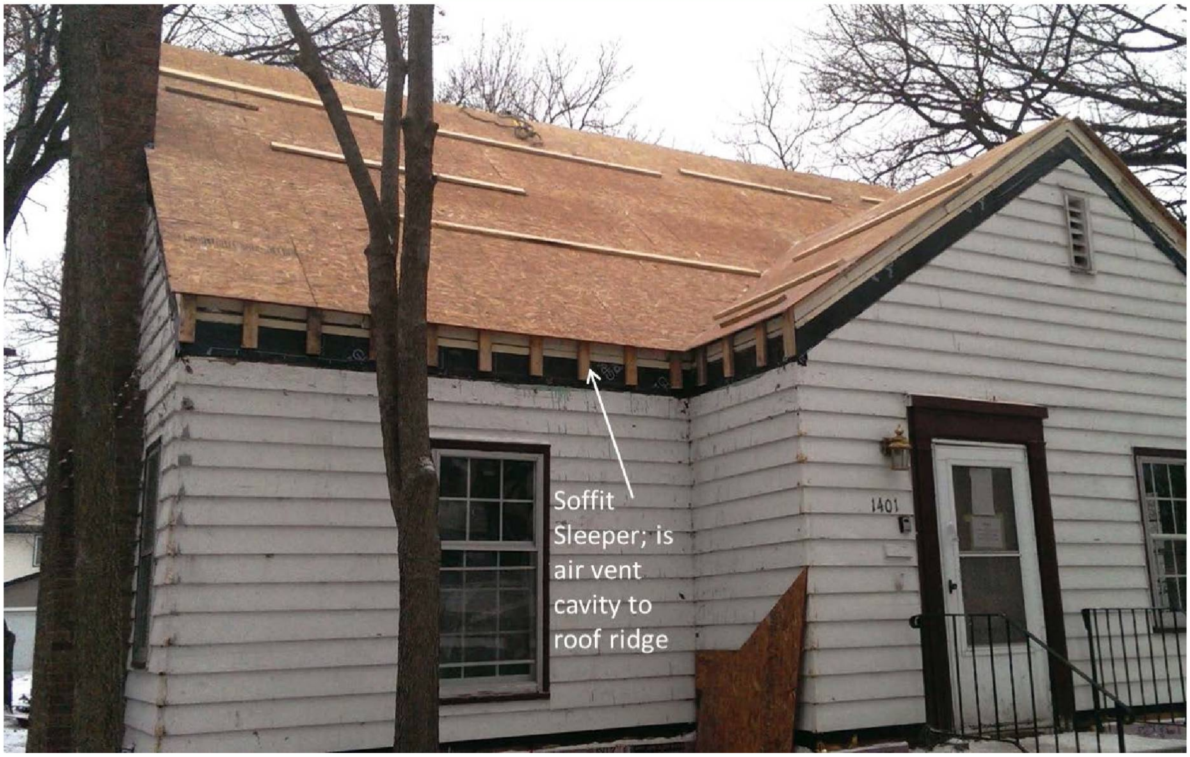

Figure 19. Vertical sleeper attached below roof furring strip

The short vertical sleepers attach to the wall to create a "soffit" cavity. They are placed directly below the roof furring strips (sleepers) and form a 1-½-in. air channel to move air from the soffit to the roof ridge vent.They were covered with stepped trim boards to finish it off. Next a bug screen was installed on the underside to complete air intake channels from soffit to ridge (Figure 20).

