Integrated Wall Retrofit Solutions for Existing Masonry Construction for Commercial Buildings

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Sixty percent of existing commercial buildings in the U.S were constructed before 1980 [6]. Energy efficient retrofits of these buildings are essential to achieve the Department of Energy (DOE) Building Technologies Office's (BTO) goal of reducing building energy use by 50% by 2030. A majority of existing buildings have masonry construction with uninsulated wall assemblies, which offer a good potential to achieve energy efficiency through improved wall retrofit strategies. Effective analysis of wall retrofits is essential to ensure improved durability when insulating masonry walls on the interior. The wall retrofit project through the Consortium for Building Energy Innovation (CBEI) evaluated best practice retrofit recommendations based on the results of hygrothermal analysis, laboratory tests, and field performance evaluations.

Scope of the Project

Standard component retrofits such as HVAC or lighting upgrades present a limited scope for retrofit. These prevent the building from realizing the greater energy savings, which can be achievable when envelope retrofit is considered along with standard component retrofits [2]. This integrated retrofit approach is essential to achieve more than 50% reduction in energy consumption.

Older masonry buildings often require a retrofit on the interior due to factors such as historic preservation, zoning issues, space restrictions or aesthetics. Adding insulation to the interior of a masonry wall, without effective analysis, can result in potential performance and durability issues such as condensation, particularly in cold climates. This is a concern because a majority of the pre-1980s buildings with masonry construction is located in the Northeast region of the U.S. [3], [5].

The objective of this project was to identify best practices for energy-efficient and cost-effective retrofits for commercial buildings with masonry construction. The metrics used to evaluate the best practice recommendations were to exceed AHSRAE 90.1 2010 performance and achieve payback of less than 15 years. The target market for the project was ASHRAE climate zones 4 and 5, which represent a majority of the northeast region of U.S.

While the field data collection for the project is currently ongoing, this article explains the process of evaluation for the recommended retrofit scenarios.

Market engagement for the project

The project was funded through the Consortium for Building Energy Innovation (CBEI) headquartered in The Navy Yard, Philadelphia. CBEI is a consortium of 14 member organizations funded through the Department of Energy (DOE) and lead by the Pennsylvania State University. The goal of CBEI is to develop and deploy market-tested pathways to achieve 50% reduction in overall building energy use by 2030 for existing Small and Medium Sized Commercial Buildings (SMSCB). The "Integrated Wall Retrofit Solutions" project supports the CBEI goal by providing envelope solutions for an integrated retrofit strategy.

The project team included collaborators representing diverse areas of the retrofit value chain. Covestro LLC, a manufacturer of raw materials for building insulation, led the project. Oak Ridge National Laboratory (ORNL) provided 3rd party verification for simulation and laboratory test evaluations. Carlisle Construction Materials and the Air Barrier Association of America (ABAA) served as market partners providing industry expertise for the project and guiding the commercialization of the project results.

A Technical Advisory Group (TAG) of industry experts in the area of building envelope was also engaged for this project. The role of the TAG members was to provide technical advice, ensure that the project outcomes were relevant to the market and confirm that the project met the set deliverables. The TAG members for this project were Fiona Aldous from Wiss, Janney and Elstner Associates, Inc., Brian Stroik from Tremco Sealants and Waterproofing, and Pat Conway from the International Masonry Institute.

Need for a wall retrofit case study

In 2012, CBEI identified a potential demonstration project, located in The Navy Yard in Philadelphia, to demonstrate energy savings using integrated retrofit strategies. The identified building was a two-story masonry building built in the early 1940s, which required a retrofit on the interior of the masonry wall. A number of integrated retrofit solutions were analyzed to identify an optimum solution providing energy and cost benefits. This analysis of an integrated retrofit required a longer time than a conventional retrofit analysis, which typically considers only the most cost-effective single component retrofit. Although the building owner appreciated this analysis, a change in the business strategy resulted in the owner not pursuing the proposed retrofit.

