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Investigation of a Process for Affordable High-Performance Enclosure Upgrades for Multifamily Buildings

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Abstract

With funding from Pacific Northwest National Laboratories, and with partners Oak Ridge National Laboratories and the University of Minnesota, a two-year study of exterior wall insulation upgrades was conducted. This study included in-situ-testing of fourteen upgrade strategies at the University of Minnesota Cloquet Residential Research Facility. Data generated there were used to calibrate energy and moisture models. Cost data obtained from general contractors was used in a techo-economic evaluation of cost effectiveness.

One of the upgrade strategies is a novel exterior upgrade derived from previous work conducted by the NorthernSTAR Building America Partnership that developed and deployed a “studless” exterior wall system. This system uses two layers of large-format oriented strand board as the home’s structural component. Control layers (air, water, vapor, thermal) and finishes are applied to the exterior of this panel. The upgrade strategy presented here eliminates one layer of OSB but is otherwise similar. A membrane, integrated with fenestrations, is the air / water / vapor control layer. Rigid insulation is the thermal control layer. This panel was a top performer in energy savings and moisture performance.

The panel is intended to be fabricated offsite, using a technique called EnergieSprong. This concept, initially developed in the Netherlands before being deployed in the EU and US, uses a 3-dimensional laser scanner to measure the existing building and generate a computer model. This model is then used to guide computer-controlled manufacturing equipment to fabricate the panels. The panels are typically shipped with fenestration and finishes pre-installed. This allows on-site work to progress rapidly, since the panels are simply mounted to the exterior of the building.

This report will describe the proposed panel, its energy and thermal performance, and proposed manufacturing and installation techniques. Mechanical system modifications will be addressed, and a discussion of cost-effectiveness will be included.

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Definition of Terms and Acronyms

ACH: Air Changes per Hour, generally calculated at 50Pa

CRRF: Cloquet Residential Research Facility

EIFS: Exterior Insulation and Finish System

EUI: Energy use intensity, expressed in kBtu/square foot/year

NREL: National Renewable Energy Lab

OPS: Overcoat Panel System, as described in this paper

ORNL: Oak Ridge National Lab

PNNL: Pacific Northwest National Lab

SEER: Seasonal Energy Efficiency Ratio

SIP: Structural Insulation Panels

SPS: Solid Panel System, as developed by U of MN and DOE’s Building America Program

Executive Summary

Opportunity

The existing multifamily housing stock in Minnesota provides rich opportunities for energy efficiency improvements that could reduce electrical and natural gas demand, improve indoor air quality and occupant comfort, and add functional lifespan to these structures. An inspiring example of a retrofit solution has been deployed in the Netherlands and around Europe, called Energiesprong, which translates to energy leap. This holistic retrofit includes the application of exterior panels to increase insulation level and manage air, moisture, and vapor infiltration, and an upgraded mechanical system to handle the reduced space conditioning loads with high efficiency. These core components are sometimes combined with other upgrades of lighting systems or appliances for increased efficiency gains. This paper explores one possible application of this retrofit package to the housing stock in Minnesota. The panel and mechanical system, referred to from now on as the Overcoat Panel System (OPS), is designed based on the principles of the 'perfect wall' and tuned for the climate (ASHRAE climate zones 6a and 7a) and capacity of Minnesota.

Background Information

As stated above, the primary inspiration for this exploratory paper is the Netherlands-based system, Energiesprong. The primary goals of an Energiesprong retrofit are: guaranteed performance for 30 years, a hassle-free, one week implementation, affordability, which is achieved through a unique financing process, attractiveness of the retrofit, and direct procurement of well-developed components with guaranteed energy performance. The OPS is designed to meet the same goals.

Assessments of the viability of this concept in the US market have been performed and contributed to the development of the OPS and the discussion of current supply chain capacity and future needs. The primary sources consulted in this paper are 'Prefabricated Zero Energy Retrofit Technologies: A Market Assessment' (2020) from REALIZE for US DOE Building America Program and 'EnergieSprong: A Dutch Approach to Deep Energy Retrofits and Its Applicability to the New York Market' (2018) from Taitem Engineering for NYSERDA. These sources agree that there is a need for climate-specific designs, as the United States has a much more diverse range of climates than the Netherlands, and that mechanical integration will be a challenge in the current market. Additionally, the financing mechanisms and ownership models of most current multifamily housing units makes this type of retrofit difficult. The relationships between property owners, residents, builders, and lenders will need to be carefully managed and may require new or revised legislation to be successfully carried out.

The building science basis of the OPS has roots in the 'perfect wall' as described by Joseph Lstiburek. The goal of the perfect wall is to "…keep the outside out and the inside in" (Lstiburek, 2010). This is accomplished by four control layers, in order of importance: rain control, air control, vapor control, and thermal control. The best place for all these layers is outside of the structure, to keep that structure safe and maintain its performance. Because the primary exposure to rain, air, vapor, and varied thermal conditions is from the exterior, it makes sense to place the control layers to the exterior of the structure. This arrangement of layers can be turned 90 degrees to create the perfect roof, and reversed again to create the perfect floor. When the OPS is installed, the existing building exterior becomes part of the interior and is therefore protected from the elements along with the structural component of the panel.

This ‘perfect wall’ has been field tested against conventional construction types as described in ‘Affordable Solid Panel ‘Perfect Wall’ System’ (2020) from the University of Minnesota NorthernSTAR Building America Partnership for US DOE Building America. This study proved the panelized wall system to have superior constructability, reduced costs, reduced energy use, and improved moisture resistance.

A survey of current supply chain capacity revealed a significant industry of producing large format building panels, including prefabricated framed wall panels, structural insulated panels (SIP), prefabricated building shell with exterior finishes, and exterior insulation and finish system (EIFS) panels. These panels are all currently designed for new construction, and would require additional technology and manufacturing capabilities to extend to retrofit applications.

Methodology

The work of this study occurred on two parallel and related paths: development of the retrofit system including a mechanical system and the panel itself, how it will be installed and connected to other panels and the existing building, and the typology study and characterization of existing multifamily housing stock in Minnesota and the potential for energy savings with a retrofit.

To develop the panel design, several conditions were considered and solved for, including: panel-to-panel connections, inner and outer corner joints, window and door openings, typical penetrations such as dryer vents and hose bibbs, existing foundation integration, roof and wall integration, and attachment of panels to the existing building. These solutions are focused on maintaining critical control layers: thermal, water, vapor, and air, as well as maintaining an attractive finish on the building exterior.

The typology study was guided by what were deemed to be ideal building characteristics, including: exterior walls less than 40’ high (to avoid assembly fire testing), minimal corners and bumpouts, simple roof forms, a lack of balconies, decks, awnings, unless they can be demounted and re-attached post retrofit, or done away with entirely, and a relatively high wall-surface to floor-area ratio. Similarly, there are ideal characteristics for mechanical system retrofits, including: system nearing end of life, inefficient equipment, systems that utilize exterior walls, and exhaust only ventilation.

To estimate the number of buildings appropriate for and OPS retrofit, a prior (2013) CARD study that characterized rental multifamily housing was referenced and a statistical sample of 120 properties was identified and analyzed. From this sample, buildings over four stories were excluded due to the previously mentioned fire rating challenges, and buildings constructed after 1990 were excluded based on an assumption of adequate insulation. The remaining 97 buildings were then classified as good or poor candidates for retrofit based on a web-based visual assessment of the desirable and undesirable characteristics as described above. The results were then extrapolated based on census data. This study suggests that 40% of all multifamily units are in buildings that could be retrofit with the OPS.

Potential energy savings with application of the OPS was calculated with a series of energy model simulations. DOE 2 energy models of four candidate buildings were developed and assessed with two versions of a baseline, one with a gas boiler and one with electric resistance heating and window air conditioning units. Envelope characteristics of the baseline models are based on practices in pre-1970’s construction. After basic model calibration based on the 2013 CARD multifamily characterization study, the whole-building energy use index (EUI) of most existing buildings was found to fall between 51.8 and 97.2, with about half of the buildings falling between and EUI of 63.3 and 78.5. The baseline buildings were analyzed with only the exterior panel retrofit and with a full panel and mechanical retrofit.

Results

The panel system design and connection details are described and shown extensively in the Results section of this report. The base panel is constructed with an oriented strand board (OSB) structural panel. A membrane is applied to this panel to control airflow, water, and vapor diffusion. This membrane is shown and discussed as a peel-and-stick product in this paper, but other forms are acceptable, such as liquid applied membranes or a structural panel with an integrated control layer. Rigid insulation is applied over the membrane. The type and amount of insulation will depend on the climate, cost, and thickness of material. Furring strips are applied over the insulation and fastened to the structural OSB panel with screws or bolts and T-nuts. Cladding material is attached to the furring strips to complete the panel. As layers are stacked, each is offset from its predecessor in two directions to create staggered seams at each panel joint, intended to reduce infiltration and ensure continuity of the control layers.

Energy modeling demonstrated significant whole-building energy savings potential with the application of an OPS retrofit. Four sample buildings were analyzed, with varied sizes and existing conditions. With an exterior panel and ventilation retrofit, energy savings range from 26-55%. With a full exterior panel and mechanical system retrofit, energy savings range from 60-75%. When these results are aggregated across the units appropriate for retrofit across the state, savings from a panel and ventilation retrofit could reach 5,348,000 MBtu/year and savings from a full retrofit could reach 8,666,000 MBtu/year. These savings are equivalent to the CO_2 emissions of energy use by approximately 139,900 and 226,700 single family homes, respectively[1].

Costs were estimated for retrofit applications, and simple payback calculated. Based on previous studies, the cost for the panel retrofit was determined to be $21 per square foot of enclosure area, and the cost for the mechanical system retrofit was determined to be a maximum of $25 per square foot of floor area. Mechanical system retrofit cost varies based on existing system, and in this analysis the 'worst case' scenario of $25 / square foot was used. The simple payback (retrofit system cost divided by annual energy cost savings) results range from 22 to 152 years. Buildings with existing electric baseboard heating had the shortest payback periods, while buildings with gas-fired heating equipment had much longer payback periods. This discrepancy is consistent with the return-on-investment challenges of gas to electric conversions due to the currently relatively low price of natural gas.

The potential for renewable energy application and net-zero electricity use was assessed using the resulting EUIs and sample building roof area. Calculations were performed using the NREL PV Watts web application. Based on a 20% panel efficiency and 80% of roof area being dedicated to PV panel installation, all four sample buildings were able to achieve net-zero electricity, and three of the four could achieve net-positive electricity. This is consistent with previous studies of net-zero potential of low-rise multifamily housing in Minnesota.

Conclusions and Recommendations

The Overcoat Panel System and mechanical system retrofit have great potential to extend the useful life of existing buildings, while reducing electrical loads and peak demand, and increasing the indoor

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[1] US EPA Greenhouse Gas Equivalencies Calculator

environmental quality of the units. There are, however, significant challenges to supply chain and technology capacity and with financing mechanisms that could be eased with investment from state and local agencies and private entities. A demonstration pilot project, while costly, is crucial for testing and proving the success of the Overcoat Panel System. Due to the need for significant investment in manufacturing technologies and equipment, a significant demand for the OPS product would need to exist. This creates a circular problem of needing to prove the technology to drive interest, while being unable to create the product without the proven demand. One approach to overcoming this issue would be a demonstration project built with conventional hand-building techniques, which would verify constructability and energy performance, but would not provide cost information at a large scale.

Introduction and Background

The commercial and residential building sectors, including on-site consumption and associated energy production, account for 31 percent of greenhouse gas emissions in the United States (US EPA, 2022), and nearly 40 percent of global CO_2 emissions (Architecture 2030, 2018). With the adoption of more stringent energy codes and improvements in building technologies, new buildings are contributing to a reduction in emissions on a per building basis. However, 65% of buildings that will exist in 2040 are already standing, and many require significant energy upgrades to improve performance (Architecture 2030, 2018). To date, these retrofits have been performed on a one-off, highly customized manner that is typically prohibitively expensive.

An innovative approach is under development, with its origin in the Netherlands. Called EnergieSprong (Energy Jump), it represents a technologically advanced process for customized offsite production of retrofit façade panels that can be applied to a building quickly. A streamlined mechanical system upgrade is typically performed at the same time to ensure energy performance and minimize risks due to combustion safety issues.

In 2019 and 2020, Pacific Northwest National Lab (PNNL), the University of Minnesota (U of M), and Oak Ridge National Lab (ORNL) studied fourteen wall insulation upgrade strategies. Field experiments were carried out at the U of M Cloquet Residential Research Facility (CRRF) in Cloquet, Minnesota (DOE Climate Zone 7A). Data from these experiments were used to calibrate energy models and hygrothermal models for extrapolation to other climates. Cost estimates were produced and used along with the energy modeling results in a techno economic analysis to establish cost effectiveness.

One of the strategies that was studied is referred to here as the Overcoat Panel System (OPS). It is derived from previous work done by the U of M for the DOE Building America program on the Solid Panel System (SPS) (Schirber, et al 2020). The original project studied a novel construction system that employed a “studless” exterior structural wall system. The wall is composed of two layers of large-format oriented strand board (OSB). The panels are 1-1/8” (28.6mm) thick, and sheets are supplied in 8-foot x 24-foot (2.44m x 7.32m) sizes. Once the exterior shell is in place, control layers for air, water, vapor, and heat are added to the exterior. Cladding is applied over these control layers, commonly installed on furring strips that are fastened back to the OSB structure. This arrangement of control layers is commonly referred to as the “perfect wall” (Lstiburek 2007). It keeps moisture sensitive materials entirely interior to the thermal control layer, which results in their maintaining temperature and humidity conditions tightly coupled to indoor conditions. If water leaks or other moisture ingress into the assembly occurs, such walls are more able to dry effectively than walls where sensitive materials are tightly coupled to the outdoor environment or sandwiched between relatively impermeable layers. The Overcoat Panel tested at CRRF was essentially identical, except that the OSB was reduced to one layer because it did not need to bear the structural loads of the building. Results from this study are shown in Figure 1,Figure 2, andFigure 3. These graphs indicate the sheathing temperature relative to the indoor and outdoor temperatures for three wall assemblies. The graphs show two months of data, from February 1 through March 31, 2021. The Interior conditions are held at 70℉ (21℃) (blue line). Outdoor air temperature is shown by the black line. Figure 1 shows the baseline, uninsulated wall. Sheathing temperatures are hovering between indoor and outdoor air temperatures. Figure 2 shows the sheathing temperatures after a cavity-only (cellulose) retrofit. Sheathing temperatures are substantially coupled to outdoor air temperature. Figure 3 shows the sheathing temperature for the OPS, where the temperature is substantially coupled to the indoor air temperature. Figure 4Figure 2 shows the relative humidity (RH) at the sheathing. The baseline uninsulated wall is shown in dark blue. It peaks just above

80% RH early in the series, before beginning a steady decline. The light blue lines at the top of the plot show the cavity insulation case (north and south exposures). RH is frequently at or near 100% for much of the series. Exterior insulation test cases are shown with red, orange, and purple lines. The graph key names them as “Ext EPS,” which is a proprietary expanded polystyrene overcladding product, “Ext Mineral Wool,” which is a rigid mineral wool product, and “Ext g-EPS,” which is a graphite-enhanced expanded polystyrene board used in the Overcoat assembly. For all of these exterior insulation strategies, RH never exceeds 60%, indicating a substantial increase in moisture safety versus the cavity insulation example. Additional funding was secured in 2020 under the Minnesota Department of Commerce Conservation Applied Research and Development (CARD) program to further develop the system.