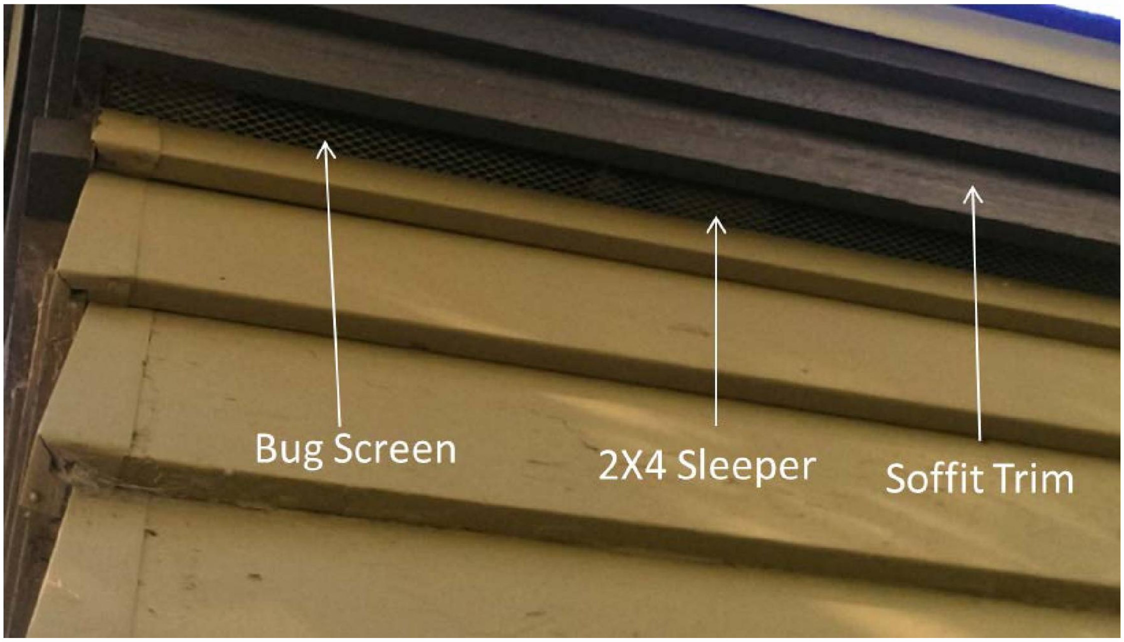

Figure 20. Trim boards attached to the vertical sleepers form air intake channels to the ridge

3.3 Cost Impact

Table 1 represents the actual costs of each of the performance upgrades as compared to the pre-construction estimate.

Table 1. Cost Impact of Applied Performance Upgrades

Measure Installed	Original Budget	Actual Cost	Subsidy Funding	Owner's Cost
Excavationless total	$5,250	$12,762	$7,500	$5,262
Hydro-vac truck	$2,750	$5,262		
Insulation	$2,500	$7,500		
Combi plus HRV	$8,400	$8,400		$8,400
Overcoat	$15,000	$15,000	$15,000	
Total	**$28,650**	**$36,162**	**$22,500**	**$13,662**

There were significant cost overruns for the hydro-vac and insulation contractors with the excavationless system. The team used the opportunity to work with the subcontractors to enhance design and methodology approaches. There was also a significant learning curve for both. When all was done there was replicable progress that will reduce costs on future projects (more discussion on this in section 5.1).

4 Energy Performance

The following performance testing and building energy optimization modeling was done on the demonstration house to measure airtightness and quantify energy cost savings.

4.1 Home Performance Testing

Airtightness was measured with a multipoint blower door test to determine CFM50 and air changes per hour at 50 Pa (ACH50) along with the flow exponent before demolition, after installation of overcoat and excavationless, after window replacement, and upon completion of final weatherization measures such as weather stripping and caulking. Infrared thermal imaging was used to guide improvements in air sealing and thermal bridging.

Table 2. Results from Blower Door Testing

Test Event	Air Leakage (CFM50)	Air Changes (ACH50)
Pre-Demolition	5,404	17.51
After Installation of Overcoat and Excavationless	2,299	7.45
After Window Installation	2,447	7.93
After Final Weatherization	1,483	4.81
Total Reduction	3,921	12.70
% Total Reduction	73%	73%

Figure 21 is a visual representation of air leakage captured by an infrared thermal imaging camera at various locations in the ½-story before demolition (center column) and upon completion of the home (right column). A full report is attached in Appendix A.

