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Airtightness Results of Roof-Only Air Sealing Strategies on 1 ½-Story Homes in Cold Climates

C. Ojczyk, T. Murry, and G. Mosiman
Northern*STAR*

July 2014

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Golden, CO 80401

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Prepared by:

C. Ojczyk, T. Murry, and G. Mosiman

Northern*STAR* Building America Partnership

University of Minnesota

2004 Folwell Avenue

St. Paul, Minnesota 55108

NREL Technical Monitor:

Stacey Rothgeb

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

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Definitions

ACH50	Air changes per hour at 50 Pascal
BA	Building America
CEE	Center for Energy and Environment
CFM	Cubic feet per minute
CFM50	Cubic feet per minute at 50 Pascal
DER	Deep Energy Retrofit
ETMMS	Exterior Thermal Moisture Management System
NEC	Neighborhood Energy Connection
SRC	Sustainable Resources Center

Executive Summary

Many approaches to ice dam mitigation in 1 ½-story homes in cold climates have been tried with varying degrees of success and failure, including interior-applied improvements to insulation and air sealing, roof raking, and exterior-applied heat tapes. In 2012, the Northern*STAR* Building America Partnership began exploring alternative methods to find long-term solutions to energy loss in 1 ½- story homes to save energy, improve comfort, and reduce the risk of ice dam formation/reformation. *Project Overcoat: An Exploration of Exterior Insulation Strategies for 1 ½-Story Roof Applications in Cold Climates* (Ojczyk et al. 2013) determined that the External Thermal Moisture Management System (ETMMS) approach warranted further evaluation as a roof-only approach for maximizing opportunities for insulation, air sealing, and roof deck ventilation.

In this second study, the team wished to analyze the before and after airtightness data from roof-only ETMMS retrofits on 1 ½-story homes in cold and very cold climates. To identify homes to analyze, we reached out to our national network of energy professionals, home performance contractors, and general contractors who had expressed interest in promoting roof-only ETMMS to clients. Five projects by three contractors were submitted for consideration as they were being done to mitigate severe ice dams for homeowners. Only two of the five projects followed a roof-only ETMMS protocol. Data from the other three projects, however, were reviewed with the airtightness data of 250 roof-only, interior-applied energy retrofits on 1 ½-story homes provided by three Northern*STAR* industry partners. These data represent homes in the general market as well as homes that were part of the state of Minnesota weatherization program.

A 44% air leakage reduction (ACH50) was achieved in the ETMMS retrofit project where the roof planes and gable ends were fully accessible for air sealing. This result was more than twice the 20% reduction seen in the ETMMS retrofit that had limited access to the gable ends. Despite the difference in the airtightness, each home reported no ice dams for the past two winters. When the data for the ETMMS houses were reviewed with data from the ancillary projects, it was noticed that there is a large variation in airtightness improvements (CFM50) being achieved in the field. Within the ancillary data, retrofits following a weatherization protocol achieved almost twice as much air leakage reduction as the market-rate retrofits.

The wide variation in air leakage reduction across the combined data indicates that there is a continued need to help contractors understand best practices for air sealing existing 1 ½-story homes, especially under the variety of conditions that might be encountered. Since a roof-only ETMMS process can be helpful and is often sought by contractors looking to mitigate ice dams for clients, further study on effectiveness and design protocol would be helpful in creating a comprehensive set of roof-only air sealing tools for contractors.

1 Introduction

One of the obstacles many older homes in cold and very cold climates face during winter months is the development of ice dams caused by energy loss from the building envelope. As shown in Figure 1 (UM 2010), ice dams are particularly a problem in 1 ½-story homes due to heat loss through the building envelope. This is important since many older homes, especially those with 1 ½-story construction, experience ice dams and resulting structural and/or interior damage and increased heating energy use. Many approaches to ice dam mitigation have been in tried in the past including: (1) interior-applied improvements to insulation and air sealing, (2) roof raking, and (3) heat tapes.

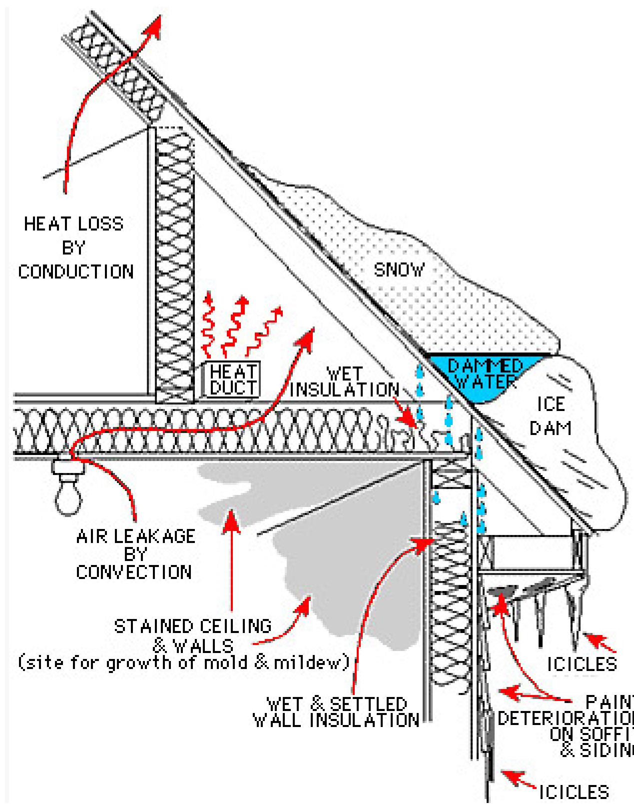


Figure 1. Ice dam formation

(Courtesy of University of Minnesota Extension)

In the Building America (BA) report *Project Overcoat: An Exploration of Exterior Insulation Strategies for 1 ½-story Roof Applications in Cold Climates* (Ojczyk et al. 2013), it was estimated that there are several million 1 ½-story homes in cold climate states nationwide. Homeowner desire to expand living area into unused attic space, however, has resulted in less than optimal conditions for providing energy efficiency, comfort, and long-term durability. This house type suffers from frequent ice dams due to one or more shortcomings that are inherent in the home design or result from attempted improvements, including:

- Difficulty upgrading insulation, air sealing, and ventilation in a half-story with finished walls and floors

- Difficulty providing adequate insulation in vaulted ceilings with shallow rafter depths
- Lack of raised heel energy truss and difficulty in preventing thermal bridging of interior heat to the roof deck, even with high R-value foam insulation in a vaulted ceiling
- Difficulty in venting the roof deck of vaulted ceilings in high snow load regions
- Challenges to properly vent the roof deck with multiple valleys created by dormers and architectural details
- Roof obstructions and penetrations such as chimneys, vent and soil stacks, skylights
- Failure to maintain air barrier continuity at wall to roof transition at soffit
- Failure to maintain air barrier continuity at roof to wall transition at dormers

The difficulty in air sealing leaves this house type vulnerable to the possibility that one-half or more of the total air leakage is at or above the first floor top plate. Even the top attic space has limited clearances for very high levels of insulation. While the lower portion (knee walls with crawlspace) may have better insulation values, it is usually compromised by air movement.

As a result of these multiple issues, these houses frequently have excess heat loss reaching the roof, which contributes to ice dam formation and compromises structural durability and integrity. Ice dams and melted snow can cause significant premature roofing failure, wet insulation, soffit/fascia deterioration, paint failure on claddings or interior surfaces, interstitial and interior mold growth, structural decay, further exacerbation of rot and water damage, and safety risks from falling ice, structural collapse of roof overhangs, and shearing of deck assemblies from ice and snow fall.

According to the Insurance Information Institute (III 2012), losses due to water damage and freezing have increased significantly across the country from 14.60% of all claims in 2005 to 23.7% in 2009 and were the second most claimed loss behind wind and hail. The Iowa Insurance Institute Communications (IIIC 2011) reported that winter storms accounted for 7.4% of catastrophe losses nationwide from 1991 to 2010, or an average of $1.3 billion per year. In 2010, more than $1 billion in claims due to winter storms were experienced on the East Coast alone (Air Worldwide 2011).

Further evaluation of a roof-only exterior overcoat process would enhance the body of solutions BA offers to builders, contractors, and other industry members such as product manufacturers and home insurance providers for creating high performance homes. For older homes the External and Thermal Moisture Managements ETMMS approach can provide unequaled opportunities for thermal and air barrier alignment and continuity. This strategy may also demonstrate significant construction delivery advantages. The work can be performed with little disruption to the interior and the occupants. Since ice dams are classic failures of the thermal and air control layers and inadequate roof deck ventilation, this could be a very attractive solution to an expensive problem. And, it could provide a substantial energy benefit.

2 Background

In a previous BA report (Ojczyk et al. 2013), the Northern*STAR* BA partnership team explored different exterior roofing strategies for existing 1 ½-story homes. The overall intent of this study was to determine which exterior overcoat approach warranted further evaluation as a roof-only approach for maximizing opportunities for insulation, air sealing, and roof deck ventilation to yield reduced air exfiltration and heat loss as well as the mitigation of ice dams. Thus, the study performed an extensive literature review to examine four exterior insulation and air sealing techniques used in new construction, whole-house deep energy retrofits (DERs), and roof-only applications. The four techniques reviewed included: (1) ETMMS, (2) structural insulated panels, (3) over-roofing, and (4) spray foam.

ETMMS was conceived for new construction as a whole-house overcoat providing continuous environmental control layers on the exterior of the house from footing to roof peak. It assumes that appropriate capillary breaks are included at the interface of the footing and slab, footing and foundation wall, and foundation wall and sill. Basement slab insulation would be included as well. With existing houses, however, addressing all these parameters is nearly impossible. A DER can come close if the soils are excavated from around the foundation and waterproof membrane and insulation are applied to all surfaces. Still not addressed would be capillary breaks unless the house were lifted to insert a membrane at the sill, and the slab were removed and newly installed with appropriate capillary breaks.