Figure 1 - PNNL Wall Upgrade Study Results - Temperature - Baseline

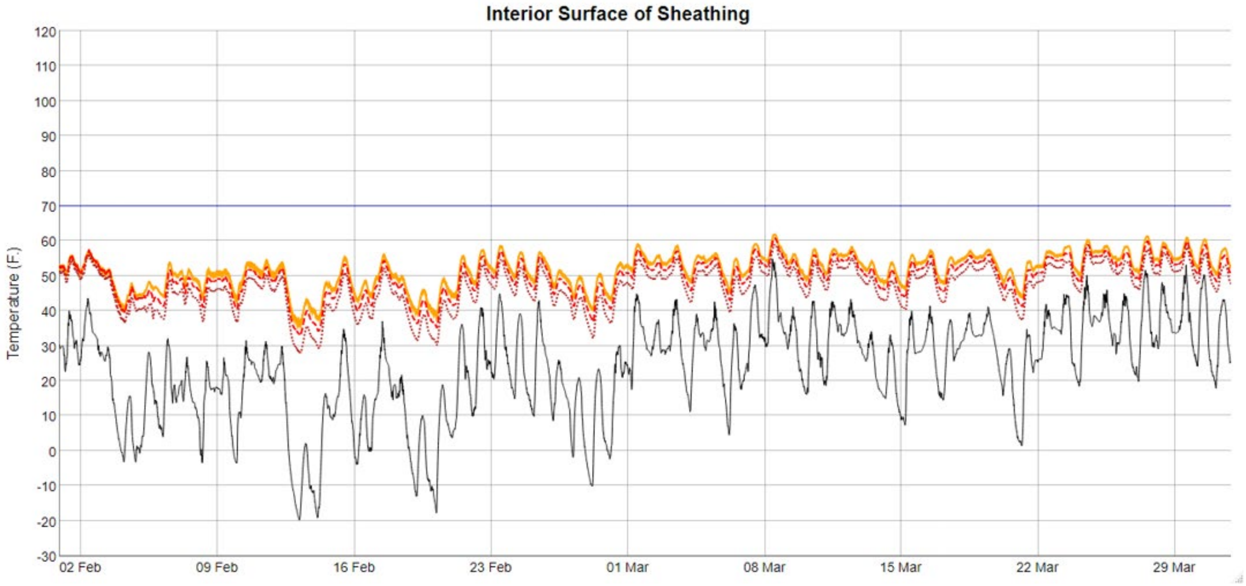


Figure 2 - PNNL Wall Upgrade Study Results - Temperature - Cavity Insulation

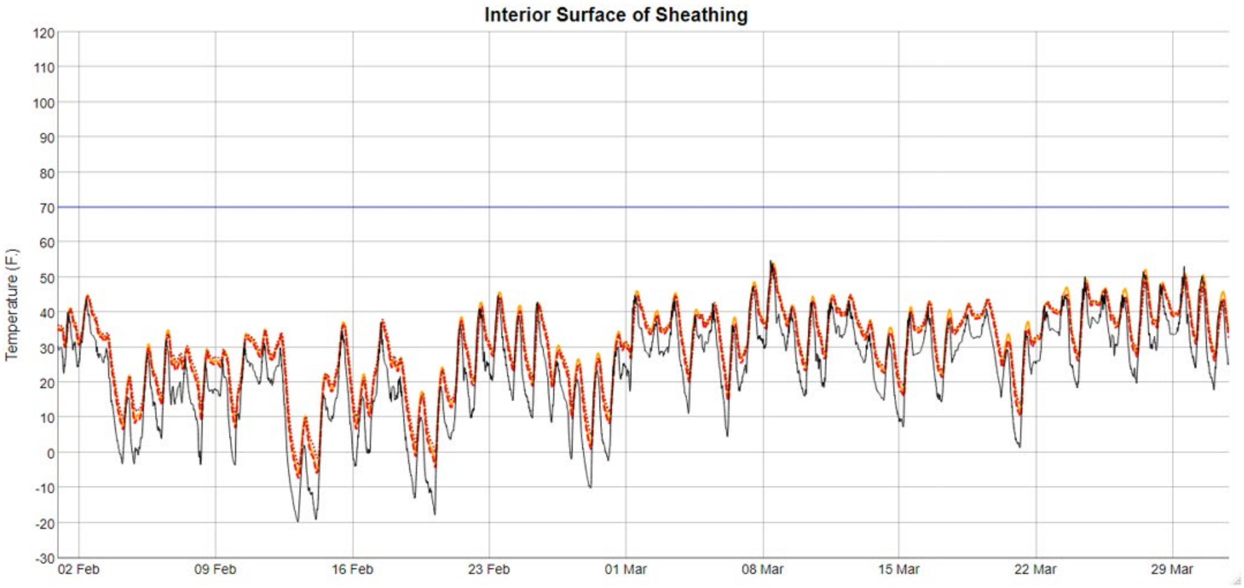


Figure 3 - PNNL Wall Upgrade Study Results - Temperature - Overcoat Panel

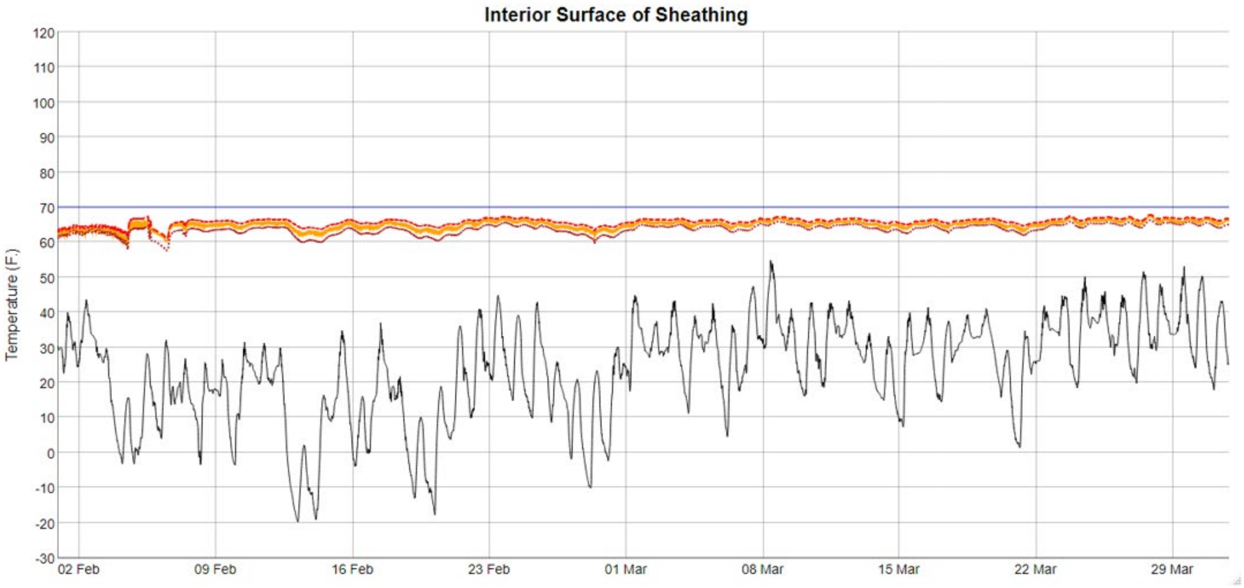
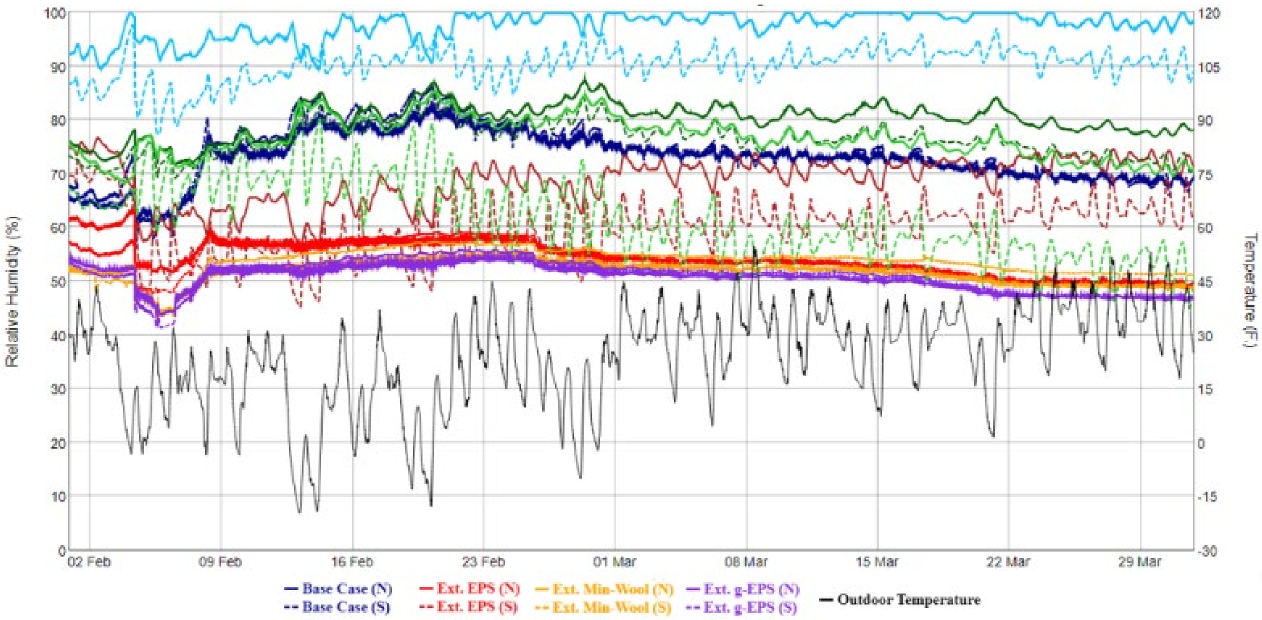


Figure 4 - PNNL Wall Upgrade Study Results - Relative Humidity



Literature Review

The goal of this project is to develop and present a novel, panelized wall and roof system to enable fast, cost-effective energy upgrades to multifamily residential buildings across Minnesota. The project focuses on the adaptation of a wall construction system developed by the University of Minnesota for new construction in a retrofit application, using techniques pioneered by the European Energiesprong movement. This wall upgrade is accompanied by a new mechanical system to handle remaining thermal and ventilation loads efficiently. The following literature review includes a review of the European program Energiesprong and assessments of the potential in the United States, and an overview of the work done locally with solid wall panel system construction. With an understanding of these precedents, the project team was well equipped to develop an approach for Minnesota and recognize the potential market deployment and energy, carbon, and cost savings that could be realized.

This section of the literature review includes an overview of the original Energiesprong process, a market assessment for this technology in the United States, and a study of the Energiesprong process applied to New York State. This review provides context for one key component of this study – the high performance retrofit panel – and the opportunities and challenges at a national and state scale. Lessons learned from these resources informed this study and will guide future implementation of an Energiesprong approach to deep energy retrofits in Minnesota.

Energiespong

Energiesprong Foundation

Energiesprong (English: energy leap) is a novel and innovative approach to retrofitting multifamily housing, originating in the Netherlands, and currently deployed in the UK, France, Germany, and Italy. The approach has been evaluated for deployment across the globe, including for New York State, which will be covered later in this literature review.

The Energiesprong model is a radical transformation – both practically and conceptually – as it focuses on creating a volume market for solutions that satisfy five key criteria:

1. Guaranteed performance for 30 years. This ensures that the quality of the product (with high indoor climate and energy performance standards) is locked in and guaranteed.
2. Hassle-free, one-week implementation.
3. Affordability. The investment is financed in two ways: through energy cost savings from tenants and by reduced maintenance and repairs costs for housing associations. The objective is that tenants have the same monthly expenses – they pay the housing association an energy service plan instead of the bill of the energy supplier. The housing association can use this new income stream to pay for the renovation.
4. Attractiveness. The quality design makes Energiesprong properties a fun, lifestyle choice, providing upgraded properties that occupants aspire to.
5. From tendering to purchasing. The traditional way of procuring – based on detailed specifications and drawings – is replaced by purchasing well-developed housing concepts with guaranteed energy and (indoor) quality performance.

The construction process for an Energiespong retrofit project is covered in more detail later in this literature review. The process generally consists of prefabricated panels and mechanical elements being fastened to the exterior of the existing building, with minor interior construction work. The goal is a fully electrified, zero-energy building. Most retrofit projects can be completed within one week with minimal resident disturbance. As of this writing, over 5500 Energiesprong upgrade projects have been completed in the Netherlands, 26 in France, 12 in Germany, and 15 in the United Kingdom.

Prefabricated Zero Energy Retrofit Technologies: A Market Assessment

REALIZE for US DOE Building America Program, 2020

This report was prepared by Amy Egerter and Martha Campbell of REALIZE, A Rocky Mountain Institute initiative, for the US Department of Energy Building America Program and the Office of Energy Efficiency and Renewable Energy. The report includes background information on the Energiesprong program, an assessment of markets in the Netherlands and the United States for retrofit facade panels and mechanical systems, and key recommendations for a program in the United States.

Two crucial pieces of program design were identified in the Energiesprong background research:

- The need for a national (or statewide, in the case of this project) typology study. The ideal buildings for retrofit were identified based on the ownership structure, geometry, energy use profile, age, and need for improvement.
- Financing for the retrofits - many barriers exist, and new legal provisions may be necessary to implement a similar program in the United States.

The former concern will be addressed later in this report and assessment and include necessary characteristics of buildings with retrofit potential. The latter concern is outside the scope of this study and will be briefly discussed in the ‘Future Work’ portion of this literature review.

The facade panel market assessment includes an overview of panel manufacturers in the Netherlands, and describes the two main manufacturing and business approaches:

- A general contractor adds manufacturing and becomes a design / build firm
- A panel manufacturer for new construction adds retrofit products to line or adapts existing panel products

In both cases, Energiesprong acted as a liaison between building owners and panel suppliers to provide specific committed unit volumes from owners and performance requirements and verification processes. This created a clear picture of the desired product and committed payment from building owners, leading to secure investments from suppliers. This approach was very successful in the Netherlands and is highly recommended for United States markets.

While the Energiesprong program is transferable to a United States application, some issues would need to be addressed, both in panel manufacturing and in mechanical systems:

- Mid and High-rise applications - in the United States, many multifamily buildings are taller than five stories and at the time of this report, no panel system in the Netherlands has been installed on a building taller than five stories.
- Fire safety concerns were not explicitly mentioned in this article but will certainly be an area of exploration for larger scale projects.
- No retrofit centralized mechanical systems in use in the Netherlands have been designed or implemented in buildings taller than five stories. It is possible that, due to the size limitations, a centralized system option may need to be designed for larger building in a United States application. An option between unitary or centralized systems is key to market uptake.
- Seismic design - crucial for some areas of the United States.
- Mechanical integration - there is potential for greater collaboration between mechanical and panel design and manufacturing to accommodate higher variability of building geometries found in the United States.
- Climate specific design criteria - The Netherlands has a similar climate throughout the country, a large scale deployment of this technology in the United States would necessitate considerations of a wide variety of climate zones.
- Electrical systems may not be compatible even if a HVAC system product has desired functionality and capacity for a United States application.
- Similarly, United States rating and testing systems including UL create time and cost barriers to direct technology transfer of the Dutch systems.
- Level of prefabrication in general is lacking, along with prefabrication and automation.
- Panel manufacturing is geared towards new construction and generally falls into modular buildings or rooms fully constructed off site, or individual facade components such as wall panels without windows and doors installed. The Energiesprong panel falls somewhere between those typologies.

The key recommendations to develop a panel and mechanical system market in the United States include:

- Characterize building stock to inform the development of retrofit wall panel systems.
- Aggregate demand to demonstrate potential volume so manufacturers can devote research and development resources with confidence in the demand for products.
- Provide research and development resources for product innovators
- Develop assemblies for mid- and high-rise building applications.
- Combine existing products to achieve functionalities desired in mechanical system

- Develop smaller mechanical system sizes for multifamily units - most existing heat pump systems are oversized for multifamily units and especially so for high performance buildings.
- Design systems so that extensive electrical upgrades are not required for full electrification - energy demand should be reduced enough to accommodate newly electrified systems without needed updated infrastructure.
- Develop standardized central systems for larger building applications.

In summary, the key recommendations for implementing and Energiesprong-style program in the United States include:

- Market research and guidance
    - Typology study
    - Market study for demand based on facade systems
    - Regional specifications for panel and mechanical systems
    - Support manufactures to act
- Research and Development
    - High-impact, low-complexity big wins - start with similar climates with large volumes of building stock and an opportunity for demand aggregation
    - Fund demonstrations and field studies needed to prove technical viability
    - Encourage development and deployment of a variety of solutions
    - Invest in internal R & D
    - Participate in knowledge sharing
- Demand aggregation
    - Building owner and developer meetings
    - Work with large portfolio owners
- Policy and market signals
    - Bold targets for performance and retrofit rates with codes or other policy mechanisms
    - Support building owners to act
    - Align signals from mission-oriented financial institutions
    - Work with utilities and other stakeholders to provide gap funding
- Workforce Development
    - Empower a cohort of service providers

EnergieSprong: A Dutch Approach to Deep Energy Retrofits and Its Applicability to the New York Market

Taitem Engineering for NYSERDA, 2018

This report was prepared by Taitem Engineering of Ithaca, New York, for the New York State Energy Research and Development Authority (NYSERDA) in March 2018. The report includes a summary of the Energiesprong program from conception to construction. Topics relevant to this study include an assessment of building stock appropriate for renovation, the technical approach to renovations with a step-by-step description of the implementation procedure, resident relationship management, and transferability considerations.

The key recommendations for adopting or modifying Energiesprong program for New York State include:

- Increased focus on lighting, appliances, and energy-efficient resident behavior - energy efficient lighting and appliances other than cooking stoves were not emphasized in the Dutch program but present additional energy efficiency improvements in a United States application.
- Set clear goals for energy reduction that are deep, consistent, and defensible. Much of the success of the Netherlands program is attributed to a consistent goal of net zero energy with full electrification.
- Standardize the scope of work while allowing flexibility in implementation. The Energiesprong approach allows flexibility in material selection, fabrication methods, finishes and appearance, warranty details, and add-on features such as age-in-place additions, automation, earthquake proofing, and anti-burglar certification. What is not flexible is the net-zero performance goal which resulted in on-site photovoltaic panels, full electrification, a well-sealed building envelope including insulation, air sealing, and efficient windows and doors, heat pumps for space and water heating, and a ventilation system.

The report describes the step-by-step implementation procedure as follows, moving from exterior to interior work and generally completed with one week of on-site work:

- 3D measurements taken of existing building
- Wall and roof sections prefabricated off-site
- Mechanical room additions prefabricated off-site
- Exterior wall elements removed
- Trench around building to insulate sub-surface foundation
- Structural fasteners attached to existing walls
- Existing windows and doors removed
- Prefabricated wall panels installed
- Prefabricated window and door extensions installed
- New tilt and turn style windows and doors installed (in some cases, new windows and doors are pre-installed on panels)
- Exterior roof elements removed
- Roof sections installed with crane
- PV panels installed with crane
- Interior work begins
    - Gas meter removed
    - Crawl space insulated with loose polystyrene chips
    - New ductwork installed, if necessary
    - Kitchen and bathroom upgrades
    - Gas stoves replaced with induction; compatible cookware provided for residents
- Exterior surface elements reinstalled or replaced

A crucial component of the success of the Energiesprong program is the relationships between project stakeholders - the housing agency who owns the property, the residents who live there, the builder, and the lender. These can be summarized into three important contractual relationships:

- Housing agency and residents – A modified lease in which the resident agrees to allow renovations and pay additional, fixed, monthly energy service charge, in exchange for reduced energy costs.
- Housing agency and builder – the builder agrees to complete renovation and provides a long-term performance guarantee (25-40 years) including maintenance of energy system(s).

- Housing agency and lender – the lender refinances building to provide capital for renovations.

Perhaps the most relevant section of this report examines the transferability of the Energiesprong program to New York state. Some transferability issues identified are specific to New York, and some are also applicable to Minnesota. The topics of climate and of technology availability are particularly pressing.

This report discusses climate differences in terms of Heating Degree Days and presents several key takeaways that are even more pressing for Minnesota's climate. Table 1 shows the number of Heating Degree Days and Cooling Degree Days in the Netherlands, New York State, and Minnesota.

Table 1 - Heating and Cooling Degree Days by Location (Degrees Fahrenheit)

Location	Heating Degree Days[a]	Cooling Degree Days[b]
Netherlands	5000-6000	5-45[c]
New York State	4500-7000	600-850[d]
Minnesota	7800-10,000[e]	300-1200[e]

a) "Heating degree days", or "HDD", are a measure of how much (in degrees), and for how long (in days), outside air temperature was lower than a specific "base temperature" (or "balance point"). In this case, the base temperature is 65°F.They are used for calculations relating to the energy consumption required to heat buildings. (DegreeDays.net)

b) "Cooling degree days", or "CDD", are a measure of how much (in degrees), and for how long (in days), outside air temperature was higher than a specific base temperature. In this case, the base temperature is 65°F. They are used for calculations relating to the energy consumption required to cool buildings. (DegreeDays.net)

c) Eurostat Data Browser (https://ec.europa.eu/eurostat/databrowser/view/nrg_chdd_a/default/table?lang=en). Degrees Celsius converted to degrees Fahrenheit for comparison.

d) NYSERDA (https://www.nyserda.ny.gov/about/publications/ea-reports-and-studies/weather-data/monthly-cooling-and-heating-degree-day-data)

e) MN Department of Natural Resources (https://www.dnr.state.mn.us/climate/historical/index.html)

The distribution of temperatures is also significantly different – the Netherlands experience very few hours above 80°F or below 20°F, while New York experiences more and Minnesota even more still. This presents some challenges for existing technologies in use in Europe, including the lack of air conditioning capacity and the inherent increased efficiency of heat pumps operating within that temperature range. These difficulties may be exacerbated by continuing changes in climate that result in more extreme temperatures for longer durations.

The Energiesprong approach clearly demonstrates potential for deep energy savings and revitalization of old building stock. When considering an application to the Minnesota climate, an opportunity to deploy a previous study product - a 'perfect wall' solid panel system for residential new construction - emerged as a natural fit. This section of the literature review explains the base concept of the 'Perfect Wall' as coined by Joseph Lstiburek, and summarizes a study in the design, construction, and performance of single-family homes in Minnesota utilizing a solid panel system designed with the principles of the perfect wall. The core concepts and field studies reviewed for this section will guide the development of retrofit panels and inform energy saving potential for residential applications in Minnesota.

The Perfect Wall

Joseph Lstiburek, 2010

This article outlines the ‘ingredients’ and ‘recipe’ for the perfect wall. Lstiburek describes the perfect wall as an “environmental separator – it has to keep the outside out and the inside in.” To do this, the wall requires four control layers, in order of importance:

- Rain control
- Air control
- Vapor control
- Thermal control

The best place for all these layers is outside of the structure, in order to keep that structure safe and performing as expected. Since most of the exposure to rain, air, vapor, and varied thermal conditions come from outside, it is only reasonable to place the layers controlling the elements to the outside. This composition of elements can be turned on its side to create the perfect roof and reversed again for the perfect floor. The control layer elements can be comprised of a variety of materials and will depend on the location, intended use, and service life of the building and the wall system. This article includes four examples – an ‘institutional wall’ built two ways, representing the most robust version of the perfect wall, a ‘commercial wall’ using metal studs, and a ‘residential wall’ using wood studs. In the case of the wood stud wall, insulation material is applied both to the exterior of the wall and inside the cavity, except in extreme cold climates.

