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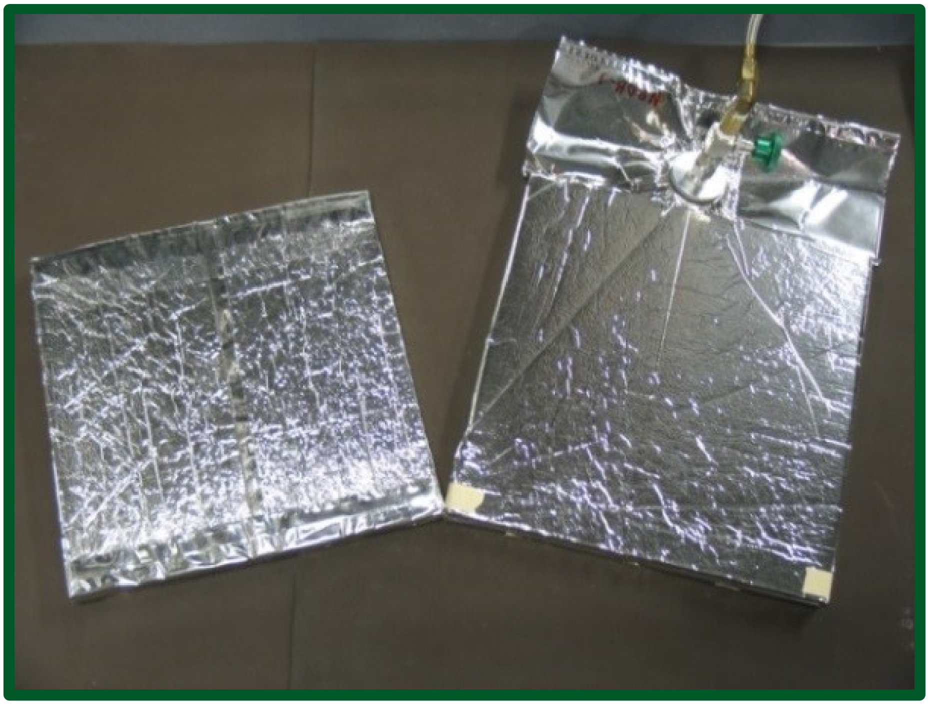
(EW-201512)



Demonstration and Cost Analysis of a Building Retrofit using High-Performance Insulation

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14. ABSTRACT
The Department of Energy (DOE) estimates that, in 2010, for all U.S. buildings (including Department of Defense [DOD] Facilities), 15.6 quads of primary energy consumption was attributable to fenestration and opaque building envelope components, of which the wall-related primary energy consumption was about 21%, or 3.3 quads. For commercial facilities, primary energy consumption attributed to walls during heating cycles was 1.48 quads, or ~30% of total energy consumption due to building envelope components. Heat loss through walls during a heating cycle is a critical component of overall facility energy use and mitigation measures are important to reduce total facility energy consumption. This project demonstrated and validated the use of modified atmosphere insulation (MAI) to reduce wall-related energy consumption in DOD facilities. A combination of facility sensors and modeling activities were used to determine the effectiveness of the MAI. By retrofitting walls and increasing their thermal resistance (R-value) by R10-20 (h-ft^2-°F/Btu), reductions of 30% or more over the baseline wall-generated space conditioning loads are possible. This report analyzes the cost and performance aspects of the MAI technology.

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ACRONYMS AND ABBREVIATIONS

AEWRS	Army Energy and Water Reporting System
ASHRAE	American Society of Heating, Refrigerating, and Air-Conditioning Engineers
ASTM	American Society for Testing and Materials
BLCC	Building Life Cycle Cost
BTU	British thermal unit
CAD	Computer-Aided Design
CERL	Construction Engineering Research Laboratory
cm^3	centimeter cubed
CMU	Concrete Masonry Unit
COGS	Cost of Goods Sold
DoD	U.S. Department of Defense
DOE	U.S. Department of Energy
EISA	U.S. Energy Independence and Security Act of 2007
EO	Executive Order
ER	Environmental Restoration
ERDC	U.S. Army Engineer Research and Development Center
ERDC-CERL	Engineer Research and Development Center, Construction Engineering Research Laboratory
ESTCP	Environmental Security Technology Certification Program
EvOH	Ethylene Vinyl Alcohol
EW	Energy and Water
ft	feet
ft^2	feet squared
ft^3	feet cubed
°F	Fahrenheit
FY	Fiscal Year
g	gram
h	hour
HVAC	Heating, Ventilating, and Air-Conditioning
in	inch
IR	Infra-red

lb pound
LEED Leadership in Energy and Environmental Design
LLC Limited Liability Corporation
LLDPE Linear Low-Density Polyethylene
LTL low temperature limit

m^2 meter square
MAI Modified Atmosphere Insulation
Mbar Millibar
MMBtu
million BTU
mPET
Metalized Polyethylene Terephthalate

N/A Not Applicable

ORNL Oak Ridge National Laboratory
OSB Oriented Strand Board

PO Performance Objective
POC Point of Contact

QC Quality Control

R Thermal Resistance
RH Relative Humidity

SERDP Strategic Environmental Research and Development Program
SiC Silicon Carbide
SiO_2 Silicone Dioxide
SIOH Supervision, Inspection, and Overhead
SIR Savings to Investment Ratio
SP Simple Payback
SPB Spun-Bound Polypropylene

VFFS Vertical Form, Fill and Seal
VIP Vacuum Insulation Panel

ACKNOWLEDGEMENTS

Funding for this demonstration was provided by the Environmental Security Technology Certification Program (ESTCP) Program under Energy and Water Project EW-201512, "Demonstration and Cost Analysis of a Building Retrofit Using High-Performance Insulation."

Various individuals and organizations participated in this demonstration and provided support (review, guidance, information, access to facilities, and logistics) that was valuable to the success of this project.

The following persons and organizations are gratefully acknowledged:

- The ESTCP Program Office for funding and providing guidance and support to this effort.
- Fort Drum Energy Manager Mr. Steve Rowley for his support during the project including assistance with coordination of on-site activities.
- Fort Drum Safety Office for providing facilities to study in this report.
- Fort Drum Carpentry and Electrical Shop staff for supporting the on-site installation and retrofit of the modified atmosphere insulation (MAI).

The following members were involved in the demonstration:

- ERDC-CERL: Mr. Tapan Patel, Mr. Lake Lattimore, Ms. Irene Andsager, Ms. Justine Yu, Mr. Sean Wallace, Ms. Megan Kreiger and Mr. Shane Hirschi.
- Oak Ridge National Laboratory: Dr. Kaushik Biswas, Dr. Som Shrestha, and Dr. Andre Desjarlais.
- Nanopore, Inc.: Dr. Doug Smith, and Mr. Ron Esparza.
- Fort Drum: Mr. Stephen Rowley.

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EXECUTIVE SUMMARY

OBJECTIVES OF THE DEMONSTRATION

The Department of Energy (DOE) estimates that in 2010, 15.6 quads of primary energy consumption was attributable to fenestration and opaque building envelope components of all U.S. buildings, including Department of Defense (DoD) Facilities, of which the wall-related primary energy consumption was about 21%, or 3.3 quads (USDOE 2004). For commercial facilities, primary energy consumption attributed to walls during heating cycles was 1.48 quads, or ~30% of total energy consumption due to building envelope components. Heat loss through walls during a heating cycle is a critical component of overall facility energy use and mitigation measures are important to reduce total facility energy consumption.

This project demonstrated and validated the use of modified atmosphere insulation (MAI) to reduce wall-related energy consumption in DoD facilities. MAI can significantly increase the thermal resistance of walls with only a marginal increase in wall thickness, thereby reducing wall-related energy consumption. By retrofitting walls and increasing their thermal resistance (R-value) by R10-20 (hours-feet squared-degrees Fahrenheit per British thermal unit [$h\text{-}ft^2\text{-}°F/Btu$]), reductions of 30% or more over the baseline wall-generated space conditioning loads are possible (greater savings are achievable with buildings of older vintage or those that are poorly insulated). A combination of facility sensors and modeling activities was used to determine the effectiveness of the MAI.

The Performance Objectives (POs) that were met are:

1. Reduce facility energy usage by 4.0% compared to the baseline energy usage of the building. The actual reduction was 6.43%.
2. Reduce electrical demand by 2.0% compared to the baseline demand. The actual reduction was 3.5%.
3. Minimize MAI panel vacuum loss to less than 5%. Only 3.3% of the MAI panels failed.
4. Increase overall R-value of envelope to R-13.8/in. The R-value was increased by R-15.2/in.
5. Achieve 70% coverage of wall area with MAI panels. The project achieved 76% coverage.
6. Reduce energy loss through walls by 20% or more. The project achieved a 31% reduction in energy losses through walls.
7. Achieve (qualitative) user satisfaction of 90% or more. The project achieved 100% user satisfaction.

The following performance objective (PO) was not met: Achieve a simple payback of 33.1 years with a Savings to Investment Ratio (SIR) of 0.62. The project demonstrated a simple payback of 198 years with an SIR of 0.13. The high simple payback and low SIR is because the facility already contained insulation. For a facility without existing insulation, the simple payback and SIR would be 28 years and 0.83, respectively. Additional cost reductions in manufacturing and installation are expected improve these economics.

TECHNOLOGY DESCRIPTION

NanoPore Inc., working in conjunction with the DOE's Building Technology Program and Oak Ridge National Laboratory (ORNL), is developing a new generation of advanced thermal insulation with the same performance as silica-based vacuum insulation panels (VIPs) but significantly reduced costs. The new insulation technology is called MAI. Vacuum insulation is the only technology that promises a step-change in performance (R40/inch [in.]) compared to conventional insulation materials that achieve up to R6-7/in. VIPs consist of an evacuated core material (usually fumed silica) with a microporous structure. The core material is encapsulated within a barrier film and sealed under vacuum. This project will specifically test the cost and performance of MAIs. Numerous studies related to VIPs in buildings can be found in the literature, but those related to actual building applications are few (USDOE 2004; Tenpierik, Cauberg, and Thorsell 2007; Brunner and Simmler 2008; Cho, Hong, and Seo 2014). ORNL and industry partners evaluated an exterior insulation and finish system that contained VIPs (Childs et al. 2013); combined experimental testing and numerical analysis indicated that whole-wall R-values of R30 h-ft^2-°F/Btu or higher were achievable using 3-in.-thick foam-VIP composites.

This demonstration retrofitted a ~2,000 ft^2 facility at Fort Drum with MAI and facility sensors including temperature, heat flux, electric, and natural gas. A similar facility was not retrofitted but was outfitted with identical sensors. By comparing the differences in measured data, and by using modeling to account for load/occupancy discrepancies across the two buildings, the energy and cost performance metrics were calculated.

DEMONSTRATION RESULTS

Results from the demonstration show that the MAI technology can significantly reduce heat flows across the facility walls. This results in energy and electrical demand reduction. Infrared (IR) images discovered some failed panels, which were likely damaged during the retrofit process. No degradation of the panel (after installation) was observed. Although the system economics are not favorable for this demonstration, the economics are expected to significantly improve for new or minimally insulated existing buildings and with additional reduction in MAI manufacturing and installation cost.

IMPLEMENTATION ISSUES

A majority of the implementation issues were discovered during the installation process. These issues included: (1) replacing J-channels and siding around windows required additional effort, (2) modification and replacement of soffit vents was not adequately anticipated, and (3) construction glue was not needed to hold the MAI panels in place temporarily. These findings are discussed in additional detail in the final report. Additional issues include the relatively intensive installation process. Future efforts are aimed to reduce installation time by creating large 4x8-ft integrated boards. These boards will combine MAI panels and polyiso foam in a matrix, which is expected to reduce installation time by 80%. The team also found that further careful handling is required during the installation process to reduce the damage to panels.

1.0 INTRODUCTION

This project, "Demonstration and Cost Analysis of a Building Retrofit using High Performance Insulation," demonstrates the advantages of modified atmosphere insulation (MAI) as an emerging technology, to mitigate energy loss through walls. Specifically, MAI can significantly increase the thermal resistance of walls with only a marginal increase in wall thickness. The idea of mitigating energy loss in building envelopes has been at the forefront of the U.S. Department of Energy (DOE) and U.S. Department of Defense (DoD). Successful demonstration of this technology will enable DoD to meet, among others, several executive orders (e.g, EO 13693 [White House 2015)), the Energy Security and Independence Act (EISA 2007), the Energy Policy Act of 2005 (EPAct 2005, Sections 102 and 103), and various mandates.

1.1 BACKGROUND

The DOE estimates that in 2010, 15.6 quads of primary energy consumption was attributable to fenestration and opaque building envelope components of all U.S. buildings, including DoD Facilities, of which the wall-related primary energy consumption was about 21%, or 3.3 quads (USDOE 2004). For commercial facilities, primary energy consumption attributed to walls during heating cycles was 1.48 quads, or ~30% of total energy consumption due to building envelope components. Heat loss through walls during a heating cycle is a critical component of overall facility energy use, and mitigation measures are important to reduce total facility energy consumption.

In Fiscal Year 2012 (FY12), DoD's annual facility energy consumption was estimated to cost $4 Billion (B)/year (~20% of total DoD energy cost). Within the U.S. building stock, 37% of primary energy is used for space heating and cooling. By this estimate, DoD spends ~$1.5B/year for space heating and cooling, split roughly as 45% for heating and 55% for cooling. Hence, during heating cycles alone, it is estimated that heat loss through walls costs DoD about $200 Million (M)/year, or about 5% of the total DoD facility energy cost. Mitigating such losses is critical for the reduction of energy consumption by DoD facilities, particularly in cold climates.

