Best Practice Recommendations for Wall Retrofit on the Two-Story Flexible Research Platform (FRP) at Oak Ridge National Laboratory (ORNL).

Wall retrofit strategies for retrofit on the interior side of masonry wall construction for existing commercial buildings.

April, 2016

Executive Summary

Energy efficient retrofits of existing commercial buildings are essential to achieve the U.S. Department of Energy (DOE) Building Technologies Office's (BTO's) goal of 50% reduction in overall building energy use by 2030. Masonry buildings constitute a significant portion of the existing building stock built prior to the 1980s in the north-east region of U.S. These buildings often have uninsulated or under-insulated walls (not up to code) which offer a good potential to achieve energy efficiency through improved wall retrofit strategies. Factors such as historic preservation, space requirements, zoning issues, etc. often require these existing buildings to be retrofitted on the inside of the wall assembly.

Wall Retrofit Project

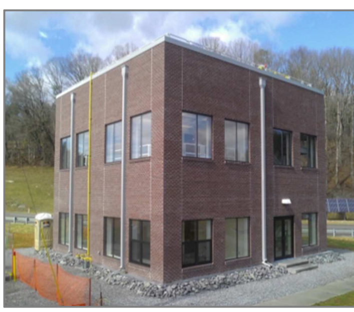
The "Wall Retrofit Solutions" project is funded through the Consortium for Building Energy Innovation (CBEI)[1]*. CBEI, funded through DOE, is a partnership of 14 member organizations with the Pennsylvania State University serving as Project Lead.

The "Wall Retrofit Solutions" project aimed at identifying the best practice recommendation for an energy efficient retrofit of existing commercial buildings with masonry construction located in climate zones 4 and 5. The best practice retrofit recommendation was identified based on field performance. The 2-story Flexible Research Platform (FRP) at ORNL was utilized to demonstrate the two top-performing scenarios down-selected through the project. Field data collection for the two scenarios is ongoing and will continue up to August 2016.

Project Partners

CONSORTIUM for BUILDING ENERGY INNOVATION (Funded the project)	covestro (Project management)	OAK RIDGE National Laboratory (3rd party simulations and evaluations)	CARLISLE CONSTRUCTION MATERIALS (Systems supplier)	air barrier abaa association of america (Trade association)

Two-Story Flexible Research Platform at ORNL



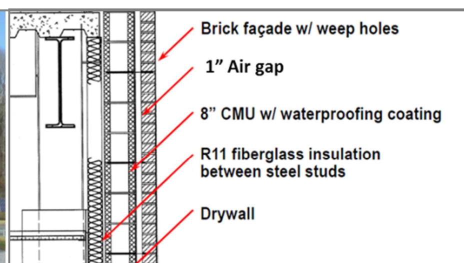


Figure 1: Baseline wall assembly

The baseline envelope system for the FRP was built to represent the wall systems typical of the majority of the existing commercial buildings built prior to the 1980s located in the 10-county region surrounding Philadelphia (Otto K., 2011[1]**). This analysis was based on CBECS and COSTAR data.

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Disclaimer:
The information presented in this document is relevant to the 2-story FRP at ORNL. These guidelines are general retrofit recommendations for the identified scenarios and not technical specifications.

[1] * *For more information on CBEI, visit http://cbei.psu.edu/*
** *Otto K. (2011). "CoStar Statistics on GPIC Mid-sized Class A Office Buildings". Robust Systems and Strategy LLC.*

Recommendations

Nine wall retrofit scenarios were initially vetted through an industry expert review in the area of building science. Hygrothermal simulations and laboratory test evaluations were then conducted for these retrofit scenarios in order to identify the two top-performing scenarios. The two down-selected scenarios were demonstrated on the 2-story Flexible Research Platform at ORNL to analyze field performance. The results of the laboratory tests and hygrothermal simulations were validated against the ongoing field performance. The two down-selected scenarios were:

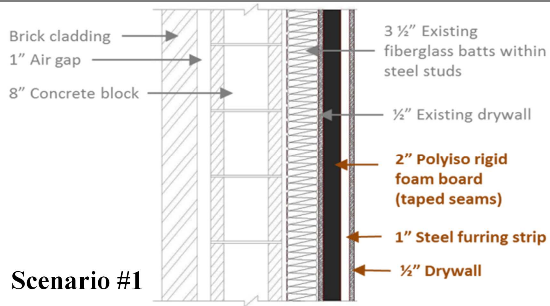


Figure 2: PIR (polyisocyanurate) foam board installed over existing wall assembly.