The analysis and interaction with the building owner were instrumental in identifying market barriers for envelope retrofits. These include initial upfront costs and lack of information regarding wall retrofit options and benefits. This requires extensive evaluation at the initial stage to identify optimum solutions and ascertain potential savings. These market barriers indicated a need to increase the database of interior insulated masonry buildings and provide validated case studies. The learnings from the case studies can reduce the need for extensive evaluations and help to accelerate the adoption of wall retrofits in the market.

The "Integrated Wall Retrofit Solutions" project utilized the two-story Flexible Research Platform (FRP) at ORNL to test wall assemblies and generate a validated case study. Energy-efficient and cost-effective solutions, identified through the extensive evaluations conducted for the building at The Navy Yard, formed the basis of evaluation for this project.

Project approach

A number of wall retrofit scenarios were evaluated through multiple stages to identify the best-practice retrofit recommendation.

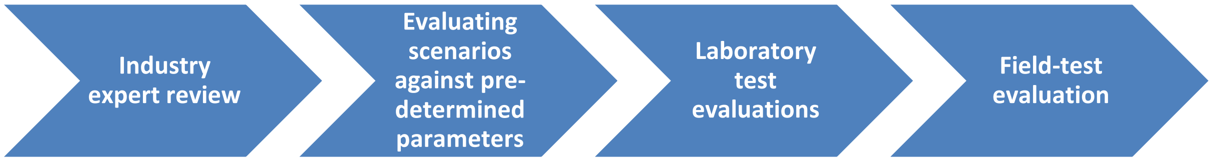


Figure 1: Multiple stages of evaluation for the project

A list of wall retrofit scenarios was vetted through an industry expert review. These scenarios were then evaluated against pre-determined critical parameters using hygrothermal modeling and industry data. Three top-performing scenarios identified through this evaluation were constructed as mock-up walls and tested in the laboratory at ORNL for thermal performance and air leakage. The laboratory test evaluations were then used to identify two top-performing scenarios, which were installed on the two-story Flexible Research Platform at ORNL.

Field data collection for the two retrofit scenarios is ongoing and will continue to span over three seasons. The field performance evaluation will be utilized to identify the best-practice retrofit recommendation.

Industry expert review

In August 2014, an expert review was conducted consisting of building science experts, contractors, and envelope consultants. The industry experts vetted a list of seven retrofit scenarios designed for the baseline wall assembly of the two-story FRP (Figure 1). The objectives of the expert review were to:

- Get input on proposed retrofit scenarios.
- Identify need for evaluating additional scenarios.
- Identify critical parameters against which the scenarios can be evaluated
- Determine weighted percentages for the identified critical parameters.

The experts recommended adding two additional scenarios resulting in a final list of nine retrofit scenarios to be evaluated through the project (Table 1).

Scenario No.	Proposed Retrofit Assemblies
A.	**Retain existing wall (w/ existing insulation)**
1	Rigid board over existing insulation (2")
B.	**Retain existing studs (w/o existing insulation)**
2	Open-cell spray foam within existing stud (6")
3	Closed-cell spray foam within existing stud (5") – added during expert review
C.	**Remove existing insulation and Studs**
4	Blown-cellulose (6") – added during expert review
5	Closed-cell spray foam (3.5")
6	Hybrid Spray foam (2")
7	Hybrid Spray foam (1.5")
8	Rigid board w a/b (2.5")
9	Rigid board w/o a/b (2.5")

Table 1: List of nine retrofit scenarios evaluated through the project

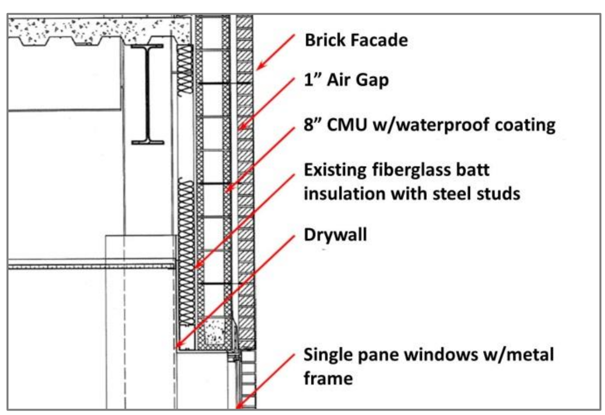


Figure 2: Baseline wall assembly for the Flexible Research Platform at ORNL.