This project demonstrates and validates the use of MAI to reduce wall-related energy consumption in DoD facilities. MAI can significantly increase the thermal resistance of walls with only a marginal increase in wall thickness, thereby reducing wall-related energy consumption. By retrofitting walls and increasing their thermal resistance (R-value) by R10-20 (hours-feet squared-degrees Fahrenheit per British thermal unit [Btu] [h-ft^2-°F/Btu]), reductions of 30% or more over the baseline wall-generated space conditioning loads are possible. Greater savings are achievable with buildings of older vintage or those that are poorly insulated.

DoD currently uses fiberglass insulation, blown-in cellulose, polystyrene, polyurethane, or polyisocyanurate (polyiso) board for wall insulation. These types of insulation have been used for many years and provide insulation with an R value per inch of 3 to 7 (R3-7/in.). Current state of the art technology, vacuum insulated panels (VIPs), are the only technology that promises a step-change in performance, providing (R40/in. compared to conventional insulation materials that achieve up to R6-7/in.). Outside of planned major renovations, insulation is typically not added in DoD buildings. Depending on the building type, traditional insulation retrofits require structural modifications and often do not address issues with thermal bridging.

The high performance of this technology and application to the exterior surface of buildings make this technology more readily implementable while reducing thermal bridging. Installing this technology on the exterior also decreases impact to occupant operations during the retrofit process.

VIPs consist of an evacuated core material (usually fumed silica for building applications) with a microporous structure. The core material is encapsulated within a barrier film and sealed under vacuum. One major hindrance for broad market acceptance of VIPs is their high cost, which is greater than \$0.25/ft^2/R. The new insulation technology, called MAI, has similar performance to a vacuum insulated panel (VIP) yet it is processed at ambient pressure using standard vertical form-fill-seal machines, which are the same type as those used to package potato chips, yielding a cost closer to \$0.10-0.15/ft^2/R. MAI's high thermal performance is a unique tool for improving building envelope energy efficiency. A thickness of 0.5 to 1 in. of MAI can dramatically improve envelope efficiency without a significant increase in wall thickness. Using conventional insulation materials to achieve a similar thermal performance improvement will require substantially thicker insulation material and hence a deeper wall assembly with associated costs of structural modifications (extended window and door jambs, longer fasteners, etc.).

For this demonstration, the building under consideration for retrofit already has R-19 fiberglass batts within the wall cavity. This means that any additional insulation has a reduced impact on the energy and cost savings. Nevertheless, this project will demonstrate the retrofit process, and the data can be extrapolated for buildings that lack insulation.

1.2 OBJECTIVES OF THE DEMONSTRATION

This project retrofitted the exterior walls of a building at Fort Drum, NY (a heating-dominated climate) with MAI panels and quantified the energy benefits. The MAI enhances the effective R-value of insulation, thus reducing heat transfer through the walls, while maintaining comfortable temperatures for the building occupants. Two similar buildings were chosen for this study. One building was the baseline, and the second was retrofitted with MAI. Energy monitoring sensors (heat flux, temperature, humidity, etc.) and building electric and natural gas meters were installed to obtain overall energy usage of the building. Once the MAI was installed, energy consumption in both buildings was monitored. Comparisons on overall building energy usage, heat flux through various surfaces, and temperatures were made. Using a complex building energy simulation model, the overall energy usage of both buildings was normalized to account for variations in building factors (occupancy, internal loads, etc.). A comparison of this normalized data is then used to provide performance validation of the technology.

Using the energy savings performance metrics (Btu/ft^2), utility rates, and the cost of the MAI panels, a detailed cost analysis of the new lower-cost, high performance MAI panels are expected to demonstrate the potential for widespread applications. MAI panels offer a significant cost benefit over traditional VIP. VIPs cost more than \$0.25/ft^2/R, whereas the MAI panels cost closer to \$0.10-0.15/ft^2/R.

Although the cost of MAI is higher than the cost of traditional fiberglass batt insulation, MAI's high thermal performance is a unique tool for improving building envelope energy efficiency.

A thickness of 0.5 to 1 in. of MAI can dramatically improve envelope efficiency without a significant increase in wall thickness. Using conventional insulation materials to achieve a similar thermal performance improvement will require substantially thicker insulation material and hence, a deeper wall assembly with associated costs of structural modifications (extended window and door jambs, longer fasteners, etc.). For retrofit purposes, MAI panels offer a significantly lower cost of structural modifications.

By retrofitting walls and increasing thermal resistance, by R10-20 (h-ft^2-°F/Btu), reductions of 30% or more over baseline wall-generated space conditioning loads, are possible in DoD. Furthermore, with targeted applications for older or more poorly insulated facilities, greater load reductions can be achieved. Financial and environmental benefits will be accompanied by increased occupant comfort.

1.3 REGULATORY DRIVERS

This technology addresses the problem faced by DoD to reduce energy intensity (Btus per ft^2) by 2.5% per year, from the 2015 baseline, as per EO 13693. This technology also addresses the requirements of the Energy Policy Act of 2005, which sets the Federal energy management requirement in several areas, including energy reduction. The project also supports EISA 2007 for increased energy efficiency in Federal buildings. Secondary drivers include the reduction of greenhouse gases by 40% from 2008 levels (EO13693) and the reduction of fossil fuel use. By reducing heat loss/gain through the walls, building energy consumption will be decreased. This will result in fossil fuel usage reduction and subsequent greenhouse gas reduction. The levels of reduction will depend on site specifics including type of heating fuel (e.g., natural gas, oil, etc.) and the makeup of electric supply (e.g., coal, natural gas, renewable energies, etc.). This technology also supports requirements for Leadership in Energy & Environmental Design (LEED) certifications in major renovations or construction, and Net Zero Energy goals.

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2.0 TECHNOLOGY DESCRIPTION

2.1 TECHNOLOGY/METHODOLOGY OVERVIEW

NanoPore Inc., working in conjunction with the DOE's Building Technology Program and Oak Ridge National Laboratory (ORNL), is developing a new generation of advanced thermal insulation with the same performance as silica-based vacuum insulation panels (VIPs) and significantly reduced costs. The new insulation technology is called MAI. Vacuum insulation is the only technology that promises a step-change in performance, providing R40/in. compared to conventional insulation materials that achieve up to R6-7/in. (Figure 1). VIPs consist of an evacuated core material (usually fumed silica) with a microporous structure. The core material is encapsulated within a barrier film and sealed under vacuum. This project will specifically test the cost and performance test of MAIs. Numerous studies related to VIPs in buildings can be found in the literature, but those related to actual building applications are few (USDOE 2004; Tenpierik, Cauberg, and Thorsell 2007; Brunner and Simmler 2008; Cho, Hong, and Seo 2014). ORNL and industry partners evaluated an exterior insulation and finish system that contained VIPs (Childs et al. 2013); combined experimental testing and numerical analysis indicated that whole-wall R-values of R30 h-ft^2-°F/Btu or higher were achievable using 3-in.-thick foam-VIP composites.

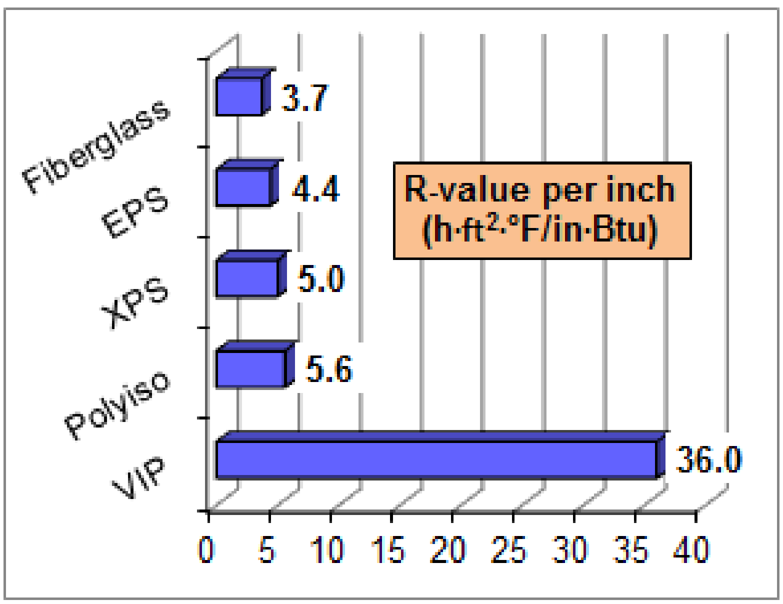
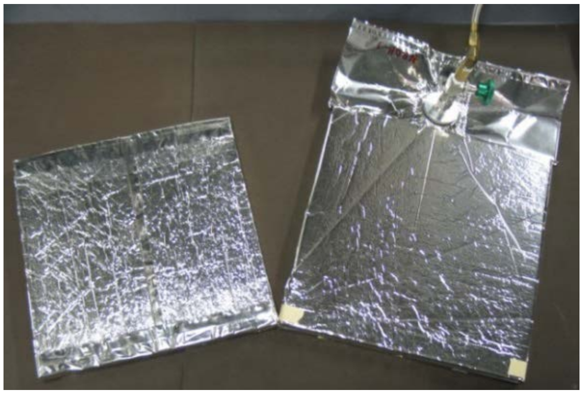


Figure 1. R-Values of VIP and Conventional Insulation Materials (Childs et. al. 2013).

The new insulation technology, MAI (Figure 2), demonstrates a performance similar to that of a VIP, but the MAI material is processed at ambient pressure using standard vertical form-fill-seal machines, the same type of machinery used to package potato chips.

The high-cost of VIPs can be attributed to processing that includes pressing fine powders into a board, cutting, drying, and then evacuating and sealing in a vacuum. MAI avoids these problems by replacing the air with a fluidized powder with a low molecular weight, low conductivity compound, resulting in fewer process steps and lower cost. For comparison, Figure 3 shows the VIP and MAI process flow diagrams.



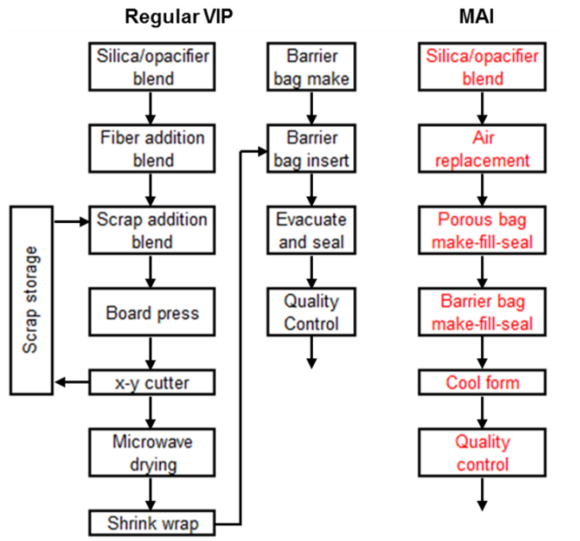


Figure 2. MAI Panels.

Figure 3. Flow Charts ff VIP and MAI Production Processes.

Within DoD, this technology is expected to be applicable to wall insulation retrofits, including buildings with construction similar to those in this project (wood-frame construction with exterior metal siding, and plywood sheathing). Other building construction types within DoD (e.g., Concrete Masonry Unit [CMU], Metal Panel etc.) are also expected to be viable candidates. The major difference in the use of this technology for various building types will be the method used to fasten/adhere the MAI panels.

2.2 ADVANTAGES AND LIMITATIONS OF THE TECHNOLOGY

2.2.1 Performance Advantages

MAI's high thermal performance demonstrates its unique capability for improving building envelope energy efficiency. A thickness of 0.5 to 1 in. of MAI can dramatically improve envelope efficiency without a significant increase in wall thickness. Using conventional insulation materials to achieve a similar thermal performance improvement would require substantially thicker insulation material and hence, a deeper wall assembly with associated costs of structural modifications (extended window and door jambs, longer fasteners, etc.).

During FY14, ORNL and NanoPore evaluated MAI panels under a DOE-funded scoping study. Under this project, the R-value of MAI panels were measured under different temperatures and internal panel pressure conditions according to standards set in American Society for Testing and Materials (ASTM) C518 (ASTM 2010). The temperatures were chosen based on the range of temperatures that are experienced by external building walls in different U.S. climate zones. The internal panel pressure was varied from 10 millibar (mbar [vacuum]) to atmospheric pressure (to simulate a damaged panel). Figure 4 shows the measured R/in. of the MAI panels. The R/in. of an intact MAI panel was higher than 32 (h-ft^2-ºF/Btu-in) at various temperatures. It is interesting to note that the MAI R/in. was higher at lower temperatures, which makes it naturally better suited for exterior envelope applications in cold, heating-dominated climates. Furthermore, even with complete loss of internal vacuum, the R/in. of the MAI panels were still higher than conventional insulation materials.