Recommended when:

- Assembly has existing insulation **and**
- Existing insulation is in effective condition.

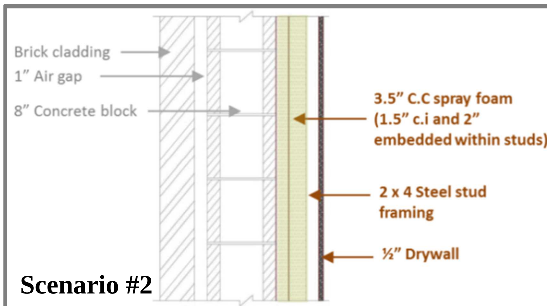


Figure 3: Closed-cell (C.C) spray foam installed continuous (c.i) over inside face of concrete block

Recommended when:

- Assembly has no existing insulation or
- Existing insulation is in poor condition and requires removal.

Energy Savings and Payback Periods

The two best practice retrofit scenarios were tested in the laboratory at ORNL for thermal performance and air leakage. The test results for the two scenarios were then utilized to compute the energy savings and payback periods. The cost data used for the two scenarios are estimates.[2]

Scenario no	Scenario	Thermal performance		Air leakage for assembly	Cost/Sq.ft	Performance measured against baseline without existing insulation (R-5)		Performance measured against baseline with existing insulation (R-11)	
		R-value (IP units)	U-value (IP units)	L/s.m^2 (cfm/ft^2)	($/sq.ft)	Total HVAC energy savings	Payback period	Total HVAC energy savings	Payback period
1	PIR over exist. assembly	20.7*	0.048	1.800 (0.36)	4.35	N/A	N/A	30%	14 yrs
2	C.c SPF over concrete block wall	21.6	0.046	0.015 (0.003)	9.40	41%	16 yrs	36%	25 yrs

Table 1: Energy savings and payback periods estimated for the two scenarios demonstrated on the 2-story FRP at ORNL (Climate Zone 4). **Assumption: Existing insulation is in effective condition.*

ASHRAE 90.1 2010 code requirements for thermal performance:
Climate Zone 4: max U-value = 0.104 (IP Units)
Climate Zone 5: max U-value = 0.090 (IP Units)

The energy savings and payback periods estimated for the 2-story FRP can be used to extrapolate potential energy savings and payback periods for existing commercial buildings with similar wall construction in climate zones 4 and 5.

[2] *The cost for the scenarios is likely to vary based on locations, distributors as well as size of project/ material volume.*

Field Test Set Up

Three types of data were collected for each retofit; interior and exterior temperatures, heat flux, and moisture performance. The moisture content within the wall assembly was measured using three relative humidity sensors - RH1, RH2 and RH3, and the locations can be found in Figure 4. Both retrofits occupied the North-West zone of the FRP. The spray foam retrofit took place on the first floor (1F), while the PIR retrofit took place on the second floor (2F). Data was analyzed for a random week each month from September to February.

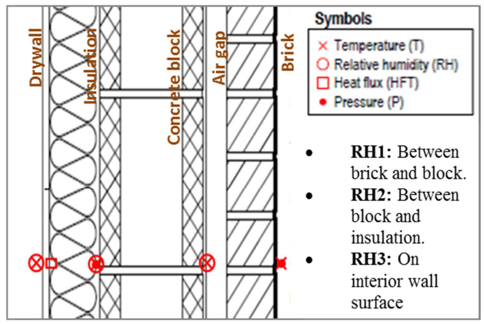


Figure 4: Sensor layout within the baseline exterior wall assembly for the two-story Flexible Research Platform.

Field Data Results

Table 2 indicates the summation of measured heat flux values for the two scenarios for a typical week for each month from September through February. This data was used as indicators of performance improvement not do not represent absolute values, because the data does not include non-performance parameters such as building interior conditions and thermal mass.