Another recommendation was to categorize the nine retrofit scenarios into three major groups:

1. Retain the existing insulation and drywall within the assembly; install retrofit over existing assembly.
2. Retain the existing studs, remove existing insulation and drywall; install retrofit within existing studs.
3. Remove existing insulation, studs and drywall; install retrofit over concrete block wall.

The experts also identified six critical evaluation parameters along with the weighted percent for each parameter:

1. Cost effectiveness – 35%
2. Moisture management/durability – 20%
3. Thermal performance – 18%
4. Air leakage – 12%
5. Disruptiveness/constructability – 9%
6. Indoor air quality – 6%

Evaluating scenarios against pre-determined parameters

The nine retrofit scenarios were evaluated against the six pre-determined parameters identified at the expert review. Data for the scenarios were obtained from multiple sources:

- Cost data for the scenarios were obtained from a contractor.
- Thermal performance and moisture durability were evaluated using the simulation software THERM and WUFI, respectively.
- Mold probability was used as a metric to evaluate the indoor air quality and was identified using WUFI-Bio.
- Air leakage data for the scenarios were based on the standard air leakage rates obtained from the Air Barrier Association of America.
- The parameter of constructability-analyzed factors such as the interior floor space consumed by the retrofit, ease of construction as well as time and labor required for installation.

The data collected for each parameter had different units. To facilitate objective evaluation, all the data values were normalized to range from 0 to 1. The normalized data values were then applied with the respective weighted percentages for each parameter. These weighted percentages for the six evaluation parameters were then added and compiled in a final performance evaluation matrix to provide overall performance for each scenario.

No.	Scenarios	Insulation type and thickness	Cost effectiveness	Moisture management	Thermal performance	Air leakage improvement	Disruptiveness/ constructability	Indoor air quality	Final ranking
A.	Retain existing wall (w/ existing insulation)								
1	Rigid polyiso foam board over existing insulation	2" rigid polyiso foam board	*high*	*high*	*high*	*low*	*high*	*high*	1st
B.	Retain existing studs (w/o existing insulation)								
2	Open-cell spray foam within existing studs	6" o.c spray foam	*moderate*	*high*	*low*	*low*	*low*	*high*	
3	Closed-cell spray foam within existing studs	4.5" c.c spray foam	*moderate*	*high*	*low*	*moderate*	*moderate*	*high*	
C.	Remove existing insulation and studs								
4	Blown-cellulose with a/b	6.0" blown-cellulose	*low*	*Poor*	*high*	*high*	*moderate*	*high*	
5	Closed-cell spray foam	3.5" c.c spray foam	*low*	*high*	*high*	*moderate*	*moderate*	*high*	3rd
6	Hybrid Spray foam	2" c.c SPF + 3.5" blown-cellulose	*low*	*high*	*high*	*moderate*	*low*	*high*	
7	Hybrid Spray foam	1.5" c.c SPF + 3.5" blown-cellulose	*moderate*	*high*	*high*	*moderate*	*low*	*high*	
8	Rigid polyiso foam board with a/b	2.5" rigid polyiso foam board	*high*	*high*	*moderate*	*high*	*high*	*high*	2nd
9	Rigid polyiso foam board w/o a/b	2.5" rigid polyiso foam board	*high*	*high*	*moderate*	*low*	*high*	*high*	

Table 2: Performance evaluation for the retrofit scenarios with respect to each parameter.