A recent report by Neuhauser and Gates (2013) provides supportive data on the energy savings potential and effectiveness of a whole-house ETMMS-like DER. In the study, 13 houses located in the northeastern area of the United States implemented overcoat DER measures. An air/water membrane was adhered to the roof decking and wall sheathing then layered with rigid insulation. Pre- and post-retrofit performance data were collected for each home over the same 12-month time period. The pre-retrofit to post-retrofit reduction of source energy ranged from 27% to 75% and nearly all homes were able to reach a post-retrofit airtightness of 1.5 ACH50.

Further literature review found a large body of design/installation details to this external air sealing and insulation approach. The design/installation details and energy studies, however, refer to whole-house (foundation wall plus above-grade wall plus roof) applications. No data specific to a roof-only overcoat process could be found. The literature review also revealed few data for roof-only structural insulated panels, over-roofing, and spray foam. Thus it seemed prudent to study a roof-only, ETMMS process due to proven effectiveness of whole-house overcoat. Applying ETMMS, with its continuous air/water membrane, to the roof-only of a 1 ½-story home could possibly correct air leaks more effectively than an interior approach that would need to address the knee wall, flat plane of the floor, and the slope planes and flat planes of the ceiling.

Figure 2 represents the basic details for the roof-only ETMMS approach:

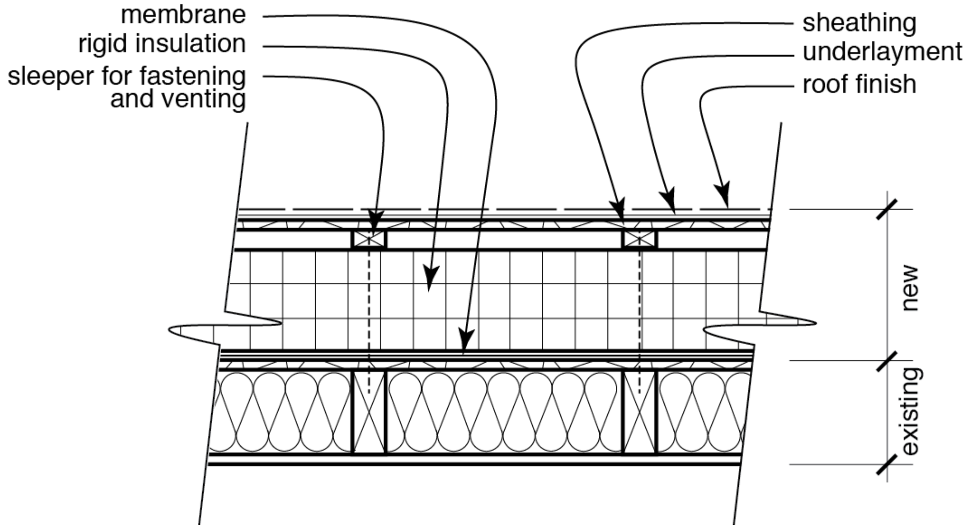


Figure 2. Details for ETMMS roof overcoat approach

The figure demonstrates the air/vapor membrane layer between the existing roof decking and the rigid insulation. Ventilation is designed into the system using sleepers attached through the insulation. Roof sheathing and underlayment are similar to standard roofing practices.

Figure 3 demonstrates the layering of the materials in the ETMMS approach:

Figure 3. Details for ETMMS exterior overcoat retrofit on 1 ½-story home

In the ETMMS process for the upper level of a 1 ½-story house, proper insulation and air sealing would be applied to everything from the upper (attic) floor and higher. That includes roof planes, gable end walls, dormer faces, and side walls. Applying ETMMS to the roof-only of existing homes may require deviation from the optimal process due to existing features that cannot be altered such as brick cladding on gable ends. Air sealing and insulation for these areas would need to be done from the inside when accessible.

Since the ETMMS approach covers the entire roof with a continuous air barrier, it is estimated that higher reductions in air exchange heat losses can be achieved beyond that which can be accomplished through interior applied air sealing. A positive pressure at the top of the home is caused by outside/inside air temperature difference. Falling cooler air and rising warm air will help create leakage infiltration paths from basement or first floor that exit out the roof. There is often the greatest potential for reducing heat loss through air leakage by sealing leaks at the attic plane using an ETMMS approach.

The previous BA report (Ojczyk et al. 2013) included interviews with six contractors in cold climate states that had experience using exterior overcoat solutions as part of whole house or roof-only energy improvements and/or ice dam mitigations. The builders commented that their preferred method to mitigate ice dams and improve energy performance was the exterior overcoat method. They were, however, not always successful at selling this method due to perceived cost increases, competition from lower priced interior solutions, and lack of supportive data showing the air sealing and heat loss prevention opportunities.

3 Air Leakage Reduction Survey

The purpose of air sealing is to prevent energy loss through direct air exchange between the interior of the home and the exterior. Ice dams are created in part when heat is lost to unconditioned space such as an attic. Creating a consistent and adequate pressure and thermal boundary is necessary for preventing ice dam formation. The Northern*STAR* BA partnership sought a greater understanding of the role of the exterior applied air sealing membrane. This membrane, which combines all three control layers (air, vapor, and water), is key to ETMMS' effectiveness. The team also wanted to learn the membrane's effect on the pressure and thermal boundaries in roof only applications on 1 ½-story homes in cold and very cold climates.

3.1 Research Questions

The following research questions served as a guide for analyzing the data provided by the participating contractors:

- Best method to connect the roof air barrier to the walls at the top plates when using ETMMS
- Best treatment to maintain air barrier continuity at a gable end wall when using ETMMS
- Potential air leakage reduction with an exterior air barrier over the existing roof deck
- Problematic areas for air sealing.

3.2 Participating Contractors

The team wished to analyze the before and after airtightness data from roof-only, ETMMS retrofits on 1 ½-story homes in cold and very cold climates to determine the impact on pressure and thermal boundaries. To identify homes to study, we reached out to our national network of energy professionals, home performance contractors, and general contractors who had expressed an interest in promoting roof-only ETMMS to clients. We presented a one-page brief on the goals of the project to the Minnesota Building Performance Association and the St. Anthony Neighborhood Association. We contacted the Twin Cities Bungalow Club. We also asked our BA industry partners—Center for Energy and Environment (CEE), Neighborhood Energy Connection (NEC), and Sustainable Resource Center (SRC)—if they had any 1 ½-story roof-only retrofits in their databases from energy upgrade and weatherization projects.

In the end, five projects by three contractors were submitted for consideration. All projects were being done to mitigate severe ice dams for homeowners. Only two projects were roof-only, ETMMS on 1 ½-story homes. Two other projects used an ETMMS-like process; however, both homes underwent whole-home retrofit rather than roof-only. A fifth project was neither ETMMS nor a 1 ½-story home. While only two of the five projects fit our parameters, the other three provided ancillary information that represents general work being done to mitigate energy loss and ice dams.

The three participating contractors that supplied project information were:

- Cocoon of Eden Prairie, Minnesota
    - Roof-only, ETMMS retrofit on 1 ½-story home in Edina, Minnesota

- Roof-only, ETMMS retrofit on 1 ½-story home in St. Louis Park, Minnesota

- Nor-Son, Inc. of Baxter, Minnesota
  - Attic floor retrofit on 2-story home in north-central Minnesota
- Byggmeister, Inc. of Newton, Massachusetts
  - Whole-house, deep energy retrofit (DER) on 2 ½-story home in Jamaica Plain, Massachusetts
  - Whole-house, DER on 2 ½-story home in Belmont, Massachusetts

3.3 Ancillary Airtightness Data From Industry Partners

The team was provided information from CEE, NEC, and SRC that included airtightness data from interior-applied, roof-only energy retrofits on 1 ½-story homes. The data represent airtightness of 250 homes participating in market-rate and weatherization programs. When initially analyzed, it was determined these data would help inform our comparison of ETMMS air sealing approach with results generally occurring in the field by showing airtightness results that a larger sample of homes were receiving.

The three BA industry partners that provided ancillary data relative to 1 ½-story homes were:

3.3.1 Center for Energy and Environment

CEE is a Minneapolis-based nonprofit that provides energy solutions to homeowners, businesses, nonprofits, and governments. CEE provided this study with data from more than 225 homes participating in their neighborhood energy efficiency program where homeowners signed up for energy audits at neighborhood meetings.

3.3.2 Sustainable Resources Center and Neighborhood Energy Connection

Both SRC—located in Minneapolis—and NEC—located in St. Paul—are nonprofits that provide weatherization assistance to income-qualified individuals. The data from the 26 projects they provided were from the state weatherization program, which requires contractors to follow a specific protocol and test in/test out process for energy assessments.

3.4 Airtightness Impact Review Process

The impact of air sealing using the ETMMS approach was to be analyzed with pre- and post-test measurements provided by participating contractors. Each participating contractor was provided a data collection template (see the Appendix for data collection template) and required to gather air leakage information through the use of a blower door test and infrared thermal imaging. Information sought for the template included:

- General company information
- Project information such as house description and roof overlay description
- Air leakage (CFM50) and air changes (ACH50) pre-test and post-test
- Pre- and post-infrared images
- Critical design details
- Answers to a list of contractor questions.

Both air leakage CFM50 and air changes per hour ACH50 were requested since they are both common indicators of building airtightness. The CFM50 would provide a general understanding of overall improvement while ACH50 would provide a greater understanding of impact on a particular house since it considers the volume of the building.

Additionally, each participating contractor was asked to provide infrared thermal images pre- and post-retrofit to study the visual impact of airtightness improvements and to ascertain problematic areas.