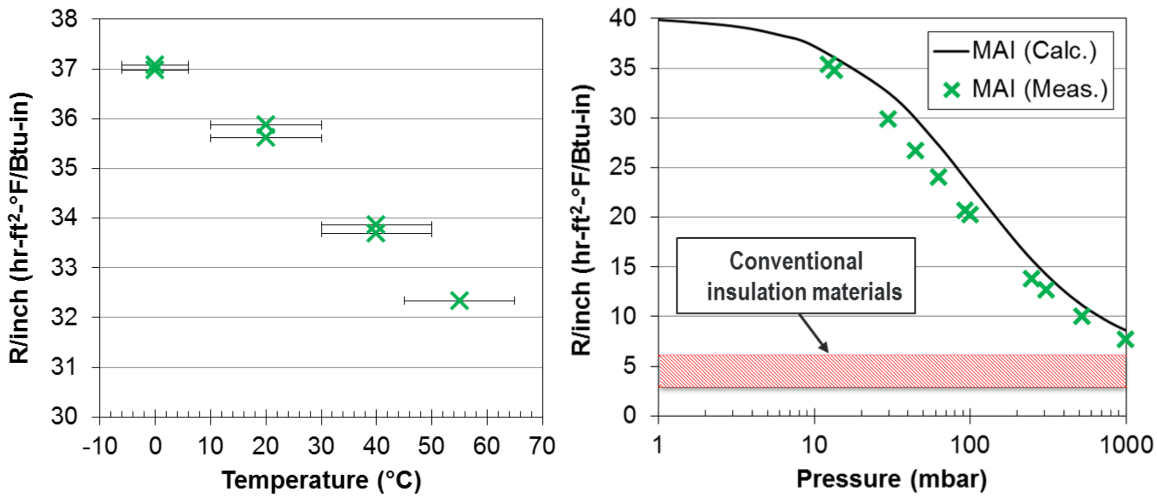


Figure 4. Thermal Resistance (R/in.) of MAI Panels, as a Function of Temperature and Pressure, Compared to Conventional Insulation Materials (Foam, Fiberglass and Cellulose).

2.2.2 Performance Limitations

The greatest potential performance limitation of the technology is primarily related to the process of installing the MAI panels in a building. Although the panels demonstrate performance superior to that of traditional wall insulation technologies (fiberglass batts, blown-in cellulose, etc.), the panels are susceptible to being punctured. However, pressure testing conducted to simulate a puncture (see Figure 4, 1,000 mbar) shows that, even when punctured, MAI panels still maintain a higher R-value/in. than traditional insulation technology.

As with any other insulation technology, the incremental energy savings associated with increasing the wall R-value are diminished. As shown in Figure 5, a 1,500 ft^2 building in a mixed-humid climate was simulated with varying levels of insulation. The associated energy savings with each incremental layer in insulation is shown. As the figure shows, insulation is most effective on buildings with little or no insulation. Any additional insulation thereafter has a diminished effect on the energy savings. For this project, the chosen building already had R-19 insulation in the walls. As a result, the energy and cost savings will be less than ideal. Nevertheless, this project will still demonstrate the effectiveness and potential applicability of the technology.

Another performance limitation relates to the potential impact on heating, ventilating, and air-conditioning (HVAC) systems. By significantly improving the envelope performance, there is a possibility of reduced load conditions (compared to design) on HVAC equipment. Specifically, heating and cooling equipment will likely cycle more often. In humid climates, the more rapid cycling can affect removal of moisture within the building. For this application in a heating dominant climate, HVAC cycling was monitored and found to be limited. Future applications should consider HVAC cycling because the impact will be dependent on several factors including building size, internal loads, occupancy, etc.

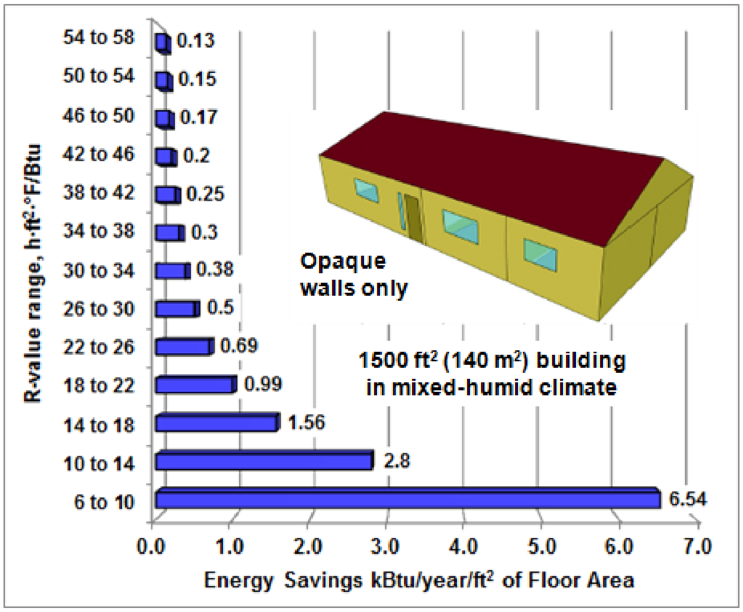


Figure 5. Effects of Increasing Insulation on Energy Savings.

2.2.3 Cost Advantages

As part of the DOE-funded project, a cost analysis of the MAI manufacturing process was performed to compare the cost of MAI to state-of-the-art VIPs. At present, traditional VIPs cost about $\$0.25/ft^2$/R-value, with the following breakdown of cost: 25% material and 75% processing/overhead. As mentioned earlier, processing of MAI entails about 50% fewer steps than VIP; consequently, the cost of MAI panels based on a pilot-scale production line is estimated to be $\$0.12$-$0.16/ft^2$/R-value (assuming R-35/in. for the MAI panels, a cost that translates to $\$4.14$-$5.52/ft^2$).

2.2.4 Cost Limitations

MAI panels are considerably cheaper than traditional VIPs. The technology, however, is considerably more expensive than conventional fiberglass insulation. For example, traditional fiberglass batts typically cost $\$0.03/ft^2$/R-value, while MAIs are almost 4-5 times more expensive than this. However, using MAI panels can offset some of the cost of structural modifications associated with using fiberglass batts.

2.2.5 Potential Barriers to Acceptance

One of the most significant potential barriers to acceptance of MAI technology is the current cost of the technology compared to traditional retrofit applications. The technology is also currently more suitable for building exterior applications. Additional research is necessary to determine how the panels can be attached to different exterior structures such as CMU. Another important issue is the presence of a vapor barrier in cooling dominated climates. For example, in the past, exterior insulation technologies, such as exterior insulating finishing system, have had issues with moisture migration, which have since been resolved. This will require further investigation. If MAI panels have issues related to moisture in their current configuration upon installation, this might be a potential barrier to acceptance.

2.3 PERFORMANCE OBJECTIVES

The innovative MAI insulation technology is expected to enhance energy efficiency in buildings by reducing the heating and cooling loads and reducing energy intensity in support of EO 13693. The MAI technology is ideally suited for cold, heating dominant climates, where the heat loss through the wall is contributes to a large portion of the overall building energy losses. The MAI technology can be installed as a retrofit, or it can be used in new construction in several facility types including typical barracks, training facilities, and Command, Control, and Administration buildings. Although the technology performs best in cold climates, it can be used in any climate zone where building insulation is recommended.

Table 1 lists the performance objectives and describes the metrics, data requirements, criteria, and results of the demonstration. The objectives are related to several areas including reduction in energy usage, cost performance, effectiveness of the MAI panels and occupant satisfaction. The energy savings and system economics are the most important for this project.

Table 1. Summary of Performance Objectives.

Performance Objective	Metric	Data Requirements	Success Criteria	Results
Quantitative Performance Objectives				
Facility Energy Usage	Reduction in Energy Use (kWh, Btu)	Meter readings of energy used by installation (kWh and Btus), weather data, occupancy hours, temperature set points	4.0% reduction compared to baseline energy usage of building	6.43% reduction, PASS
Demand Reduction	Reduction in Demand (kW)	Meter readings of energy used by buildings (kW)	2.0% reduction compared to baseline demand of building	3.5% reduction, PASS
Percent of Panels Experiencing Loss of Vacuum	Percent of Panels Experiencing Loss of Vacuum (%)	IR thermographic images	<5% Panels experiencing loss of vacuum	3.3% experiencing loss of vacuum, PASS
Overall R-value of walls with MAI	Increase in R-value	IR thermography images, panel layout, internal and external temperature data, heat flux	Increase in overall R-value >13.8/in.	15.2/in., PASS
Coverage of Wall Area with minimal MAI Panels	% of Total Wall Area Covered with Minimal Number of MAI Panel sizes (%)	Total wall area (ft^2), Wall area covered by MAI panels (ft^2), Number of different panel sizes	>70% coverage with four or fewer different MAI panel sizes	76% coverage, PASS
Energy Loss Through Walls	Reduction in Energy Loss through the Walls (watt/meter squared [m^2])	Wall heat flux (watt/m^2), wall temperature sensors (interior and exterior)	Reductions of 20% or more over baseline wall-generated space conditioning loads	31% reduction, PASS
System Economics	Simple Payback (SP) in Years, Savings investment Ration (SIR)	$ costs, discount rate, usable life, energy reduction, energy rates	SP = 33.1 years, SIR = 0.62	SP = 198 years, SIR = 0.13, FAIL
Qualitative Performance Objectives				
User Satisfaction	Degree of Satisfaction	Likert Scale Survey	90% Satisfaction	100% Satisfaction, PASS

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3.0 SITE DESCRIPTION

The MAI panels were installed on the walls of Fort Drum, NY Directorate of Public Works Bldg. 432B. Bldg. 431B was used as a control building. The 2,000 ft^2 buildings are located within 100 feet of each other and constructed in an identical manner (2x6 wood frame, metal siding, R-19 wall insulation, R-40 roof insulation, glazing size and orientation). Bldg. 431B was used for classroom motorcycle training courses and Bldg. 432B was used for cold weather equipment training. Figure 6 shows the location of both buildings relative to each other. Figure 7 shows the southern face of Bldg. 432B. Both buildings are operated by the Fort Drum Safety Office.

3.1 GENERAL FACILITY/SITE SELECTION CRITERIA

The facility/building selection was based on:

- The simple construction of the building and the ease of installing the MAI panels.
- Availability of the building for easily installing instrumentation without detrimental interruption to normal use
- Size of the buildings
- Side-by-side baseline / technology demonstration.

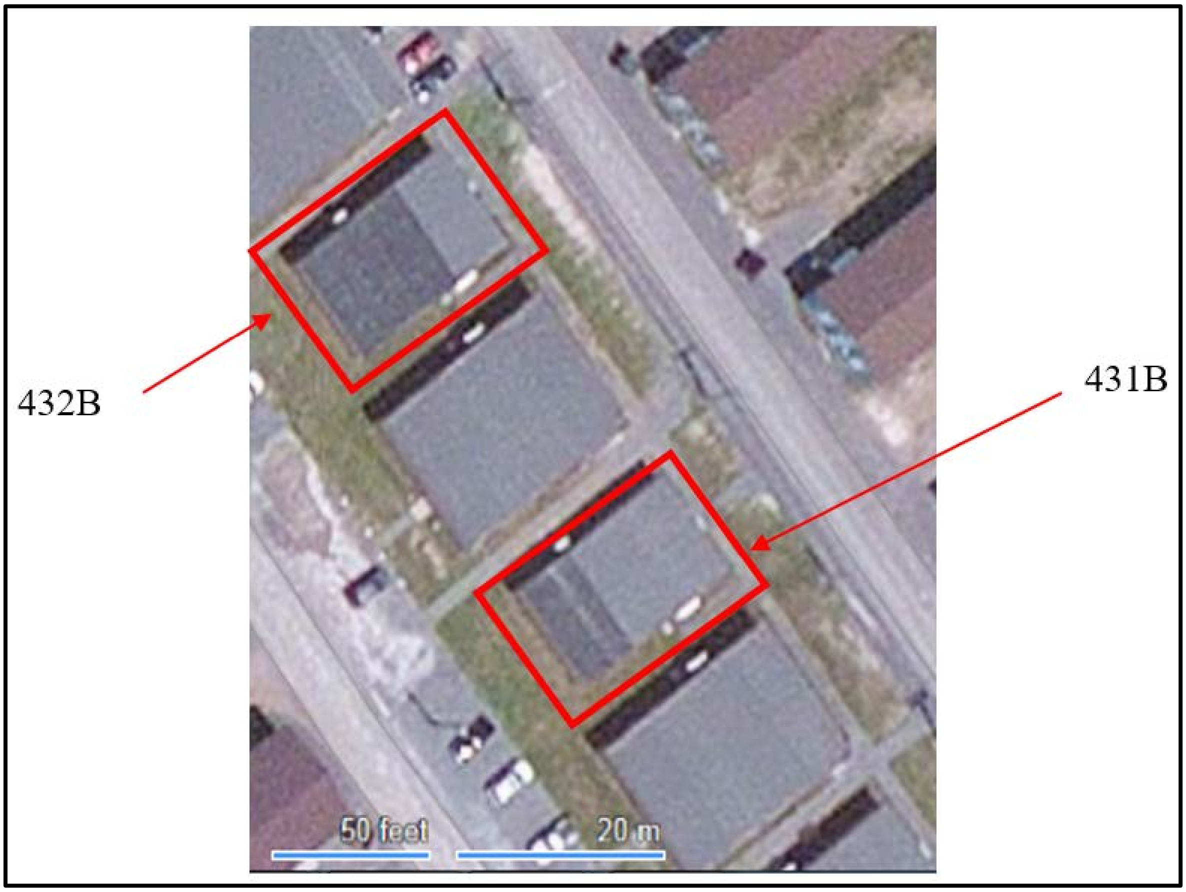

Figure 6. Plan View of Building Locations.

Figure 7. Fort Drum Retrofit Facility.

3.2 DEMONSTRATION FACILITY/SITE LOCATION AND OPERATIONS

One of the important factors in choosing Fort Drum for this demonstration was its climate. Fort Drum is in American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) climate zone 5A (Figure 8). As shown in Figure 4, colder climates increase the effective R-value/in. of the MAI technology. Furthermore, both buildings are constructed identically and physically located within 50 yards of each other, a proximity required to effectively use one of the buildings as a control building. Both buildings are operated and occupied by the Safety Office, which simplified coordination and logistics of the work activities for the buildings. Although the two buildings have similar purposes, ORNL conducted EnergyPlus modeling to account for energy use due to varying occupancy, temperature set points, weather conditions, plug loads, etc. Construction Engineering Research Laboratory (CERL) coordinated with the Safety Office and other Fort Drum staff to obtain the relevant information for the EnergyPlus models.