Affordable Solid Panel “Perfect Wall” System

University of Minnesota NorthernSTAR Building America Partnership for US DOE Building America Program, 2020

This report was prepared by Tom Schirber, Rolf Jacobson, Garrett Mosiman, Dan Handeen, and Patrick Huelman of the University of Minnesota NorthernSTAR Building America Partnership, for the United States Department of Energy Building America Program, Office of Energy Efficiency and Renewable Energy. This report examines the construction and performance of a panelized wall system designed for residential new construction and with the concepts of the high performance “perfect wall” as popularized by Dr. Joseph Lstiburek and as described above. The solid panel system (SPS) home construction was tested against two other construction types, one representing a code base case achieving Energy Star Certified performance and one with a hybrid wall construction with two layers of insulating material that meets the EPA Zero Energy Ready Home standards. Construction costs, constructability, and performance were carefully analyzed for each type.

Costs

- The material selections of the SPS provided cost savings for interior finishes.
- More uptake of this approach will drive down construction costs as knowledge and experience increase.
- In operation, the SPS houses demonstrate substantial energy cost savings.

Constructability

- Installation crews working on their second house reduced both crane time and labor time, confirming that wide uptake of this approach will decrease construction time and cost.
- Training was provided for installation crews in a combination of in-person and online sessions and videos, and with live construction experience guided by the project team.

Performance – Energy

- Energy models of the SPS construction and the hybrid wall construction indicated a 40% reduction in heating energy and a 25% reduction in cooling energy compared to the code baseline.
- Energy models indicate the SPS construction and hybrid wall construction will achieve a 50% energy savings and 30% energy cost reduction compared to the 2015 Minnesota Energy code.

Performance – Moisture

- Moisture modeling and actual monitoring results indicate the hybrid wall construction and SPS wall construction provide more robust air and water leakage control, and place the sheathing in a warmer, more protected position.

Performance - Market Delivery

- After completion of this study, one non-profit housing partner plans to continue using the SPS construction method, and two for-profit builders are investigating projects utilizing the Solid Panel System.
- As with all housing production, the market uptake of this method is highly dependent on availability of labor and materials, and on demand for this technology.

SPS Building Technology

- Structural panels – the OSB panels used in this project are 1-1/8” thick, in an 8’x24’ sheet. Panels are cross laminated to simultaneously serve as columns, beams, and sheathing. Wall plates are securely fastened together and interlocked with the horizontal plates of the roof and floor.
- This panel system is designed to be flexible, however early designs have focused on optimizing the dimensions to fully utilize panels and reduce waste. The panels easily accommodate standard window and door openings. The current home design has a 24’x32’ footprint (770ft^2) and requires 24 panels for the walls and 8 panels for sheathing the first and second floor plates.
- The typical construction sequence is outlined below:
    - Site preparation and excavation
    - Footings, foundation wall, and basement slab are constructed with cast-in-place concrete. All basements include at least one egress window.
    - First floor platform panels are installed on a modified sill plate which is attached to the foundation. This modified sill plate also accommodates the vertical panel installation.
    - Exterior wall vertical panels are installed by crane, starting with the corners, and attaching to the modified sill plate.
    - Exterior wall first floor horizontal panels are placed interior to the vertical panels. Any first-floor pre-framed interior partition walls also installed.
    - Second floor joists are installed inside exterior panels and on top of interior horizontal panels, sheathing installed.

- Exterior wall second floor horizontal panels are placed interior to vertical panels. Any second-floor pre-framed partition walls installed.
- Roof trusses are installed interior to vertical panels and on top of interior horizontal panels and sheathing is installed. This concludes crane work on site.
- Window openings are cut. In this case, the design was simplified to three window sizes and the material cut from the wall panel was utilized in the stair treads.
- Exterior control layers are applied, beginning with priming the OSB panels and applying a fully adhered "peel and stick" membrane from the foundation to the head of first floor windows and doors. First floor windows are then installed, and the process repeats for the second floor. Exterior rigid board insulation is installed in two layers with a staggered pattern. Furring strips are installed outside of insulation and attached back to the exterior OSB panel.
- Exterior cladding and trim are attached to furring strips.
- Interior framing is completed.
- Mechanical, electrical, plumbing (MEP) systems are roughed in. All MEP penetrations to the exterior are preplanned and pre-cut, and special sleeves and devices are used for each opening to ensure integration with the water control membrane.
- Interior finishes are installed and applied. The OSB interior panels may be covered in drywall and finished in typical manner or may be primed and painted as-is. Similarly, if floor panels are protected during construction, they maybe sanded and sealed with no additional material needed.
- Mechanical, electrical, and plumbing fixtures, hook-ups and, and finishes are installed.

This literature review has generated a good understanding of the broad and specific Energiesprong process, the market requirements and considerations, and an idea of potential use in Minnesota. As work progressed, the project team completed marketplace analysis including building characteristics and stock, and supply chain research including the needs and current capacity. The proposed system includes both a panel system and mechanical system to meet an established performance target. Energy and carbon reductions and cost effectiveness were modeled and evaluated and final reports and results generated.

For an Energiesprong approach to work in the United States and in Minnesota, some policy and financing mechanisms may need to be introduced, rewritten, or removed. For example, in the initial round of Energiesprong projects, a new law was introduced that allows tenants to pay the equivalent of an energy bill directly to the property owner to pay for the retrofit which will eliminate the electricity bill. These are crucial concerns to be resolved before a large scale deployment of this approach could be realized. However, these topics are outside the scope of this report and will be addressed in future work as this approach is further researched and realized.

The precedents explored in this literature review leave this project primed to combine the well established concepts of prefabricated retrofit panels and 'perfect wall' solid panel construction into a transformative approach to deep energy savings for multifamily residential buildings in Minnesota.

Current Supply Chain Capacity

There are a significant number of companies that routinely produce large-format building panels, though none are directly analogous to the Overcoat panel concept. Additionally, these panels are produced exclusively for the new construction market, and do not address retrofit applications. This is significant because retrofit applications will require accommodation of existing building imperfections such as walls that are out of plumb and window openings that are not square.

Such accommodations are not economically feasible unless a computer controlled cutting and fabricating process, directed by a detailed computer model is used to produce the panels. While most of the large panel manufacturers currently use computer models to design their panels, along with automated cutting machines to process the lumber, their ultimate goal is to produce panels that are square and true. So existing factories would need to be upgraded to produce the “imperfect” panels needed for retrofit applications.

3-D Laser Scanning

There are a large number of firms in Minnesota who currently offer the required 3-D laser scanning service. Some of these are divisions within engineering firms, while others are specialty companies using laser scanners or other technology to precisely document existing conditions of buildings, pipelines, landscapes, and other features. The vast majority of these companies would be capable of producing a point cloud of a subject building for use in the Overcoat process.

Panel Manufacturing

Large format panel manufacturers produce panels that generally fall into one of four categories:

Prefabricated framed wall panels

These manufacturers represent most offsite panel production in the state. They produce panels that consist of structural framing using dimensional lumber (2x4, 2x6, etc.). Exterior and interior panels are available, with exterior panels shipping with sheathing attached. The panels are commonly used in low- and mid-rise construction, often for apartment buildings.

The panels are shipped to the site on flatbed trucks, carefully arranged to facilitate the construction sequence. The panels substitute for onsite framing and sheathing activities, with the chief advantages being increased speed and accuracy, and reduced downtime due to weather. Once the panels are erected, typical steps such as application of the water / air control layer, window and door installation, exterior finish application, insulation, and interior finishing are completed in a traditional fashion.

Structural insulated panels (SIPs)

SIP manufacturers represent another large segment of the offsite manufactured market. SIPs consist of an expanded polystyrene insulation foam core, which has interior and exterior OSB skins attached by adhesive. The panels are available in sizes up to 8’ x 24’. Window and door openings are typically cut at the factory, and wood framing is installed around the opening to facilitate attachment of flashings and fenestrations.

Panels are typically installed by specialty contractors, rather than being supplied as a commodity to the general construction market. Once panels are assembled onsite, control layers, flashings, doors and windows, and exterior and interior finishes are applied. The foam core of SIPs provides continuous insulation with substantially less thermal bridging than framed walls with cavity insulation, and connection details generally result in a high degree of air tightness.

Prefabricated building shell with exterior finishes

This is a specialty product commonly used for single-story light framed commercial buildings such as fast-food restaurants and convenience stores. Panels include structural framing made of dimensional lumber with conventional wood- or gypsum-based sheathing. A water control layer is factory applied, along with exterior finish materials such as brick or stucco. Smaller windows and doors can be factory installed, however larger storefront glazing systems are installed at the site. Insulation and interior finishes are installed in the field.

EIFS prefabricated exterior wall panels

These panels are used in commercial building projects, typically mid-rise applications such as apartment buildings and hotels. Structure for the panel is provided by a framed cavity wall using steel studs. Gypsum board sheathing is attached, along with an EIFS (exterior insulation and finish system) cladding and insulation system. Fenestration can be factory installed. Unlike the prefabricated framed wall panels, these panels are not intended to provide primary structural support for the building, but are attached to a structural frame like a curtain wall system.

In addition to these panelized systems, another relevant market exists in Minnesota: volumetric modular offsite construction. In this system entire volumes of a building are produced in a factory, typically including all interior and exterior finishes. Modules are assembled on a site-built foundation to make up a complete building. Current applications are typically those that use repetitive elements for buildings like apartments and hotels.

In addition, there is one manufacturer of manufacturing equipment for offsite fabrication factories located in Minnesota. This company produces equipment appropriate for fabrication of many of the products listed above.

Table 2 briefly summarizes the current state of offsite building panel manufacturing in Minnesota. It includes panel types, structural material, included layers, and the number of Minnesota manufacturers.

Table 2 - Offsite Building Panel Manufacturing in Minnesota

Building Element	Prefabricated Framed Walls	Structural Insulated Panels (SIPS)	Prefabricated Building Shell with Exterior Finishes	EIFS Prefabricated Exterior Wall Panels
Structure	X	X	X	X
Sheathing	X	X	X	X
Continuous Insulation		X		X
Cavity Insulation				
Water Control			X	X

Building Element	Prefabricated Framed Walls	Structural Insulated Panels (SIPS)	Prefabricated Building Shell with Exterior Finishes	EIFS Prefabricated Exterior Wall Panels
Fenestration			X	X
Exterior Finish			X	X
Framing Material	Wood	Sandwich Panel	Wood	Light Gauge Steel
Number of Manufacturers	>10	1	1	1

Panelized, off-site construction is a mature industry in Minnesota. However current manufacturing capabilities would need to be augmented to enable deployment of the Overcoat technology. Specifically, current manufacturing utilizes automated machinery for simple tasks like cutting wood structural members to identical lengths for use in typical panels. But the Overcoat technology anticipated here will require much more automation so that the inevitable imperfection of the retrofit candidate buildings can be quickly accommodated during the manufacturing process. Fortunately, Minnesota is well-positioned to add this capacity, possessing both a significant panel manufacturing base, as well as industries involved in the design and fabrication of manufacturing machinery and production lines. Additionally, our extreme climate maximizes the potential to achieve cost-effectiveness of potentially expensive retrofit solutions.

Significantly, industry currently has little interest in deviating from the technologies they employ for the markets they serve. They are quite busy satisfying customers in the new construction marketplace and find little incentive to entice them into entering into the historically difficult retrofit market. This is a phenomenon the EnergieSprong organizations have confronted head-on by aggregating demand and financing instruments to demonstrate a reliable market for contractors and manufacturers to gear up to serve. Such a market intervention is likely to be necessary to incentivize companies to create manufacturing capability to produce novel retrofit technologies such as the Overcoat panel.

Methodology

System Origins and Development

This proposed retrofit system is a spinoff concept emerging from earlier work done at the University of Minnesota with funding from DOE and HUD, with the assistance of many industry partners. The technology was developed as an alternative to traditional stick framing for single family new construction homes. For new construction, it is referred to as the Structural Panel System (SPS).

In 2002, the University of Minnesota and Wilder Foundation secured a grant from HUD to investigate a novel panelized system of construction for affordable housing projects. These projects used a new oriented strand board (OSB) panel product that had been developed by Huber Engineered Woods (HEW). This new product was available in large, 8 foot x 24 foot sheets, and was 1 1/8 inches thick. This panel is still available and forms the foundation for the retrofit concept explored in this white paper.

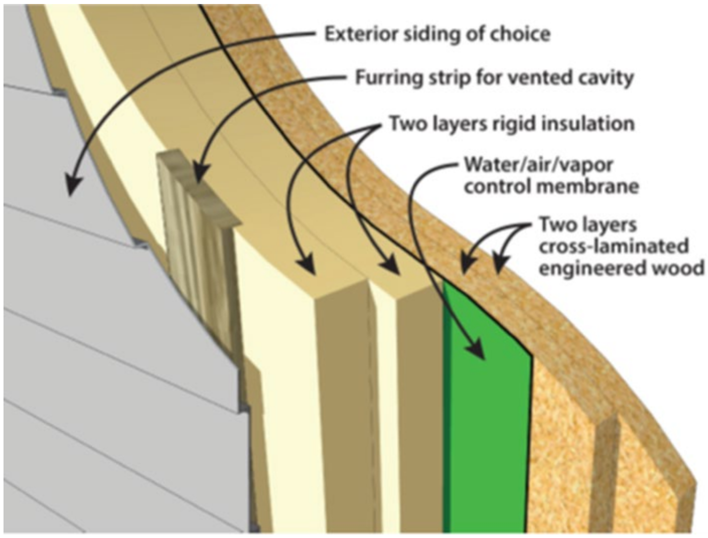
Four prototype houses were constructed under this HUD grant. Three were built with the St. Paul Community Development Corporation, and one with Minneapolis Public Housing Authority. These first four houses are shown in Figure 5:

Figure 5 – Prototype SPS Houses 1-4

In 2014, a collaboration between a developer, Spero Environmental Builders, and an enclosure contractor called Monopath, built seven houses based on the third Wilder prototype. These became the basis of a new DOE Building America grant that the U of M managed. Ultimately five SPS houses were built under the DOE grant, and another eleven were built independently by Spero.

The defining feature if this construction system is the structural component. Typical single-family construction uses 2x4 or 2x6 nominal dimension lumber to create a structural frame, which is sheathed with thin structural panel goods to prevent wracking, and to provide a substrate for exterior layers. The SPS system has no studs. Instead, it relies on two layers of 1 1/8” OSB for support against gravity loads. The exterior surface can support exterior layers, and the interior can be simply painted as a final finish layer. A schematic of the SPS wall system is shown in Figure 6. The elimination of stud framing enables extremely rapid construction; houses built by Monopath could be “dried in” (sealed against weather) in five days.

Figure 6 - SPS With Exterior Control Layers



The other driver for the development of the SPS is the sequence and arrangement of control layers. These layers control the movement of heat, air, water, and water vapor across the building enclosure. Building science first principles, as well as numerous studies, show that application of these control layers to the exterior of any moisture susceptible components such as wood structures, makes them inherently safe from moisture damage. Although not a recent development, this concept is perhaps most succinctly presented in a May 2007 article in the ASHRAE Journal by Joseph Lstiburek of the Building Science Corporation, titled "The Perfect Wall." The three components of the enclosure that are described in the article, from interior to exterior are: a) structure b) control layers c) drained cladding.

For the SPS houses there are two control layers to handle all four flows mentioned above: a peel-and-stick membrane for air, water, and vapor control, and rigid insulation for thermal control.

After erection of the OSB structure, a peel-and-stick membrane is applied. This membrane manages the flow of air (air barrier), water vapor (vapor retarder), and is the last line of defense against rainwater intrusion (water control layer). Window and door flashings, and penetrations such as dryer vents or electrical conduits are integrated with this layer.

For purposes of the Overcoat panel, this layer must ensure a durable, airtight seal and safely manage rainwater. With all the insulation to the exterior, vapor control characteristics are not as critical. Peel and stick membranes can self-heal around fastener penetrations and are resistant to damage. This ensures they can perform their intended functions for the lifetime of the building. They are, however, labor intensive to install. The SPS team has considered using a spray-applied membrane material in this application. Such liquid applied membranes are common in commercial construction and can be considered by panel manufacturers if their performance is similar to that of peel and stick membranes.

Outboard of that layer is the thermal control layer, handled in the SPS houses with rigid extruded polystyrene board (XPS). Other rigid board products like expanded polystyrene (EPS), polyisocyanurate (PIR) or rigid mineral wool are also acceptable. 1x4 wood furring strips are applied over the insulation and fasted to the OSB structure with long screws. Cladding is attached to the furring strips. The space between the foam and back side of the cladding allows for drainage and drying of liquid water that penetrates the cladding layer. Where fire resistance of the cladding layer is a concern, use of rigid mineral wool products may have a significant advantage over foam plastics since it does not support combustion.

Cladding choices are abundant. Most lightweight cladding materials (metal panel, fiber cement, wood composite, etc.) are appropriate. Heavier claddings would require additional structural accommodation. Vinyl siding would require a continuous backup surface between the wood furring strips, since it is flexible and would otherwise deform between the strips.

The Overcoat panel advanced in this paper is essentially identical to the SPS construction method, with two exceptions: 1) one layer of OSB can be used, because the Overcoat panel does not need to support the building. Additionally, it may be possible to move to a thinner OSB panel. These changes reduce material cost and panel weight. 2) The panel is fabricated offsite rather than being site fabricated. This is anticipated to increase accuracy and to reduce costs versus onsite construction.

The Overcoat retrofit panel has been further developed and was included in a project sponsored by Pacific Northwest National Laboratory (PNNL). That project studied fourteen retrofit insulation upgrade packages. These were applied to a base case wall consisting of a 2x4 un-insulated stud frame, 1x6 board sheathing, tar paper water control layer and cedar siding. This base case was intended to represent typical practices in residential construction up to approximately 1950. The retrofits were installed at the University of Minnesota Cloquet Residential Research Facility (CRRF) and monitored for energy and moisture performance for at least one year. In addition, the data collected were used to calibrate energy and moisture transport computer models.

This paper will expand on the PNNL prototype, which was a simple 4 foot x 7 foot panel with no doors, windows, corners, penetrations, or other features typical of real buildings. A series of details will be presented that accommodate typical building conditions. These details include:

- Vertical panel-to-panel joints
- Horizontal panel-to-panel joints
- Inside corners
- Outside corners
- Window / door details
- Typical penetration details (dryer vents, hose bibs, etc.)
- Foundation details
- Roof / wall intersection details
- Schematic detail for attachment of panels to a building

These details will be focused on maintaining the continuity of the critical control layers: thermal, water, air, and vapor, as well as achieving an attractive exterior finish.

Prior to panel fabrication, precise measurements must be made of the target building. Since the Overcoat concept anticipates that features such as new doors and windows will be integrated with the panel at a factory, locations of these features must be accurate to high tolerances. Additionally, buildings in the real world are rarely strictly square, plumb, and regular. This is due both to initial inaccuracies in construction, but also to factors such as settlement and later alterations. Done manually, measuring a building to this level of accuracy is an extremely time-consuming process. EnergieSprong processes therefore typically employ automated measurement techniques, typically using a 3-dimensional laser scanner. These scanners send laser signals from a fixed point in space, and record the time it takes for the signal to return to the scanner. A few fixed points are required to completely record the exterior of a typical building, since this is a line-of-sight technology.

Once compiled, the result is known as a “point cloud.” This point cloud is a computer record of the precise 3-dimensional location of each of the reflected laser signals recorded by the scanner. These point clouds can be further refined into 3-dimensional vector representations of the whole building, and from there 2-dimensional drawings can be made that precisely locate features such as windows and corners. These are used to animate computer-controlled manufacturing equipment to create panels that precisely fit the underlying building.