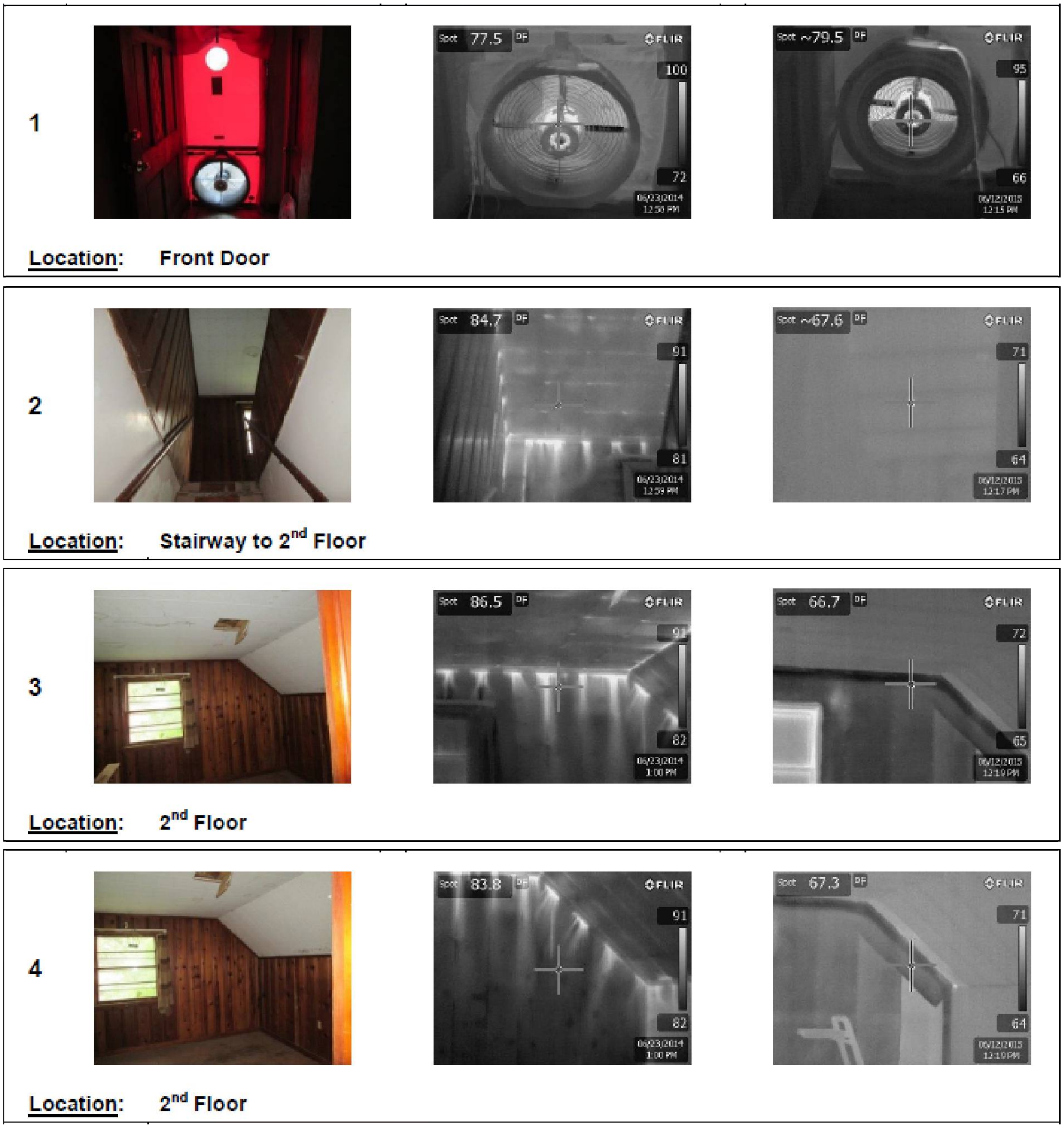

Figure 21. Thermal imaging of the ½-story pre- and post-construction

4.2 BEopt Energy Savings Modeling

Because the research grant period was scheduled to end before the house could be occupied, actual energy use following the rehab efforts could not be measured. To quantify the energy savings, two BEopt building energy optimization software models were completed: a pre-retrofit model based on blower door tests and a survey of the initial conditions, and a post-retrofit model incorporating all the energy and airtightness upgrades. For the pre-retrofit BEopt model, the second floor was modeled with a thermal boundary following the insulated floor joists, knee walls, slants, and a micro-attic, matching pre-existing conditions. For the post-retrofit BEopt model, the second floor was modeled with the thermal boundary at the roof plane, matching the overcoat retrofit. The exterior geometry and finished square footage of the BEopt model did not change. BEopt's Minneapolis-St. Paul International Airport climate file was selected for the simulations.

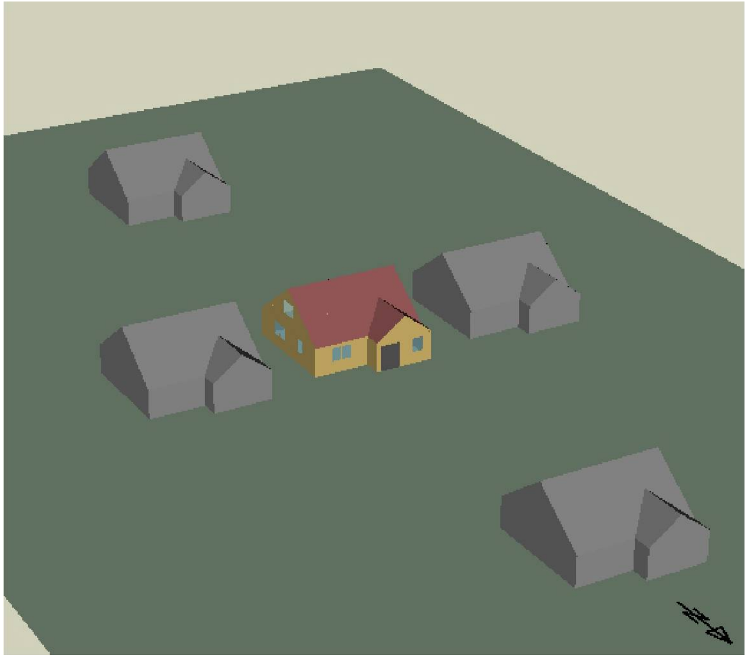

Figure 22. BEopt model orientation, geometry, and neighboring structures

The modeling parameters for the pre- and post-retrofit BEopt models are listed in Table 2.