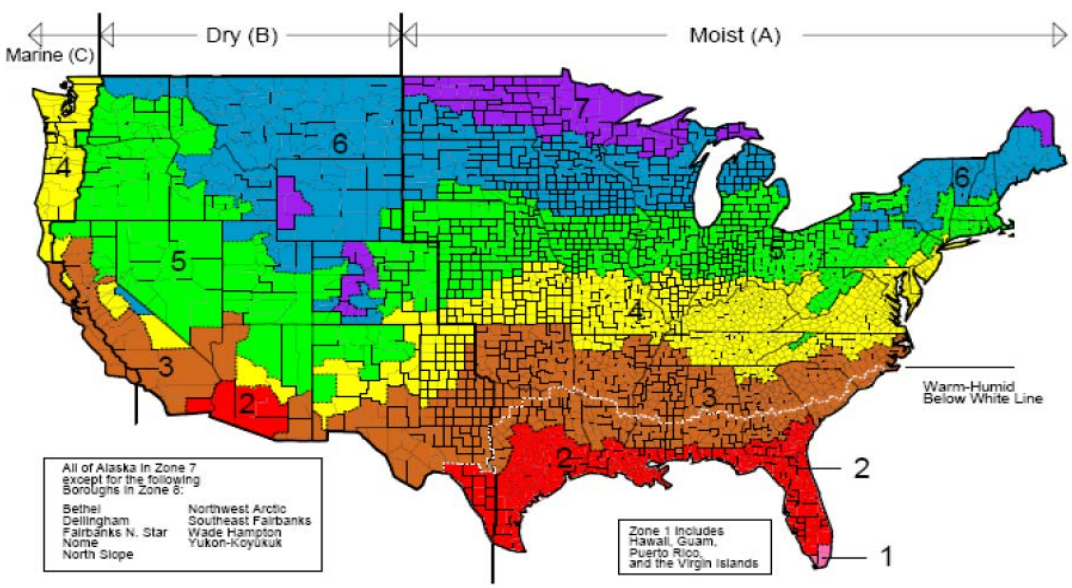

Figure 8. ASHRAE Climate Zones.

4.0 TEST DESIGN

The demonstration was intended to show reduced energy losses through walls, overall energy savings, and to validate of the effectiveness of the MAI compared to traditional insulation. The fundamental problem and question that this demonstration addresses are:

- Fundamental Problem: Energy loss through the walls accounts for approximately 5% of DoD facility energy consumption.
- Demonstration Question: The project will demonstrate the extent of reduced energy loss through the walls and resulting decrease in overall facility energy and utility cost. This demonstration will determine the cost effectiveness of MAI insulation.

4.1 CONCEPTUAL TEST DESIGN

The MAI supplemented the existing R-19 fiberglass batt insulation currently in the walls of Bldg. 432B at Fort Drum, the baseline building. The MAI panels are expected to provide additional insulation and reduce heat gains and losses through walls by 20% or greater. Comparison of the energy consumption in both buildings, and subsequent energy modeling showed the benefits of using this high R-value/in. technology for retrofit applications.

Two facilities, with identical construction, were used for the study. The team measured differences in temperatures and heat fluxes using a suite of instruments, flush with the internal walls and the exterior insulation. The impacts of installing the insulation were measured by the reduction heat transfer through the walls. Heat flux curves were generated from the data collected. The areas underneath the heat flux curves versus time provide a means of correlation of excess heat loss or gained for each day.

Periodic IR inspections were conducted prior to the demonstration and during the demonstration period to: (1) compare thermal bridging reduction in the baseline and post-retrofit cases, and (2) determine if there is any degradation in performance of the MAI panels. Immediately after the retrofit, results from the IR inspection were used to determine if any panels failed during the installation process. Information on these thermal breaks will be used to inform and improve the design for future MAI installations. Ongoing periodic IR inspections helped determine whether additional panels had failed or were slowly failing due to slow leaks.

The EnergyPlus software allowed the team to develop accurate building models using data from the temperature and heat flux sensors. Instrumentation was installed to capture impacts of weather and solar radiation on the building consumption. The weather data were used as inputs to the energy models. Each model was calibrated for both the baseline and the retrofit building (calibrated models). The models were then normalized to eliminate the effects of varying occupancy, internal loads, and schedule (normalized models). The models were used to determine the reduction in energy loss through the walls, reduced building energy consumption and resulting utility cost savings, and success/failure against the performance objectives.

4.2 BASELINE CHARACTERIZATION

Bldg. 431B was used to characterize the baseline for this project. This building was monitored for over 12 months, in a side-by-side comparison with the retrofit building, to ensure that the effects of seasonal variations were captured. The baseline building energy model will be used to determine the energy losses and energy consumption of a building without the MAI panels. Identical sensors will be placed in identical locations in both buildings. Only the weather and solar stations will be installed in Bldg. 432B. Due to the proximity and orientation of both buildings, the weather is also identical.

4.3 DESIGN AND LAYOUT OF SYSTEM COMPONENTS

For this project, custom sized 1-in. thick (R-35 equivalent) MAI panels were manufactured. Fort Drum did not have elevation drawings of the proposed buildings. CERL staff travelled to Fort Drum in April 2015 to obtain measurements of the exterior face of the building. Computer-Aided Design (CAD) drawings of the fastener locations were created. These drawings were used to select the most common sizes for the MAI panels. Since the fasteners need to go into the oriented strand board (OSB), the areas with the fasteners did not have MAI under them. Instead, 1-in. thick foam strips were used. A gap of 1-in. was left on each side of the fasteners. Since all the fasteners are not perfectly aligned with each other, this allowed for some flexibility in installing the MAI panels and provided a margin of safety.

4.4 OPERATIONAL TESTING

There were six test phases for this project:

- *Phase 1: Pre-test preparation*: Purchase sensors and determine sensor layout, coordinate with building occupants, purchase peripheral equipment to support data collection and reporting, determine exact sizes of MAI panels, and manufacture MAI panels.
- *Phase 2: Sensor installation*: Install heat flux and temperature/relative humidity (RH) sensors in both buildings. Record exact location within buildings. The location information was used in the energy modeling process. Install weather station and solar station on Bldg. 432B. Connect all sensors to data collection unit using conduits where necessary. Install electric meters and natural gas pulse kits. Talk to occupants to determine internal loads, occupancy, and internal set points.
- *Phase 3: Sensor calibration and verification*: Verify that all sensors are functional; calibrate sensors and ensure that data are being transmitted over class C phone lines.
- *Phase 4: Install MAI panels in Bldg. 432B*: Distribute Likert surveys to obtain data for pre-retrofit observations, occupant comfort, and ease of installation.
- *Phase 5: Data collection*: On a weekly basis, download data from both buildings. The data collection period is 9-12 months, covering the heating (winter), swing (spring or fall), and cooling (summer) periods. Calibration of the models was conducted using 1 week from each of the winter, summer and spring/fall periods. Periodic IR images of the walls were captured.
- *Phase 6: Data analysis*: Data analysis included developing EnergyPlus models, and calibrating the models against heat flux, temperature/RH sensors, weather data, utility electric, and natural gas data. The data analysis relies heavily on energy modeling. Section 5.4 details the energy modeling process.

Table 2 lists the actual start dates and duration of each activity.

Table 2. Timelines.

Activity	Start Date	Actual Duration
Install sensors	08/17/2015	1 week
Data monitoring	08/24/2015	2 months
Retrofit bldg. with MAI panels	11/15/2015	1 week
Data collection	09/18/2015	18 months

4.5 EQUIPMENT CALIBRATION AND DATA QUALITY ISSUES

All heat flux transducers, thermocouples, and relative humidity sensors were calibrated by ORNL before installation. All weather station sensors and data collection units were also tested and calibrated, or testing/calibration documents were requested from the vendors. Communication with all on-site equipment was also tested before data collection begins.

Temperature sensors (thermistors) and RH sensors used factory calibrations. The RH sensors are HIH-4000 Series humidity sensors from Honeywell. The solar sensors were also factory-calibrated and the calibration certificates are also included.

4.6 SAMPLING RESULTS

The final report discusses the sampling results for all sensor data in the context of the calibrated energy models. Chapter 5, "Performance Assessment," includes the analysis regarding the normalized energy models.

Figure 9 illustrates one example of data from the final calibrated models in which the simulated electric baseline is compared against the measured baseline. As seen, the simulated electric trends match well with the measured trends. In some cases, the trends vary on certain days. This could be due to higher plug loads, higher than normal number of occupants, or other variables that were not measured. The team did not change these parameters to reflect day-to-day building operation, but rather to represent seasonal variations. This results in a more representative model. The final report provides additional details and several other comparisons.

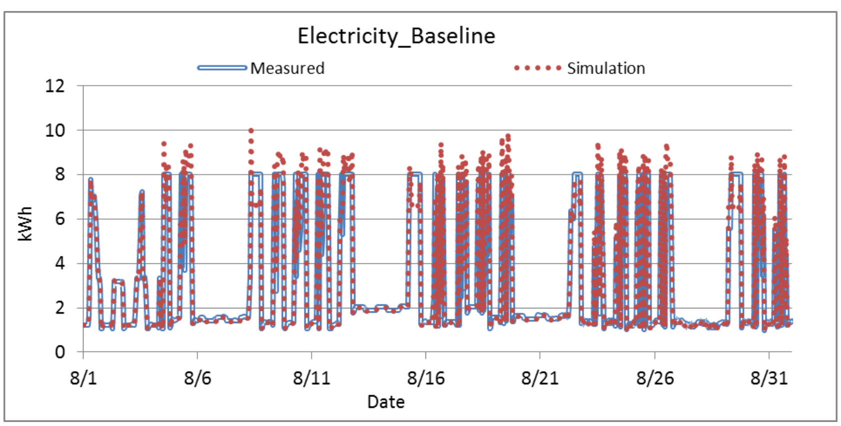

Figure 9. Summer Baseline Total Electric Use.

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5.0 PERFORMANCE ASSESSMENT

After the calibrated models were complete, the team then normalized the two facilities by using DOE small office commercial prototype building models to normalize the internal loads, occupancy, and thermostat setpoint schedules. Although the two facilities at Fort Drum are not necessarily small offices, their construction, loads, and schedules match most closely with the DOE small office prototype. The results and comparison are discussed in the following sections based on the performance objectives. For these purposes, annual normalized simulations are conducted with actual weather data from May 2016 to April 2017. The results are presented from January through December, for ease of discussion.

Some of the assumptions for the models used for the annual energy simulations, based on load profile from prototype building model were: internal load, occupancy, and thermostat setpoint schedule used on the commercial prototype building model for small office building was used.

5.1 FACILITY ENERGY USAGE

Figures 10, 11, and 12, respectively, show month-by-month comparisons of the facility electric, HVAC (cooling) electric, and natural gas use. As seen, the results from the total electric and HVAC electric use are somewhat counter-intuitive. Rather than decreasing, these loads are slightly higher. One probable reason is that the retrofit building captures and retains heat from internal loads better than the baseline facility. As expected, natural gas usage is substantially lower for the retrofit facility.

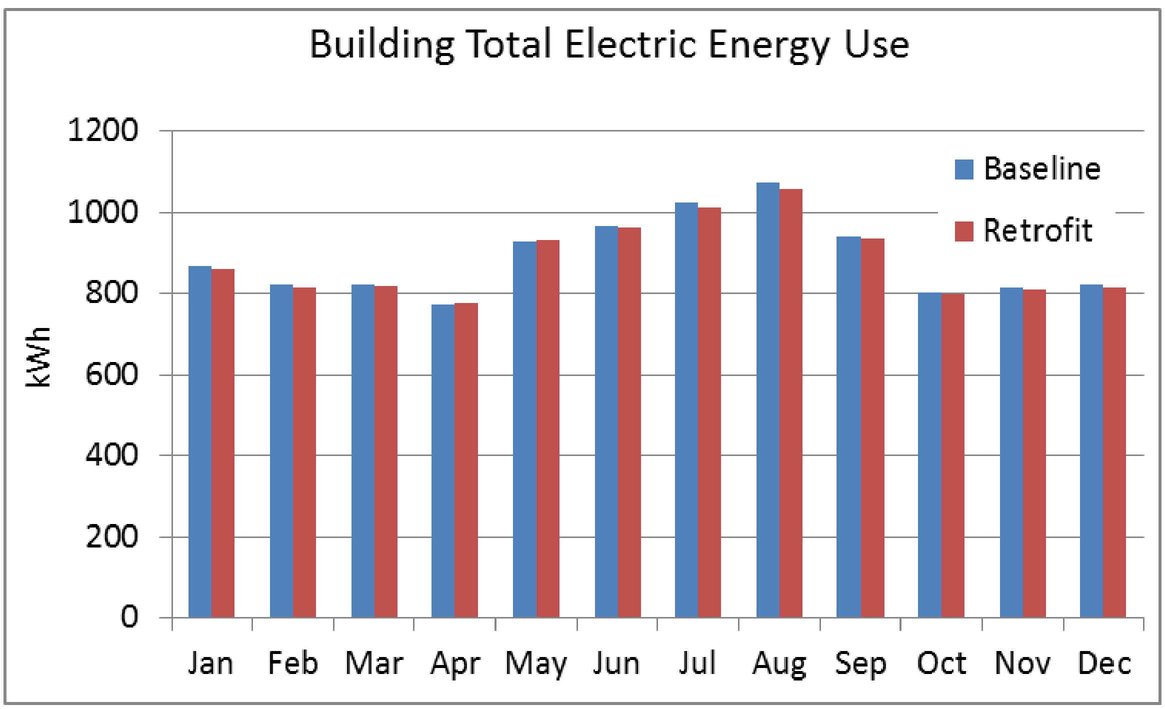

Figure 10. Normalized Total Electric Energy Use.