This technology is commonly used by professionals in the building industry to create precise “as built” sets of drawings for a variety of purposes, including documentation of existing building for historic preservation projects. The technology is mature, and many contractors are available in the State of Minnesota to perform this service.

Energy and moisture performance

For the DOE Building America study, the SPS system was compared to two other systems: Energy Star Version 3 (Habitat for Humanity’s typical standard) and a system called OptiMN developed by students at the University of Minnesota for the DOE Solar Decathlon contest. Projects were all constructed by Twin Cities Habitat for Humanity (TC HfH). In the study, the same house design, called the Cedar 2.0, was constructed using each of the three techniques: SPS, Energy Star Version 3, and OptiMN. The Cedar 2.0 design was developed by Monopath and is optimized for large format OSB panels used in the SPS system. It is a 24 x 32 foot, two story house with a full basement. Figure 7 shows the Cedar 2.0 SPS house.

Figure 7 - Cedar Model (2014)

The Energy Star program is administered by the US EPA and represents a step up in energy performance from houses built merely to satisfy building code requirements. The system used to achieve this certification was 2x6 stud framing with R 21 batt insulation in the cavity, 7/16" OSB sheathing, housewrap water control layer, and one inch of XPS continuous insulation. A poly vapor retarder is used on the interior of the framing to prevent moisture intrusion into the cavity.

OptiMN is a "hybrid" approach. It uses a 2x4 stud frame with R13 batt insulation in the cavity. Sheathing is 7/16" OSB, with a peel and stick water / air control membrane. 3 inches of XPS continuous insulation is applied over this membrane, anchored with furring strips attached with long screws driven into studs. No interior vapor retarder is required, since the exterior continuous insulation keeps the sheathing warm, eliminating most risk of moisture accumulation in that layer. Table 3 describes the components of each of the previously discussed assembly types.

Table 3 - Construction Type Comparison

Feature	SPS	ES v.3	OptiMN	Overcoat
Internal Vapor Varrier	None	Poly vapor retarder	None	According to existing conditions
Framing	Two layers 1 1/8" OSB	2x6 studs	2x4 studs	One layer 1 1/8" or ¾"OSB
Cavity Insulation	None	R-21 batt	R-13 batt	According to existing conditions
Sheathing	None	7/16" OSB	7/16" OSB	None
Exterior Vapor Barrier Control Layers	Peel and stick water/air control membrane	Housewrap water control	Peel and stick water/air control membrane	Peel and stick water/air control membrane
Exterior Insulation	4" XPS	1" XPS	3" XPS	R-20 modeled

Air tightness

One critical component of energy efficiency is the degree to which a building enclosure can prevent uncontrolled exchange of indoor and outdoor air. This characteristic is called air tightness, and it can be measured using a blower door test. All homes in the study received commissioning by a third-party rater, and a blower door test was conducted as a part of this process. Air tightness results are shown in Table 4. Results are shown in three ways. The most common presentation is "ACH@50," which means air changes per hour at 50 Pascals pressure difference between inside and outside. This pressure difference is maintained by a blower door, which is a calibrated fan sealed tightly in an exterior door opening.

Table 4 - Blower Door Results and HERS Scores

House	Enclosure Type	ACH@50	CFM@50	CFM@50Pa per sf shell	HERS	Conditioned Shell Area - sf
2921 18th Ave S	2x6 Energy Star v3	1.38	489	0.106	48	4563
2352 James	2x4 OptiMN Hybrid	0.85	290	0.064	43	4563
2313 James	Solid Panel System	0.26	88	0.019	41	4563
3015 Thomas	Solid Panel System	0.41	140	0.031	39	4563
2954 Morgan	Solid Panel System	0.44	146	0.032	39	4563

All houses built by TC-Habitat for Humanity

The results show a significant difference in air tightness between the three technologies, with the SPS homes outperforming the OptiMN design, which in turn outperforms Energy Star. For comparison, the highly aggressive PassiveHouse standard requires ACH@50 of 0.6 or less; all three SPS houses significantly outperform this standard. It's important to note also that these homes were not built by professionals, but rather by volunteers. These extremely high levels of air tightness are inherent in the design of the system, and not dependent on high level craftsmanship to achieve.

Also shown in the table are the HERS ratings for the homes. HERS stands for Home Energy Rating System. It is a comprehensive energy efficiency score developed by Resnet and certified by HERS raters. A HERS score of 100 is a home built to the energy code, and lower numbers indicate better energy performance.

Energy performance

Extensive instrumentation was installed in the completed houses to track energy use. This data collection package could indicate what devices in the house (e.g., clothes dryer, furnace, A/C, range hood, etc.) were consuming energy recorded by the utility meters. However, the small sample size, combined with uncontrollable occupant behavior makes direct comparisons complex. Therefore, energy modeling studies were conducted in parallel. Table 5 shows the heating and cooling design loads for the various construction technology solutions. This is the energy demand during the coldest (for heating) and warmest (for cooling) hours of the year. Two approaches not previously described are included: a house built just to code, and one built to DOE Zero Energy Ready Home (ZERH) standards. ZERH is intended to be a significant step above Energy Star.

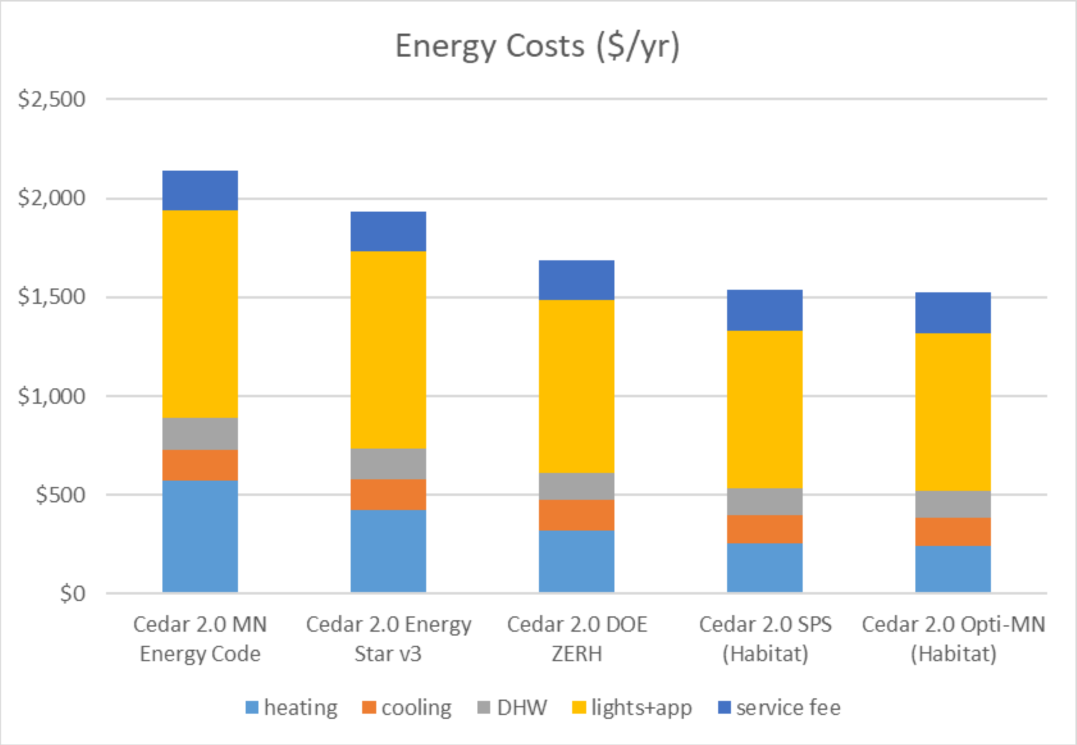
Table 5 - Modeled Design Loads

Model Name	Heating kBtu/hr	Cooling kBtu/hr
Cedar 2.0 MN Energy Code	40.2	19.0
Cedar 2.0 Energy Star v3	34.0	17.7
Cedar 2.0 DOE ZERH	27.9	15.2
Cedar 2.0 OptiMN (Habitat)	23.0	14.5
Cedar 2.0 SPS (Habitat)	23.9	14.6

This table shows that OptiMN slightly outperforms SPS in heating and cooling. This is due to the fact that OptiMN has a slightly higher whole-wall R-value than SPS; if desired it is a simple matter to add more thickness to the insulation layer to increase the thermal performance of SPS.

In addition to design loads, annual whole-house energy use was modeled. Figure 8 shows predicted whole-house energy consumption in dollars for the same five technologies. Again here, OptiMN slightly outperforms SPS due to the reduced heating and cooling loads.

Figure 8 - Annual Energy Consumption Breakdown by Type

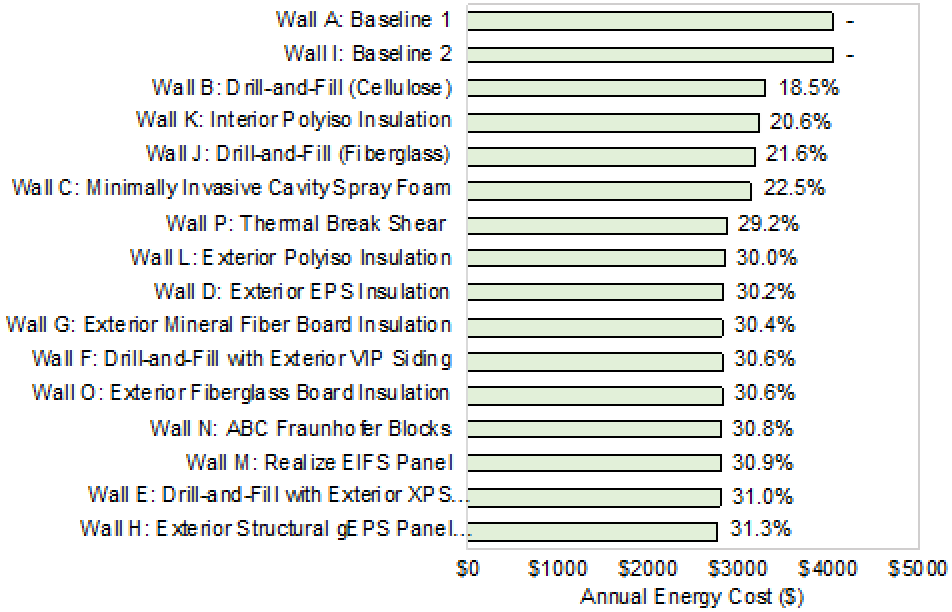


Following this DOE work, a prototype of a retrofit panel was tested at the Cloquet Residential Research Facility (CRRF) under a grant from PNNL. CRRF sits on the property of the University of Minnesota

Cloquet Forestry Center outside Cloquet, Minnesota. This panel was one of fourteen retrofit approaches tested during the two-year study. Like the DOE work, data were collected on the performance of the panel in the real world, then calibrated energy models were created to validate the monitored performance, and to extrapolate results to other climates.

Figure 9 shows the energy cost savings of the fourteen retrofits. These are measured against a baseline wall. The baseline wall was uninsulated and intended to represent construction practices up to approximately 1950. The Overcoat wall is Wall H, "Exterior Structural gEPS panel." Models were created for all US climate zones; Climate Zone 6 includes the Twin Cities. Of the walls tested at CRRF during this study, the Overcoat panel saves the most energy. Differences between the DOE and PNNL results can be attributed to a variety of factors, including differing house designs, different window selections, and different air tightness assumptions.

Figure 9 - Simulated Energy Results for Climate Zone 6



Moisture performance

For the DOE study, sheathing in the various houses was monitored for temperature, relative humidity, and moisture content. Monitoring devices were installed at six locations around the building enclosure. In addition, moisture modeling via computer model was also conducted. Figure 10 and Figure 11 show model results for the three technologies. Figure 10 represents conditions at the interior face of the sheathing, and Figure 11 represents the exterior face.

Figure 10 - WUFI Plus Simulation, OSB inner surface moisture content over three years

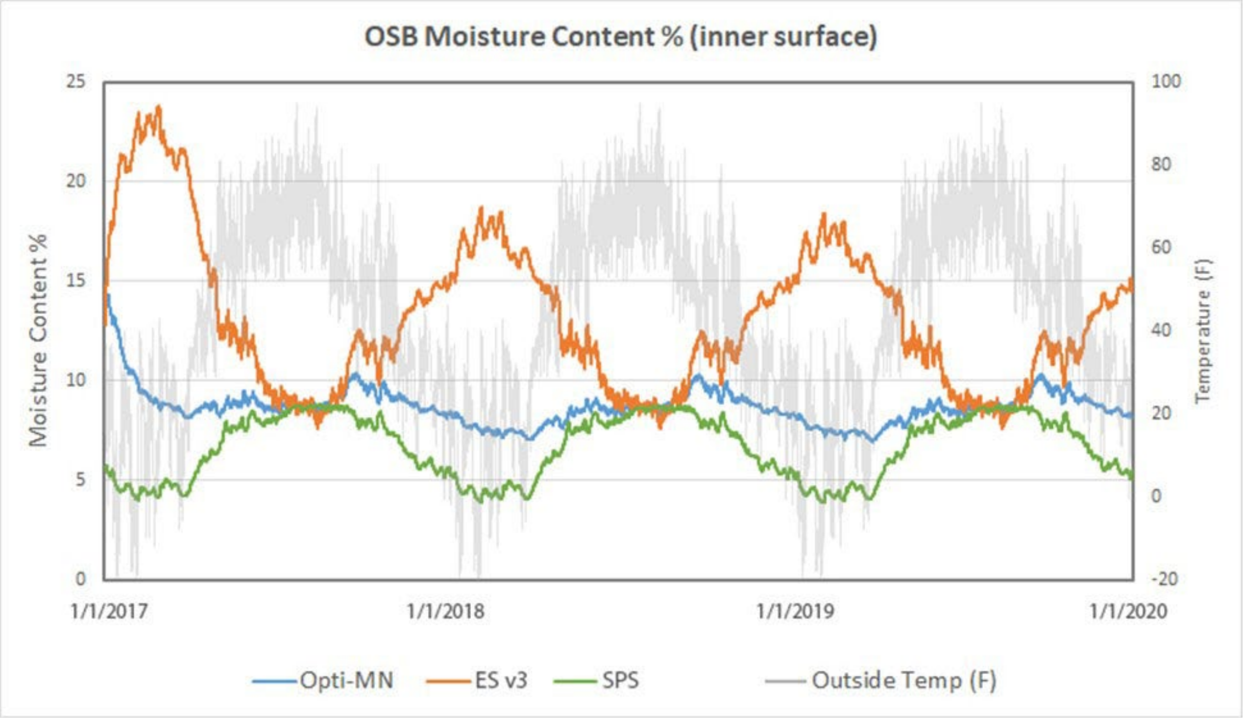
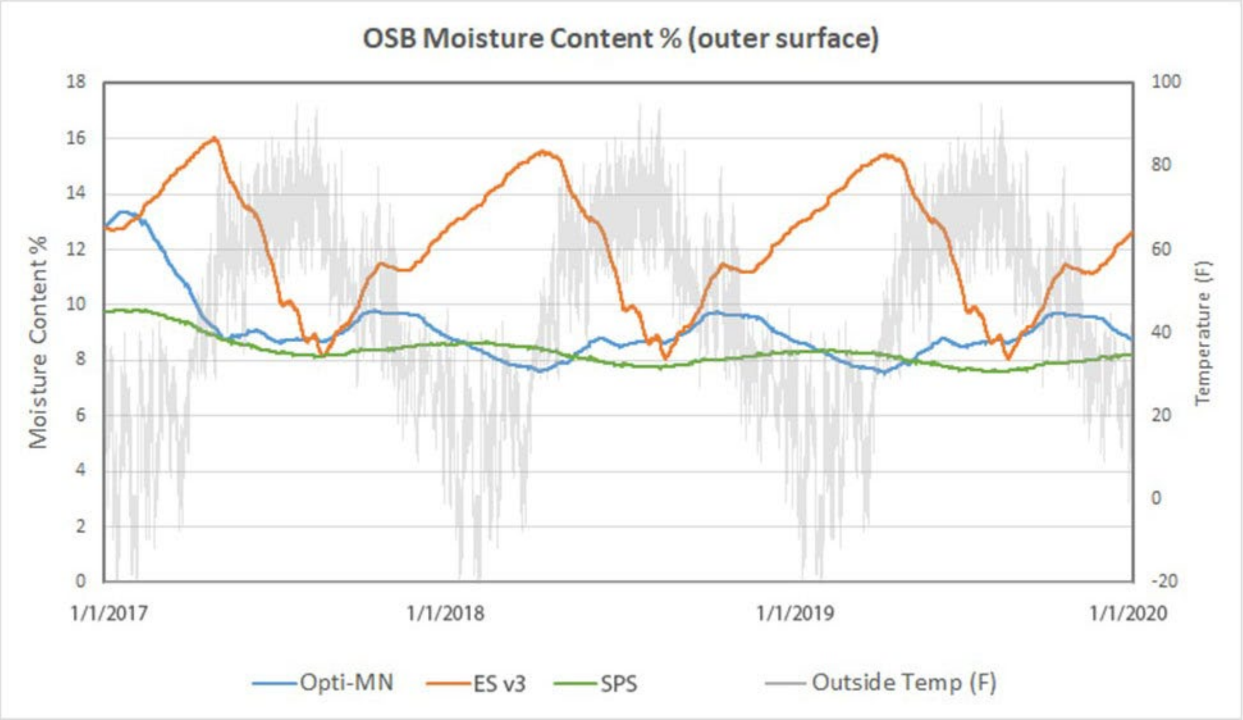


Figure 11 - WUFI Plus Simulation, OSB outer surface moisture content over three years



Moisture content here is expressed as a percentage; it is the weight of water adsorbed into the wood matrix divided by the weight of the wood. In general, moisture contents below about 12% are considered “safe,” while moisture contents above 15% can begin to cause concern. As the graphs show, the SPS approach shows lower overall moisture contents than the other two, and they remain extremely stable over time. This is due to the fact that all the thermal insulation is toward the outdoors, and therefore the susceptible wood component spends its lifetime at essentially ambient indoor conditions. With most of the insulation in the cavity, the Energy Star home shows the highest peaks in winter moisture content, however these peaks are still within a reasonable margin of safety. However, it is important to note that this modeling does not anticipate any bulk water intrusion. Because of its design (vapor retarder on the interior, foam insulation on the exterior) this wall has a significant risk of mold or decay should something like a window leak occur.

The Cloquet / PNNL study examined different metrics, opting to use a “mold index” to rate the performance of the walls. Like the SPS study, cavity-insulated options showed increased risk compared to exterior insulation approaches like the Overcoat panel. Also like the SPS study, no wall was found to fail, however no water leaks were modeled.

A key factor in the design of retrofit energy upgrades is the need to “do no harm” to the integrity of the existing building. Retrofits will change the flows of heat, air, and moisture through the building enclosure. This can have unintended negative consequences. For instance, if a cavity retrofit approach like drilling and filling with fiberglass insulation is applied to a home with leaking window openings, an enhancement of moisture damage risk is expected. This is because the insulation lowers the temperature of wood components that are toward the exterior surface. Once wetted, materials can only dry by vapor diffusion, which is enhanced by the addition of heat. If the design denies heat, then materials won’t dry. In many cases, there will be existing materials like poly vapor retarders and impermeable finishes that additionally impede drying. For this reason, retrofit approaches that leave the existing wall untouched, and accommodate all control layer functions outside the plane of the existing wall are safer since they will tend to bring all existing wall layers closer to ambient indoor conditions and promote drying.