Scenario		Sum of Absolute Values of HF		Ratio (Post/Pre)
#	Type	(Pre)	(Post)	
1	PIR	624.2	323.2	0.52
2	Spray Foam	614.7	423.0	0.69

Table 2: Sum of Absolute Values of Heat flux for Both Retrofit Scenarios

Figure 5 indicates the hourly values for moisture content measured by the sensor located between the insulation and the masonry wall (RH2) for the two scenarios for a typical week in December. The trends observed for moisture content were similar for both the scenarios with moisture contents staying well within safe levels. Table 3 shows the sensor maximum, minimum, and average values for the same one week/month interval. Although there are short term peaks in the moisture content that exceed the mold criteria threshold (approximately 84%), these peaks are for a fairly short duration. The spray foam retrofit (1F RH) has some periods of moisture content at 100 percent relative humidity; the PIR retrofit (2F RH) does not exhibit this behavior.

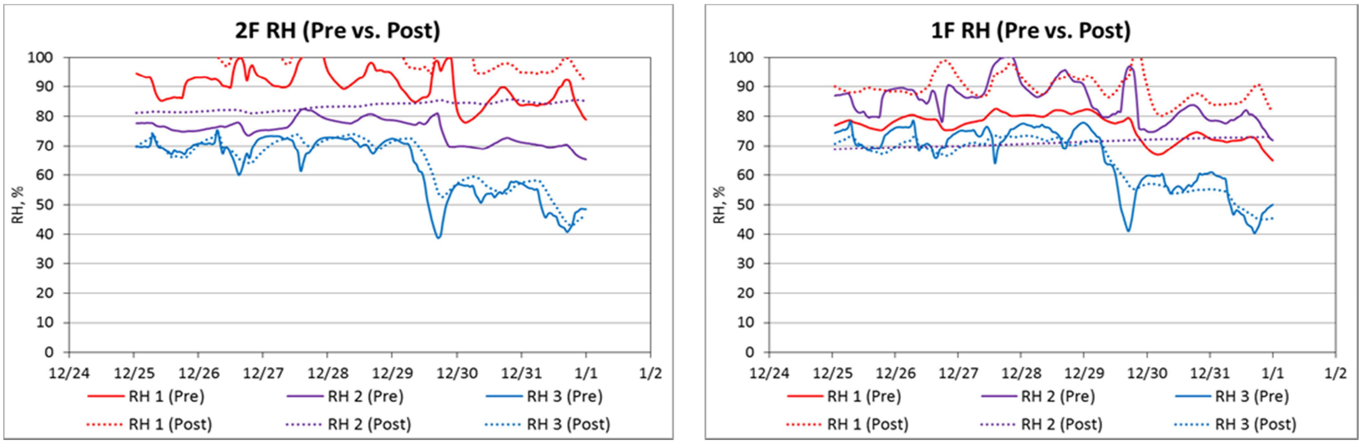


Figure 5: Moisture Performance Analysis for the Two Scenarios Based on RH2 Sensor

Week	RH2 for PIR Scenario						RH2 for Spray Foam Scenario					
	Pre-Retrofit			Post-Retofit			Pre-Retrofit			Post-Retofit		
	Max	Min	Avg.	Max	Min	Avg.	Max	Min	Avg.	Max	Min	Avg.
Sep, 2015	59.5	42.3	49.6	55.2	48.9	**51.7**	68.8	42	51.3	56	53.8	**54.8**
Oct, 2015	79.3	47.7	64.3	73.8	56.3	**66.2**	93.9	41.3	62.7	59.3	55.4	**57.6**
Nov, 2015	63.9	34.2	46.2	68.4	51.3	**58.5**	78.6	31	50.3	62	59.3	**60.9**
Dec, 2015	82.5	65.4	75.2	85.7	81	**83.4**	100	72	85.3	73.2	68.9	**71.1**
Jan, 2016	69.1	45	57	85.4	63.7	**74.1**	91.9	54.4	68	74.3	73.6	**74**
Feb, 2016	74.8	47.5	60.2	86.1	69.4	**77**	93.5	37.2	69.3	75.2	73.3	**74.4**

WUFI estimates mold growth issues if RH>84% for extended time periods.