Major changes between the pre- and post-retrofit models include a reduction in air leakage from 17.5 ACH50 to 4.8 ACH50, replacement of the original domestic hot water (DHW) heater and furnace with the Polaris combi system, modeled at 92% efficiency for both space and DHW heating, and the overcoat roof insulation retrofit. Because the insulation retrofit included an application of ccSPF to the gable-end walls, the exterior wall R-value for the house as a whole was recalculated using an area-weighted average that included the spray foam. This increased the exterior wall R-value from approximately R-7 to R-8.3. Other improvements included a programmable thermostat with a night setback to 65°F, new double-glazed low-e windows with exterior storms, modelled with a combined U-value of 0.27, a Venmar Eko HRV with 80% sensible heat recovery efficiency, a lighting upgrade from 100% incandescent to 60% compact fluorescent (CFL) light bulbs, and major appliance upgrades to ENERGY STAR standards.

Table 3. Pre- and Post-Retrofit BEopt Model Parameters

CATEGORY NAME	PRE-REHAB	POST-REHAB
BUILDING		
Orientation	North	North
Neighbors	Left/Right at 15ft, Front/Back at 80ft	Left/Right at 15ft, Front/Back at 80ft
WALLS		
Wood Stud	R-6 cellulose batt	Area-weighted average R-8.3
Wall Sheathing	OSB	OSB
Exterior Finish	[Wear Out] Wood, Light	[Wear Out] Wood, Light
Interzonal Walls	R-6 cellulose batt knee walls	NA
CEILINGS/ROOFS		
Unfinished Attic	Uninsulated, Vented	NA
Finished Roof	R-7 fiberglass batt	R-35 polyiso exterior continuous
Roof Material	[Wear Out] Asphalt Shingles, Medium	[Wear Out] Asphalt Shingles, Medium
Radiant Barrier	None	None
FOUNDATIONS/FLOORS		
Finished Basement	Uninsulated	R-13.5 (XPS + ccSPF) Excavationless install
Carpet	0% Carpet	0% Carpet
THERMAL MASS		
Floor Mass	Wood Surface	Wood Surface
Exterior Wall Mass	5/8 in. Drywall	5/8 in. Drywall
Partition Wall Mass	5/8 in. Drywall	5/8 in. Drywall
Ceiling Mass	5/8 in. Drywall	5/8 in. Drywall
WINDOWS & DOORS		
Window Areas	F12 B12 L12 R12	F12 B12 L12 R12
Windows	U-0.49, SHGC-0.56 Single glazed w storms	U-0.27, SHGC-0.26 Double glazed low-e w storms
Interior Shading	Summer = 0.7, Winter = 0.7	Summer = 0.7, Winter = 0.7
Door Area	40 ft^2	40 ft^2
Doors	[Wear Out] Wood	[Wear Out] Wood
Eaves	None	None
Overhangs	None	None
AIRFLOW		
Air Leakage	17.5 ACH50	5 ACH50
Mechanical Ventilation	None	[Wear Out] Venmar Eko1.5 80%, 2010 ASHRAE 62
Natural Ventilation	Cooling Months & Overlap, 7 days/wk	Cooling Months & Overlap, 7 days/wk
SPACE CONDITIONING		
Furnace/Boiler	[Wear Out] Gas, 78% AFUE	[Wear Out] Gas, 92% Best of Nstar Combi
Ducts	In Finished Space	In Finished Space
Ceiling Fan	[Wear Out] Standard Efficiency	[Wear Out] Standard Efficiency
Dehumidifier	None	None
SPACE CONDITIONING SCHEDULES		
Cooling Set Point	None	None
Heating Set Point	68 F	71 F w/ Setback 65 F
Humidity Set Point	None	None
WATER HEATING		
Water Heater	[Wear Out] Gas Standard, 0.59EF	[Wear Out] Gas, 92% Best of Nstar Combi
Distribution	[Wear Out] Uninsulated, TrunkBranch, Copper	[Wear Out] Uninsulated, TrunkBranch, PEX
LIGHTING		
Lighting	[Wear Out] 100% Incandescent	[Wear Out] 60% CFL
APPLIANCES & FIXTURES		
Refrigerator	[Wear Out] Top freezer, EF = 10.5, 727 kWh/yr	[Wear Out] Top freezer, EF = 14.1, 540 kWh/yr
Cooking Range	[Wear Out] Gas	[Wear Out] Gas
Dishwasher	None	None
Clothes Washer	[Wear Out] Standard	[Wear Out] EnergyStar
Clothes Dryer	[Wear Out] Electric	[Wear Out] Electric
Hot Water Fixtures	1	1
APPLIANCES & FIXTURES SCHEDULES		
Refrigerator Schedule	Standard	Standard
Cooking Range Schedule	Standard	Standard
Dishwasher Schedule	Standard	Standard
Clothes Washer Schedule	Standard	Standard
Clothes Dryer Schedule	Standard	Standard
Hot Water Fixtures Schedule	Standard	Standard

Table 3. (continued) Pre- and Post-Retrofit BEopt Model Parameters

MISCELLANEOUS		
Plug Loads	1	1
MISCELLANEOUS SCHEDULES		
Plug Loads Schedule	Standard	Standard
HVAC SIZING		
Cooling Capacity	0.00 tons (Output)	0.00 tons (Output)
Heating Capacity	74.30 kBtu/hr (Output)	31.24 kBtu/hr (Output)