Three top-performing scenarios were identified through the performance evaluation matrix, to be evaluated through the next stage. The down-selected scenarios were:

Scenario ranking 1st: Retain existing insulation and drywall; install 50.8 mm (2”) PIR (polyisocyanurate) foam board insulation with taped seams on existing wall.
Scenario ranking 2nd: Remove existing insulation, steel studs and drywall; install 63.5 mm (2.5”) PIR foam board insulation with a separate air barrier (a/b) layer applied on the inner face of the concrete block.
Scenario ranking 3rd: Remove existing insulation, steel studs and drywall; install 89 mm (3.5”) of closed-cell spray polyurethane foam (SPF) of which 38mm (1.5”) is installed as a continuous insulation layer on the inner face of the concrete block.

Laboratory test evaluations

The three top-performing scenarios were constructed as mock-up walls and tested in the laboratory at ORNL for:

- Thermal performance - tested in accordance with ASTM C1363.
- Air leakage - tested in accordance with ASTM E283.

The results obtained for the two laboratory tests were used as inputs for an existing energy model created by ORNL for the two-story FRP. This energy model provided potential energy savings and payback period for the three scenarios. The performance of the three scenarios was evaluated against two baselines:

1. Baseline with no existing insulation on the interior of the masonry wall [R-value for baseline assembly – R-0.88 (R-5); Air leakage – 8 L/s-m^2 (1.6 cfm/ft^2)].

2. Baseline with existing fiberglass batt insulation on the interior of the masonry wall [R-value for baseline assembly – R-1.85 (R-10.5); Air leakage – 8 L/s-m² (1.6 cfm/ft²)].

Scenario no	Scenario	Thermal performance		Air leakage for assembly	Performance measured against baseline without existing insulation [R-0.88 (R-5)]		Performance measured against baseline with existing insulation [R-1.85 (R-10.5)]	
		R-value SI unit (IP units)	U-value SI unit (IP units)	L/s-m^2 (cfm/ft^2)	Total HVAC energy savings	Payback period	Total HVAC energy savings	Payback period
1	PIR over exist. ins.	3.65 (20.7)*	0.27 (0.048)	1.8 (0.36)	N/A	N/A	30%	**14 yrs**
2	PIR w/ separate a/b	3.10 (17.6)	0.32 (0.056)	0.28 (0.056)	31%	17 yrs	25%	29 yrs
3	C.c SPF	3.70 (21.6)	0.27 (0.046)	0.015 (0.003)	41%	**16 yrs**	36%	25 yrs

Table 3: Laboratory test evaluations for the three down-selected retrofit scenarios. *(*Assumption: Existing insulation is in effective condition).*

The results for the two laboratory tests and the estimated payback periods for the three scenarios were evaluated for compliance against the previously defined metrics for the project. Two top-performing scenarios chosen based on this evaluation were:

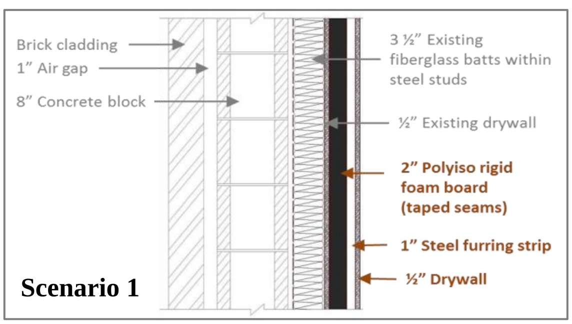


Figure 3: PIR foam board installed over the existing assembly.

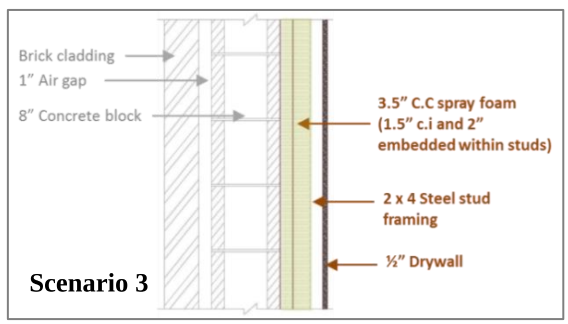


Figure 4: Closed-cell spray foam installed over the concrete block wall.