4 Results

4.1 Overview of Homes Submitted by Participating Contractors

Tables 1 through 3 provide an overview of the five projects contributed by contractors in response to our request for data for roof-only, ETMMS ice dam mitigation projects on 1 ½-story homes. Only two of the five projects submitted were roof-only, ETMMS projects and are noted below. Data from the remaining three projects were included for comparison as they were ice dam mitigation projects and their data provide insight into energy strategies used in the field. Table 1 provides a general overview of each home, size, location, and architectural features of the roofs.

Table 1. House Description From Data Collection Template

House Location	Edina	St. Louis Park	Northern Minnesota	Belmont	Jamaica Plain
Contractor	Cocoon	Cocoon	Nor-Son	Byggmeister	Byggmeister
Year Built	1936	1946	n/a	1920	1907
Total Square Footage	3,566	3,125	5,065	5,478	3,885
Total Volume Conditioned Space	28,863	25,000	44732	31,860	29,138
House Type	1 ½-story	1 ½-story	2-story	2 ½-story	2 ½-story
# Dormers	0	1	0	0	2, one on each side
# Gables	5	3	6	1 gable ell, 2 main gable ends	2
# Hips	0	0	0	0	0

Table 2 provides a summary of the roof overlay questions gathered from the data collection template provided to each contractor when they agreed to provide information on their projects. These questions provide details of the energy strategies used to mitigate ice dams.

Table 2. Roof Overlay Questions From Data Collection Template

House Location	Edina	St. Louis Park	Northern Minnesota	Belmont	Jamaica Plain
Contractor	Cocoon	Cocoon	Nor-Son	Byggmeister	Byggmeiste r
Was this an ETMMS, roof-only process?	Yes	Yes	No	No	no
Were eaves removed?	Yes	Yes	No	Yes	No
Type of membrane/barrier?	Grace Perm-A-Barrier	Grace Perm-A-Barrier	n/a	Fully taped foil-faced polyisocyanurate insulation	n/a
Insulation type and thickness?	6-in. fiberglass faced isocyanurate over roof decking	2-in. closed cell spray foam at base of rafter cavities/ exposed heel, 6-in. ISO rigid insulation over roof decking	Closed cell spray foam and blown cellulose	3 layers of 2-in. polyiso on top of roof sheathing with 5-in. dense-packed cellulose in rafters	1.5 in. polyisocyanurate between rafters and spray foam in rafter bays
Furring strips used on top of insulation?	Yes	Yes	N/A	NO	N/A
Sheathing on top of furring strips?	Yes	Yes	N/A	Sheathing on top of polyiso	N/A
Type of roof cladding?	Asphalt shingle	Asphalt shingle	Asphalt shingles	Asphalt shingles	slate
Was new roof system vented?	Yes	Yes	Yes	No	Yes

Table 3 summarizes the impact of the retrofit solutions on air leakage in each participating home.

Table 3. Airtightness Data From Blower Door Testing

House Location	Edina	St. Louis Park	Northern Minnesota	Belmont	Jamaica Plain
Contractor	Cocoon	Cocoon	Nor-Son	Byggmeister	Byggmeister
Was this a roof-only, ETMMS process?	Yes	Yes	No	No	No
Pre-Test Air Leakage (CFM50)	2371	2925	3249	5700	7729
Post-Test Air Leakage (CFM50)	1880	1607	2112	590	1802
Reduction (CFM50)	491	1318	1137	5110	5927
% Reduction	21%	45%	35%	90%	77%
Pre-Test Air Changes (ACH50)	4.9	7.0	4.36	8.7	11.0
Post-Test Air Changes (ACH50)	3.9	3.9	2.83	0.9	2.4
Reduction (ACH50)	1.0	3.1	1.53	7.8	8.6
% Reduction	20%	44%	36%	90%	78%

The participating contractors were asked a series of questions on the data collection template. One question sought to learn the common areas of air leakage prior to retrofit. The responders noted that air leakage was common at the roof/wall connections, interior and exterior wall tops, plumbing chase ways, recessed lights, rim leakage, and windows.

Another question sought to learn the architectural/construction details in the existing homes that created challenges when installing the new roof overcoat system. Because the overcoat process adds height to the roof due to the additional sheathing and rigid insulation, issues had to be addressed regarding window details, dormer walls, and eave areas. There were also complications from the roof/gable end wall connection and truss heel/wall connections. Responses from Cocoon and Byggmeister indicate that the projects were undertaken to alleviate ice dams as well as to help the homeowners improve energy efficiency.

4.2 Homes Submitted by Cocoon

Cocoon LLC provided two roof-only ETMMS retrofit projects with ice dam problems that were located in Minnesota. Both houses underwent complete roof overcoats that were achieved through the same basic process with slight variances in the products used and design details due to different roof typologies and obstacles. Cocoon's process for achieving the ETMMS roof-only retrofits is listed chronologically here:

1. Removed all the roofing materials down to the existing roof deck. Gutters, fascia, and soffits were also removed and rafter tails were cut back to the existing top plates using a chainsaw approach (Figure 15). Roof deck was removed at roof/gable wall connection.

2. Revented existing bath fans out gable walls to reduce the number of roof penetrations.
3. Air sealed roof/wall connection at top plates using closed cell spray polyurethane foam.
4. Air sealed roof/gable wall connections from the exterior using closed cell spray polyurethane foam (Figure 17).
5. Air sealed roof/gable wall connections from interior. (Optimal air sealing in the ETMMS process would occur from the exterior by wrapping the roof plane membrane over a membrane applied to the wall sheathing on the gable ends. Since these two homes were clad in brick, the air sealing had to occur from inside the attics. The attic in the St. Louis Park house was fully accessible allowing for greater air sealing continuity (Figure 10).
6. The ½-story in the Edina house was recently finished, and the only accessible gable ends were above the ceiling (Figure 24).
7. Applied membrane primer to roof deck (Figure 18).
8. Applied air/water/vapor membrane over the exposed roof deck and lapped over the exterior walls (Figures 8 and 19).
9. Installed new soffit framing and subfascia to accommodate the additional thickness of the roof and to match the existing architectural style of the house (Figures 8, 9, and 16).
10. Installed two layers of rigid insulation board, seams staggered, over the rubber membrane (Figure 20).
11. Installed furring strips over the rigid insulation board to allow for continuous ventilation (Figure 21).
12. Attached new roof decking through the furring strips with a special type of long screw (Figure 22).
13. Extended roof waterproofing and finish materials over the decking: extended plumbing stacks and followed proper flashing protocol.
14. Installed new continuous soffit and fascia venting and insect barrier before gutters were installed (Figure 24).
15. Installed roofing materials along with a continuous ridge.

Details specific to each project are below.

4.2.1 St. Louis Park House

The following project details were provided by Cocoon for a full brick 1 ½-story house located in St. Louis Park, Minnesota. The home underwent a complete ETMMS roof-only overcoat. Details are provided in the Figures 4 through 12 below.

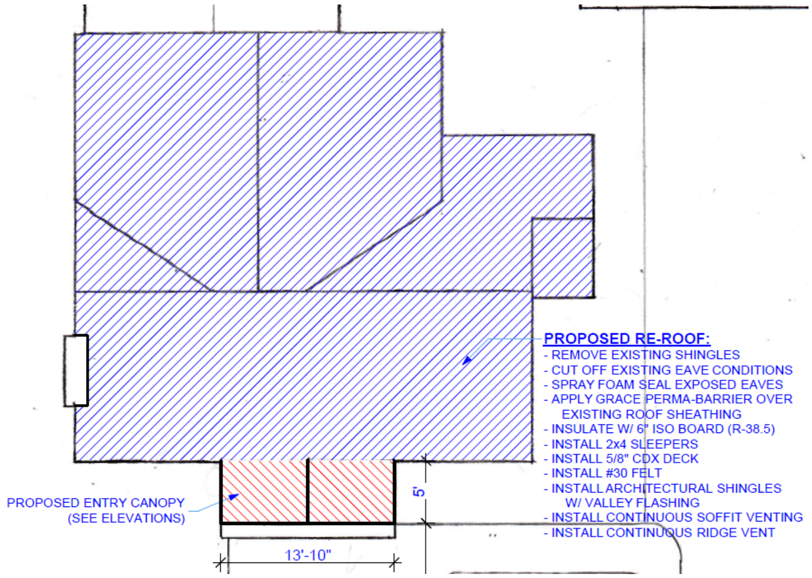


Figure 4. Roof overview of Cocoon St. Louis Park House pre-retrofit with proposed details of portico in red

(Courtesy of Cocoon)

Figure 5. Front view of Cocoon St. Louis Park house pre-retrofit

(Courtesy of Cocoon)

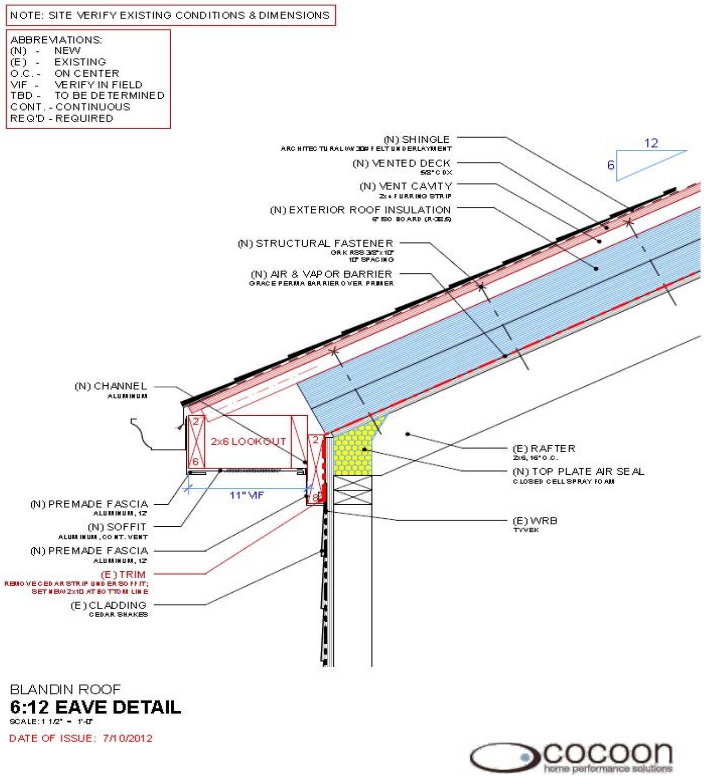


Figure 6. Proposed eave details for Cocoon St. Louis Park house

(Courtesy of Cocoon)