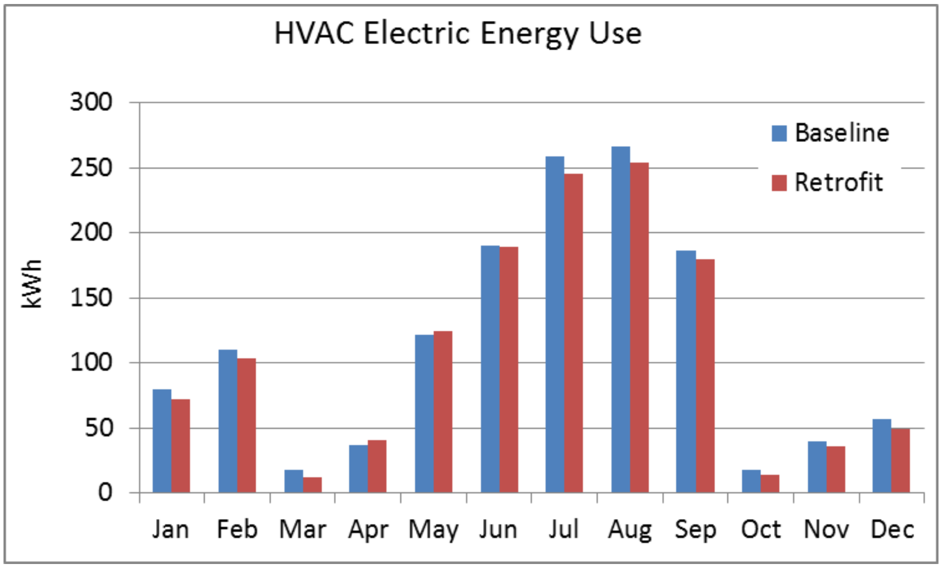

Figure 11. Normalized HVAC Electric Energy Use.

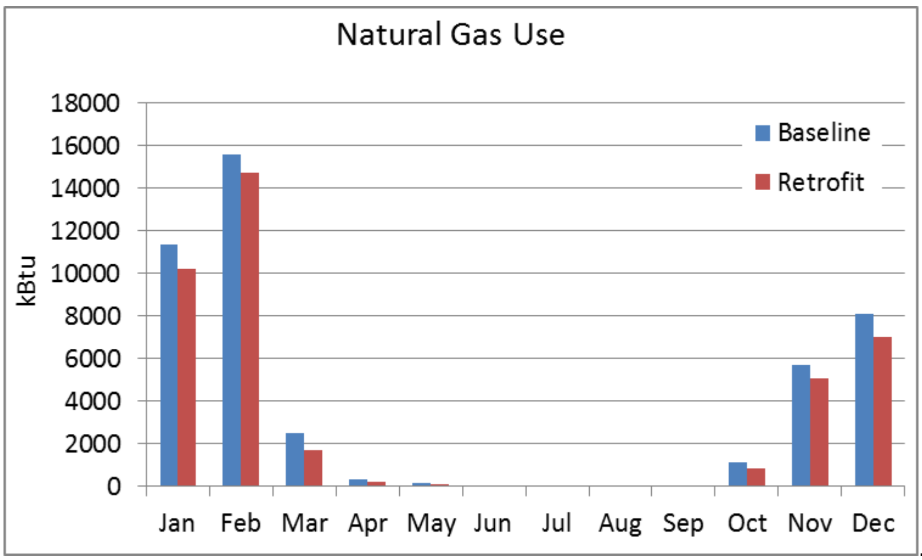

Figure 12. Normalized Natural Gas Use.

Table 3 lists the normalized energy usage.

Table 3. Normalized Energy Usage.

	Baseline	Retrofit	% Difference
Total electric (kWh)	10,660.4	10,597.9	–0.58%
Natural gas (kBtu)	44,919.9	39,908.9	–11.15%
Total (kBtu)	81,294.6	76,070.3	–6.43%

The overall reduction in energy was 6.43%, which is higher than the performance objective (PO) of 4%. Therefore, this metric is a success.

5.2 DEMAND REDUCTION

Figure 13 shows the maximum electric demand during any 1-hour interval for both facilities. As shown in the Figure 13 and listed in Table 4, the peak demand occurs in August. Generally, the highest rates are charged during summer months and result in the greatest savings.

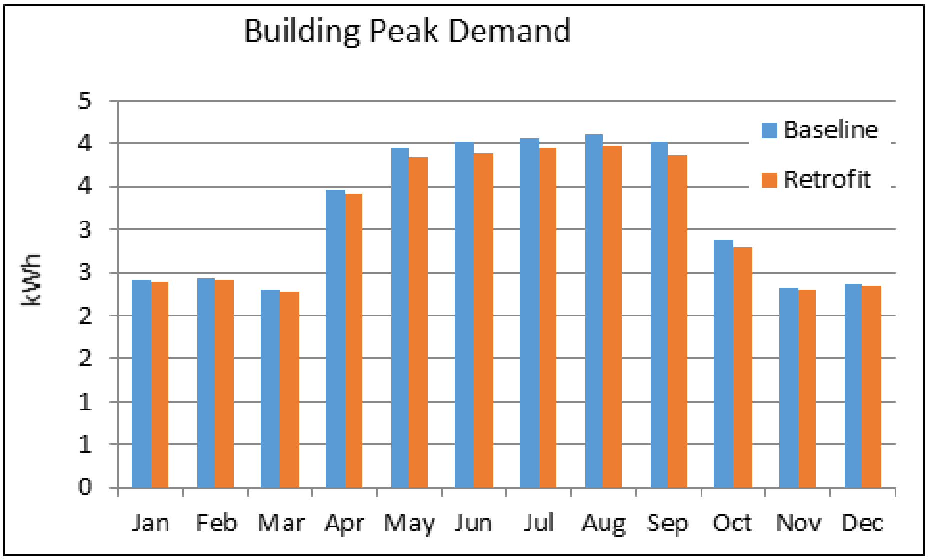

Figure 13. Normalized Peak Demands (kW).

Table 4. Peak Demand by Month.

Peak Demand	Baseline (kW)	Retrofit (kW)	Difference (%)
Jan	2.406	2.381	-1.0%
Feb	2.433	2.415	-0.7%
Mar	2.295	2.289	-0.3%
Apr	3.469	3.418	-1.5%
May	3.954	3.840	-2.9%
Jun	4.013	3.895	-2.9%
Jul	4.064	3.950	-2.8%
Aug	4.118	3.973	-3.5%
Sep	4.019	3.869	-3.7%
Oct	2.884	2.798	-3.0%
Nov	2.317	2.305	-0.5%
Dec	2.364	2.341	-1.0%
Avg	**3.195**	**3.123**	**-2.2%**

As seen, during the highest peak month, there is a 3.5% reduction in peak demand. This meets the PO requirements and is therefore a success. If the average peak demand is considered, then there is an average 2.2% reduction.

5.3 PERCENT OF PANELS EXPERIENCING LOSS OF VACUUM (%)

Infrared (IR) thermography images of the facility were taken immediately after the installation. These images were used to determine whether any panels have failed. Figures 14 to 17 show several IR images taken at various times after the installation. All images were taken during winter.

In Figure 14, the darker squares show the MAI panels. The lighter rows between the panels, and the left column show the polyiso foam. Because the R-value of the polyiso foam is significantly less than MAI, there is relatively higher heat loss from those sections. Figure 15 shows an image of a panel that was damaged, but not removed. The failed panel is clearly visible, and the temperature differences confirm this. Figures 14 and 15 were taken immediately after the retrofit.

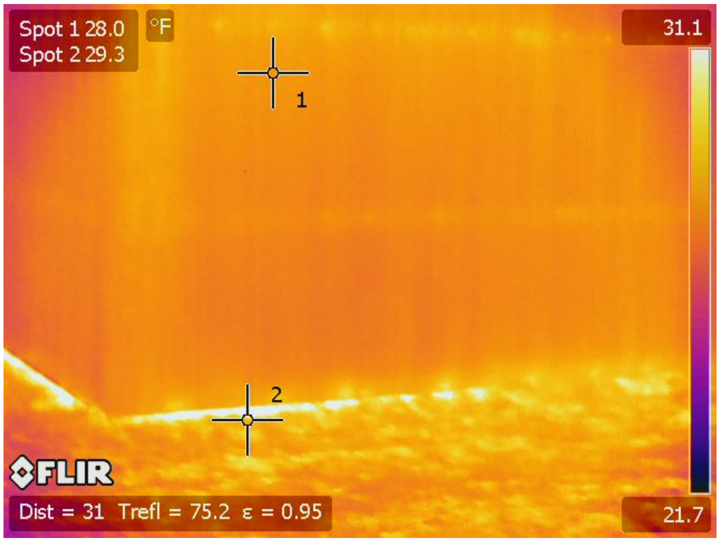

Figure 14. IR image of East Face.

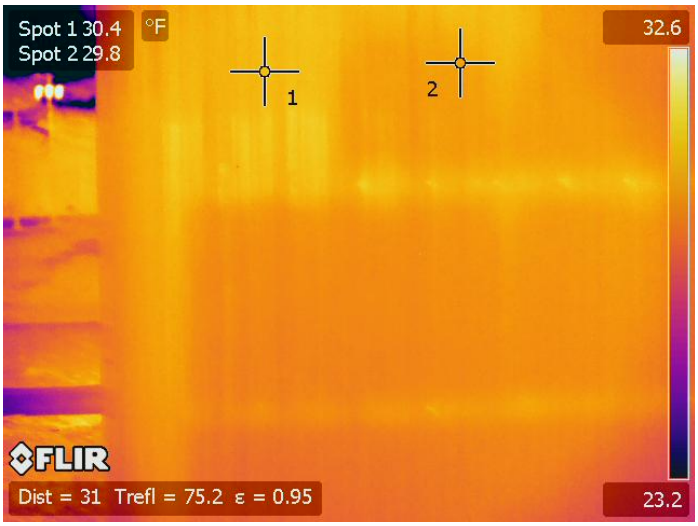

Figure 15. IR Image Showing Failed Panel (top left).

Figures 16 and 17 show IR images taken on a subsequent trip (Feb 2016), approximately 3 months after the installation. After the installation, Fort Drum staff installed building signs in both facilities. Due to a lack of coordination, the signs were installed with 2-in. screws and punctured several panels in the process.

Figure 16. Failed Panels above Sign (South Face).

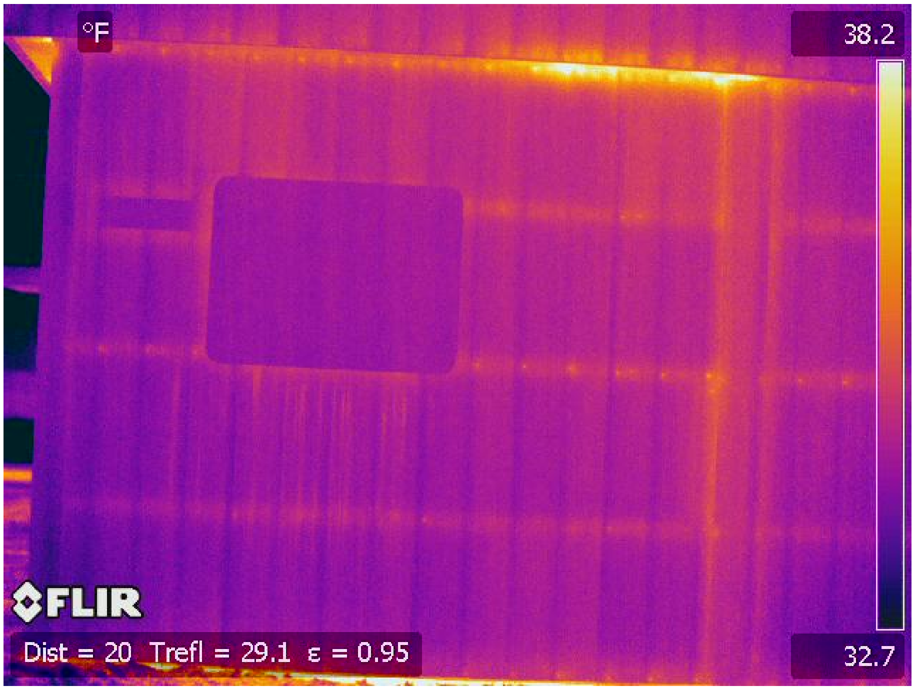

Figure 17. Failed Panels above Sign (North Face).

A total of five panels had failed above two signs in the retrofit facilities. In addition to the single punctured panel that was intentionally left in place, the team found an additional five panels that had failed (11 total). Although it was not immediately evident why these last five had failed, the team suspects the panels were damaged during the install and slowly leaked over time. With 331 total panels installed, 11 total panels were found to have failed (3.32%). This exceeds the PO criteria and is therefore a success.

5.4 OVERALL R-VALUE OF WALLS WITH MAI (%)

The overall R-value increase was calculated by using the planned MAI layout and associated dimensions as described in the final report. The area weight average R-value increase is 15.16, which exceeds the PO requirement. Therefore, this metric is considered successful.