Table 3: Minimum, Maximum, & Average Sensor Values for Both Retrofit Scenarios

Model Validation

The EnergyPlus model of the FRP was modified to reflect construction of the retrofitted wall section. Table 4 shows the material layers (outside-in). Since the instrumentation that was installed in the FRP monitored the center of cavity performance, the model was modified to compare center-of-cavity thermal performance. The input data for the center of-cavity model is also detailed in Table 4.

	Layers	Thickness, in.	Conductivity, Btu.in/h.ft^2.F	R-value, h.ft^2.F/Btu
First Floor	Brick cladding	3.625	9.091	0.40
	1" air gap			0.89
	8" concrete block	8.0	9.092	0.88
	3.5" C.C. spray foam	3.5	0.146	24.04
	1.5" air gap			1.02
	Dry wall	0.625	1.11	0.56
	Total			**27.8**
Second Floor	Brick cladding	3.625	9.091	0.40
	1" air gap			0.89
	8" concrete block	8	9.092	0.88
	3.5" fiberglass batt	3.5	0.32	10.94
	Dry wall	0.625	1.11	0.56
	2" polyiso rigid foam board	2	0.181	11.07
	1" air gap			0.89
	Dry wall	0.625	1.11	0.56
	Total			**26.2**

Table 4: Wall Constructions & Cavity Performance Data

EnergyPlus simulations were conducted using the updated model and measured weather data. Simulation predicted exterior and interior surface temperatures and heat flux at the HFT location of North wall were compared with measured values for following three weeks: Sep 13 through 19, Nov 11 through 17, and Nov 23 through 29, 2015. Table 5 shows the summary results for the three weeks. The difference between average simulation predicted and measured surface temperatures were within 1.5° and the heat fluxes were within 0.07 Btu/h.ft^2 (or within 13%). The simulation tool was then employed to assess energy savings and payback for the two retrofit strategies.

Location	Exterior Surface Temperature, °F		Interior Surface Temperature, °F		Heat Flux, Btu/h.ft^2	
	Measured	EnergyPlus	Measured	EnergyPlus	Measured	EnergyPlus
First Floor	53.9	54.5	68.8	67.8	0.52	0.51
Second Floor	56.0	54.6	69.8	68.4	0.50	0.57

Table 5: Measured vs Simulated Thermal Performance Data

Energy Savings and Payback Periods

Simulations were conducted for Knoxville and Philadelphia using TMY3 weather files for the corresponding locations. Lab evaluated overall air-to-air thermal resistance of the retrofitted wall samples (ASTM C1363) were used for annual energy simulations to account for the thermal bridging impacts. Air leakage for building assemblies were determined following ASTM E283 procedure. Two levels of assembly R-values and air leakage rates were assumed for the baseline construction. Table 6 shows the thermal resistance and air tightness of the wall assemblies.

Construction details	Overall surface-to-surface R-value, h.ft^2.F/Btu	Air leakage at 75 Pa., L/s.m^2
Baseline Wall	10.1 & 5	2.7 & 8
Demolish existing insulation + 3.5' C.C. SPF	21.6	0.015
Retain existing insulation + 2" PIR boards with taped seams	20.7	1.8

Table 6: Measured R-Value & Air Tightness Values

To convert from annual cooling load to cooling energy, two levels of equipment coefficient of performance (COP) were considered; 2.9 and 1.93 (derated 1/3rd for aging). Electrical energy cost was used as $0.1031/kWh and $0.0944/kWh and natural gas cost was used as $0.823/Therm and $0.981/Therm for Tennessee and Pennsylvania, respectively[3].

[3] http://www.eia.gov/state/seds/data.cfm?incfile=/state/seds/sep_sum/html/sum_pr_com.html&sid=US

Table 7 shows the annual heating and cooling loads, energy use, and energy cost and payback for two locations assuming COP 1.9. Overall, the annual energy cost savings from the retrofit walls range from $868 to $1041 for Knoxville and $1101 to $1403 for Philadelphia.