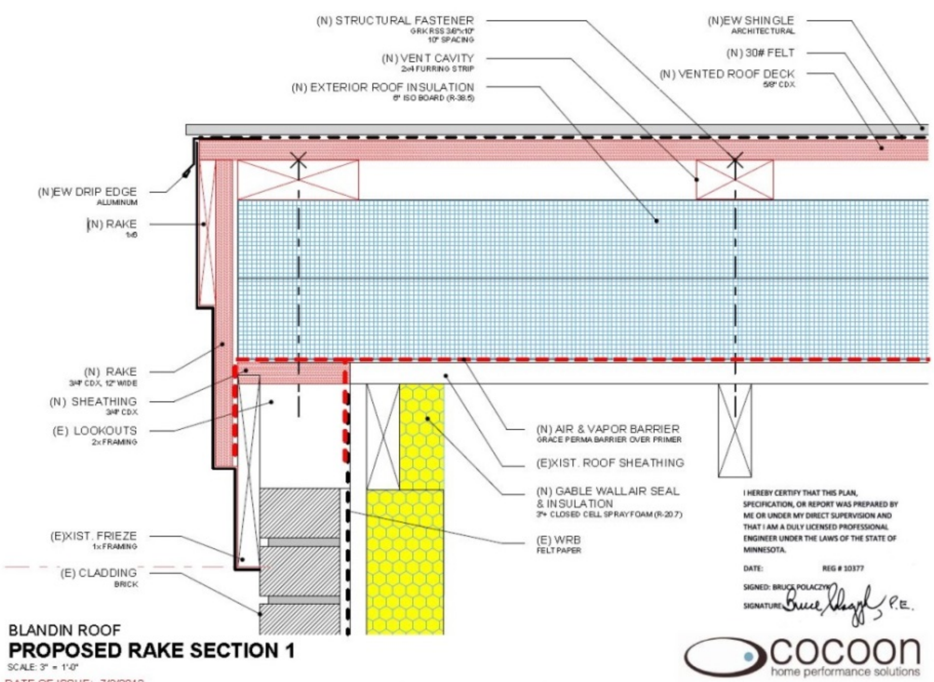


Figure 7. Proposed rake details for Cocoon St. Louis Park house

(Courtesy of Cocoon)

Figure 8. Details of bump-out after the application of rubber membrane, rigid insulation, furring strips for ventilation, and rebuild of soffit assembly for Cocoon St. Louis Park house

(Courtesy of Cocoon)

Figure 9. Details of soffit assembly rebuild after the application of rubber membrane, rigid insulation, furring strips for ventilation, rake board, and new roof deck

(Courtesy of Cocoon)

Figure 10. Details of air sealing brick-clad gable wall from the interior using closed cell spray polyurethane foam in Cocoon St. Louis Park house

(Courtesy of Cocoon)

Figure 11. Front view of Cocoon St. Louis Park house post-retrofit

(Courtesy of Cocoon)

Figure 12 below represents the infrared thermal images taken by Cocoon before and after the roof overcoat. Cocoon uses thermal imaging to verify their work for customers and to support their warranty. The crosshairs in the images are part of the camera function that pinpoints the location of the first image when taking a follow-up image. The reduction in air leakage and thermal bridging is seen by the lack of bright and dark elements in the after photos.

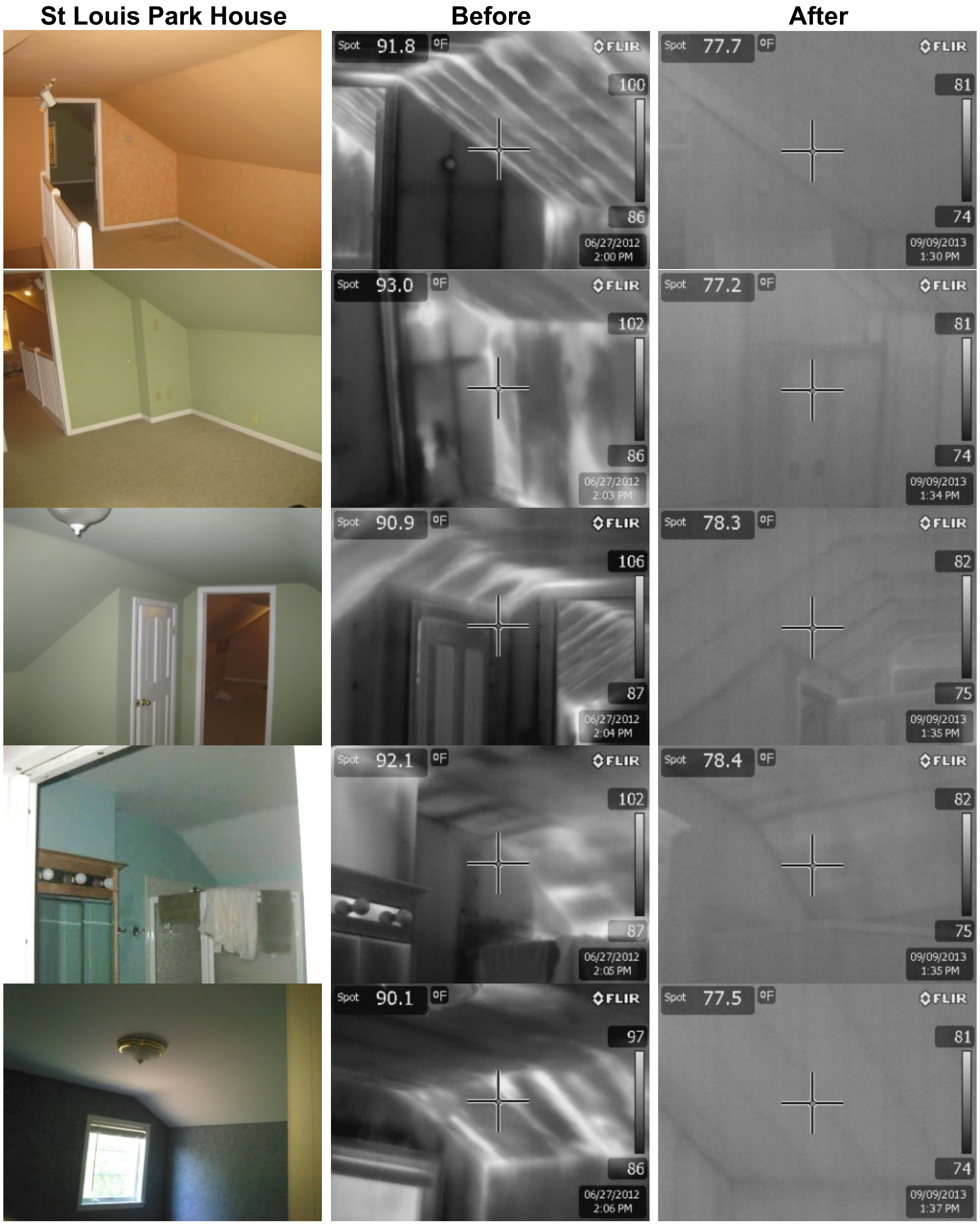


Figure 12. Before and after infrared images for Cocoon St. Louis Park house

(Courtesy of Cocoon)

There were some challenges with the roof overcoat approach surrounding process and and aesthetics. As previously mentioned, the gable ends were clad in brick and could not be altered, yet the recently gutted attic had gable ends that were fully accessible. The gable ends were sprayed with foam from the interior rather than from the exterior as prescribed for an optimal roof-only ETMMS (Figure 10). Redesigning the soffit and fascia details to account for the additional roof height was a challenge. The differences can be seen in the rake and eave details pre-retrofit (Figure 5) and post-retrofit (Figure 11).

4.2.2 Edina House

This brick house located in Edina had been remodeled prior to the roof retrofit. As a result, interior walls could not be disrupted, leaving little access to the gable ends from the interior except for the area above the ceiling in the ½ story. Specific details are illustrated in Figures 13 through 27 below.