5.5 COVERAGE OF WALL AREA WITH MINIMAL MAI PANELS

Achieving optimal coverage of the wall area is dependent on the shape of the facility, the number of penetrations, and the size/number of windows and doors. To achieve the desired increase in R-value and coverage, the team worked with the manufacturer to determine the cost and increased resistance associated with multiple sizes of panels. Table 5 lists the final MAI panel sizes and respective numbers of MAI panels.

Table 5. Final MAI Panel Sizes.

	X (in)	Y (in)	No. of MAI panels
A	19.95	28.00	87
B	21.29	28.00	83
C	19.17	25.50	26
D	20.58	25.50	135
		Total	331

Figure 18 shows the area weighted MAI coverage for each face. As seen in this graph, using four different panel sizes provides ~76% coverage.

Since the area weighted coverage for four panels exceeds 70%, this PO is considered successful.

5.6 ENERGY LOSS THROUGH WALLS

The energy lost through walls is comprised of both heat gain across the walls and heat loss across the walls. The heat gain (into the building) is dominant during the cooling season (i.e., summer) whereas the heat loss (out of the building) is dominant during the heating season. However, day-to-day fluctuations in temperature, internal loads, and occupancy can cause walls to experience heat gain or heat loss depending on these conditions. Heat flux from the normalized models was time-integrated into monthly bins to produce the total heat gain/loss across the walls during each month.

Table 6 lists the magnitude of gain/loss through the walls and the total percent reduction/increase over the baseline facility. As seen, the percent reduction across the year was 31%, greater than the PO of 20%.

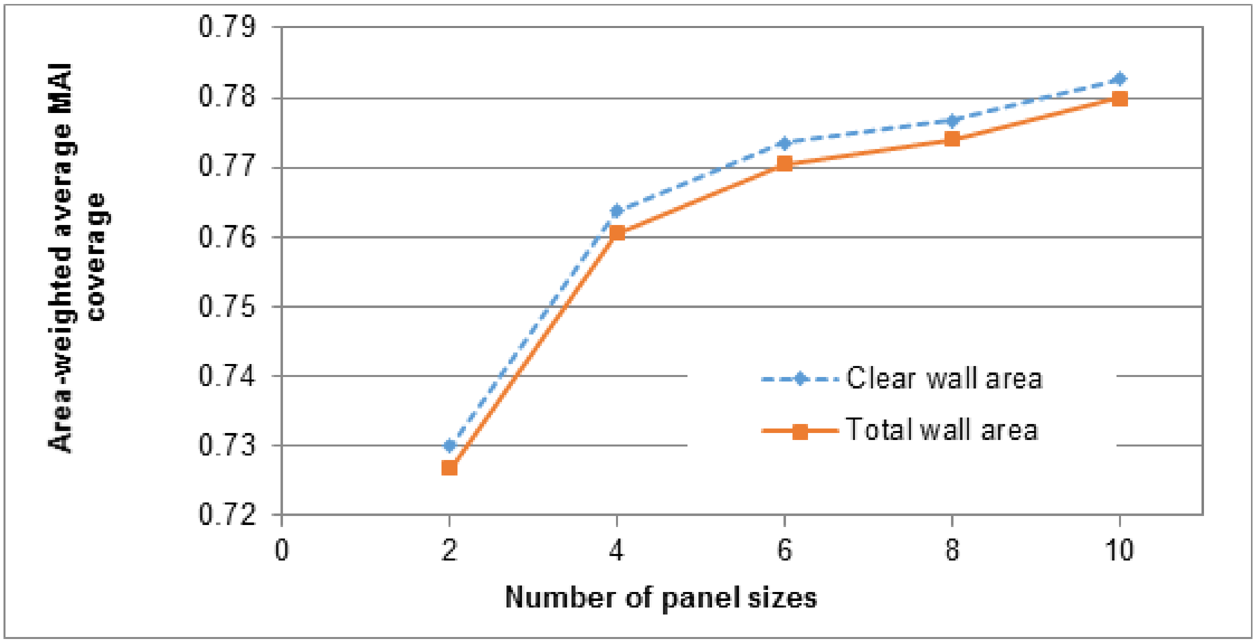

Figure 18. Number of Panel Sizes vs Area Weighted Coverage.

Table 6. Total Heat Loss/Gain through Wall.

Month	Baseline heat gain (kBtu)	Baseline heat loss (kBtu)	Retrofit heat gain (kBtu)	Retrofit heat loss (kBtu)	Baseline - total wall heat gain/loss load (kBtu)	Retrofit - total wall heat gain/loss load (kBtu)	% difference
Jan	24	2018	115	1256	2042	1370	-33%
Feb	63	1656	140	1050	1719	1190	-31%
Mar	22	1995	69	1232	2017	1302	-35%
Apr	127	997	117	665	1124	782	-30%
May	219	713	144	484	932	629	-33%
Jun	305	329	193	228	634	422	-34%
Jul	426	123	250	91	548	341	-38%
Aug	427	120	248	82	547	330	-40%
Sep	320	336	197	208	656	404	-38%
Oct	296	815	319	573	1111	892	-20%
Nov	182	1235	257	864	1416	1121	-21%
Dec	22	1937	121	1193	1959	1314	-33%
Total	***2432***	***12273***	***2170***	***7927***	***14705***	***10097***	***-31%***

5.7 ECONOMICS

See Chapter 7, “Cost Assessment,” for a detailed discussion of the economics of this work.

5.8 LIKERT SCALE RESULTS

The team originally planned to distribute Likert surveys to both installers and occupants. However, due to the nature of the retrofit facility usage, the team was unable to find any occupants that used the facility regularly both before and after the retrofit. Additionally, because the facilities were unoccupied during the retrofit, many of the Likert questionnaire questions are not applicable. Therefore, this project did not consider the Likert questionnaire for occupants. Three installers completed questionnaires and those results are used to assess this metric. Table 7 lists the results from each questionnaire.

Table 7. Likert Questionnaire Tabulated Responses.

Questionnaire #	Strongly disagree	Disagree	Neutral	Agree	Strongly Agree	N/A	Weighted Score
1	0	0	3	3	3	0	9
2	0	0	2	4	3	0	10
3	0	0	2	3	4	0	11

Each of the surveys (100%) resulted in a weighted score greater than 0, therefore this metric is considered a success.

5.9 PERFORMANCE ASSESSMENT WITHOUT INSULATION

As discussed in previous sections, the existing cavity insulation results in lower energy savings. Using the normalized models, a secondary scenario analysis was conducted to determine the potential economic impact of retrofitting a facility that did not already have existing insulation. This secondary analysis is more relevant for new buildings where alternative insulation technologies are being considered. Full year results for the energy reduction, and heat transfer through the walls for this secondary analysis are discussed in the following sections.

5.9.1 Energy Consumption

Table 8 lists the simulated difference in energy consumption for the secondary analysis scenario.

Table 8. Energy Comparison for Non-Insulated Facility Retrofit.

	Baseline	Retrofit	% Difference
Total electric (kWh)	11,233.2	10,692.9	-5%
Natural gas (kBtu)	77,699.7	43,970.3	-43%
Total (kBtu)	116,029.1	80,456.0	-31%

The 31% reduction is higher than the 6.41% reduction in a facility with existing cavity insulation.

5.9.2 Heat Transfer through the Walls

Table 9 lists the numerical values of the heat gain and loss in the walls.

The analysis shows that the total heat transfer reduction in the walls is 73%, which is significantly higher than the 31% shown in the previous sections.

Table 9. Secondary Scenario Wall Heat Transfer.

Month	Baseline heat gain (kBtu)	Baseline heat loss (kBtu)	Retrofit Heat Gain (kBtu)	Retrofit Heat Loss (kBtu)	Baseline - total wall heat gain/loss load (kBtu)	Retrofit - total wall heat gain/loss load (kBtu)	% difference
Jan	89	7,809	27	1,911	7,898	1,938	-75%
Feb	179	6,198	61	1,562	6,377	1,623	-75%
Mar	114	7,468	30	1,896	7,582	1,926	-75%
Apr	479	3,002	138	965	3,482	1,103	-68%
May	935	1,974	223	692	2,909	915	-69%
Jun	1,170	1,002	306	334	2,172	641	-71%
Jul	1,632	419	413	133	2,051	546	-73%
Aug	1,605	434	416	131	2,039	547	-73%
Sep	1,277	1,155	325	350	2,432	675	-72%
Oct	635	2,718	300	799	3,353	1,099	-67%
Nov	422	4,289	181	1,185	4,711	1,366	-71%
Dec	63	7,657	28	1,835	7,720	1,862	-76%
Total	**8,602**	**44,124**	**2,448**	**11,793**	**52,726**	**14,241**	**-73%**

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6.0 COST ASSESSMENT

6.1 COST MODEL

The hardware and labor costs of the installation were tracked to determine the life-cycle costs of this technology. Cost estimates for the MAI panels at full scale production are used for the economic analysis. The annual reduction in facility energy (based on normalized models) serves as the basis for cost savings and performance of the technology. There are no maintenance costs for this technology. Table 10 lists the elements of the cost model and Table 11 lists each cost element and how it was collected.

Table 10. Cost Model.

Cost Element	Data Tracked During the Demonstration
Hardware capital costs	Cost of purchasing the MAI panels ($\$/ft^2$), ($\$/R\text{-value}/ft^2$) at full scale production
Installation costs	Labor and material required to install. ($\$/ft^2$ of wall area)
Facility operational costs	Reduction in energy required vs. baseline data

Table 11. Data Collection for Each Cost Element.

Cost Element	Data collection methodology
Hardware capital costs	• Hardware costs from this demonstration • Estimated costs at full scale production
Installation Costs	• Labor costs and time from this demonstration • Estimated labor costs for buildings of a similar size
Facility Operational Costs	• Collected data from electric and gas meters in baseline and retrofit buildings • Estimated energy reduction based on E+ models • Using utility rates, estimate facility operational costs.

6.2 COST DRIVERS

Cost drivers are discussed for individual components in Section 6.3.

6.3 COST ANALYSIS AND COMPARISON

6.3.1 MAI Panels

Researchers worked with the manufacturer to project costs for three different sized MAI plants. The economic analysis for this demonstration assumes that a commercial plant of 5M ft^2 is in place for this technology. Projected costs range between $\$2.49/ft^2$ and $\$3.24/ft^2$ for 1-in. thick MAI (similar to that used in the demonstration). For simplicity, an average of $\$2.87/ft^2$ will be used for the economic analysis. The following sections describe the economic analysis in detail.

MAI offers a significant decrease in cost per area for high performance (>R30/in.) thermal insulation panels as compared to traditional VIPs. VIP use in building applications have been limited by their high cost per unit area, the large number of different panel sizes which complicates automation and optimization, and handling on job sites is difficult unless the panels have been pre-made into a construction system. Traditional VIP production is not highly automated because:

1. The large number of panel sizes (x, y, z)
2. Different barrier materials for different applications (short-lifetime packaging, medium-lifetime refrigerators and trucks, and long-lifetime buildings)
3. Very different dimensional and shape tolerances for different applications
4. The small production scale of most VIP plants, which should be considered primarily as pilot plants
5. The residence time and complexity of powder compaction into a board, drying, and evacuation.

In contrast, by eliminating the powder compaction, drying, and evacuation steps, MAI enables the use of conventional, high-speed packaging equipment that simplifies automation and large-scale production. This study explored the economics of two scales of plants. A pilot plant with a capacity of 300,000 ft^2/year and two commercial plants of 5,000,000 and 25,000,000 ft^2/year are used as the design basis for the economic analysis. The main elements of the cost are; raw materials, labor, overhead, and equipment (capital and operating). These costs are a function of plant size, plant location, and the number of different panel sizes (one to five sizes are assumed, all 1-in. thick). For a pilot plant, the MAI cost (ex-works) ranges between \$4.79/ft^2 and \$6.22/ft^2 with an initial capital cost of \$1.5M assuming an existing building. Because of the economies of commercial scale, costs decrease to between \$2.49/ft^2 and \$3.24/ft^2 with an initial capital cost of \$2.3M for a 5,000,000 ft^2/year plant. Costs further decrease to between \$1.97/ft^2 and \$2.56/ft^2 with an initial capital cost of \$6.8M for a 25,000,000 ft^2/year plant. All costs are in 2017 dollars.

6.3.2 Design Basis

As with all cost predictions, one must make a set of assumptions to form the basis for the analysis. In this report, we explore three different size plants; a 300,000 ft^2/year pilot plant, and commercial-scale plants of 5,000,000 and 25,000,000 ft^2/year. Table 12 summarizes the key operating parameters for each plant.

Table 12. Operating Parameters for All Three Plant Sizes.

Parameter	Pilot Plant	Commercial Plant #1	Commercial Plant #2
Weeks/year	48	50	50
Days/week	5	7	7
Hours/day	16	20	24
% uptime[1]	90	95	97
[1] Exclusive of product changeover time			

Another key variable that affects cost (both production and capital) is the panel size and size mix. For this study, we expect to make between one and five sizes. For building applications, almost all panels will be 1-in. thick. Table 13 lists the five sizes to be studied.

Table 13. Assumed MAI Panel Sizes.