The closed-cell spray foam scenario provided a high payback against a baseline with existing insulation; however, the payback against a baseline without existing insulation bordered on the range of 10-15 years. This, along with the fact that spray foam provided the highest energy savings, resulted in down selecting this scenario for the next stage of the project.

Field test evaluations

The two top-performing scenarios were installed over the two-story Flexible Research Platform at ORNL to collect field data.

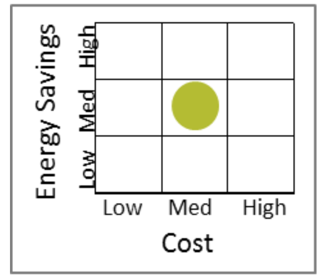
The baseline wall assembly of the FRP was built to represent the typical wall assembly for a majority of the existing commercial buildings built before 1980. The two-story FRP is divided into eight zones with four zones on each floor. Each zone has the capability to be monitored separately. The two top-performing scenarios were installed in two of these eight zones, having similar orientation.

The intent of field analysis was to analyze the field performance and constructability for the two retrofit scenarios.

PIR foam board retrofit performance:

The PIR foam board retrofit scenario was designed as an integrated solution addressing improved thermal performance, reduced air infiltration and improved durability for the wall assembly.

The high R-value per inch for the PIR foam provided better energy performance at minimized thickness. The low air permeance of the board, along with taped seams and sealed junctions, qualified the material as an air barrier according to ASTM E2178. The foam board, with coated-glass facers, provided a vapor permeance of less than 1 perm minimizing the risk of interior moisture reaching the cold surface of the masonry block wall. This reduced the potential for moisture accumulation and mold probability.



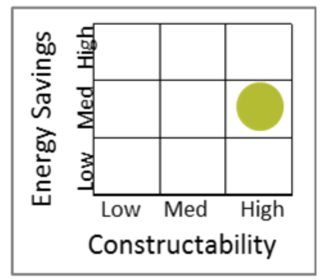


Figure 5: Cost and constructability analysis against energy savings for PIR foam board retrofit.

Installation of this scenario over the existing assembly eliminated the cost of demolishing existing insulation within the assembly. However, installing a retrofit over the existing assembly requires investigation of the insulation to ensure effective performance. As a result, the applicability of this scenario is dependent on the condition of the existing insulation. For this project, investigation of existing insulation was not required as the insulation installed for the two-story FRP baseline was relatively new. As a result, the cost estimates used to predict payback for this scenario did not take into account the cost needed to investigate the existing insulation.

The energy modeling conducted for this scenario, estimated a payback of 14 years against a baseline with existing insulation. However, the field data being collected will be utilized to calculate a refined estimate of the payback period.

Closed-cell spray foam retrofit performance:

The closed-cell spray foam served as an air and moisture barrier along with providing thermal insulation.

This scenario required the tear down of existing insulation within the assembly. The steel studs were offset from the wall by 38mm (1.5”) to provide for continuous insulation. Closed-cell spray foam is considered air impermeable at a minimum thickness of 19 mm (¾”), providing the air barrier within the assembly. With a perm rating of less than 1 perm at 38 mm (1.5”), closed-cell spray foam serves as a Class II vapor retarder. This helped minimize the risk of interior moisture being transported to the cold surface of the masonry block wall and reduced the potential for moisture accumulation and mold probability for this scenario.