Figure 13. Roof overview of Cocoon Edina house

(Courtesy of Cocoon)

Figure 14. Front view of Cocoon Edina house pre-retrofit

(Courtesy of Cocoon)

Figure 15. Creating a connection between the brick wall and roof by removing the original soffit and wrapping the membrane over the top of the wall

(Courtesy of Cocoon)

Figure 16. Building a structure for the new soffit

(Courtesy of Cocoon)

Figure 17. Air sealing the gable wall/roof connection using closed cell spray polyurethane foam

(Courtesy of Cocoon)

Figure 18. Applying primer before installing the membrane

(Courtesy of Cocoon)

Figure 19. Membrane applied over original sheathing

(Courtesy of Cocoon)

Figure 20. 5-in. of rigid insulation sealed at the seams, each layer with seams offset

(Courtesy of Cocoon)

Figure 21. Furring strips configured to allow for side motion ventilation at the valleys

(Courtesy of Cocoon)

Figure 22. Installing outer layer of sheathing to support asphalt shingles

(Courtesy of Cocoon)

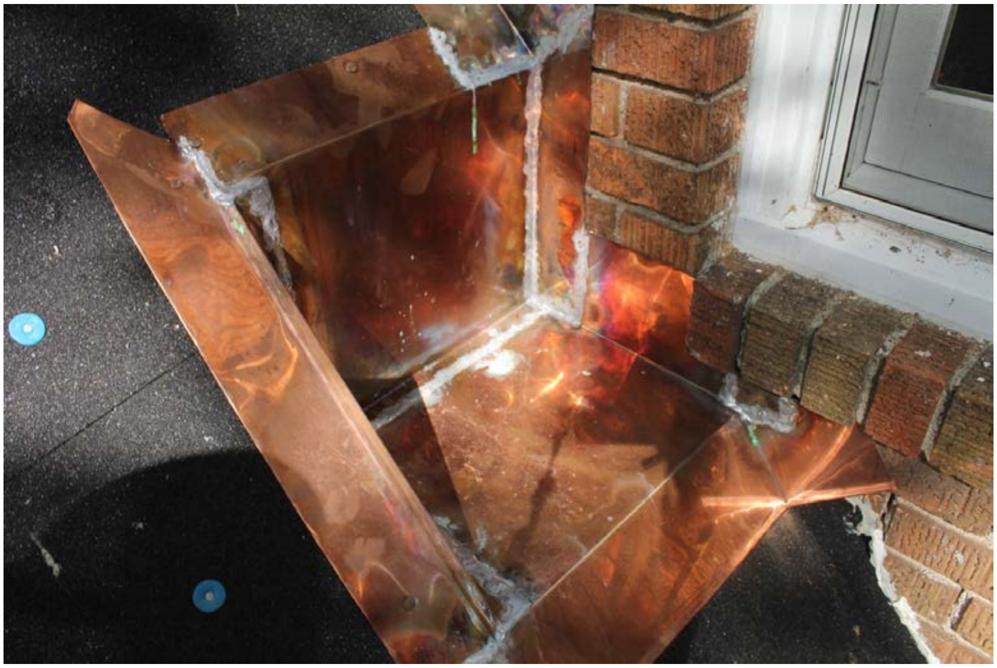


Figure 23. Creating a copper "birds mouth" to accommodate thickness of overcoat layers without impeding window

(Courtesy of Cocoon)

Figure 24. Mesh ventilation with insect barrier

Courtesy of Cocoon)

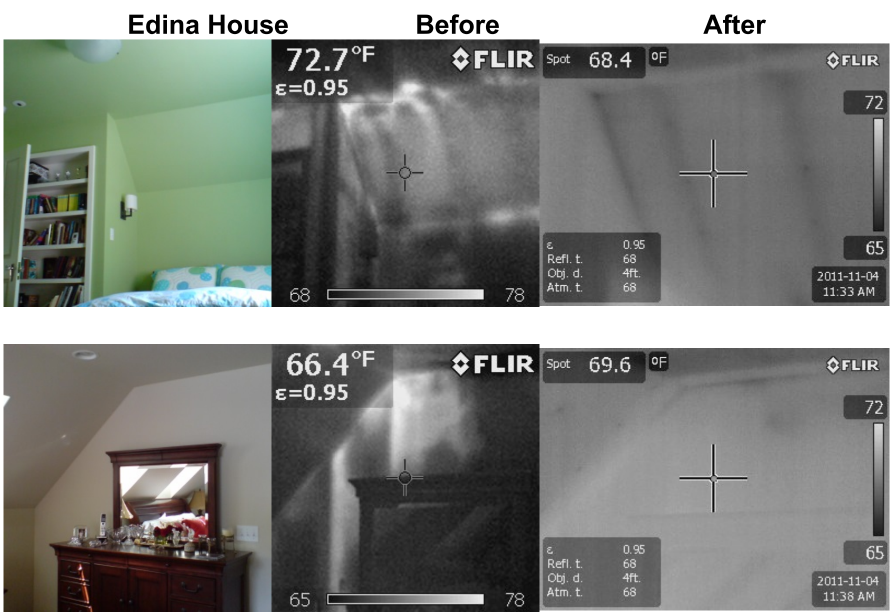
Figure 25. Gable ends above ½ story ceiling sprayed with closed cell spray foam

(Courtesy of Cocoon)

Figure 26. After view of Cocoon Edina House post-retrofit

(Courtesy of Cocoon)

Figure 27 below represents the infrared thermal images taken by Cocoon before and after the roof overcoat. The reduction in air leakage and thermal bridging is seen by the lack of bright and dark elements in the after photos.



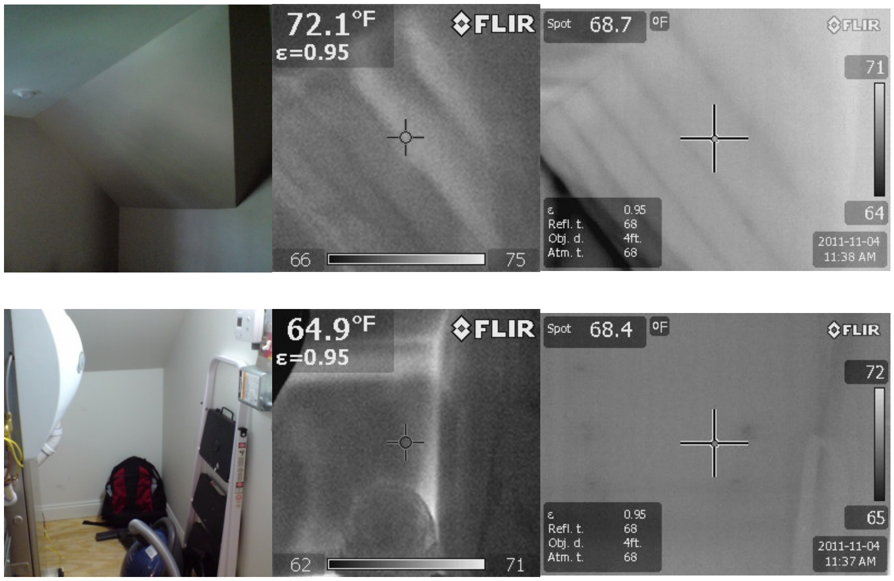


Figure 27. After view of Cocoon Edina house post-retrofit

(Courtesy of Cocoon)

There were some challenges with the roof overcoat approach surrounding functionality and performance as well as aesthetics. Redesigning the soffit and fascia details to account for the additional roof height was a challenge. Because the interior of the ½ story had been finished in a previous retrofit, the gable ends of the brick home could not be fully insulated and air sealed except in the area of the attic above the ceiling.

Special details needed to be created for several windows located close to the roofline to accommodate the extra height of the insulation and sheathing. A "birds mouth" made of copper (see Figure 21) was used to frame the window corner. Careful attention to flashing details was important to prevent water leakage.

4.2.3 Cocoon Interior-Applied Insulation and Air Sealing Project

A Cocoon project completed as we were writing this report is pertinent in light of the discussion regarding conventional, interior-applied air seal results. This Cocoon project was a 1 ½-story house with two gable ends, four dormers, and a shed roof. Instead of using the ETMMS approach as they did in the two houses reported above, they insulated and air sealed from the inside. The old insulation was completely removed and spray foam, batts, and blown cellulose were applied in appropriate areas. In order to access all attic/roof/wall connections and surfaces they strategically removed portions of the roof sheathing to make sure all air sealing was complete. The blower door test yielded the following numbers for whole-house testing:

- Pre-blower door 3361 CFM50
- Post-blower door 1791 CFM50
- 1570 CFM Reduction
- 47% reduction in air leakage.

4.3 Home Submitted by Nor-Son

The Nor-Son house, represented in Figures 28 through 32, was not a roof-only, ETMMS retrofit but was submitted by the contractor for inclusion in the study as it was an ice dam mitigation project and pre- and post-CFM50 and ACH50 were available. The information from the project was included in this report as a comparison study on air leakage improvements for ice dam mitigation. Thermal imaging, however, was not available. All work was done from the interior on the attic floor using a vacuum, spray, blow protocol described below:

- Remove all insulation on the attic floor using specialized vacuum equipment that removes fine pieces and dust (see Figure 28).
- Install closed cell spray polyurethane foam over the clean attic floor to provide an air sealing layer and insulation. The foam also provides a vapor barrier for this home with its tongue and groove ceiling (see Figure 29).
- Place on top of the foam a layer of cellulose insulation to enhance the R-value (see Figure 30).