Panel #	1	2	3	4	5
Width (in.)[1]	12	12	12	16	16
Length (in.)[1]	12	24	32	24	32
Area (ft^2)	1.0	2.0	2.67	2.67	3.56

[1]Dimensional tolerances: ±⅛-in. on x-y, ±1/16-in. on z

6.3.3 Plant Location

As with most insulation plants, location is important in an economic analysis. However, a MAI plant is different than conventional foam or fiberglass insulation plants. With conventional insulation, the raw material volume is usually much smaller than the resulting insulation volume so one desires the plant to be close to the customer to minimize total freight costs; also, cost of incoming raw material freight is a very small fraction of the total cost of goods sold (COGS). However, the situation is reversed if fumed silica is used as the core as in-coming fumed silica has a bulk density ~0.04 grams per centimeter cubed (g/cm^3) whereas the final MAI panel has a silica density of 0.14 g/cm^3. Depending on insulation plant scale, the plant location relative to the fumed silica supplier becomes a significant consideration in insulation plant location. There are currently four fumed silica plants in the United States (Midland, MI, Tuscola, IL, Mobile, AL, and Watervliet, NY) with a fifth plant under construction in Charleston, TN. The distance between the fumed silica and MAI plant drives not just freight, but transport method (low temperature limit [LTL], truckload, railcar, or direct pipe) and packaging costs.

6.3.4 Raw Material Costs

For a MAI panel, there are four main raw materials:

1. *Fumed silica*: This is the major component and cost. For MAI (and VIPs), this is typically 300 m^2/g grade produced by Evonik, Cabot, or Wacker for on-shore suppliers or a number of off-shore suppliers. The final density of fumed silica in an MAI panel is 0.14 g/cm^3, which fixes the weight of fumed silica required per ft^2 of panel at 1-in. thickness.
2. *Opacifier*: There are a range of opacifiers and opacifier weight loadings that can be used. This study assumes the use of silicon carbide at a 10% weight percent of the core. Because the weight percent is low and industrial grade silicone carbide (SiC) is much cheaper than fumed silica, the COGS uncertainty associated with this opacifier choice and weight loading is small.
3. *Barrier film*: There is a wide range of barrier films available for use in MAI panels including foils, laminated foils, coextruded films with ethylene vinyl alcohol (EvOH) barrier layers, and multi-layer laminates based on multiple mPET (metalized polyethylene terephthalate) layers with a linear low-density polyethylene (LLDPE) seal layer. This test assumes the use of Hanita's V085HB3 multi-layer laminate. The area of film required per unit area of insulation is a function of panel size because of the z-dimension and the material required for flaps. Based on our experience in panel production, we take the barrier film area for a given 1-in. thick panel as: 2*(width + 3-in.)*(length +3-in.)/144.

4. *Porous inner bag*: We assume the use of spun-bound polypropylene (SPB) as the inner bag material because of its high strength, high gas/vapor permeation, hydrophobicity, and processability. As with the barrier film, the area of SPB required is a function of panel size. We take the SPB area for a given 1-in. thick panel as: 2*(width + 2-in.)*(length +2-in.)/144.

Based on these raw materials, we can calculate how much of each raw material is required for the different plant size scenarios (Table 14). Both silicone dioxide (SiO_2) and SiC consumption are independent of panel size. However, the barrier and porous films are a function of panel size and we report the minimum (all 16x32-in. panels) and maximum (all 12x12-in. panels) areal demand.

Table 14. Raw Material Consumption for All Three Plant Sizes.

Nameplate plant capacity (ft2/year)	300,000	5,000,000	25,000,000
Hours of operation per year	3,840	7,000	8,400
Hours of production per year	3,456	6,650	8,148
Required capacity (ft2/hr)	86.81	751.88	3,068.24
Silica use (lb/hr)	63.19	547.37	2,233.68
Powder capacity (lbs/hr)	70.22	608.19	2,481.86
Annual silica use (lbs)	218,400	3,640,000	18,200,000
250 lb supersack/day	4	42	208
Truck of SS (8,000 lb)/week	0.57	9.10	45.50
Railcar (20,000 lb) per week	0.23	3.64	18.20
Annual SiC (lbs)	24,267	404,444	2,022,222
Annual SBP ft2 (minimum)	717,188	11,953,125	59,765,625
Annual SBP ft2 (maximum)	816,667	13,611,111	68,055,556
Annual SBP ft2 (average)	766,927	12,782,118	63,910,590
Annual barrier ft2 (minimum)	779,297	12,988,281	64,941,406
Annual barrier ft2 (maximum)	937,500	15,625,000	78,125,000
Annual barrier ft2 (average)	858,398	14,306,641	71,533,203

6.3.4.1 Fumed Silica

Because of the low density of fumed silica before processing, freight and packaging are key cost considerations. Depending on the quantity, fumed silica is normally transported as palletized 10 kg paper bags, 250 pounds (lbs) FIBC's (supersacks), bulk tank trucks, rail cars, or a direct pipeline. The method of transportation affects both the freight cost and the supplier's cost of packaging. Another factor in fumed silica logistics is incoming raw material storage. The following sections discuss realistic options for the various plant scenarios we are modeling.

6.3.4.1.1 Pilot Plant

As indicated by the data Table 14, supersacks are the logical best choice because, at this scale, consumption is only four supersacks per day (a truckload every other week). This choice both decouples insulation plant location from the fumed silica plant and minimizes capital investment in fumed silica storage. The general rule for the cost of a 250 lb supersack is that there is $0.25/lb in packaging cost and $0.25/lb in transport. Our experience is that this yields a delivered cost of $2.25/lb ($1.75/lb material, $0.25/lb packaging and $0.25/lb transport) based on our direct experience at these (<300,000 lb/year) quantities. Table 15 lists raw material costs for all three plant sizes.

Table 15. Raw Material Costs for All Three Plant Sizes.

Nameplate plant capacity (ft^2/year)		300,000		5,000,000		25,000,000
Raw material cost						
Silica	$	491,400	$	6,370,000	$	27,300,000
SiC	$	19,413	$	242,667	$	1,112,222
SBP	$	18,406	$	255,642	$	1,150,391
Barrier	$	95,823	$	1,463,963	$	6,654,376
Raw material cost/ft^2	**$**	**2.08**	**$**	**1.67**	**$**	**1.45**

6.3.4.1.2 Commercial Plant #1

At the 5,000,000 ft^2/year scale, supersacks reach their range of economic viability as shown in Table 5 (depending on distance from the fumed silica plant). A much better solution is to locate the plant on a rail siding and to receive the fumed silica in bulk railcars (~20,000 lbs./railcar). This also helps with raw material storage, as the cost of demurrage, if any, will be less than a dedicated series of silos. Railcars must go back to the plant empty to prevent contamination, so the insulation plant must be within 500 miles of the fumed silica supplier. Since there is no packaging, the delivered cost is reduced to $1.75/lb ($1.65/lb material and $0.10/lb freight).

6.3.4.1.3 Commercial Plant #2

At 25,000,000 ft^2 per year plant scale, any kind of packaging/shipment becomes cost prohibitive given the volumes of fumed silica required. So just like most silicone companies (Dow Corning, Momentive, Bayer, Wacker, etc.), a large MAI plant would be located in a fence-line operation with a fumed silica plant. This reduces the silica cost to ~$1.50/lb (based on supplier discussions). Note that as with any large volume procurement, issues like "take or pay" clauses, supply chain guarantees, etc. can affect the cost by ±20%.

6.3.4.2 Silicon Carbide

This application requires only impure opacifiers, which are available at low cost and in large quantities. For the pilot plant, this would be received in 2,000 lb supersacks at a cost of $0.80/lb (delivered). For the larger plants, the cost would be reduced to $0.60/lb because of both higher usage and reduced freight cost because full truck-loads would be purchased.

6.3.4.3 Barrier Film

Although there is a wide range of possible barrier films available, we would use Hanita's (a division of Avery Dennison) V085HB3 film that is $1.20/$m^2$ delivered. At the larger volumes, this would come down to $1.1/$m^2$ and $1.0/$m^2$ based on quotes from the supplier.

A “3D Porous inner bag” is an SPB that NanoPore’s sister company, NanoCool, uses in quantities similar to the pilot plant size of this study. The current price NanoCool pays is \$0.024/ft^2. At larger scales, this would reduce to \$0.02/ft^2 and \$0.018/ft^2 because of the higher volumes and full truck-load freight.

So even at the largest scale with a fence-line operation for fumed silica, the cost of the fumed silica is 75% of the raw materials cost. Hence, we maintain a continued interest in finding lower cost/higher performance core materials for MAI panels.

6.3.5 Labor and Overhead Cost

The number of people and their costs (Tables 16 and 17) are based on NanoPore experience with its sister company, NanoCool Limited Liability Corporation (LLC), and its VIP production operation, which was formerly NanoPore Insulation before being sold to Sealed Air Corporation, and which is now known as Kevothermal. The overhead rate of 30% of combined raw materials and labor reflects the overhead at the two production operations described in the previous sections.

Table 16. Labor Costs with Benefits for All Three Plant Sizes.

Nameplate plant capacity (ft^2/year)	300,000	5,000,000	25,000,000
Labor			
Plant Manager	\$ -	\$ 175,000	\$ 175,000
Shift supervisor	\$ 160,000	\$ 320,000	\$ 480,000
Operators, warehouse, maintenance, admin	\$ 320,000	\$ 768,000	\$ 1,024,000
Labor/ft^2	**\$ 1.60**	**\$ 0.25**	**\$ 0.07**

Table 17. Overhead and Total Costs of Goods Sold (COGS) for All Three Plant Sizes.

Nameplate plant capacity (ft^2 /year)	300,000	5,000,000	25,000,000
Overhead			
Overhead/ft	**\$ 1.11**	**\$ 0.58**	**\$ 0.45**
COGS	**\$ 4.79**	**\$ 2.49**	**\$ 1.97**

At the higher volumes, the COGS are similar to foams on a \$/R-value basis. That said, the COGS does not include the cost of capital equipment or building, and does not provide for a profit margin.

6.3.6 Capital Equipment, Description, and Cost

Table 18 lists equipment required for each of the three different plant sizes. All employ the same MAI process flow (Figure 3, p 6), but differ primarily in raw material sourcing and handling. The 25,000,000 ft^2/year is essentially four 5,000,000 ft^2 production lines in parallel as the VFFS machines reach their capacity limits. The sources of equipment costs are:

1. *Previous NanoPore and affiliated company purchases*: Flexicon bulk bag unloading station, powder conveying system, Tecweigh weigh feeder, conveyors, dust collection systems, Quality Control (QC) inspection.
2. *Quotes from Solids Technology*: 1,000 feet cubed (ft^3) silo, Viking VFFS machines, gravimetric opacifier mixing, inserter.
3. *Quotes from Supply 1*: Pallet wrapper, automatic palletizer, fork lift
4. *NanoPore*: Estimate based on scale-up of existing lab-scale equipment: Air replacement tunnel, cold forming conveyor

Table 18. Capital Equipment Costs for All Three Plant Sizes.

Nameplate plant capacity (ft^2/year)		300,000 ft^2/year		5,000,000 ft^2/year		25,000,000 ft^2/year	
Description	Unit cost	#	Total Cost	#	Total Cost	#	Total Cost
Flexicon bulk bag unloading station	$ 38,000	2	$ 76,000	1	$ 38,000	2	$ 76,000
1,000 ft^3 silo	$ 52,000	0	$ -	2	$ 104,000	4	$ 208,000
Powder conveying systems	$ 25,000	1	$ 25,000	4	$ 100,000	8	$ 200,000
Gravimetric opacifier mixing system	$ 40,000	1	$ 40,000	2	$ 80,000	4	$ 160,000
Techweigh weigh feeder	$ 22,000	1	$ 22,000	4	$ 88,000	8	$ 176,000
Viking VFFS machine for SPB bag	$ 95,000	1	$ 95,000	1	$ 95,000	4	$ 380,000
Air replacement tunnel	$ 150,000	1	$ 150,000	1	$ 150,000	4	$ 600,000
Viking VFFS machine for barrier bag	$ 80,000	1	$ 80,000	1	$ 80,000	4	$ 320,000
Inserter for VFSS	$ 30,000	1	$ 30,000	1	$ 30,000	4	$ 120,000
Cold forming conveyors	$ 45,000	1	$ 45,000	1	$ 45,000	4	$ 180,000
Material handling conveyors	$ 8,000	4	$ 32,000	4	$ 32,000	16	$ 128,000
Pallet wrapper	$ 40,000	0	$ -	1	$ 40,000	0	$ -
Automatic palletizer	$ 110,000	0	$ -	0	$ -	1	$ 110,000
Forklift	$ 25,000	1	$ 25,000	1	$ 25,000	4	$ 100,000
Air handling/dust collection system	$ 60,000	1	$ 60,000	2	$ 120,000	4	$ 240,000
QC inspection station	$ 15,000	1	$ 15,000	1	$ 15,000	4	$ 60,000
Total equipment			$ 695,000		$ 1,042,000		$ 3,058,000
Design and Engineering (20% of equipment)			$ 139,000		$ 208,400		$ 611,600
Equipment Install (50% of equipment)			$ 347,500		$ 521,000		$ 1,529,000
Automation/integration (30% of equipment)			$ 208,500		$ 312,600		$ 917,400
Contingency (20% of equipment)			$ 139,000		$ 208,400		$ 611,600
Total			**$ 1,529,000**		**$ 2,292,400**		**$ 6,727,600**

For simplicity, an average of \$2.87/ft^2 will be used for the economic analysis. For this demonstration, a total of 1,261 ft^2 of MAI was used. Therefore, the cost of the MAI panels (at full production scale) is 1,261 ft^2 * \$2.87/ft^2 = \$3,619.07.

Approximately thirteen (13) 4-feet (ft) x 8-ft x 1in. boards of polyiso were used at a cost of $20 per board. This is a total of $260. Therefore, the cost of MAI and polyiso is **$3,879.07**.