Ideal Building Candidates

The Overcoat Panel System has the capability to be produced as complete panels up to 8 feet by 24 feet (2.44m x 7.32m). The maximum cost efficiency will be realized if these panels can be installed at sizes as close to this maximum as possible. This minimizes panel-to-panel connections, which require field labor to ensure continuity of the control layers. This efficiency is most profoundly compromised by deviations from simple planar building geometry like bump-outs, bay windows, attached balconies, and cantilevers.

One other critical cost consideration is code requirements for fire testing. In 2017, retrofit cladding on the Grenfell Tower in London caught fire, which rapidly spread vertically and horizontally to engulf the entire building. 72 people died as a result of the fire, with many more injured. This caused a profound reconsideration of fire codes in this country, especially in applied façade treatments on existing buildings. Partly because of this, applied assemblies in the US are required to meet the requirements of National Fire Protection Association Standard 285 (NFPA 285). This standard requires full-scale testing of complete assemblies (not single materials) for application to walls taller than 40 feet. This testing would be cost prohibitive for technologies in early stages of commercialization.

The list of criteria that will be used in selecting Minnesota buildings for examination in this study follows:

- Critical criteria:
    - Exterior walls less than 40 feet high, measured from grade (to avoid assembly fire testing under NFPA 285)
    - Minimal corners / bump-outs in building plan (simple rectangular is best)
- Slightly less critical:
    - Simple roof forms:
        - simple gable
        - simple hip
        - minimal (if any) dormers
        - flat roofs
    - Lack of balconies, decks, porch roofs, awnings, etc. unless they can be supported independently from building structure (or willingness to dispense with them)
    - Relatively high wall-surface to floor-area ratio (maximized importance of enclosure to building energy performance).
    - Known (by vintage or other means) to be un- or under-insulated
- Other positive attributes:
    - Poor building energy performance
    - Dilapidated exterior finishes (need for replacement anyway)
    - Comfort (cold) complaints
    - Consolidated ownership structure (one owner, many buildings)

Replacement Considerations for Mechanical Building Systems:

Using the data retrieved in the housing stock analysis heating, cooling, domestic hot water, ventilation system types, and utility metering structure were characterized for each of the “good” candidate projects for overcoat. These system types are currently in the process of being assessed for the following considerations for replacement or retrofit:

- Near end of life or inefficient equipment
    - Electric baseboard heating
    - Window units
    - Steam or non-condensing boilers
- Equipment utilizing the exterior walls
    - Sleeve AC units
    - Exhaust vents or ducts
- The ability for combustion equipment to draft and ventilate
    - Non-condensing heating systems
- The ability to provide fresh air ventilation to homes
    - Exhaust only driven ventilation

Heating and Cooling System Characteristics:

For the heating systems, we found that the predominate heating type in this study was hydronic non-condensing boilers.

However, the 2013 CARD Multifamily Rental Characterization study highlights a discrepancy between the majority of gas heating buildings found within its 120 building sample set compared to the findings in the American Community Survey. As shown in Table 6, the most current 2014-2018 survey indicates that nearly 40% of Minnesota multifamily properties use electric baseboard heating. To account for this we have made an adjustment to the number of electric baseboard projects to align with the American Community Survey data. Note 68 buildings were considered eligible of the 120 building sample set for retrofit based on exterior characteristics.

Table 6 - Sample Set Heating System Types

Heating	Count	Percent
Hydronic Boiler	31	46%
Hydronic Condensing Boiler	5	7%
Steam Boiler	1	1%
Electric Baseboard	27	40%
Furnace	4	6%
Total	**68**	100%

As shown in Table 7, no central cooling systems were present in the sample with sleeve AC being the predominant source of cooling.

Table 7 - Sample Set Cooling System Types

Cooling	Count	Percent
None	4	6%
Sleeve AC	45	66%
Window AC	19	28%
Total	**68**	100%

Heating and Cooling Replacement Considerations:

The most common heating system types were hydronic non-condensing boilers and electric resistance baseboard. Both of these systems are relatively inefficient compared to condensing boilers and heat pump technology respectively.

An area of concern is the modulation, temperature rise limitations, and control of the existing boiler and radiator systems. With a highly insulated envelope, the loads on the building will be much smaller, thus requiring lowering the heating hot water supply temperature of a hydronic heating system, modulating the flow, or both.

While only 1% of good-candidate projects remain as steam heat some of those older conversions may still need updated zone controls to reduce comfort concerns. It is more challenging to evenly heat a building avoiding large temperature swings which would be made worse by dramatically lower envelope loads. Steam systems were predominate before 1960 accounting for 24% of the good-candidate projects.

Buildings built after 1960, generally have separate zoning for each unit and could take advantage of lower operating temperatures and modulation to maintain conditioning under reduced envelope loads. Non-condensing boilers and those serving dual purpose heating and hot water would have a challenge changing operating temperatures: these would be good candidates for replacement with condensing systems at the time of retrofit. Existing condensing boilers could remain in place.

A tightly sealed envelope < 0.5 AHC may pose problems for natural draft gas fired heating equipment. Of the gas fired boilers, 24% are not provided with combustion make-up air, with no real difference between pre- and post-1960 buildings.

Generally, boilers that are non-condensing (46% of buildings) should be retrofitted to direct-vent sealed condensing systems.

Non-condensing furnace systems (3% of buildings) could also have similar problems with make-up combustion air and should be considered for retrofit. A possible high-efficiency alternative would be individual air-source heat pumps, though at current natural gas and electricity prices, this could increase tenant heating bills.

While cooling was provided in nearly all of the sample buildings, no central cooling systems were present with sleeve AC making up 66% of buildings and window AC units covering 28% percent of buildings. These systems are inherently inefficient, very leaky, and are expected to be of an age with SEERs below that of current energy code. Additional retrofit works would also need to be done to accommodate the through wall sleeve AC units with the Overcoat Panel System.

A holistic system that provides both heating and cooling using heat pump technology would be a viable solution. This is especially true where electric baseboard heating is being replaced, thus ensuring adequate electrical-panel capacity for the heat pump system.

Domestic Hot Water System (DHW) Characteristics:

Though the good-candidate properties in the sample have a mix of fuel types and individual-unit versus central systems, the predominant system provides domestic hot water with one or more central, non-condensing hot water heaters using natural gas as shown in Table 8:

Table 8 - Sample Set Domestic Hot Water System Types

DHW	Count	Percent
Electric Individual	5	7%
Electric Central	0	0%
Gas Individual, non-condensing	3	4%

DHW	Count	Percent
Gas Central, non-condensing	51	75%
Gas Central, condensing	4	6%
Gas Shared with Heating, non-condensing	3	4%
Gas Shared with Heating, condensing	2	3%
Total	**68**	100%

Domestic Hot Water Replacement Considerations:

For the dominant system type of commercial non-condensing water heaters in a central mechanical room, the main retrofit consideration would be provision of adequate combustion air after the building is tightened. For the properties in the original characterization study, three in four were in mechanical rooms that already had provisions for makeup air, but roughly one in four would likely need to have combustion makeup air provided following retrofit. Another option would be to replace these inefficient water heaters with a high-efficiency sealed-combustion gas unit or a heat pump water heater at the time of retrofit. However, the original characterization study estimated that DHW accounts for only about 10 percent of energy use in multifamily properties, so replacement of these systems may be a lower priority. Buildings where space-heating and domestic hot water needs are met by the same equipment would require more complicated decision-making regarding replacement options and costs.

Non-condensing individual gas water heaters could also face make-up air issues following retrofit and thus may need to be replaced. Smaller residential style residential heat pump water heaters are readily available in the market. An important consideration is that because these units absorb heat from their surroundings, provisions to avoid undesired cooling of mechanical spaces or unit living spaces are needed. While electric resistance DHW would not face combustion-related concerns following retrofit, these could likely be cost-effectively replaced with heat pump water heaters that would use about 60 percent less electricity—provided the aforementioned potential issues with undesired space-cooling can be addressed.

Ventilation Systems Characteristics:

22% of properties had visible ventilation vents on the exterior walls. It is likely that majority of these represent properties with bathroom-exhaust ventilation systems with no make-up air.

Ventilation Replacement Considerations:

Overcladding the properties will significantly reduce infiltration levels to approximately 1 ACH or less, depending on roof sealing. This reduction in envelope leakage poses challenges to conventional exhaust driven (bathroom fan) ventilation solutions that pull make-up air from cracks and openings to the outside.

One solution would be to install louvered trickle vents on the side of the unit to provide a source of make-up air for ventilation, but these can result in undesirable cold drafts–and would reduce the energy savings potential of the retrofit.

A better solution would be to temper the makeup air through an energy recovery system that supplies balanced ventilation to the building while minimizing the associated heat loss (Minnesota energy code requires such systems in low-rise new construction). This system would provide a low level of constant supply and exhausts. Constant exhaust sources would be located in both the bathroom(s) and the kitchen. In many properties this could be done through individual-unit systems, though at some cost. Some systems also recover humidity, helping maintain healthy indoor humidity levels in the winter. If additional and or intermittent exhaust is required for clothes dryers or kitchen hood exhaust, a more conventional makeup air unit would be required so that the units remain properly pressurized with balanced and tempered supply air.

“Combi” Systems

In addition to the individual space-heating and cooling, domestic hot-water and ventilation strategies described above, it should be noted that efforts are underway to commercialize individual-unit “combi” systems to provide most or even all of these services in a self-contained, drop-in unit for the U.S. market. One such unit, produced by Danish manufacturer Systemair and already available in Europe, is the focus of a current DOE-funded research effort. Such systems could radically simplify the HVAC and domestic hot water adaptions and efficiency improvements associated with overcladding multifamily properties. For the time being, however, these systems are still on the horizon for the most part.

Utility Metering Arrangements

When considering mechanic system upgrades it is important understand the utility metering within the property. Whether the landlord or the tenants pay the space-heating and cooling and domestic hot water energy bills has a bearing on decision-making regarding system change-outs at the time of retrofit.

For the majority of properties from the original characterization study that were identified as good retrofit candidates, as shown in Table 9, the landlord is paying for the gas heating and domestic hot water, while the tenant is responsible for in-unit electricity, which typically includes a room or sleeve air conditioner:

Table 9 – Sample Set Tenant Paid Utilities

Tenant pays	Count	Percent
Heat	9	13%
Elec	61	90%

Projects that would replace centralized hydronic heating with individual heat pumps would likely move the burden of heating utility payments to the renter. This could create more positive cashflow for the owner but would result in higher utility bills for the tenant.

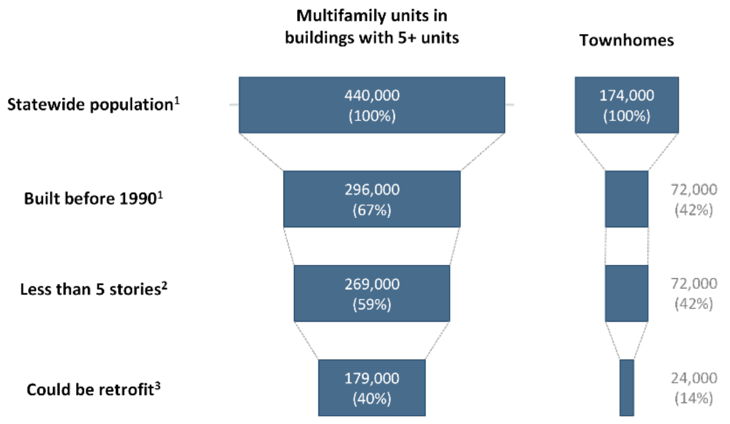
Housing Stock Analysis

The goal of the housing stock analysis was to estimate the proportion of Minnesota multifamily housing that could be retrofitted with the Overcoat system, as well as to identify key indicators of good (or poor) candidates for retrofit.

To conduct the analysis, we relied on a statistical sample of 120 properties identified in a prior CARD study that characterized 5+ unit multifamily housing and single-family-attached townhomes[2,3]. Because the Overcoat retrofit would be difficult to apply to taller properties without extensive assembly fire testing, we screened the characterization-study sample to properties that were four stories or less in height. We also eliminated properties built in the 1990s or later, because these would likely already be reasonably well insulated. We then used publicly available imagery to classify the 97 remaining properties as good or poor candidates for retrofit based on a visual review of the complexity of the facade, architectural features and other building aspects that might hinder retrofit. Finally, we used Census data to extrapolate the results to the latest estimates for the statewide population of townhomes and multifamily housing units.

The results suggest that about 40 percent of all multifamily housing units are in buildings that could be retrofit with the Overcoat system as shown in Figure 12. The number of townhomes that could be retrofit is much lower, because the population of townhomes is considerably less, townhomes are more likely to be newer and thus already well insulated and because we judged fewer townhomes to be amenable to retrofit based on a visual review. However, our sample of townhomes consisted of only six properties, so there is considerable uncertainty in the last step.

Figure 12 - Estimated Number of MN Housing Units Appropriate for Overcoat Retrofit



1. Source: 2015-2019 Census American Community Survey
2. Source: 2013 Minnesota Multifamily Rental Characterization Study
3. Based on visual review of Rental Characterization Study sample properties

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[2] Pigg, Scott, Jeannette LeZaks, Karen Koski, Ingo Bensch and Steve Kihm. 2013. "Minnesota Multifamily Rental Characterization Study," report prepared for the Minnesota Department of Commerce, Division of Energy Resources, Energy Center of Wisconsin and Franklin Energy, June 2013.

[3] Note that the characterization study was heavily skewed towards properties with gas heat. On a population basis more than a third of 5+ unit multifamily and townhome housing units are heated with electricity.

Figure 13 and Figure 14 show examples of properties that were classified as good and poor candidates for retrofit. Good candidates have simple form factors with large wall surfaces and few corners to deal with. Poor candidates have more complex form factors with many smaller surfaces and corners. Some historic buildings also have facades with complex architectural features that would be difficult work around—and where an Overcoat retrofit would substantially alter the visual character of the property.

Figure 13 - Examples of Good Candidates for Retrofit

Figure 14 - Examples of Poor Candidates for Retrofit

The visual review revealed balconies to be a key factor in amenability to retrofit: some properties have integral balconies that cannot be removed for retrofit work and would be difficult to work around.

Others have no balconies or have wooden balconies that are supported from the ground and could be unbolted from walls for retrofit, as shown in Figure 15.

Figure 15 - Example of Temporary Removal for Retrofit

Somewhat surprisingly, we did not find any significant relationship between the age of a multifamily property and its amenability to retrofit, at least among the pre-1990s, low-rise properties that were reviewed: a solid majority of properties in all age categories could likely be retrofitted as shown in Table 10. Note, however, that existing wall insulation was not well determined in the original characterization study and thus not a part of our screening criteria here. The 1980s was a transition decade in terms of insulation levels, as the first energy codes came into effect around the start of the decade. Statewide, a quarter of all pre-1990s multifamily housing was constructed in the 1980s, as was nearly half of townhomes.

Table 10 - Multifamily Property Amenability to Retrofit

Decade Built	% Amenable to Retrofit – Yes	% Amenable to Retrofit – No
<1940	64%	36%
1940s	75%	25%
1950s	67%	33%
1960s	82%	18%
1970s	70%	30%
1980s	75%	25%
Overall	73%	27%

Roof types varied among multifamily properties judged to be amenable to retrofit, as shown in Table . Properties judged to be suitable for retrofit had one or more of several roof types: “flat” roofs with and without parapets, sloped roofs that terminate in a gable end, and sloped roofs that terminate in hips. The historical approach used in EnergieSprong projects includes adding retrofit panels over existing roof structure and finishes. This may be appropriate for some candidate buildings; however an attic floor energy upgrade may be more cost effective in many cases. Approaches to these various conditions will be explored later in this paper. Some properties that we examined had false-mansard-roof architectural features that could be retrofitted if the false-mansard feature was removed, as shown in Figure 16.

Table 11 – Roof Types for Multifamily Properties Amenable to Retrofit

Roof Type	% of Properties
Flat without parapet	29%
Flat with parapet	18%
Pitched – Gable	29%
Pitched – Hip	23%
Mixed	2%

Figure 16 - Example of Permanent Removal for Retrofit

Almost all of the properties that were judged to be amenable to retrofit had wall-mounted items that would need to be dealt with during the retrofit, as shown in Table . Most common was the presence of sleeve air conditioning units: these could conceivably be eliminated if the HVAC system for the property was also revamped to rely on an alternative cooling strategy, such as mini-split heat pumps.

Table 12 - Wall Mounted Items Observed on Multifamily Properties Amenable to Retrofit

Item	% Properties with Observed Instance [f]
Sleeve air conditioner	60%
Drainpipe(s)	41%

Item	% Properties with Observed Instance [f]
Entry overhangs or awnings	37%
Exterior lighting	35%
Electric or gas service	25%
Wall venting (dryers, etc.)	22%
Satellite dishes	6%
Window shutters	4%

f) Observed incidence is for items visible in publicly available imagery, which often includes only part of the building exterior.

Energy Savings Methodology

A series of energy models were developed to assess potential energy savings, utility cost impacts, and carbon reductions from both the overcoat insulation system and recommend mechanical upgrades. The analysis was conducted using a DOE 2 energy model based on four candidate buildings as a representative sample ranging in construction type, age, and size . These buildings are the same properties used to investigate the costs for overcladding.

A series of energy models were developed to assess potential energy savings, utility cost impacts, and. These buildings are the same properties used to investigate the costs for overcladding. Details about these for buildings are shown below, in Table 13.

Table 13 - Candidate Building Characteristics

Characteristic	Building 1	Building 2	Building 3	Building 4
Building Area (ft2)	5,000	9,100	58,600	22,000
Number of Stories	3	2	3	3
Number of Units	5	8	123	23
Exterior Wall Construction	Standard wood frame, no insulation [h]	Standard wood frame, no insulation [h]	Brick cavity wall, no insulation [h]	Standard wood frame, no insulation [h]
Alternate Exterior Wall Construction	Standard wood frame with R-13 batt insulation	Standard wood frame with R-13 batt insulation	n/a	Standard wood frame with R-13 batt insulation

Characteristic	Building 1	Building 2	Building 3	Building 4
Roof Construction	6-inch batt insulation (R-19)	12-inch loose fill insulation (R-30)	6-inch batt insulation (R-19)	6-inch batt insulation (R-19)
Window Type	Single pane (U = 1.05, SHGC = 0.86)[i]	Single pane (U = 1.05, SHGC = 0.86)[i]	Single pane (U = 1.05, SHGC = 0.86)[i]	Single pane (U = 1.05, SHGC = 0.86)[i]
Infiltration	4-6 Air Changes Per Hour @50 Pa	4-6 Air Changes Per Hour @50 Pa	4-6 Air Changes Per Hour @50 Pa	4-6 Air Changes Per Hour @50 Pa
HVAC System	Electric baseboards with through-wall air conditioners [j]	Hot water boiler [k] with through-wall air conditioners [j]	Hot water boiler [k] with through-wall air conditioners [j]	Electric baseboards with through-wall air conditioners [j]
Ventilation	Bath fan only	Bath fan only	Bath fan only	Bath fan only

h) Modeled as a U-value of 0.20 Btu/hr.sqft.F

i) Obtained from DOE-2 software Glass Library

j) 10.7 EER

k) 80% thermal efficiency

Table 14 shows the post-retrofit characteristics of the modeled buildings. Two model runs were conducted: one to test the effect of the Overcoat enclosure upgrade alone, and one to measure the effect of a mechanical system upgrade to include mini-split heat pumps for space conditioning. Since the enclosure upgrade is anticipated to significantly decrease infiltration of outdoor air, balanced ventilation was included in the enclosure-only retrofit package to ensure good indoor air quality.