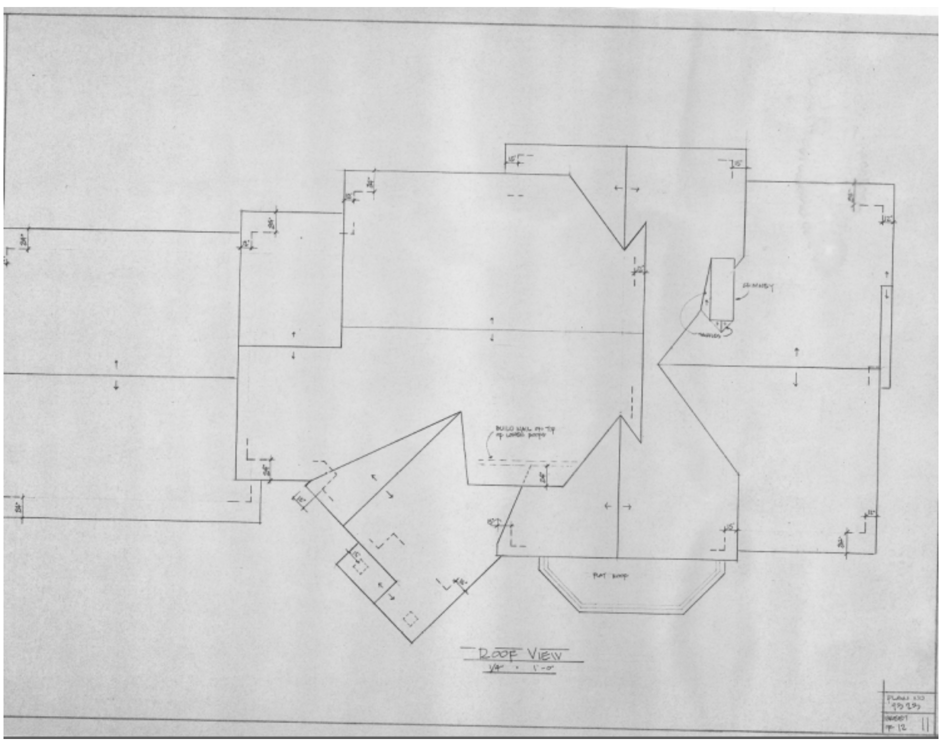


Figure 28. Roof overview of Nor-Son house

(Courtesy of Nor-Son)

Figure 29. Front view of Nor-Son house

(Courtesy of Nor-Son)

Figure 30. Nor-Son house attic floor post-vacuum

(Courtesy of Nor-Son)

Figure 31. Nor-Son house attic floor spray-foam stage

(Courtesy of Nor-Son)

Figure 32. Nor-Son house attic floor post-insulation

(Courtesy of Nor-Son)

4.4 Homes Submitted by Byggmeister, Inc.

Byggmeister provided two exterior overcoat projects undertaken for both severe energy and ice dam problems. The overcoat approach uses the same membrane/insulation protocol as ETMMS. These two projects, however, address whole-house air leakage, not just leakage at the roof: The membrane and external insulation were applied to the roof as well as the walls. While these projects cannot provide a direct comparison to the data for the roof-only ETMMS projects, they are included here for discussion on airtightness and ice dam mitigation solutions. CFM50 and ACH50 data were available. Infrared thermal imaging, however, was not provided.

Some details for each project are provided in Figures 33 through 36 to show the similarities of the membrane and insulation to roof-only ETMMS and some of the details needed to address a whole-house application. Figure 36 demonstrates the impact of unique architectural features that prevent a complete ETMMS process on an existing home. In this retrofit, the homeowners did not want to remove and replace the slate roof. Insulation and air sealing for the roof planes occurred from inside the attic while ETMMS was applied to the walls. This dual approach required extensive details for aligning air and thermal layers, also seen in Figure 36.

4.4.1 Belmont House

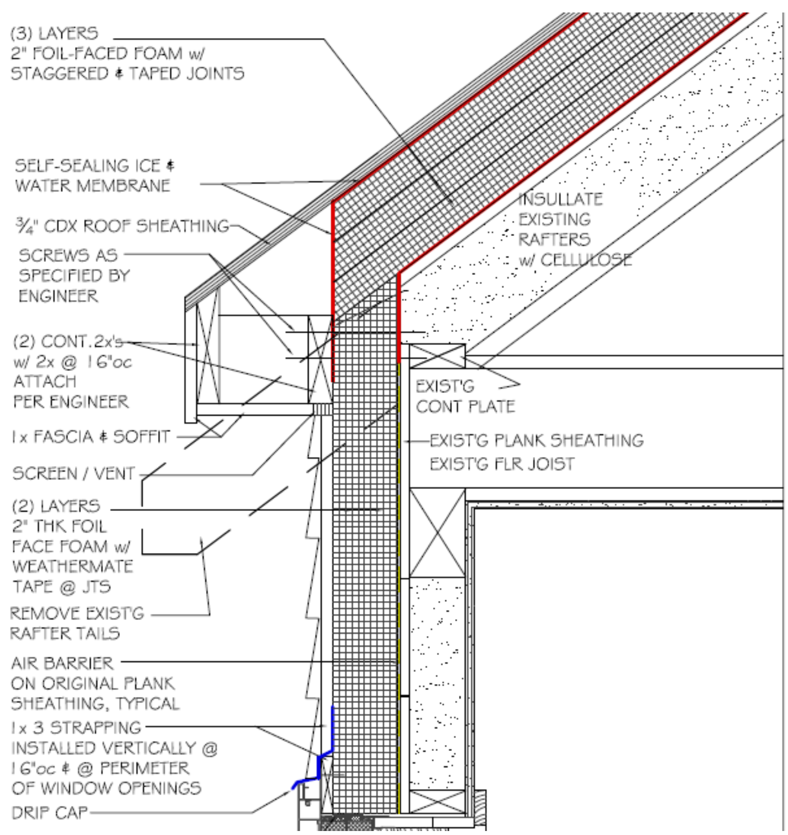


Figure 33. Details of roof/wall intersection for Byggmeister Belmont whole-house DER

(Courtesy of Byggmeister, Inc.)

Figure 34. Details of external insulation and furring strips for ventilation used by Byggmeister for Belmont DER

(Courtesy of Byggmeister, Inc.)

4.4.2 Jamaica Plain House

Figure 35. Line drawings for Byggmeister Jamaica Plain house

(Courtesy of Byggmeister, Inc.)

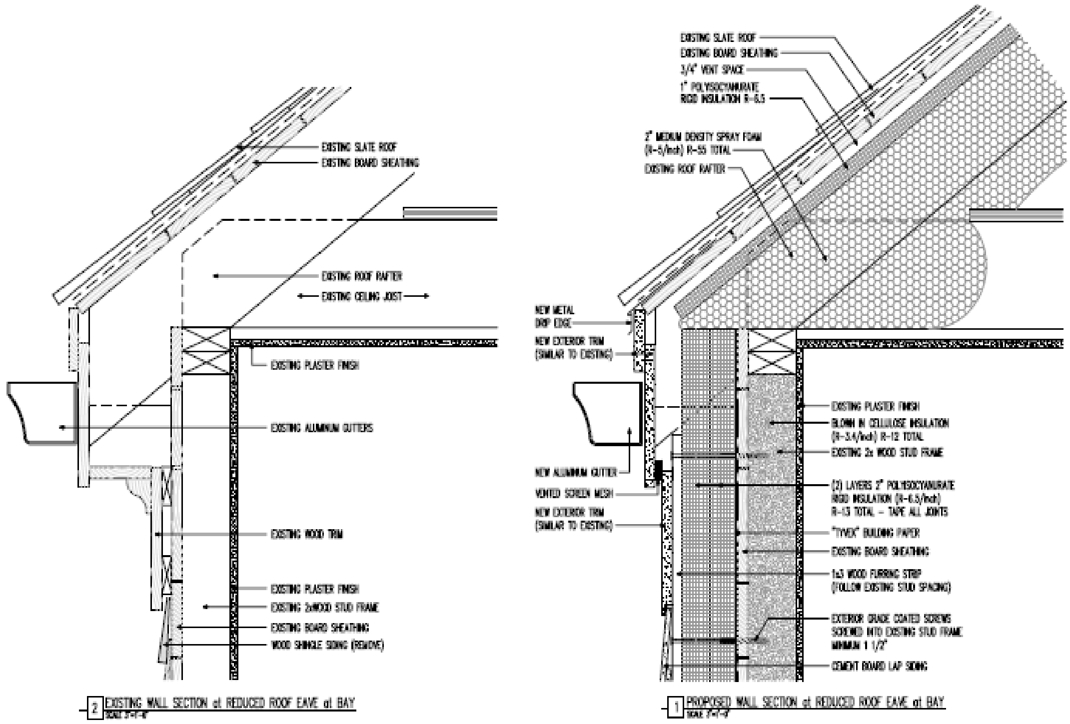


Figure 36. Details for roof/wall connections for Byggmeister Jamaica Plain house

(Courtesy of Byggmeister, Inc.)

The detailed drawings and comprehensive approach to whole house insulation and air sealing enabled the contractor to effectively apply retrofit solutions that led to significant reductions in air leakage.

4.5 Ancillary Airtightness Data Provided by Industry Partners

When the team was searching for roof-only, ETMMS projects to study, industry partners CEE, NEC, and SRC provided ancillary airtightness data from 250 interior-applied, roof-only retrofits on 1 ½-story homes where the attic space was used as living space. Since the data generally represent results being achieved in the market in regards to air sealing from the interior, they were included here for discussion purposes. While the team sought both CFM50 and ACH50 data, only CFM50 results were provided for all homes. Little else was provided about the retrofit projects such as house volume or actual air sealing strategies applied.

Figure 37 is a visual overview of the CFM50 reduction results from all 250 homes combined. While the data are of minimal value because the variables are so great from project to project, the data show the extent of variation in airtightness reduction achieved through an interior approach. Several of the projects also produced highly unusual negative reductions in airtightness. The data do not indicate why or how the homes were leakier after the retrofit than before.