6.4 INSTALLATION COSTS

The installation costs for this demonstration were tracked during the week of the install. The installation took 3.5 days with multiple people and hours worked per day.

Other costs included a portable table saw for cutting foam, and power tools. These costs are not included in this estimate because they are common for most commercial construction contractors.

Table 19 lists the detailed labor breakdown, assuming a cost of $60/h per person.

The labor cost of the installation for the demonstration is estimated as $14,040. The installation covered almost 2,000 ft^2 of wall area, which is approximately $7.02/$ft^2$. Based on the assignment of tasks, future installations could easily require one less person for the installation. In that case, the total labor hours are reduced to 187 at a total cost of **$11,220.** This installation cost is used for the economic analysis.

Table 19. Detailed Labor for Installation.

Day	Number of Personnel	Hours Worked Ea.	Total Hours	Tasks
Monday	1	3	3	Verify layout against building dimensions. Clean and prep site.
Tuesday	8	9	72	Unpack items, setup site, assign responsibilities, remove siding, and install MAI. 60 panels installed on east side total. Reinstall siding in case of rain.
Wednesday	8	9	72	Continue MAI install. 120 panels installed. East and north completed. Reinstall siding
Thursday	7	9	63	Continue MAI install. 162 panels installed. South completed. West side complete (except around window). Reinstall siding
Friday	6	4	24	Complete install. Reinstall siding. Clean up.
Total	-	-	234	

6.5 TOTAL COST

For purposes of this economic analysis, two separate costs are considered. The first only includes the cost of the MAI and Polyiso foam. Because the technology is not completely mature, the cost of the installation is extremely high. Installation costs are expected to be reduced by 80% or more. This will be achieved through large 4x8-ft MAI/foam integrated boards that are produced on the manufacturing line. These boards are currently under pilot development and as such there are no cost estimates yet.

The cost with installation is calculated as:

MAI ($3,879) + Installation ($11,220) = ($15,099 + supervision, inspection and overhead (SIOH) (6%, $905) and Design (10%, $1,510) = **$17,514**

The cost without installation is calculated as:

MAI ($3,879) + SIOH (6%, $233) and Design (10%, $388) = **$4,500**

6.6 SAVINGS AND RATES

The 2017 Fort Drum electric rate is $0.0732/kWh. There is no demand-based pricing at Fort Drum because there is an on-site biomass plant that provides electricity. This rate was obtained by averaging Fort Drum FY17 Army Energy and Water Reporting System (AEWRS) Data:

Natural Gas (2017) = $3.633/million Btu (MMBtu)

Table 20 lists the normalized energy savings.

Table 20. Normalized Energy Savings.

	Baseline	Retrofit	Savings	% Difference
Total electric (kWh)	10,660.4	10,597.9	62.5	-0.58%
Natural gas (kBtu)	44,919.9	39,908.9	5,011	-11.15%
Total (kBtu)	81,294.6	76,070.3	5,224	-6.43%

The system economics for the technology was calculated using the Building Life Cycle Cost (BLCC) tool. The economics were calculated with and without installations costs. The low SIR and SP can be attributed to the low energy savings (due to existing insulation) and the low utility rates. Figures 19 and 20, respectively, illustrate the economics with and without installation costs.

6.7 SECONDARY SCENARIO COST ANALYSIS

A cost analysis for the secondary scenario (no original wall insulation) was conducted. This analysis used the energy consumption values listed in Table 21.

Table 21. Secondary Scenario Energy Consumption Analysis.

	Baseline	Retrofit	Savings	% Difference
Total electric (kWh)	11,233	10,693	540	-5%
Natural gas (kBtu)	77,700	43,970	33,729	-43%
Total (kBtu)	116,029	80,456	35,573	-31%

6.7.1 Cost Analysis – Secondary Scenario – with Installation

A cost analysis was conducted for the secondary scenario using the same natural gas and electricity rates described earlier (Figure 21).

As seen, the SP of 108 years and SIR of 0.21 is better than the original scenario with a SP of 769 years and SIR of 0.03.

6.7.2 Cost Analysis – Secondary Scenario – without Installation

Figure 22 illustrates the BLCC cost analysis without installation costs.

Without installation costs, the secondary scenario SP of 28 years and SIR of 0.82 is better than the SP of 198 years and SIR of 0.12.

Based on these cost analyses, it is clear that the existing cavity insulation in the facility impacts the system economics significantly. In facilities with no or very little insulation, the MAI is more promising. The relatively low cost of Fort Drum utilities also negatively impacts the economics. Additional work is underway to significantly reduce installation costs, which should help improve the cost economics further.

NIST BLCC 5.3-17: ECIP Report

Consistent with Federal Life Cycle Cost Methodology and Procedures, 10 CFR, Part 436, Subpart A

The LCC calculations are based on the FEMP discount rates and energy price escalation rates updated on April 1, 2017.

Location:	New York	Discount Rate:	3%
Project Title:	Ft. Drum ESTCP MAI Analysis	Analyst:	Tapan Patel
Base Date:	September 1, 2017	Preparation Date:	Sun Sep 17 16:09:15 CDT 2017
BOD:	September 1, 2017	Economic Life:	30 years 0 months
File Name:			

1. Investment

Construction Cost	$15,099
SIOH	$905
Design Cost	$1,510
Total Cost	$17,514
Salvage Value of Existing Equipment	$0
Public Utility Company	$0
Total Investment	$17,514

2. Energy and Water Savings (+) or Cost (-)

Base Date Savings, unit costs, & discounted savings

Item	Unit Cost	Usage Savings	Annual Savings	Discount Factor	Discounted Savings
Electricity	$21.45281	0.2 MBtu	$5	23.444	$107
Natural Gas	$3.63300	5.0 MBtu	$18	25.514	$464
Energy Subtotal		5.2 MBtu	$23		$572
Water Subtotal		0.0 Mgal	$0		$0
Total			$23		$572

3. Non-Energy Savings (+) or Cost (-)

Item	Savings/Cost	Occurrence	Discount Factor	Discounted Savings/Cost
Non-Annually Recurring				
Non-Annually Recurring Subtotal	$0			$0
Total	$0			$0

4. First year savings $23

5. Simple Payback Period (in years) 768.96 (total investment/first-year savings)

6. Total Discounted Operational [illegible]

Figure 19. Economics with Installation Costs.

NIST BLCC 5.3-17: ECIP Report

Consistent with Federal Life Cycle Cost Methodology and Procedures, 10 CFR, Part 436, Subpart A
The LCC calculations are based on the FEMP discount rates and energy price escalation rates updated on April 1, 2017.

Location:	New York	Discount Rate:	3%
Project Title:	Ft. Drum ESTCP MAI Analysis	Analyst:	Tapan Patel
Base Date:	September 1, 2017	Preparation Date:	Sun Sep 17 16:03:50 CDT 2017
BOD:	September 1, 2017	Economic Life:	30 years 0 months
File Name:			

1. Investment

Construction Cost	$3,879
SIOH	$233
Design Cost	$388
Total Cost	$4,500
Salvage Value of Existing Equipment	$0
Public Utility Company	$0
Total Investment	$4,500

2. Energy and Water Savings (+) or Cost (-)
Base Date Savings, unit costs, & discounted savings

Item	Unit Cost	Usage Savings	Annual Savings	Discount Factor	Discounted Savings
Electricity	$21.45281	0.2 MBtu	$5	23.444	$107
Natural Gas	$3.63300	5.0 MBtu	$18	25.514	$464
Energy Subtotal		5.2 MBtu	$23		$572
Water Subtotal		0.0 Mgal	$0		$0
Total			$23		$572

3. Non-Energy Savings (+) or Cost (-)

Item	Savings/Cost	Occurrence	Discount Factor	Discounted Savings/Cost
Non-Annually Recurring				
Non-Annually Recurring Subtotal	$0			$0
Total	$0			$0

4. First year savings	$23	
5. Simple Payback Period (in years)	197.57	(total investment/first-year savings)
6. Total Discounted Operational Savings	$572	
7. Savings to Investment Ratio (SIR)	0.13	(total discounted operational savings/total investment)
8. Adjusted Internal Rate of Return (AIRR)	-3.85%	(1+d)*SIR^(1/n)-1; d=discount rate, n=years in study period

Figure 20. Economics without Installation Costs.

NIST BLCC 5.3-17: ECIP Report

Consistent with Federal Life Cycle Cost Methodology and Procedures, 10 CFR, Part 436, Subpart A
The LCC calculations are based on the FEMP discount rates and energy price escalation rates updated on April 1, 2017.

Location:	New York	Discount Rate:	3%
Project Title:	Ft. Drum MAI With Installation	Analyst:	
Base Date:	April 1, 2017	Preparation Date:	Wed Nov 01 14:08:41 CDT 2017
BOD:	April 1, 2017	Economic Life:	30 years 0 months
File Name:			

1. Investment

Construction Cost	$15,099
SIOH	$905
Design Cost	$1,510
Total Cost	$17,514
Salvage Value of Existing Equipment	$0
Public Utility Company	$0
Total Investment	$17,514

2. Energy and Water Savings (+) or Cost (-)
Base Date Savings, unit costs, & discounted savings

Item	Unit Cost	Usage Savings	Annual Savings	Discount Factor	Discounted Savings
Electricity	$21.42350	1.8 MBtu	$39	22.967	$907
Natural Gas	$3.63300	33.7 MBtu	$123	23.008	$2,819
Energy Subtotal		35.6 MBtu	$162		$3,726
Water Subtotal		0.0 Mgal	$0		$0
Total			$162		$3,726

3. Non-Energy Savings (+) or Cost (-)

Item	Savings/Cost	Occurrence	Discount Factor	Discounted Savings/Cost
Non-Annually Recurring				
Non-Annually Recurring Subtotal	$0			$0
Total	$0			$0

4. First year savings	$162	
5. Simple Payback Period (in years)	108.09	(total investment/first-year savings)
6. Total Discounted Operational Savings	$3,726	
7. Savings to Investment Ratio (SIR)	0.21	(total discounted operational savings/total investment)
8. Adjusted Internal Rate of Return (AIRR)	-2.18%	(1+d)*SIR^(1/n)-1; d=discount rate, n=years in study period

Figure 21. Cost Analysis for the Secondary Scenario.

NIST BLCC 5.3-17: ECIP Report

Consistent with Federal Life Cycle Cost Methodology and Procedures, 10 CFR, Part 436, Subpart A
The LCC calculations are based on the FEMP discount rates and energy price escalation rates updated on April 1, 2017.

Location:	New York	Discount Rate:	3%
Project Title:	Ft. Drum MAI With Installation	Analyst:	
Base Date:	April 1, 2017	Preparation Date:	Wed Nov 01 14:10:25 CDT 2017
BOD:	April 1, 2017	Economic Life:	30 years 0 months
File Name:			

1. Investment

Construction Cost	$3,879
SIOH	$233
Design Cost	$388
Total Cost	$4,500
Salvage Value of Existing Equipment	$0
Public Utility Company	$0
Total Investment	$4,500

2. Energy and Water Savings (+) or Cost (-)
Base Date Savings, unit costs, & discounted savings

Item	Unit Cost	Usage Savings	Annual Savings	Discount Factor	Discounted Savings
Electricity	$21.42350	1.8 MBtu	$39	22.967	$907
Natural Gas	$3.63300	33.7 MBtu	$123	23.008	$2,819
Energy Subtotal		35.6 MBtu	$162		$3,726
Water Subtotal		0.0 Mgal	$0		$0
Total			$162		$3,726

3. Non-Energy Savings (+) or Cost (-)

Item	Savings/Cost	Occurrence	Discount Factor	Discounted Savings/Cost
Non-Annually Recurring				
Non-Annually Recurring Subtotal	$0			$0
Total	$0			$0

4. First year savings	$162	
5. Simple Payback Period (in years)	27.77	(total investment/first-year savings)
6. Total Discounted Operational Savings	$3,726	
7. Savings to Investment Ratio (SIR)	0.83	(total discounted operational savings/total investment)
8. Adjusted Internal Rate of Return (AIRR)	2.35%	(1+d)*SIR^(1/n)-1; d=discount rate, n=years in study period

Figure 22. BLCC Cost Analysis without Installation Costs.

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7.0 IMPLEMENTATION ISSUES

Minor issues and lessons learned are discussed here for end-user consideration:

1. Replacing J-channels and siding around doors/windows: The MAI and polyiso add 1 in. of thickness to the entire envelope. Therefore, provisions to increase the thickness of J-channels around doors and windows is necessary. This usually involves purchasing deeper channels and or fabricating custom channels if necessary.
2. Due to the increase in envelope thickness, facilities with soffit vents will need additional modifications. At Fort Drum, the soffit vents all needed to be trimmed by 1 in. This was accomplished by using a table saw. However, it is recommended that new soffit vents (cut to the correct size) are ordered. This avoids significant work in trimming, replacing and adjusting soffit vents.
3. After removing the exterior metal siding, commercial glue was used to glue the MAI panels to the Tyvek-type wrap. However, after some experimentation, the team determined that the glue is not necessary. If the polyiso foam is placed correctly, the MAI panels can be held in place between two rows of foam.
4. After the MAI and polyiso was installed, the team re-fastened the exterior metal siding to the building. The team had to take great care in ensuring that all fastener holes were lined up with the polyiso strips to avoid damaging the panels. Due to lighting conditions, it was difficult to ensure that the fasteners were being placed into the foam. The team recommends applying red tape to the polyiso before attaching the exterior siding. This red tape is easier to see and will help to make sure that fastener holes are lined up with the foam.

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8.0 REFERENCES

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