Table 14 - Modeled Characteristics Post Retrofit

Characteristic	Building 1	Building 2	Building 3	Building 4
Exterior Wall Construction	R-20 or R-30 overcladding, installed over existing wall	R-20 or R-30 overcladding, installed over existing wall	R-20 or R-30 overcladding, installed over existing wall	R-20 or R-30 overcladding, installed over existing wall
Roof Construction	R-60 insulation	R-60 insulation	R-60 insulation	R-60 insulation
Window Type	Triple pane (U=0.2, SHGC=0.34)	Triple pane (U=0.2, SHGC=0.34)	Triple pane (U=0.2, SHGC=0.34)	Triple pane (U=0.2, SHGC=0.34)
Infiltration	1 air change per hour @50 Pa	1 air change per hour @50 Pa	1 air change per hour @50 Pa	1 air change per hour @50 Pa
HVAC System 1	Same As Baseline	Same As Baseline	Same As Baseline	Same As Baseline

Characteristic	Building 1	Building 2	Building 3	Building 4
Ventilation 1	75 cfm in-unit balanced ventilation with energy recovery ventilator [l]	75 cfm in-unit balanced ventilation with energy recovery ventilator [l]	75 cfm in-unit balanced ventilation with energy recovery ventilator [l]	75 cfm in-unit balanced ventilation with energy recovery ventilator [l]
HVAC System 2	Retrofit with mini-split heat pumps [m]	Retrofit with mini-split heat pumps [m]	Retrofit with mini-split heat pumps [m]	Retrofit with mini-split heat pumps [m]
Ventilation 2	75 cfm in-unit balanced ventilation with energy recovery ventilator [l]	75 cfm in-unit balanced ventilation with energy recovery ventilator [l]	75 cfm in-unit balanced ventilation with energy recovery ventilator [l]	75 cfm in-unit balanced ventilation with energy recovery ventilator [l]

l) Enthalpy heat exchanger with 50% total energy recovery effectiveness
m) 12.5 EER / 10.6 HSPF

The baseline condition for comparison was developed for both gas boiler and electric resistance heating systems and window air conditioning units for cooling. Building ventilation was assumed to be exhaust driven through intermittent bathroom fan operation. Envelope performance was established for windows, wall and roof insulation, and infiltration based on the prevalent construction practices at the time of construction pre-1970. A second baseline case was also developed to investigate impacts on properties with some internal insulation included at the time of construction or as part of a retrofit.

A basic model calibration based on expected residential energy use was conducted to help inform baseline conditions in conjunction with data reviewed in the 2013 CARD Multifamily Rental Characterization study. Key unknown building parameters were adjusted until the baseline simulations' distribution of Energy Use Intensities (EUIs) aligned with the distribution from the characterization report data set.

When calibrated to the data, the whole-building EUI of most existing buildings falls between 51.8 and 97.2 kBtu/sqft per year, with about half of buildings falling between 63.3 and 78.5 kBtu/sqft. Buildings with lower levels of infiltration and with modest existing levels of wall insulation fall towards the lower end of this scale, while leakier buildings without any preexisting insulation fall towards the higher end.

The proposed models represent an overall improvement in wall insulation and reduction in infiltration from the OPS, addition of new high-performance windows, and improved roof or attic insulation. In cases where electric resistance heat was considered the baseline heating condition the HVAC system was upgraded to include heat pumps and energy recovery ventilation. Where gas heating was the baseline condition, two proposed cases were analyzed. The first, Retro-A, was an upgrade to condensing heating and the other, Retro-B, was to electrify systems with heat pumps. In both cases energy recovery ventilation was included.

For utility costs, 2022 Xcel Energy rate code A01, Residential Service, was used for electricity using the monthly charge for overhead service and the standard option for the energy charge. Rate code 101, Residential Firm Service, was used for gas. Carbon emission estimates were based on emissions factors taken from the US Energy Information Administration State Electricity Profile for Minnesota for electricity[4] and from the US EPA Center for Corporate Climate Leadership GHG Emission Factors Hub for natural gas[5].

Sensitivity Analysis

Given the wide range of envelope conditions present in the building stock, significant uncertainty exists when considering an individual retrofit case. This uncertainty is primarily driven by infiltration rates due to site conditions and the leakiness of the existing envelope, and by the presence or absence of existing insulation. The baseline model calibration described previously is a way to characterize the sensitivities due to differences in existing conditions. The findings indicate that these differences do impact the magnitude of savings, and that the greatest impact comes from whether or not insulation already exists in a building. When preexisting cavity insulation was included in the baseline, savings potential is reduced by about 6 percentage points compared to an uninsulated wall. We also performed a sensitivity analysis on baseline infiltration rates between 4 ACH and 6 ACH against the anticipated improvement down to 1.0 ACH. This resulted in a +/- 6 percentage point change in EUI savings compared to a midrange infiltration of 5 ACH. While important to consider, these impacts are generally small relative to the total potential savings generated by an overcoat retrofit. When further increasing the overcoat insulation from 4 inches of XPS (R-20) to 5 inches (R-30) we found the energy improvement is negligible. The bulk of the energy savings comes from the initial increase in continuous exterior insulation and the reduction in infiltration.

Supply Chain Requirements

Panels

As presently conceived, the proposed panel consists of a base sheet of 1 1/8" thick oriented strand board (OSB) that is 8 feet wide and 24 feet long. A water control layer is applied over this, integrated with flashings for doors and windows. This layer is followed by a rigid insulation thermal control layer. Wood furring strips are laid over the insulation and attached to the OSB using long screws. Cladding is attached to the furring strips.

A variety of materials are under investigation for the water control and thermal control layers; however we do not anticipate using any materials that are not readily available in the marketplace.

Process

The Energiesprong upgrade process includes these steps:

1. Create a three-dimensional digital model of the recipient building, using 3-D laser scanning technology or photometry.
2. Use the 3-D model to design overcladding panels to precisely fit the surfaces on the building.

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[4] U.S. Energy Information Administration, Minnesota Electricity Profile 2021, (https://www.eia.gov/electricity/state/minnesota/)

[5] Environmental Protection Agency, GHG Emissions Factors Hub, (https://www.epa.gov/climateleadership/ghg-emission-factors-hub)

3. Fabricate the panels. Panels using this process are "unitized," meaning that they incorporate all material layers, as well as doors and windows. Fabrication is significantly aided by computer numeric control (CNC) machinery working from digital models.
4. Fabricate any mechanical "pods" or devices that will be installed with the overcladding.
5. Perform any required demolition on the target building. This includes:
    a. Decks, awnings, cornices, and other architectural obstructions
    b. Obsolete mechanical equipment
    c. Exterior electrical devices like lighting and receptacles
    d. Gas meters
6. Attach anchor points to the building to support the panels.
7. Deliver and install the panels, ensuring that all control layers and finishes are continuous across the building surfaces. Panels are typically installed using a crane.
8. New mechanical systems that are integrated with the overcladding are installed simultaneously.
9. Demolish existing doors and windows.
10. Extend window and door jambs.
11. Make any required interior mechanical connections or additions.

This process involves some specialized skilled trades and facilities:

1. A building "survey" team who can create a 3-D computer model based on data acquired with 3-D laser scanners and / or photometric data generated from photographs (often taken from a drone).
2. A team that utilizes the 3-D models to design the suite of panels for a particular project. These designs will be described in CAD models.
3. A manufacturing facility that can use these CAD models in a computer assisted manufacturing (CAM) process to cut and assemble panel components.
4. An installation team that does the following:
    a. Upgrades foundation insulation as required (likely includes some excavation to expose below-grade foundation)
    b. Performs any required demolition
    c. Fastens anchor points to the building
    d. Picks panels off the delivery truck with a crane, and installs them to the anchor points
    e. Makes control layer and finish layer connections to complete the enclosure upgrade
5. A finish carpentry team that extends window and door jambs to meet the new windows and doors in the panels.
6. A mechanical installation team that performs any required mechanical demolition and installs new equipment, to the extent the new equipment is not integral with the overcladding.

In practice, many of these steps will likely be integrated under one commercial entity. For instance, steps 1-5 are commonly integrated under one company for projects that have been completed in the Netherlands. This integration will tend to decrease "friction" between trades and steps, reducing costs and increasing speed.

Panel transportation is anticipated to be a significant cost driver, since panels are large and must be packed carefully to avoid damage. This indicates that panel manufacturing should occur within reasonable trucking distance of proposed projects.

Mechanical contractors are specially licensed in Minnesota; however, it may be preferable to employ a specialized mechanical team under the same organizational umbrella. This is because the techniques and technologies involved are likely to be outside the expertise of typical practitioners, and quoted prices in the open marketplace are commonly very high for innovative technologies. A specialized workforce employed by the prime contractor (or independent contractors certified and retained for the Energiesprong work) will likely drive down costs.

Other services or processes that are important but not studied in depth in this study include:

1. R&D funding mechanism for process and project development
2. Project funding mechanisms
3. Marketing
4. Energy modeling
5. Hazardous material assessment and abatement if required
6. Renewable energy system design and installation
7. QA / QC to verify the upgrade is installed correctly and performs as intended

Results

Overcoat Panel System Implementation

The OPS is designed to be fabricated offsite. The first phase of construction involves the creation of a 3-dimensional model of the candidate building to enable the production of panels that precisely fit the building, and accommodate deviations from plumb, square and level conditions that are common in existing buildings. EnergieSprong processes typically employ automated measurement techniques, often using a 3-dimensional laser scanner. These scanners send laser signals from a fixed point in space and record the time it takes for the signal to return to the scanner after it reflects back from the building. A few fixed points are required to completely record the exterior of a typical building, since this is a line-of-sight technology. The resulting model is called a point cloud.

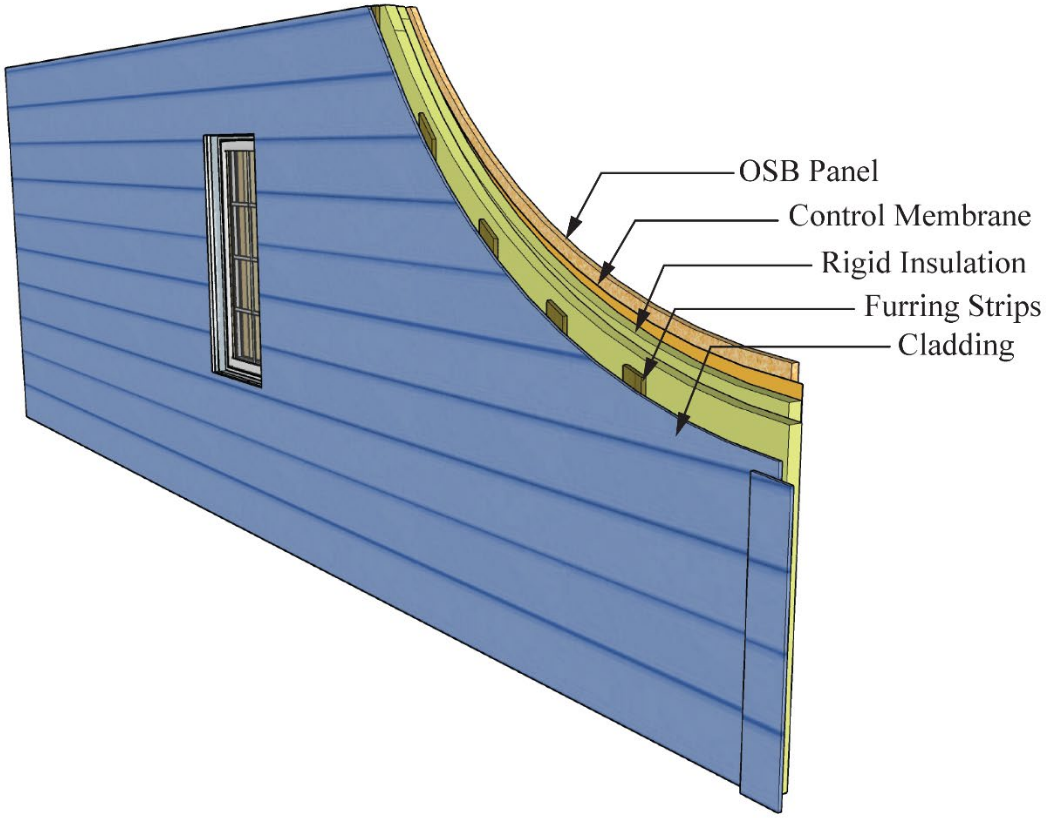
These point clouds can be further refined into 3-D vector representations of the whole building, and from that point 2-dimensional drawings can be extracted that precisely locate features such as windows, corners, and penetrations. These drawings, in turn, are used to drive computer numeric controlled (CNC) machinery that cuts the panels precisely to fit the candidate building.

Windows and doors would be installed at the factory and integrated with the water control layer. Insulation and furring strips would also be factory installed, along with the cladding material. Complete panels could then be shipped to the jobsite and installed quickly with minimal disruption to occupants.

Figure 17 shows a diagram of the Overcoat Panel concept. It is constructed on an OSB structural panel. A membrane is applied to this panel for control of airflow, water, and vapor diffusion. To date this membrane has been a peel-and-stick material, however other materials like liquid applied membranes and structural panels with an integral control layer function are also appropriate. Rigid insulation is applied over the membrane. This layer could be foam plastic, fibrous insulation like mineral wool, or vacuum panels. Furring strips are laid over the insulation and fastened back to the OSB using screws or bolts and t-nuts. The T-nut would be inset into the back side of the OSB panel, with the bolt inserted through the furring strips, insulation and OSB to engage the threads. A T-nut connection enables the use of thinner OSB substrates, since thread engagement depth in the OSB is eliminated as a concern. The Overcoat panel is attached to the existing building using a French cleat style which ties to the existing structural system. This attachment is described further on Page 68.

The furring strips provide a fastening surface for the cladding and create a gap between the insulation and cladding for ventilation, drainage, and to enhance drying potential. A wide variety of cladding materials could be used, including metal panels, or wood, composite, or fiber-cement siding systems.

Figure 17 - Overcoat Panel Diagram



Continuity of air control and thermal control layers is critical to ensure achieving the energy saving and moisture performance potential of the system. Therefore, joint details were developed to ensure the continuity of these layers. Figure 18 shows a typical horizontal panel-to-panel joint. Each layer is offset from its predecessor to provide continuity of the control layers in this “blind” connection. The structural connection is made to the building and is shown later in this section. The water control layer here is depicted as peel-and-stick membrane applied to the OSB; modified details would be required for alternate water control layers such as liquid applied membranes. At the bottom edge of the upper panel in the upper panel in Figure 18, the membrane is adhered to the adjoining rigid insulation using an adhesive or double-faced tape. The release paper is left attached to the adhesive face of the exposed portion of the membrane until just before panel installation. This adhesive engages shingle-style with the membrane on the previously installed lower panel. The membrane on the lower panel is raised off the plane of the OSB by a compressible space (shown here as a wedge) to ensure a robust airtight seal once the upper panel is set in place.

The rigid insulation, in turn, is assembled in two layers, and offset to reduce air infiltration at the joint. The insulation is permanently held in place by the wood furring strips, attached to the OSB using T-nuts or long screws. A variety of claddings are appropriate. Metal siding is shown here, with a flashing that ensures good protection from precipitation.

The assembly diagrams also depict a “squishy layer.” Building surfaces are often not flat and coplanar. The OPS is intended to be applied over most existing claddings to eliminate the cost of demolition in many cases. We utilize a lightweight filler material between the back of the panel and the exterior surface to fill any gaps. This filler material, referred to colloquially as the “squishy layer” is compressible, and serves to limit air movement behind the panel. Though details at panel seams and terminations are designed to eliminate airflow that would bypass the thermal control layer, convective movement of air in this interstitial space could still compromise thermal or moisture performance. The material chosen should be able to drain any accumulated water down and out of the assembly. Figure 18 shows a horizontal panel seam connection installed over lap siding. The squishy layer fills the spaces between the irregular cladding surface and the back of the panel.

Figure 18 - Horizontal Panel Seam - Section View

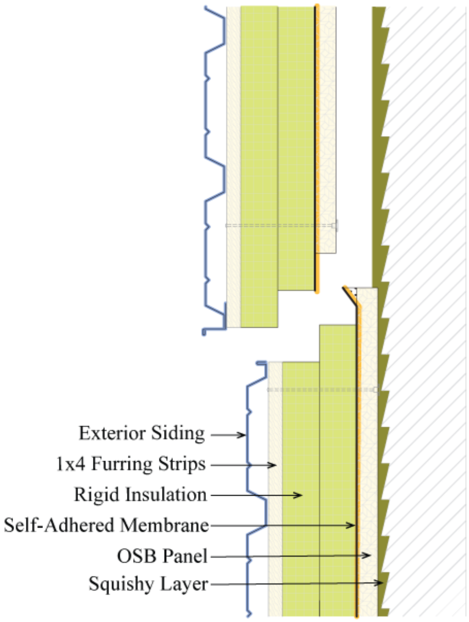


Figure 19 shows a vertical panel-to-panel seam. A similar approach has been taken here to ensure continuity of the control layers.

Figure 19 - Vertical Panel Seam, Plan View

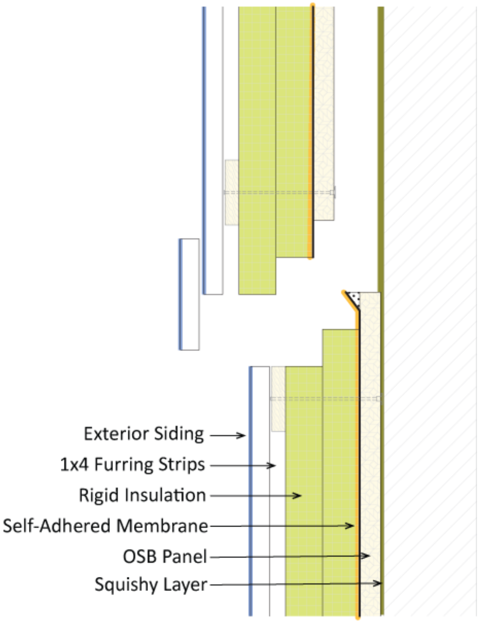


Figure 20 and Figure 21 show an alternate insulation scheme using vacuum insulation panels (VIPs), applied to a vertical panel-to-panel joint. VIPs achieve high R-values in thin profiles, on the order of R-20 in a 1-inch-thick panel, which greatly reduces the overall panel thickness. The VIPs consist of a sealed envelope surrounding a lightweight but rigid core, from which the air has been evacuated. The chief vulnerability of VIPs in service is to penetration by fasteners, since this violates the vacuum seal and significantly reduces the thermal resistance of the panel.

For this reason, we propose fastening the VIPs to the Overcoat panel using a system of extruded mounting blocks, produced from a low thermal conductivity material like certain plastics. These mounting blocks would secure the VIPs to the Overcoat panel and provide a fastening location for cladding systems.