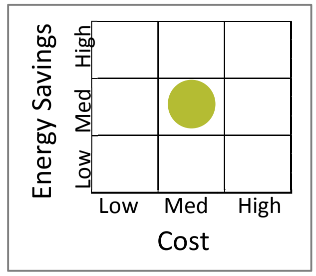
Retrofit #	Scenario	Thermal performance (based on field data)		Climate Zone 4				Climate Zone 5			
				Performance measured against baseline without existing insulation (R-5)		Performance measured against baseline with existing insulation (R-10)		Performance measured against baseline without existing insulation (R-5)		Performance measured against baseline with existing insulation (R-10)	
		R-value (IP units)	U-value (IP units)	Yearly HVAC energy savings	Payback Period	Yearly HVAC energy savings	Payback Period	Yearly HVAC energy savings	Payback Period	Yearly HVAC energy savings	Payback Period
1	PIR over exist. assembly	20.7	0.048	NA	NA	$868	16	NA	NA	$1206	12
2	CC SPF over concrete block wall	21.6	0.046	$1041	22	$918	32	$1403	17	$1101	27

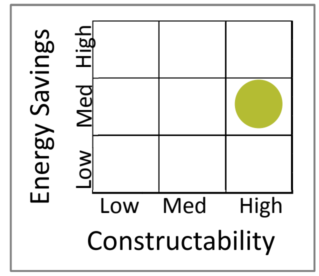
Table 7: Proven Energy Savings & Payback Periods for the Two Scenarios in Two Climate Zones

The PIR field test data indicated a 10% improvement in payback period versus earlier calculations based on simulated values. The spray foam retrofit mearsured results were very similar to the simulated values, so the payback period did not change. The PIR retrofit would be appropriate for both climate zones, while the spray foam retrofit has more realistic payback periods for climate zone 5. Both retrofit paybacks would continue to improve as the location of the retrofit migrated further north.

Advantages:

- High R-value/inch (R-6/inch) compared to conventional foam board insulations.
- Moisture resistant foam core.
- Designed for use as continuous insulation.
- Serves as moisture and air barrier (as long as seams are taped and junctions sealed).
- More cost-effective than scenario #2.





Retrofit Installation:

PIR foam boards with coated-glass facers were installed over the existing drywall. The seams for the board were taped according to manufacturer's recommendation and the junctions and penetrations were effectively sealed. The roof to wall junction was sealed using closed-cell spray foam application.

Performance Characteristics for the PIR Foam Board:

Thermal Performance: PIR foam board, installed as continuous insulation over existing wall assembly, provided an overall R-value of R-20.7.

Moisture vapor permeance: The coated-glass faced PIR foam board served as Class III vapor retarder.

Air permeance: The PIR foam board with low air permeance, taped seams and sealed junctions served as the air barrier layer within the assembly.

Analysis of moisture accumulation within the assembly			Mould growth evaluation of steady state year
Relative humidity	Moisture accumulation	Failure risk	Interior surface mould index[3]
87%	No	-	0

Table 8: Modelled Indoor WUFI Analysis for Retrofit Scenario #1

Retrofit Constructability:

- This scenario resulted in a loss of interior commercial floor space (3.5" along the perimeter).
- It is dependent on the condition of the existing insulation within the assembly and might require time and money to conduct forensic investigation of the existing insulation.
- Installation over the existing assembly made it difficult to judge the position of existing cables and wires within the assembly.
- The PIR board had to be installed without any gaps between the board and the wall in order to prevent convective loops transporting moisture and heat. 3/8" thick by 3" diameter dabs of approved adhesive were spaced evenly across the length of the board at no more than 16" o.c. *(Refer manufacturer's recommendations for adhesive patterns).*
- Maintaining the air and moisture seal for the PIR board layer was challenging in critical areas which were not readily accessible.
- The increased wall thickness for this scenario required addressing details such as extending window sills.