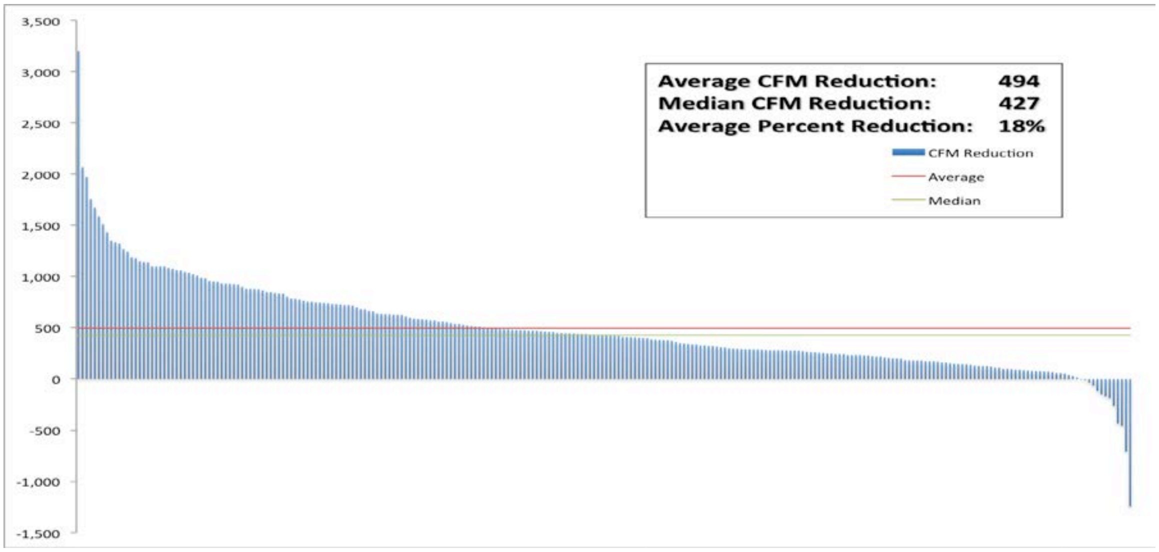


Figure 37. Overview of all program data from three partner groups

Figure 38 represents CFM50 reduction from the 224 data points provided by CEE's home energy program in the Minneapolis, Minnesota region. Several of the projects produced highly unusual negative reductions in airtightness. The data do not indicate why or how the negative numbers were achieved. When the negative numbers were included in computation, the average CFM reduction was 455 CFM, representing an average 16% reduction in air leakage between pre- and post-retrofits.

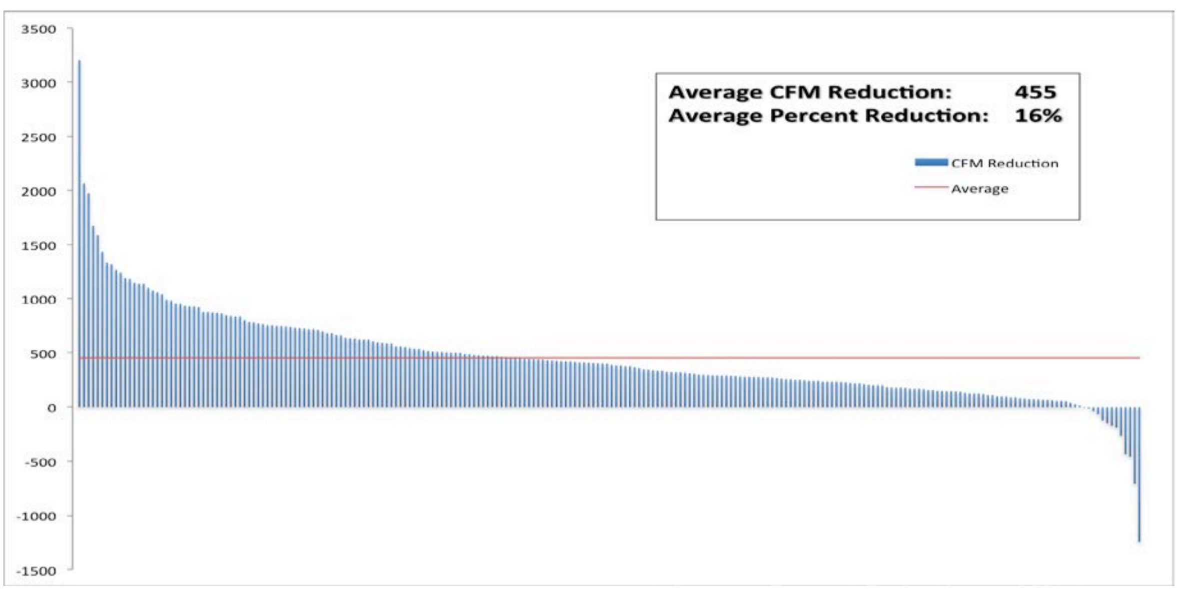


Figure 38. Overview of all CFM reduction data provided by CEE for 1 ½-story roof-only retrofits

The team was not given an explanation as to why there were negative CFM reductions. Since it is generally impossible to achieve negative results after air sealing, Figure 39 represents the results of removing the negative numbers to inform performance without the outliers include. The average CFM reduction and percent reduction improved as expected.

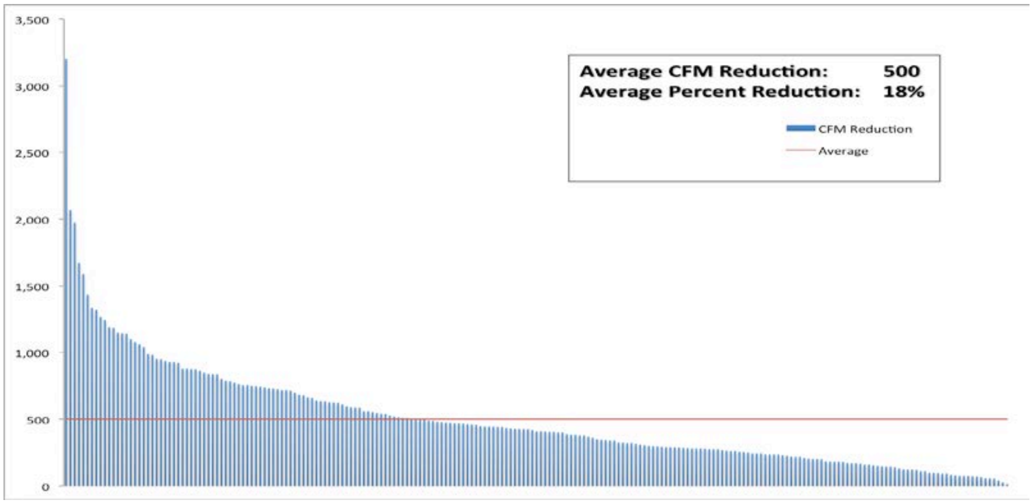


Figure 39. Overview of CFM reduction data provided by CEE for 1 ½-story roof-only retrofits with negative data points removed

Figure 40 below summarizes airtightness data provided by SRC and NEC from a total of 26, 1 ½-story roof-only weatherization projects. After comparing the CEE home energy program results with the weatherization houses it was noticed that weatherization homes had significantly more CFM reduction. This seems to indicate that there are multiple levels of quality control in the general market.

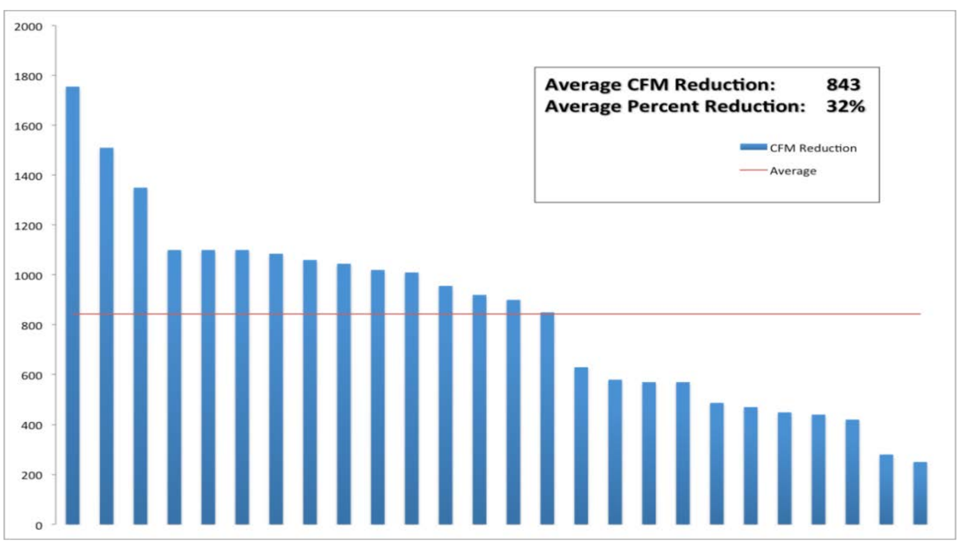


Figure 40. Overview of CFM reduction data provided by SRC and NEC for 1 ½-story roof-only weatherization retrofits

4.6 Comparison of ETMMS Data Versus Ancillary Airtightness Data

One question the team sought to explore was how air leakage improvements in the ETMMS overcoat process compared to interior-applied energy retrofits. While airtightness measured using ACH50 would normalize the data to make more meaningful comparisons, the majority of the ancillary data were presented using CFM50. Table 4 thus compares the air leakage results in CFM50 from the contractor supplied projects as well as the ancillary data supplied by the NorthernSTAR industry partners. It is also noted that the information from CEE, NEC, and SRC is represented as an average of multiple homes versus the single responses provided by the participating contractors. To draw confident conclusions about ETMMS versus interior-applied processes would require a greater data set of ETMMS retrofit projects. A few general comments, however, can be made about the results.

The two Cocoon ETMMS projects experienced a range of airtightness outcomes much the same as the projects representing roof-only, interior air sealing retrofits. The 45% reduction in the Cocoon St. Louis Park home, however, indicates that a very well-applied air membrane combined with thorough foaming and air sealing around the attic floor and exterior gable walls can achieve high levels of air leakage reduction. Similar airtightness results were achieved by Cocoon in their interior-applied approach to air sealing. The graphs in Figure 37 to 40 indicate that some interior-applied retrofits in the market rate and weatherization programs were achieving this level of airtightness and better.

As expected, the Byggmeister whole-house DERs produced airtightness improvement significantly higher than the roof-only projects.