Figure 20 - Vacuum Panel Insulation Assembly - Exploded Plan View

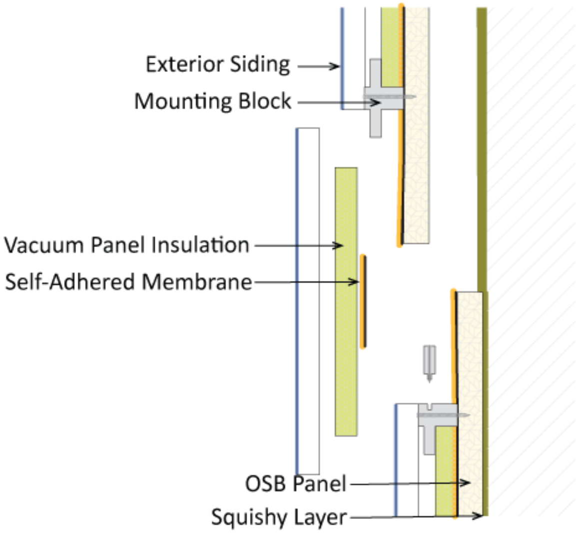
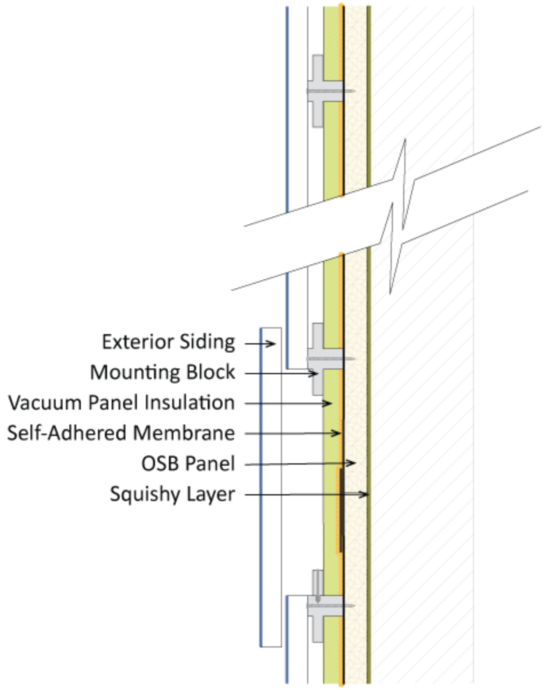


Figure 21 - Vacuum Panel Insulation Assembly – Plan View



During assembly in the field, joints where panels meet or at inside and outside corners, can be handled in one of two ways: “blind” connections, where the control layers are connected by virtue of their geometry as one panel is placed against another, and “open” connections, where the final connection is made by technicians in the field. Figure 22 and Figure 23 show a blind connection at an outside corner. For blind connections, air barrier continuity is the main challenge, since a slight out-of-plane condition between the adjacent panels could lead to a gap between the adhesive (inner) side of one panel’s membrane and the outer surface of its adjacent panel’s membrane. This discontinuity could allow air leakage, which would compromise energy and moisture performance. For this reason, we recommend a compressible wedge or similar extrusion that pushes one panel’s membrane out of plane with the panel to ensure good adhesion (see Figure 18). Staggered seams in the insulation layer serve to limit air leakage at joints and are common to both joint types.

In Figure 22, the two wall panels join at the corner in a blind configuration. In Figure 23, A separate prefabricated corner component connects the control layers of the adjoining wall panels. Especially for buildings with significant geometric defects, this configuration may be preferable to ensure control layer continuity.

Figure 22 - Outside Corner Connection – Blind, Option 1 – Plan View

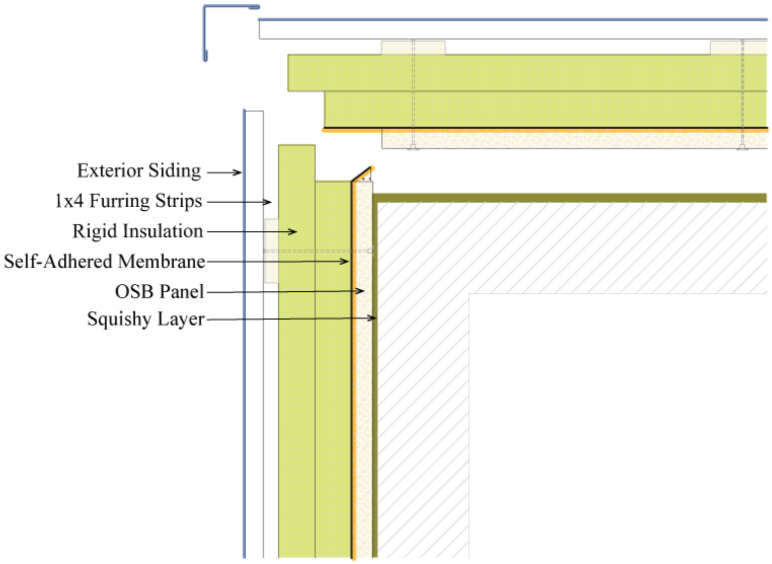


Figure 23 - Outside Corner Connection – Blind, Option 2 - Plan View

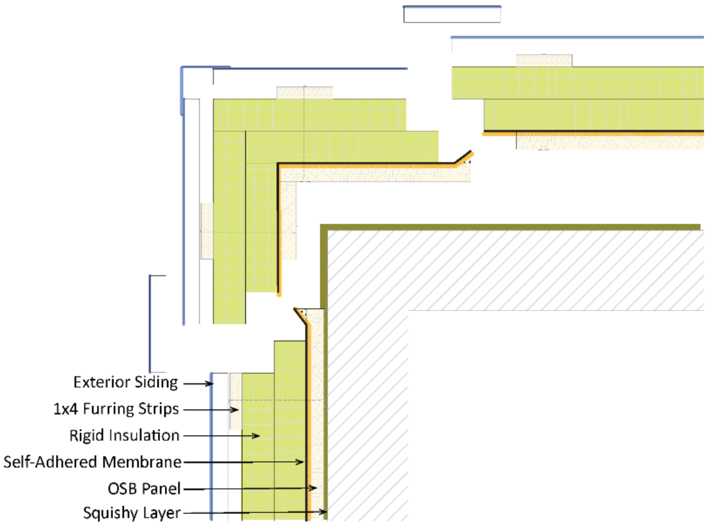


Figure 24 shows a solution for an outside corner connection using an open connection. The open configuration relies on a third step once the two panels have been attached to the building. In this step, a technician manually connects the membrane using a narrow strip of compatible membrane material. Once the seal is made, a component that includes insulation, furring, and cladding is attached to ensure continuity of the layers, and to conceal the membrane connection.

Figure 24 - Outside Corner Connection – Open – Plan View

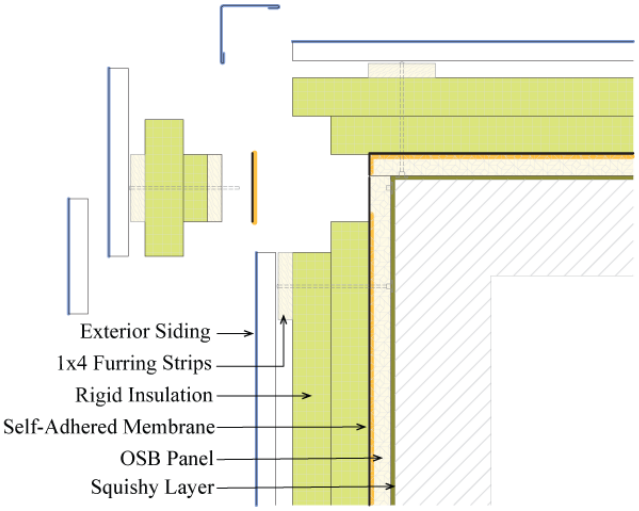


Figure 25 and Figure 26 show "blind" inside corner solutions. In Figure 25, the water control layer is turned up and adhered to the edge of the rigid insulation. The liner paper on the adhesive surface is left on until just before installation. During installation it is pressed against the backer side of the water control layer on the adjacent panel, which is raised by a compressible wedge to ensure a robust connection. Figure 26 shows another version of a "blind" connection, where sidewall panels engage with a separate, prefabricated corner component.

Figure 25 - Inside Corner Connection – Blind, Option 1 – Plan View

Figure 26 - Inside Corner Connection – Blind, Option 2– Plan View

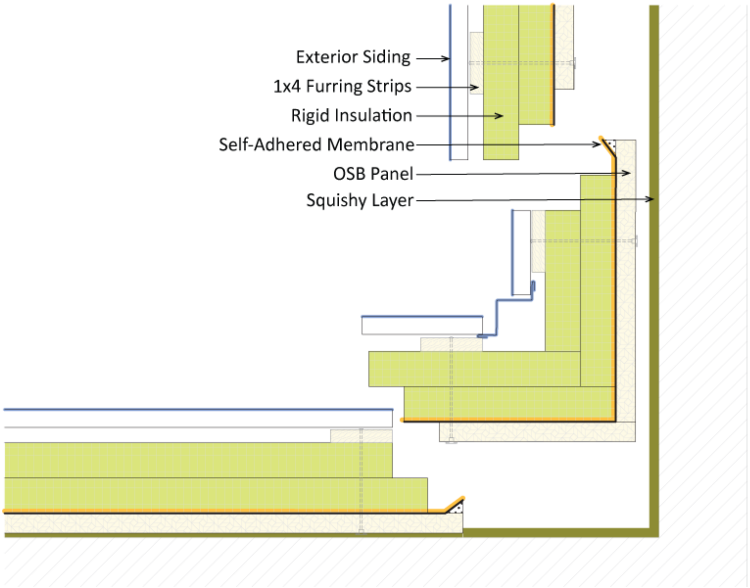
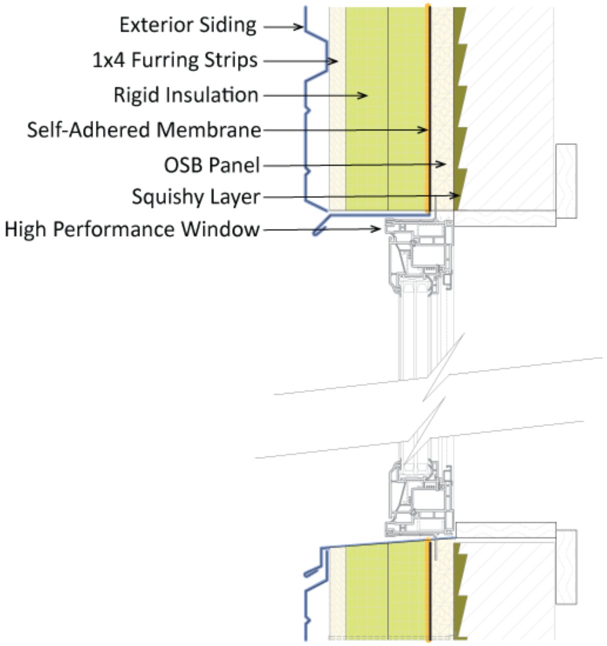


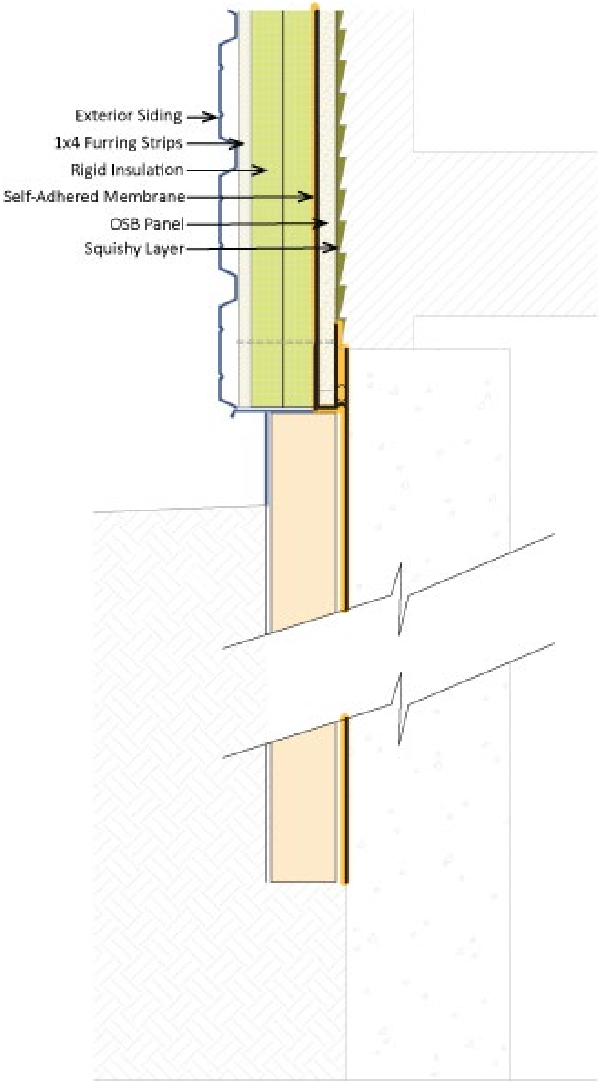
Figure 27 shows a sill and head details at a window. Door details will be similar. At the window head, a head flashing, along with the window flange, is integrated under the water control layer before insulation and other subsequent layers are installed. This provides for positive drainage of any water that penetrates beyond the cladding at this location. Similarly, a sill flashing is used at the sill to provide a finished surface, and to prevent ingress of precipitation.

Figure 27 - Window Opening – Section View



The OPS is also not designed for below grade use. However, foundations in existing buildings are commonly not insulated. Areas of the foundation wall that are above grade, and extending at least down to the frost line, can be significant sources of heat flow. We recommend that these walls be partially or fully excavated so that a waterproofing material can be applied to the foundation. Rigid insulation (typically extruded polystyrene) is applied over the waterproofing. Figure 28 shows the integration of this foundation insulation retrofit to the OPS.

Figure 28 - Below Grade Insulation - Section View



Penetrations such as hose bibs, dryer vents, and utility service penetrations must be sealed against air, water, and vapor movement. This is accomplished with a premanufactured flashing device that is integrated with the peel and stick membrane. Figure 29 shows several of these devices installed on a new-construction SPS home in Minneapolis, MN. The devices are readily available in the marketplace. They consist of a mounting flange to enable secure attachment, and a rubber membrane with a properly sized hole that is created at the factory.

Figure 29 - Example of Prefabricated Flashing

Retrofit solutions must also address roofs and foundations to ensure a high-performance outcome. For pitched roofs, panels similar in construction to the OPS wall panel can be applied over the existing roof plane. This can be an especially attractive option if the attic includes occupied space since it ensures complete thermal control coverage at the roof plane. This approach is commonly referred to as a "chainsaw retrofit," since the existing soffits must be removed so that the control layers of the wall panels can be connected to the control layers in the roof panels. Historically this has been done using a chainsaw, hence the name. However, such roof panels will not have finish layers applied at the factory, to facilitate robust roof edge detailing. After application of the panels, soffits can be either constructed on site, or prefabricated soffits can be attached. At that point roof finish layers can be applied. Figure 30 and Figure 31 show this chainsaw retrofit application during the installation and after.

Figure 30 - Chainsaw Retrofit for Sloped Roof – Exploded Section View

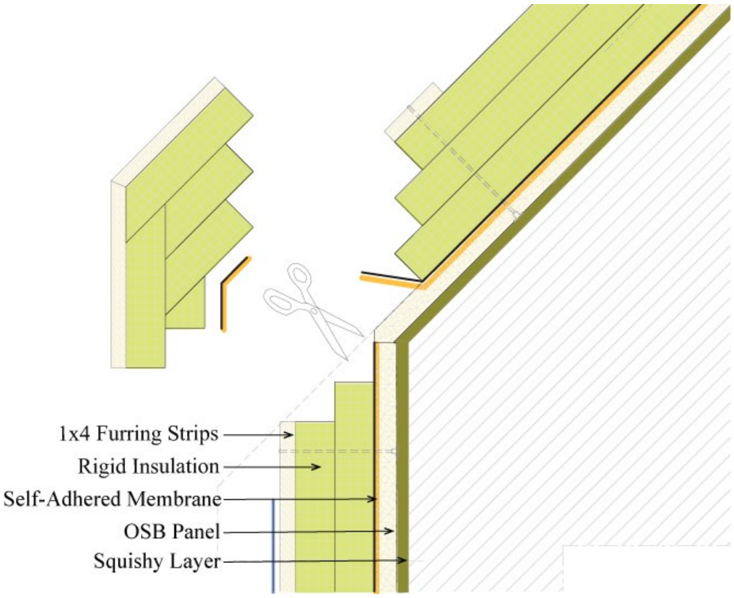
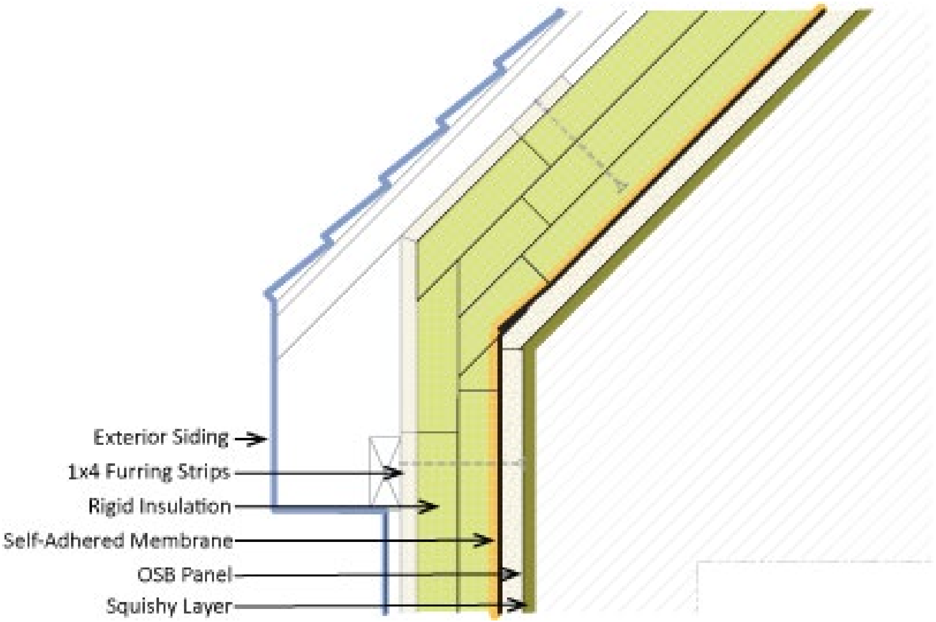


Figure 31 - Sloped Roof Application with Roof Panel – Assembled Section View



The OPS presented here is not designed for flat roof applications, or for cases where attic floor insulation is desired. In these cases, a variety of methods are available to ensure control of air, water, vapor, and heat flow. These will often involve more traditional techniques. Figure 32, Figure 33, Figure 34, and Figure 35 show schematic diagrams of several of these conditions.

First, it is critical that the air control layer of the OPS panel (the membrane) be connected correctly to the air control layer of the roof or attic floor. These diagrams show this connection schematically with a black line. Next, the thermal control layers must be connected. Thermal control layers of the existing building are shown schematically as a salmon-colored block.

Figure 32 shows an unconditioned attic, with insulation at the attic floor. Figure 33 shows a flat roof with no parapets or roof overhangs. Figure 34 shows a flat roof with a parapet. Here, the air and thermal control layers are run through the structure of the parapet wall, which works well for parapets that are framed with wood. Figure 35 shows a variation of the flat roof with a parapet, where the air and thermal control layers are applied as a wrap to contain the parapet wall. This solution is more appropriate with high thermal conductivity framing systems like steel, and for masonry parapets.