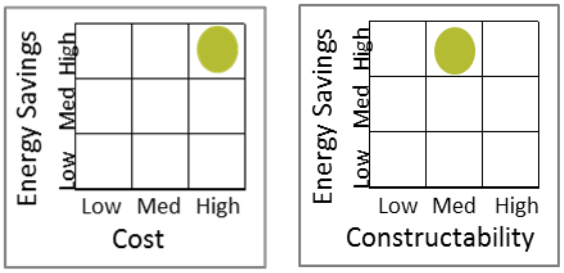


Figure 6: Cost and constructability analysis against energy savings for c.c SPF retrofit.

The installation of closed-cell spray foam scenario eliminated the need for additional materials to address air and moisture infiltration resulting in less labor and material cost. The energy modeling conducted for this scenario estimated a payback of 16 years against a baseline assembly with no existing insulation and 25 years against a baseline with existing insulation. However, the field data being collected will be utilized to calculate a refined estimate of the payback period.

Constructability for the installed retrofit scenarios

The constructability for the two scenarios was evaluated based on the interior floor-space consumed by the retrofit scenarios, ease of construction, ability to address critical details and the disruption to building occupants.

	PIR foam board retrofit	Closed-cell spray foam retrofit
Loss of interior commercial floor-space	Scenario was installed over existing assembly resulting in a loss of 89mm (3.5”) of interior floor-space.	Scenario required the steel studs to be offset by 38mm (1.5”) to accommodate for continuous insulation layer resulting in a loss of 38mm (1.5”) of interior floor-space.
Installation	A general contractor completed the installation.	Installation required a certified spray foam contractor.
Ease of construction	PIR boards had to be effectively sealed to existing wall surface to prevent convective loops between the board and wall from transporting moisture and heat.	Spray foam sprayed directly on to the concrete block surface conformed to the wall configuration, effectively filling cracks and construction gaps and eliminating convective loops.
Seams and junction details	Seams between boards had to be effectively taped. The wall-to-ceiling detail was addressed using closed-cell spray foam.	Closed-cell spray foam provided a seamless layer of insulation. The junction details such as wall-to-ceiling were effectively sealed.
Air and moisture barrier	Seams, penetrations and junctions for boards had to be effectively taped and sealed to serve as air and moisture barriers. Maintaining the air and moisture seal in critical junction areas, which were not readily accessible, was challenging.	Spray foam was applied as a monolithic layer serving as the thermal insulation as well as an air and moisture barrier. Sealing critical junction areas, which were not readily accessible, was comparatively easy.
Impact on other components	Increased wall thickness required addressing details such as extending window sills by 89mm (3.5”).	Increased wall thickness required addressing details such as extending the window sills by 38mm (1.5”).
Disruption to occupant activity	Re-occupancy was permitted after the retrofit installation.	The re-occupancy was permitted 24 hours after the retrofit installation.

Next steps

The next stage of the project is to collect and evaluate field data for the two retrofit scenarios demonstrated on the two-story FRP at ORNL. The field data collection is ongoing and will continue to span over three seasons. The two demonstrated scenarios will be evaluated based on their field performance to identify the best practice retrofit recommendation.

Conclusion

This project identified two top-performing wall retrofit recommendations for commercial buildings with masonry construction based on a multi-stage evaluation process.

The PIR foam board scenario evaluated as a retrofit installed over existing assembly was identified as the most cost-effective retrofit scenario. However, this scenario is dependent on the condition of the existing insulation and is applicable only if the existing insulation is in effective condition to be retained. Increased steps in installation (such as taping of board seams, sealing junctions or sealing boards to wall surface) require vigilant inspection on job-site to ensure quality installation.

The closed-cell spray foam scenario was identified as the most energy-efficient retrofit. However, this scenario requires the tear down of existing insulation within the assembly, which can be an added cost in terms of time and labor. The spray application method by a single trade (certified spray foam contractor) can help ensure installation quality on the job-site.

The evaluation conducted through the project compared the two integrated retrofit solutions based on cost, energy performance and constructability. This information will provide the industry with guidelines for best practice retrofit recommendations and help building owners and design professionals make informed decisions regarding the most suitable retrofit option for their buildings.

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