Table 4. Comparison of Percent Reduction in Air Leakage by Project Type

Contractor	Type of Project	CFM50 Reduction	% Reduction
CEE	Roof-only, interior applied	500 (average)	18%
SRC/NEC	Roof-only, interior applied	843 (average)	32%
Cocoon, Edina House	Roof-only, ETMMS	491	21%
Cocoon, St. Louis Park House	Roof-only, ETMMS	1318	45%
Cocoon,	Roof-only, interior applied	1570	47%
Byggmeister, Belmont House	Whole-house, DER	5110	90%
Byggmeister, Jamaica Plain House	Whole-house, DER	5927	77%
Nor-Son	Roof-only, interior applied	1137	35%

5 Conclusions

5.1 Response to Research Questions

The following summarizes the responses to the research questions based on the data from five test homes provided by the participating contractors and the supplemental data provided by the Northern*STAR* BA industry partners.

5.1.1 Best Method To Connect the Roof Air Barrier to the Walls at the Top Plates When Using ETMMS

The ETMMS overcoat approach enables direct access to the top plate area when the existing soffits are cut away. This enables the roof membrane to be easily wrapped over the top of the wall. Prior to wrapping, the top wall plates can be spray foamed for further air sealing.

5.1.2 Best Treatment To Maintain Air Barrier Continuity at a Gable End Wall When Using ETMMS

The peel-and-stick membrane used in the ETMMS overcoat approach provides a continuous membrane that could cover the entire gable end effectively. The cost is higher, but the effectiveness is optimal because of better access to all problem areas and potential barriers.

5.1.3 Potential Air Leakage Reduction With an Exterior Air Barrier Over the Existing Roof Deck

The data from the participating contractors as well as the supplemental data from the BA industry partners show a large variation in airtightness improvement results in both exterior- or interior-applied air sealing processes. Both approaches, however, can produce significant improvements in airtightness. As would be expected, the greatest air leakage reduction was achieved through the two whole-house DERs.

The interior-applied, roof-only data from the market-rate homes show air leakage reductions with an average of 18% reduction. The average air leakage reduction in the weatherization homes was roughly double the average of the market-rate homes. The Cocoon interior-applied project achieved airtightness results that were more than double the market rate average but in line with some of the individual projects that achieved high levels of airtightness.

As for the two projects that did follow the ETMMS protocol, the airtightness results were varied. The Cocoon St. Louis Park project points to the opportunities to achieve high reductions in air leakage from a roof-only approach. Even though the home was clad in brick, the ½-story was unoccupied and the gable ends accessible for air sealing and air barrier continuity via spray foam.

The Cocoon Edina project, on the other hand, highlights the consequences of starting with greater obstacles. In this home, the interior walls of the attic living space were in place and could not be opened from the inside. This left a large percentage of the brick-clad gable end walls without air sealing. Air leakage reduction was less than anticipated. It should be noted, however, each Cocoon project exhibited significant change in the pre- and post-retrofit thermal imaging. It must also be pointed out that the Edina home was renovated in the last 5 years and the envelope had been tightened. The pre-test for the overcoat project started with some air leakage reduction already achieved.

5.1.4 Problematic Areas for Air Sealing

The ETMMS overcoat process adds height to the roof due to the additional sheathing, rigid insulation, and furring strips used for ventilation. Architectural and construction consideration has to be given to maintain a continuous membrane at windows, dormer walls, and eave areas. There may also be complications from the roof/gable end wall connection if the current cladding prohibits access to the area from the exterior. Air sealing from the interior to maintain air barrier continuity can be compromised by the condition of the interior as well. Finished ½-stories make it difficult to address gable ends.

Interior approaches encounter many problems in air sealing based on the condition of the space prior to the retrofit. An unoccupied ½-story enables thorough air sealing. Finished ½-stories complicate access to the rafter connections where spray foam could be used to air seal the top wall plate and outside of the plates. Finished ½-stories also prevent air barrier continuity between the knee walls and ceiling planes and may prevent access to thorough air sealing around dormers and penetrations such as chimneys, vent and soil stacks, and skylights.

The additional market data provided by the BA industry partners allowed us the opportunity to look more closely at roof-only air sealing as a means to significantly improve whole-house airtightness. Average air leakage reductions by contractors participating in weatherization were roughly twice those of non-weatherization data. It would be beneficial to study air seal in the broader market with larger data pools and more data points to determine a relative baseline for the general market methods. Clearly this would help determine best practices and encourage contractors to achieve better results.

5.2 General Conclusions

The previous BA report (Ojczyk et al 2013) indicated that there is contractor interest in using a roof overcoat process to mitigate ice dams. The same study, however, pointed to the lack of design details and supporting data for roof-only ETMMS approach. The design and project details provided by the contractors in this study—especially the roof-only, overcoat details from the Cocoon projects—will be helpful to industry professionals seeking to understand and apply roof-only overcoat principles. The small dataset of two ETMMS homes, however, indicates that more study of the roof-only ETMMS process still needs to be undertaken.

The Northern*STAR* BA partnership sought a greater understanding of the impact on the pressure and thermal boundary when ETMMS was used in roof-only applications on 1 ½-story homes in cold climates. The small amount of data from the two ETMMS projects, however, did not provide enough information to determine if ETMMS impacts the pressure and thermal boundaries.

The goal of the U.S. Department of Energy's BA program is to reduce home energy use for existing homes by at least 30% to 50% compared to pre-retrofit energy use. It was observed in both the ETMMS homes and ancillary data that roof-only air sealing, whether from the exterior or the interior, can achieve significant improvements in airtightness. The data also indicated that the air sealing protocol used by contractors can make a significant impact on the outcome of leakage reduction. The weatherization approach averaged double the leakage reduction compared to the general market contractors. The wide range of outcome also indicates that greater effort to help contractors understand air sealing best practices may help improve whole house energy efficiency outcomes using roof-only improvements.

References

III (2012). Insurance Information Institute, "Homeowners and Renters Insurance: Causes of Homeowners Insurance Losses." Accessed October 20, 2013. www.iii.org/media/facts/statsbyissue/homeowners.

IIIC (2011). Iowa Insurance Institute Communications, "Is Your House Properly Winter-Proofed?" Accessed October 21, 2013. www.iowains.org/homeowners-and-renters-article.aspx?id=12&Is+Your+House+Properly+Winter-Proofed%3f+.

Neuhauser, K.: Gates, C. (2013). "Initial Performance Results for Massachusetts DER Pilot Program." Golden, CO: National Renewable Energy Laboratory.

Ojczyk, C.: Yost, P.: Mosiman, G.: Huelman, P.: Schirber, P.: Murry, T. (2013). *Project Overcoat – An Exploration of Exterior Insulation Strategies for 1 ½-Story Roof Applications in Cold Climates*. Golden, CO: National Renewable Energy Laboratory. Accessed October 31, 2013. www.nrel.gov/docs/fy13osti/56145.pdf.

UM (2010). University of Minnesota Extension, "Ice Dams." accessed October 20, 2013. www.extension.umn.edu/distribution/housingandclothing/DK1068.html#causes.

Appendix: Data Collection Template

NorthernSTAR

Project Overcoat for 1 ½ Story Homes

Measuring Air Leakage on External Roof Insulation Overlay.

May 2013

The following data collection template will allow contractors participating in Building America's Northern*STAR* research **"Project Overcoat: Airtightness Strategies and Impacts for 1-1/2 Story Houses"** to submit details from their projects.

The research will evaluate the installation of air/moisture barrier, ventilation, and insulation on top of the existing roof on houses that have attic living spaces. We are gathering information from our industry partners regarding their experience with various similar techniques. We will evaluate outcomes and methods for future retrofit approaches.

NorthernSTAR

Company & Contact Information

Company Name:
Address:
Phone:
Website:

Contact Name:
Title:
Phone:
Email:

Project Information

Please fill out the general information below regarding the roof overlay project. (Attach drawings or photos if applicable.)

Subject House Description:

Location (City, State):
Year Built:
*Total Square Footage:
Total Volume of cond. space:
Describe House Type/Style:
Describe Roof Plan/Layout:
# of Dormers/shed dormers:
# of Gables:
# of Hips:

Roof Overlay Description:

Were eaves removed?
Type of membrane/barrier:
Insulation Type and Thickness:
Were furring strips used on top of insulation?
Sheathing on top of furring?
Type of roof cladding:
Was new roof system vented?
Other information?

*Consists of all conditioned spaces including unfinished basements.

NorthernSTAR

Data Collection

A multi-point Blower Door Test should be conducted at each phase of construction: Pre, Mid (During) and Post. Enter the data collected from each test below.

MEASUREMENT	PRE TEST	MID TEST	POST TEST	REDUCTION	% REDUCTION
Air Leakage (CFM50)					
Air Changes (ACH50)					

MEASUREMENT	PRE TEST	MID TEST	POST TEST
Flow Coefficient (C)			
Exponent (n)			

Infrared Images

Please insert the most compelling before and after infrared photos below – or include photos as an attachment.

Digital Photo of IR Images | IR Image Before Roof Overlay | IR Image After Roof Overlay

Digital Photo of IR Images | IR Image Before Roof Overlay | IR Image After Roof Overlay

NorthernSTAR

Digital Photo of IR Images | IR Image Before Roof Overlay | IR Image After Roof Overlay

Digital Photo of IR Images | IR Image Before Roof Overlay | IR Image After Roof Overlay

Please answer the following questions:

1. What were the main areas of air leakage?

2. What areas saw improvement?

3. What areas did not see improvement?

NorthernSTAR

Critical Design & Installation Details

Please attach detail drawings (if available) or photographs of the design and construction methods used for:

- soffit
- gable/rake
- ridge
- valley
- section view of roof overlay system

Contractor Questions

Please answer the following questions:

1. What was your scope of work for this project?
2. What were the overall results and were they expected?
3. How did you sell this overcoat approach to your client?
4. What were the problematic areas for air sealing?
5. What architectural/construction details in the existing homes created challenges in the new roof overcoat?
6. Were there changes made along the way to the initial roof overcoat design? If yes, what were they?
7. What recommendations do you have on design, installation and assessment details that could improve the process?

Other Comments:

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