Simulation results showed a large reduction in site heating energy use, which dropped by more than 50%. This reduction was due to both a drop in heat loss through the roof, windows, and air leakage, as well as efficiency gains with the mechanical system. A smaller but still significant reduction in energy use was achieved for DHW heating, due primarily to improvements in the efficiency of the mechanical system. Simulation results showed smaller savings for the air handling unit fan, lighting, and large appliances. Very small increases in ventilation fan energy use resulted from the addition of the Venmar HRV, which provided approximately 60 cfm continuous (meeting the requirements of ASHRAE 62.2 2010) and an increase in miscellaneous energy use such as plug loads. Simulated site energy savings (total) amounted to slightly more than 80 MMBtu/yr, almost a 46% drop in energy use.

Table 4. Modeled Pre- and Post-Retrofit Site Energy Use and Savings

	Hot Water (G)	Heating (G)	Heating Fan/Pump (E)	Lights (E)	Vent Fan (E)	Lg. Appl. (E+G)	Misc. (E)	Total (E+G)
Pre-Rehab Energy Use (site) MMBtu/yr	20.8	129.1	3.2	8.3	0.1	8.5	8.1	178.0
Post-Rehab Energy Use (site) MMBtu/yr	11.2	60.4	0.3	6.9	1.5	7.5	8.5	96.3
Savings MMBtu/yr	9.6	68.7	2.9	1.4	-1.4	1.0	-0.5	81.7
% Reduction	**46.1%**	**53.2%**	**91.3%**	**17.3%**	**-2,366%**	**12.0%**	**-5.8%**	**45.9%**

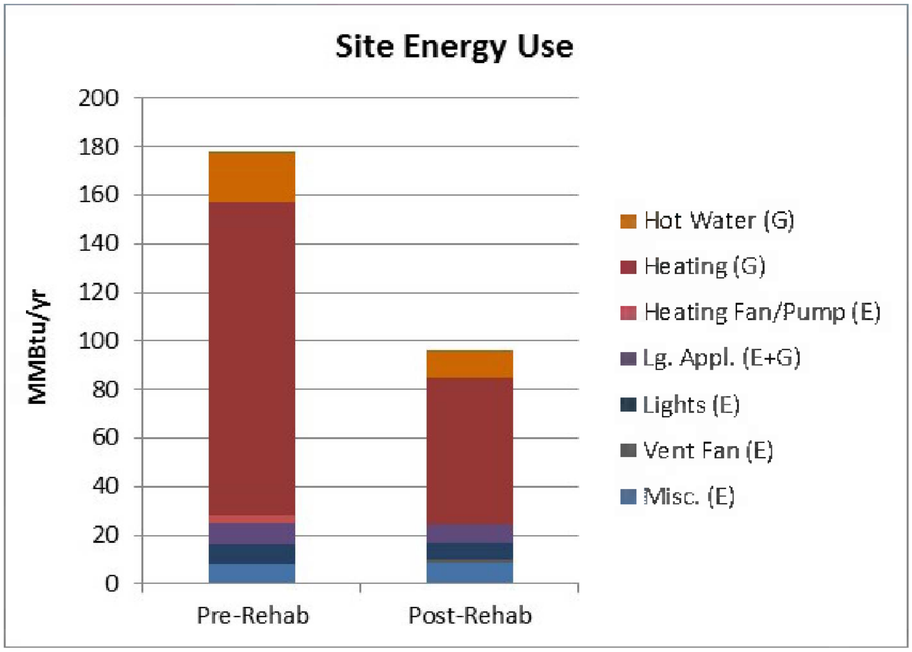

Figure 23. Modeled pre- and post-retrofit site energy use and savings

Source energy use savings were also calculated using BEopt's site-dependent source-to-site energy conversion ratios for electricity and natural gas. These were 3.15 for electricity and 1.09 for natural gas. Total simulated source energy use was reduced by 95.4 MMBtu/yr.

Table 5. Modeled Pre- and Post-Retrofit Source Energy Use and Savings

	Hot Water (G)	Heating (G)	Heating Fan/Pump (E)	Lights (E)	Vent Fan (E)	Lg. Appl. (E+G)	Misc. (E)	Total (E+G)
Pre-Rehab Energy Use (source) MMBtu/yr	22.6	140.7	10.1	26.1	0.2	21.0	25.4	246.1
Post-Rehab Energy Use (source) MMBtu/yr	12.2	66.7	0.9	21.6	4.7	17.8	26.9	150.7
Savings MMBtu/yr	10.4	74.0	9.2	4.5	-4.5	3.2	-1.5	95.4
% Reduction	**46.0%**	**52.6%**	**91.4%**	**17.3%**	**-2,483%**	**15.1%**	**-5.8%**	**38.8%**

5 Discussion

When new measures and methods are developed to improve performance and reduce energy consumption there is usually a learning curve that better informs design, materials, methods, and cost on future projects. Determining who should bear the cost of the learning curve is usually a hurdle in the adoption of new strategies. Generally, the contractor who stands to benefit from the new measure will contribute time and materials. Nonprofits providing affordable housing often have little desire for the cost that accompanies experimentation and unknown risk. They may, however, be willing to let research partners use their projects as a living laboratory if cost is not significantly impacted and if there is a plan in place to get help when things don't go as anticipated. The three performance measures used in the demonstration house provided a means to further inform nonprofit housing developers about high performance measures.