Figure 32 - Sloped Roof with Attic Insulation - Section View

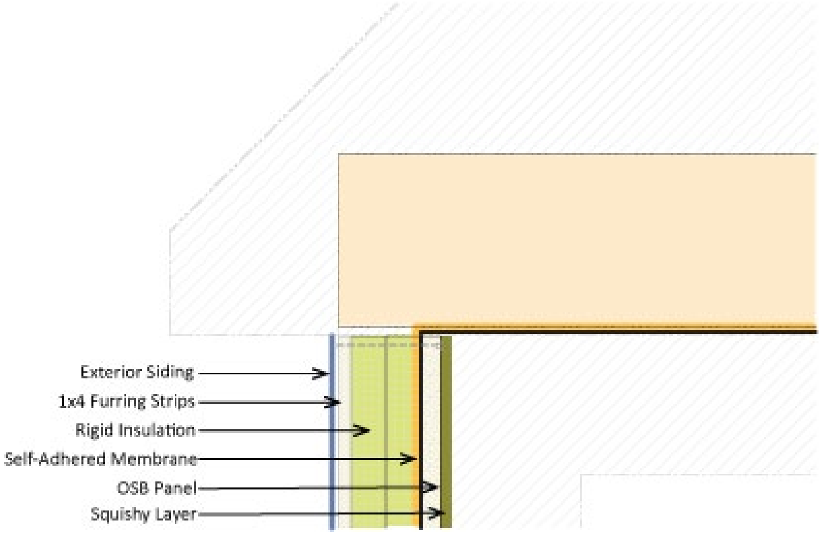


Figure 33 - Flat Roof – Section View

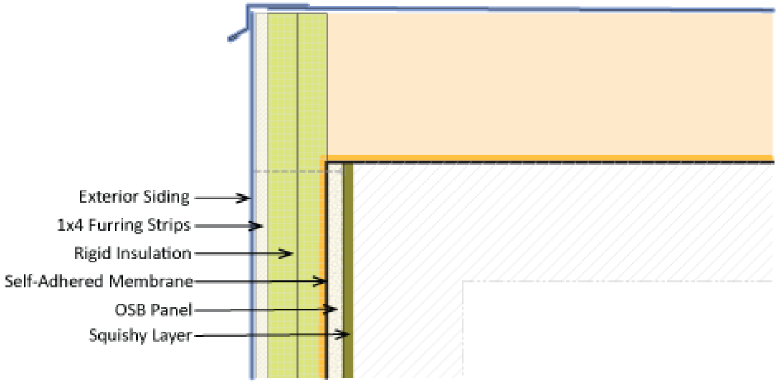


Figure 34 - Flat Roof with Parapet, Option 1 – Section View

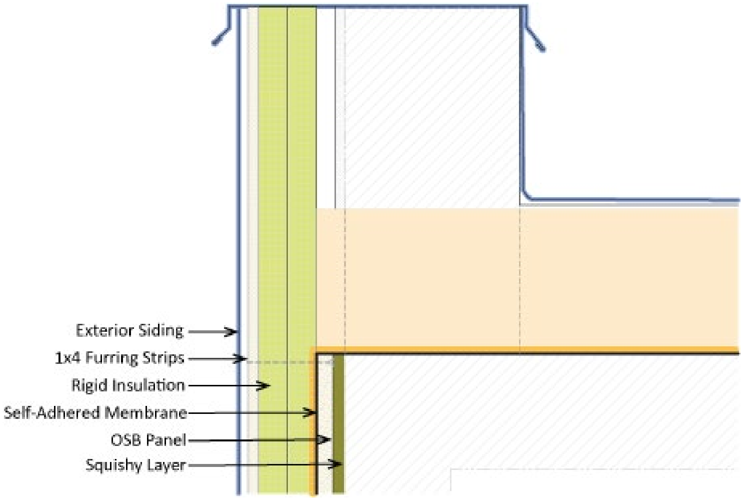
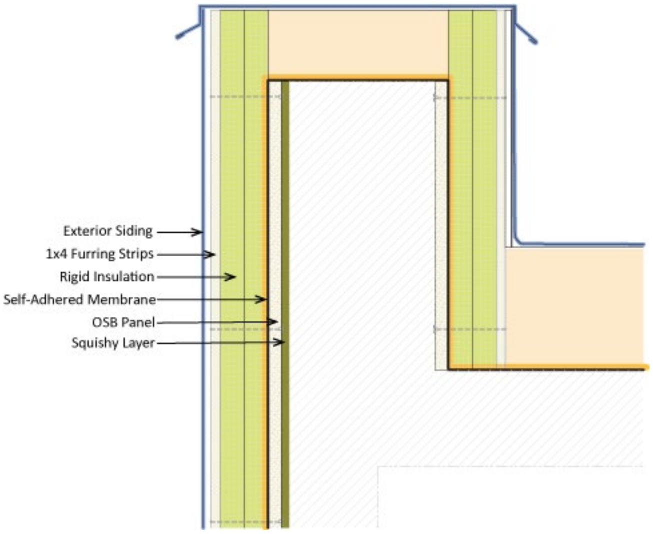
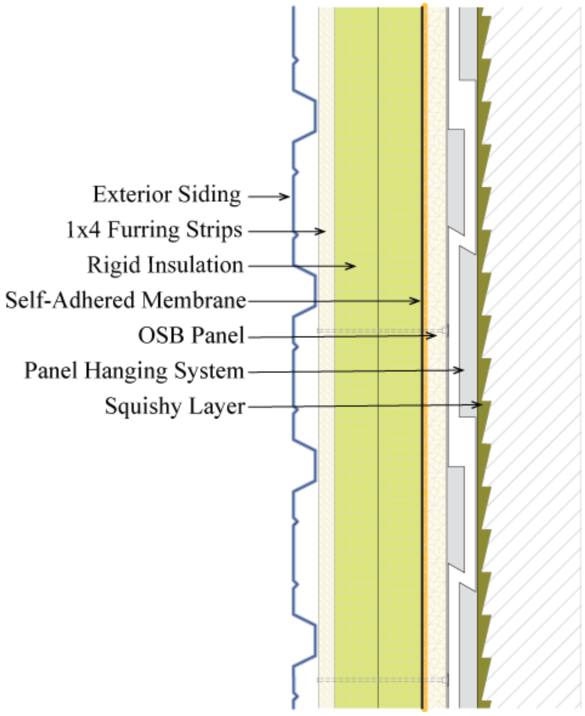


Figure 35 - Flat Roof with Parapet, Option 2 – Section View



Panels are fastened to the building using a linear “French cleat” device that is fastened to the building structure. A schematic drawing of the device is shown in Figure 36. This cleat transfers vertical and horizontal (wind) loads to the building structure. A small number of fasteners can be used to secure the panel to the cleat, if necessary.

Figure 36 - Panel Hanging System – Section View



Energy Savings and Cost Effectiveness

Energy and Cost Savings

Installation of the OPS shows very robust whole-building site energy savings, even accounting for the energy penalty associated with providing dedicated ventilation air. Savings are even more significant with the substitution of heat pumps for space conditioning, ranging from a low EUI savings of 60 percent to a high of 75 percent. EUI and cost savings are summarized in Table .

Table 15 - Energy and Cost Savings

Building	Scenario	Pre-Retrofit EUI (kBtu/ft2*yr)	Post-Retrofit EUI (kBtu/ft2*yr)	Percent Reduction	Cost Savings
Building 1	Overcoat + Ventilation	93	42	55%	$9,250.00
Building 1	Heat Pump Conversion	93	23	75%	$12,800.00
Building 2	Overcoat + Ventilation	84	46	45%	$1,638.00

Building	Scenario	Pre-Retrofit EUI (kBtu/ft2*yr)	Post-Retrofit EUI (kBtu/ft2*yr)	Percent Reduction	Cost Savings
Building 2	Heat Pump Conversion	84	23	73%	$4,459.00
Building 3	Overcoat + Ventilation	65	48	26%	$2,344.00
Building 3	Heat Pump Conversion	64	26	60%	$15,236.00
Building 4	Overcoat + Ventilation	69	36	48%	$26,620.00
Building 4	Heat Pump Conversion	70	21	70%	$39,380.00

Statewide Theoretical impact

Approximately 179,000 multifamily units within 5+ unit buildings would make good candidates for the overcladding retrofit. Of those we estimate a 60/40 split between gas heated and electric resistance heated buildings. The average area per unit is about 900 square feet. Savings per unit without a heat pump conversion equals 29,900 kBtu/yr. After converting either electric resistance or gas heat to heat pumps that increase to 48,400 kBtu/yr. In total the technical savings potential could reach 5,348,000 Mbtu/yr for overcoat plus ventilation upgrades or 8,666,000 Mbtu/yr in combination with a heat pump conversion. Broken out by end use, this savings without a heat pump conversion is 790,00 kWh/yr and 29,000 therms, or with heat pumps installed, 1,120,000 kWh/yr and 47,000 therms.

Retrofit Costs

There are two challenges in providing a fair estimate of costs for the OPS and mechanical system upgrades: first, material and labor costs have dramatically increased over the past two years, and the market is vastly more volatile than is typical. Therefore, costs that have been derived during this time and are reflected here are likely higher than what would be considered typical.

Second, the costs for the OPS were derived during the PNNL study and reflect a bespoke site-built retrofit and not the highly mechanized EnergieSprong retrofit process that is envisioned. In fact, no manufacturing capability for this type of panel currently exists in the US, though many projects are in development. That being the case, it is not possible to credibly speculate about savings that will flow from process streamlining, bulk material purchases, material optimization and minimization, and similar industrial optimization steps. For these reasons costs shown here should be considered as conservative, with substantial potential for cost reduction.

The cost of the OPS determined for the PNNL study was $21 per square foot of enclosure area ($226 / m^2). Costs for mechanical replacement derived for the Minnesota CARD study varied according to what system type was replaced. The maximum cost was determined to be $25 / ft^2 of floor area ($269 / m^2).

Table shows the costs for the OPS installation and mechanical system upgrades, along with the annual energy savings derived from energy models. These are used to calculate simple payback, which ranges from a low of 22 years to a high of 152 years. The most obvious difference between the buildings where relatively short paybacks were observed and the long payback cases was the heating system. Buildings with shorter paybacks in this sample both used electric baseboard heat, therefore their absolute energy cost savings were substantially higher than the other two buildings, which used gas-fired heating equipment. This range in simple payback showcases the challenges with the return on investment when including a gas to electric fuel conversion. Even without the addition of a new heat pump heating and cooling system, significant payback periods exist for the gas heated buildings of approximately 50 years. Reductions in the cost of installation along with the future cost of natural gas would likely be critical a determining factor in the decision to overclad.

Table 16 - Costs and Simple Payback

Building	Floor Area (ft^2)	Enclosure Area (ft^2)	Overcoat Panel System cost [n]	Mechanical Cost [o]	Total Cost	Annual Energy Cost Savings	Simple Payback (years)
Building 1	5,000	7,750	$162,750	$125,000	$287,750	$12,800	22
Building 2	9,100	11,080	$232,680	$227,500	$460,180	$4,459	103
Building 3	58,600	40,450	$849,450	$1,465,000	$2,314,450	$15,236	152
Building 4	22,000	22,750	$477,750	$550,000	$1,027,750	$39,380	26

n) $21 / square foot of enclosure

o) $25 / square foot of floor space

Net-Zero Potential and Renewable Capacity

Renewable energy potential for each studied building was assessed based on a roof-mounted photovoltaic panel system. The calculations were performed in the web tool PV Watts, developed by the National Renewable Energy Lab. It was assumed that 80% of roof area would be available for panel installation and that panels would have an efficiency of 20%. The resulting generation capacity is summarized in Table . In each case, net-zero electricity is possible, and buildings 2, 3, and 4 have the potential to operate at net-positive electricity. Selling excess electricity produced back to the utility may help offset costs and decrease the simple payback periods described above.

Table 17 - Renewable Energy Production Potential

Building	Post Retrofit EUI - Demand (kBtu/ft^2/yr)	Floors	Roof Area (ft^2)	Floor Area (ft^2)	PV System Size [p] (kW)	Produced kWh per year [q]	Produced kBtu per year	EUI - Produced (kBtu/ft^2/yr)
Building 1	23	3	1667	5,000	24.8	33,329	113,719	23

Building	Post Retrofit EUI - Demand (kBtu/ft^2/yr)	Floors	Roof Area (ft^2)	Floor Area (ft^2)	PV System Size [p] (kW)	Produced kWh per year [q]	Produced kBtu per year	EUI - Produced (kBtu/ft^2/yr)
Building 2	21	2	4549	9,100	67.6	86,441	294,937	32
Building 3	20	3	19533	58,600	290.3	390,142	1,331,165	23
Building 4	21	3	7222	22,000	107.4	143,831	490,751	22

p) Assumes 80% of roof area utilized, PV panel efficiency of 20%

q) Results from PV Watts analysis. Location based, Premium Module, Fixed Roof Mount, Default: System Losses, Tilt, and Azimuth.

Conclusions and Recommendations

In order to reduce risks associated with a warming climate caused by greenhouse gas emissions, it is critical to address existing buildings, which comprise one of the largest emissions sectors. The OPS presented here is capable of substantially reducing energy consumption for heating and cooling. The panel successfully manages the flow of heat, air, water, and vapor to ensure a durable retrofit that won't compromise the integrity of the existing building. Substitution of heat pumps for existing mechanical systems further reduces emissions and brings net-zero operation within reach when combined with a renewable energy system. Ventilation added with the mechanical retrofit ensures good indoor air quality. Significant increases in thermal performance of enclosures of existing buildings will also have the effect of peak load reduction when compared to the unimproved existing building.

However, preliminary costs identified here are too high to facilitate mass adoption under current industry conditions. To be successful in the marketplace prices will need to be brought down significantly, both for the enclosure retrofit and the mechanical upgrade. Promising approaches pioneered by the EnergieSprong movement including highly mechanized prefabrication and packaged all-in-one mechanical systems are appearing that are shown to significantly reduce prices. Significant investments by public or private entities are needed to bring these solutions to scale.

At this time, cost data are highly speculative, and no industry base exists in Minnesota to produce the panels and coordinate installation on the building. Therefore, this technology is currently not appropriate for consideration in CIP programs. A pilot phase is necessary to verify the constructability and savings potential of the technique. Piloting is critical for two reasons: a) to verify the construction details and methods outlined here, and b) to establish actual costs for the technology and to identify methods to bring costs down without compromising performance.

A critical component of the success of the EnergieSprong approach in Europe has been the business model employed to overcome these obstacles. Demand aggregation, the process of enrolling large numbers of projects prior to investment in manufacturing capacity, has enabled the significant adoption of similar technologies. This strategy reduces risk for the manufacturer / installer, enabling them to make investments in manufacturing capacity with the knowledge that a market for their products is ready and waiting. It would be highly advantageous to employ a similar strategy to create a new industry at scale in Minnesota. However, any pilot would not necessarily need to reach such an advanced state of maturity in the industry to be useful; the technique can be employed in a "hand-built" mode, using more manual labor to fabricate panels. This lower intensity approach could still validate constructability and energy savings aspects of the technology, though significant cost reductions expected from extensive automation would not be realized.

This white paper identifies an integrated OPS approach that yields impressive energy savings, and leaves behind buildings with enhanced durability, combustion safety, and indoor air quality. Given the need to rapidly reduce carbon emissions to avoid catastrophic climate impacts, it will be necessary to develop technologies and delivery systems capable of meeting the challenge of upgrading enclosures on existing buildings while doing no harm to occupants or the building itself. OPS technology, if fully realized, is well-positioned to fill this need.

References

Architecture 2030. (n.d.). Why the building sector? Retrieved March 29, 2022, from https://architecture2030.org/why-the-building-sector/

"Cooling and Heating Degrees by Country - Annual Data ." EuroStat Data Browser, European Commission, ec.europa.eu/eurostat/databrowser/view/nrg_chdd_a/default/table?lang=en.

"Degree Days Calculated Accurately for Locations Worldwide." Degree Days.net, www.degreedays.net/.

Egerter, Amy, and Martha Campbell. 2020. Prefabricated Zero Energy Retrofit

Technologies: A Market Assessment. Oakland, CA. DOE/GO-102020-5262. https://www.nrel.gov/docs/fy20osti/76142.pdf

Energiesprong. "Energiesprong Explained." Energiesprong, energiesprong.org/.

EPA. 2022. Draft Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2020. U.S. Environmental Protection 8 Agency, EPA 430-P-22-001. https://www.epa.gov/ghgemissions/draft-inventory-us-greenhouse-gas-emissions-and-9 sinks-1990-2020.

Lstiburek, Joseph W. "The perfect wall." ASHRAE Journal, vol. 49, no. 5, 2007, p. 74+

"Monthly Cooling and Heating Degree Data" NYSERDA Weather Data, NYSERDA, https://www.nyserda.ny.gov/about/publications/ea-reports-and-studies/weather-data/monthly-cooling-and-heating-degree-day-data

"Retrieve Climate Data from National Weather Service Reporting Stations - station data as monthly tables" Minnesota Department of Natural Resources Climate Data. MN DNR, https://www.dnr.state.mn.us/climate/historical/acis_stn_data_monthly_table.html?sid=mspthr&sname=Twin%20Cities%20Area&sdate=por&edate=por&element=cdd&span=annual&counts=no

Taitem Engineering, P.C. 2018. Energiesprong A Dutch Approach to Deep Energy REtrofits and Its Applicability to the New York Market. Ithaca, NY. NYSERDA Report 18-10

Tom Schirber, Rolf Jacobson, Garrett Mosiman, Dan Handeen, and Patrick Huelman. 2020. Affordable Solid Panel "Perfect Wall" System. University of Minnesota NorthernSTAR Building America Partnership. St. Paul, MN.

Appendix A: Mechanical System Replacement Considerations

Heating System Type	Replacement Priority	Equipment Considerations	Implementation / Spatial Concerns
Hydronic Boiler	Medium	Replace with condensing boiler and zone control if needed	Limited – one-for-one replacement
Hydronic Boiler	Medium	Replace with air source ductless heat pump	Condensing unit location, mechanical plumbing, and wall mount mini-split
Hydronic Condensing Boiler	Low	Replace with air source ductless heat pump	Condensing unit location, mechanical plumbing, and wall mount mini-split
Steam Boiler	High	Replace with condensing boiler and zone control	Single pipe distribution and radiators would need to be replaced
Steam Boiler	High	Replace with air source ductless heat pump	Condensing unit location, mechanical plumbing, and wall mount mini-split
Electric Baseboard	High	Replace with air source ductless heat pump	Condensing unit location, mechanical plumbing, and wall mount mini-split
Furnace	Medium	Add air source heat pump and coil	Condensing unit location, mechanical plumbing, and coil retrofit

Cooling System Type	Replacement Priority	Equipment Considerations	Implementation / Spatial Concerns
Sleeve AC	Medium	Replace with air source ductless heat pump	Condensing unit location, mechanical plumbing, and wall mount mini-split
Window AC	High	Replace with air source ductless heat pump	Condensing unit location, mechanical plumbing, and wall mount mini-split

Domestic Hot Water System Type	Replacement Priority	Equipment Considerations	Implementation / Spatial Concerns
Electric Individual	Medium	Heat pump water heater	Requires venting of mechanical space
Electric Central	Medium	Heat pump water heater	Requires venting of mechanical space and secondary storage
Gas Individual, non condensing	Medium	Condensing water heater	limited as it's a one for one replacement
Gas Central, non-condensing	Medium	Condensing water heater	limited as it's a one for one replacement
Gas Central, condensing	Low	NA	NA
Gas Shared with Heating, non-condensing	High	Condensing water heater	Needs to be coordinated with heating system selection
Gas Shared with Heating, condensing	Low	NA	NA

Ventilation and Exhaust System Type	Replacement Priority	Equipment Considerations	Implementation / Spatial Concerns
Make-up air	High	Energy recovery ventilator	Either individual ERVs or a centralized system could be used. Individual would require space near an exterior façade and either ceiling or closet space. Centralized could supply air through a corridor, roof space and ductwork coordination would be required
Kitchen and or clothes dryer exhaust	High	Ducted exhaust to outdoors	Wall penetration coordination and electrical connections