Before any measures could be applied, though, a home in need of renovation had to be located that would benefit from the three proposed performance measures. The Northern*STAR* team worked with UHW to find a 1-½-story bungalow that was plagued with ice dams, had an uninsulated yet livable basement, and also needed a new furnace and water heater.

5.1 Evaluation Criteria

Northern*STAR* and UHW established criteria to help evaluate the installed high performance measures and their applicability to future UHW projects and projects proposed by other nonprofit affordable housing developers. Evaluation criteria included:

- Constructability in the context of affordable housing
- Impact of cost on scope of work
- Impact of house performance, such as energy savings and durability
- Developer's desire to use one or more of these measures in the future
- Training or guidance required to use these measures.

5.2 Excavationless Exterior Foundation Insulation Evaluation

When the house was acquired by UHW the basement had bulk water coming in through the foundation from three of the four sides. This was a result of improper landscaping with negative drainage, broken basement windows, and overgrown plants next to the house. However, the basement could function as a livable space if it could be made warm and dry.

The hydro-vac contractor used for a prior excavationless project charged $275 per hour. Anticipating an increase in their rates over the previous project, the budget for the hydro-vac portion was estimated at $330 per hour. During the time between budget development and construction, a larger hydro-vac company that had been in business longer provided a bid of only $235 per hour and was chosen to do the job. It was not understood at the time of commitment what the impact of their drive time would be on the budget to get to and from their home base. A few additional charges including a dumping charge to empty the truck and extra hours for their learning curve resulted in a cost increase of 40% over budget. While the cost was higher to use the company, the results were considered good. As the previous pictures show, the trench was precisely 4-in. wide. The soil did not cave in as had happened with previous projects. They were also able to tunnel under both concrete stoops at the front and back doors. During debriefing, the crew stated that future projects of similar size could be done in less time, with one less trip charge, one dump charge, and 5 hours less of on-site work.

Cocoon has been the spray foam contractor and industry partner on several Northern*STAR* projects, including all excavationless projects. Throughout their work they have sought ways to improve installation while decreasing budget. The job site problem solving outlined above, in which the rigid insulation was attached to the furring strips in two pieces, helped the team pour the liquid foam more efficiently. This provided greater confidence in achieving full foam coverage, and ensured a flat above-grade surface for finishing. This approach was helpful for this project as well as future excavationless projects.

5.2.1 Constructability in the Context of Affordable Housing

Excavationless systems are a reasonably straightforward opportunity. A hydro-vac excavation subcontractor would need to be hired, but many exist in almost every town. An insulator with the equipment and knowledge of using pourable foam, ccSPF, and rigid foam would also need to be hired. Volunteer labor could be used for above-grade transitions and window installation.

5.2.2 Impact of Cost on Scope of Work

The cost of this measure exceeded the estimate mainly due to lack of understanding of variable rates charged by hydro-vac contractors. Future jobs of similar size could cost less with better understanding of hydro-vac rates as well as hiring a contractor with previous excavationless experience.

5.2.3 Impact of House Performance

Air-tightness results from Table 2 indicate that the combination of excavationless and overcoat made a significant impact in reducing air leakage—improving it by almost 60%. During the lengthy remodeling process, workers noted the basement stayed warm during the winter of 2014–2015 and dry during the summer of 2015 even with abundant rain. The basement is usable as-is by painting the walls, thus avoiding extensive wall building.

5.2.4 Developers' Desire To Use This Measure

UHW says they would use this method if the benefits outweighed the cost. For instance, if the basement of a house was finished but not insulated it would be of benefit to insulate from the outside.

5.2.5 Training or Guidance Required

The process could be learned by training one superviser in an organization. The training could be done with a "how to" video and a manual. The expectation is that future efforts are less costly as professionals gain skills and confidence as they repeat the process.

5.3 Combi Space and Water Heating System Evaluation

The strength of the combi performance measure is that the system has been thoroughly tested in a laboratory setting and monitored in real-world houses. It has also been installed more than 200 times in the Minneapolis, Minnesota, region.

The combi system in the demonstration house underwent a fairly straightforward installation. The contractor had a lot of experience with these systems as a partner in the aforementioned combi study. They noted that they became quickly accustomed to the technology after several installations. Additionally, the basement was completely unfinished during installation making it easy to work in. Four new duct runs needed for the HRV system were installed before any internal remodeling was done. This type of scheduling made their work more cost-effective.

5.3.1 Constructability in the Context of Affordable Housing

Combination heating and hot water systems have been around for a number of years. Familiarity with the systems lowers the learning curve for installation.

5.3.2 Impact of Cost on Scope of Work

The cost for a combi system and installation is similar to the costs for a new high-efficiency sealed-combustion furnace and water heater, yet only one sealed-combustion vent is needed. Combi is most appropriate for projects where both the existing furnace and water heater need to be replaced. The system installed for this project required concurrent installation of an HRV system and four duct runs due to the improved air tightness from the insulation and air sealing measures. The combi system cost $8,400 with the HRV. The majority of retrofits the team has studied were combi systems installed without an HRV. The cost for the HRV generally runs about 25% of the total on a retrofit. This system without the HRV would have cost about $6,300.

5.3.3 Impact of House Performance

As stated in the aforementioned combi study, average measured energy savings were about 20%. The systems will also provide more hot water than most water heaters.

5.3.4 Developers' Desire to Use This Measure

Affordable housing developers that visited the site, as well as UHW, stated they would consider the combi system as an efficiency solution for renovation projects and new homes as long as it fits the budget and the system proves easy to maintain.

5.3.5 Training or Guidance Required

Most experienced HVAC installers will incur a learning curve but will be confident in the system after the first one is completed.

5.4 Overcoat External Roof Air/Water Barrier, Insulation, and Ventilation System Evaluation

One of the positive aspects of roof overcoat is that it is not highly technical. Once the design and detailed scope of work are specified, the steps are relatively simple carpentry. Details such as transition to siding, roof edges, and valleys are critical, but with some guidance most experienced construction workers will adapt quickly.

UC2 was chosen to install overcoat as they have more advanced skills than other students in training. While they have done mostly concrete work in the past, they were seeking to learn other aspects of renovation. The group was supervised by a construction manager with years of experience. After a briefing with Northern*STAR* staff, the manager decided that his crew could handle the job. He stated clearly that there would be a learning curve for the group and they would take longer to complete the job than a much more experienced crew. The first thing learned was that half the crew did not feel comfortable working on a ladder and up on a roof. The other half was only somewhat comfortable on the roof. Additional time was needed to help the willing crew get used to ladders and heights. The other half of the crew was trained to cut and fabricate the materials on the ground before being used on the roof.

The crew was able to remove the shingles, trim, and soffit and prep the roof for primer and peel-and-stick membrane without any problem. They did an excellent job on the membrane but it took longer than anticipated. The application of the insulation panels, the furring strips, and roof deck also went slower than expected, but the desired outcome was achieved. It was noted by the crew that they became faster and more effective at installing the 10-in. lag screws through 7-¼-in. of material and hitting a 1-$^{1}/_{5}$-in. rafter after having installed about 10% of the system. Due to their commitment to another project, the crew left the demonstration house before completing overcoat on the front of the home. Two carpenters were hired to complete the overcoat on the front half of the house as well as the soffit and facia.

The first thing learned from the roof overcoat portion of the project was that crews in training can learn to install this measure if the plan includes sufficient time for learning. It was clear to all that the second and third time would go more quickly. Secondly, when training groups or volunteers help to install overcoat there should be at least one skilled carpenter and one skilled roofer to help with the training. An unexpected difficulty encountered was that working on a roof takes considerable practice and the proper equipment.

5.4.1 Constructability in the Context of Affordable Housing

As earlier stated the overcoat installation process is not highly technical. When volunteer or training groups do the work, however, it is best to have an experienced roofer/carpenter trained on overcoat to supervise the installation. The learning curve was minimally experienced primarily when applying the membrane and installing a portion of the furring strips. With both of these, the learning curve dissipated after about 10% of the job was completed. The most significant obstacle was the fact that none of the crew had experience working on a steep roof. Some did not feel comfortable being on the roof at all so they worked with the material as needed from the ground. Those on the roof had difficulty maneuvering with safety harnesses and roof jacks. This increased their labor costs significantly. However, because the contractor, UC2, is also a training program, some of the labor was covered by a different budget. For future jobs the team recommends the use of scaffolding on the soffit end of the roof and possibly a platform lifting and extending forklift (e.g., a Lull forklift).

5.4.2 Impact of Cost on Scope of Work

Overcoat is typically more expensive than other air-sealing and insulation methods, making it more difficult to convince a developer of the appropriateness to a project. The key benefits of overcoat, however, may outweigh the costs if reoccurring ice dams and the long-term impact of high energy bills are considered. The continuous air-tight thermal barrier and ventilation system eliminates stack effect, reduces heat loss, and eliminates ice dams. The costs for an overcoat project are easier to absorb when the shingles need replacing or if the interior of the ½-story is already remodeled but experiencing problems. It is helpful to have a discussion with nonprofit partners about the long-term needs of low-income families and whether this measure will truly help the family with short- and long-term costs, comfort, and health.

Table 6. Estimated Cost for Overcoat

Description: Insulation and Air Sealing: Roof Overlay—Exterior Insulation and Ventilation	Material	Labor
Demolition		
Remove shingles		$ 442.00
Remove and recycle existing gutters		$ 120.00
Cut off rake and eave overhangs flush to outside of exterior walls		$ 400.00
Exterior Insulation and Ventilation		
Install membrane primer over entire roof deck	$ 285.00	$ 200.00
Install rubberized asphalt/peel-and-stick membrane at roof deck	$ 987.00	$ 450.00
Insulation 3-in. sheets (40) polyiso	$ 1,472.00	$ 1,900.00
Insulation 2-in. sheets (40) polyiso	$ 985.00	
Fasteners		
Gun nails	$ 64.00	
700 GRK 10-in. by ⅜-in. screws at $2.14	$ 1,498.00	$ 800.00
Interior Attic Insulation		
Install 3-in. ccSPF (R-20.3) at gable walls of upper level and around entire perimeter of attic level	$ 1,522.00	
Eave and Soffit Framing		
Frame new soffit and rake overhangs	$ 196.50	$ 500.00
Install new frieze board and trim	$ 90.00	$ 350.00
Lumber		
2X4 sleepers fastened to rafters	$ 289.00	
42 sheets of ½-in. OSB decking fastened to sleepers	$ 371.00	$ 600.00
Trim for soffit, facia, and vent openings	$ 690.00	$ 300.00
Contingency	$ 500.00	
	$8,949.50	$6,062.00
	Total Cost	**$15,011.50**

5.4.3 Impact of House Performance

Air-tightness results from Table 2 indicate that the combination of excavationless and overcoat made a significant impact in reducing air leakage—improving it by almost 60%. Infrared thermal imaging echoes the measured air leakage reduction. This will significantly reduce or eliminate ice dams and help to lower energy bills. In Climate Zone 6, in which this house is situated, most attic living spaces are very cold in the winter and hot in the summer. The overcoat eliminates these temperature extremes, improves noise reduction, and controls long-term durability.

5.4.4 Developers' Desire To Use This Measure

Developers will certainly take a look at this but may experience a hurdle in adoption unless a cost/benefits analysis is undertaken along with an assessment of a particular home's specific and variable issues.

5.4.5 Training or Guidance Required

Instruction in every aspect of installing overcoat will be needed. Drawings and videos that were made during this project will go a long way in educating developers with installation questions. Specification of materials and detailed explanation of the process including sequence, edge, and penetration details will need to be provided within a scope of work.

5.5 Demonstration and Education

At the start of the demonstration project a media alert was issued to attract stories in local and national publications. Nonprofit housing developers, builders, architects, and other industry partners were notified and invited to stop by, observe, and ask questions at any time during installation of the high performance measures. Each week an updated time table was published indicating work for the week. While there had been intent to provide formal training as well as the casual drop-in learning opportunities, the unpredictable nature of working with volunteer crews, student crews, and the weather hampered efforts to do so.

Approximately 30 individuals did visit the house including contractors, architects, building performance professionals, and building inspectors. A videographer was hired to develop three informational videos that could be searched on Youtube.com. Presentations will display the photos, videos, data, and lessons learned at upcoming conferences, contractor trainings, and other meetings.

6 Conclusion

The mission of many affordable housing programs is to enhance the socio-economic wellbeing of people who live in low-income neighborhoods. Reducing monthly bills through improved energy efficiency and building durability while reducing medical bills via healthier homes provides opportunities to achieve the mission. Understanding how to effectively achieve these desired outcomes through design, construction, budget, and with volunteer help has been a hurdle in the affordable housing industry.

This demonstration project showcased three high performance measures not typically used in affordable housing. While most homes will not need all three measures, the demonstration home provided opportunity for UHW and other nonprofit developers to see live installation and engage in conversation on technique, budget, benefits, and concerns. Oversight by the Northern*STAR* team and its experienced research and industry partners provided the necessary technical knowledge to implement more advanced measures. Collaboration with UHW from the beginning stages, including selection of a house appropriate for the measures, gave Northern*STAR* the opportunity to identify ways to reduce costs through volunteer and student labor.

The costs for the measures are typically higher than alternative measures, but the benefits gained may outweigh the price—especially if additional money can be found to justify the performance additions. The air-tightness measurements and thermal imaging indicate the effectiveness of the excavationless and overcoat systems to reduce air leakage. Subsequent installations are expected to be lower in cost compared to the first project as the learning curve goes down as skill and confidence increases.

Several informational videos were created during the installation of the measures to help other professionals as they seek to understand the benefits, techniques, and costs of these high performance measures applied to an affordable demonstration house. They can be viewed at the following links:

- Overview: https://www.youtube.com/watch?v=ooJBuo1XAu8
- Excavationless: https://www.youtube.com/watch?v=rNJ6HcANWxw
- Combi: https://www.youtube.com/watch?v=M6Ud1-SHHK0.

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Appendix A

Double-click the icon below to see a full copy of the final Home Performance Assessment – Post Evaluation II.

1401 16th Ave Post Evaluation II-1.pdf

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