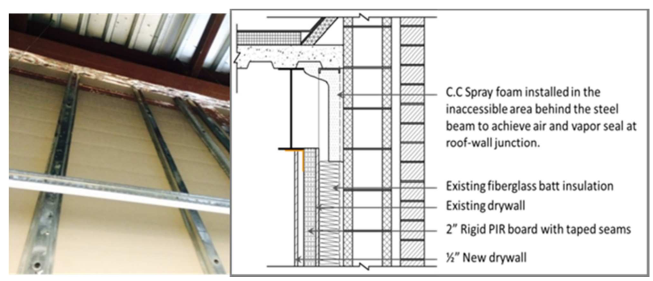


Figure 6: The presence of 12" deep steel beam underneath the roof deck for the FRP made the roof-to-wall junction inaccessible for installing rigid PIR foam boards. Spray foam was used to seal this junction.

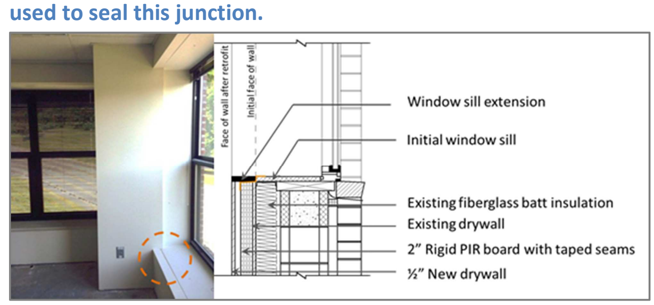


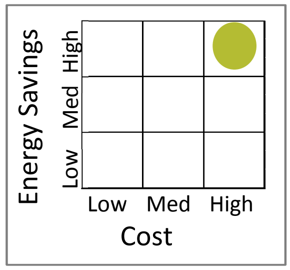
Figure 7: Extended window sill over additional retrofit components

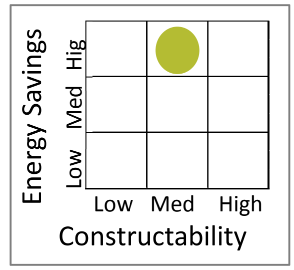
Junction Details

Closed-cell Spray Foam Retrofit Guidelines *(Scenario #2)*

Advantages:

- Provides a seamless, continuous insulation layer.
- High R-value/inch (R-6.5 – R-7/inch) compared to conventional insulation.
- Conforms to unusual shapes and configurations, sealing penetrations and junctions effectively.
- Serves as air and moisture barrier.
- More energy efficient than scenario #1.





Retrofit Installation:

The existing fiberglass insulation and drywall were removed. The existing steel studs were offset 1.5” from the concrete block wall. Then 1.5” of closed-cell spray foam was installed between the studs and the bare concrete block wall, which provided a layer of continuous insulation. Lastly, 2” of spray foam was installed between the studs.

Performance Characteristics:[4]

Thermal Performance: Closed-cell spray foam installed as a seamless insulation layer provided an overall R-value of R-21.6.

Moisture vapor permeance: Closed-cell spray foam serves as Class II vapor retarder with less than 1 perm vapor permeance at 1.5”.

Air permeance: Closed-cell spray foam is considered air impermeable at minimum 3/4”.

Analysis of moisture accumulation within the assembly			Mould growth evaluation of steady state year
Relative humidity	Moisture accumulation	Failure risk	Interior surface mould index[3]
84%	No	-	0

Table 9: Modelled Indoor WUFI Analysis for Retrofit Scenario #2

Retrofit Constructability:

- This scenario required the steel studs to be offset from the concrete block wall, resulting in a loss of 1.5” of interior commercial floor space along the perimeter.
- This offset of 1.5” required the window sill to be extended.
- Installation of closed-cell spray foam required a certified spray foam contractor.
- Closed-cell spray foam layer served as thermal insulation as well as air and moisture barrier; thus, eliminating the need to involve multiple trades.
- Spray application of this insulation material helped to effectively address critical details, such as inaccessible cracks, with minimum labor.
- The work area where spray foam was being installed had to be vacated with access restricted to certified personnel wearing appropriate personal protective equipment. The reoccupancy of the retrofit space was permitted 24 hours after the installation. *(Refer manufacturer’s recommendations to determine specific reoccupancy period)*.

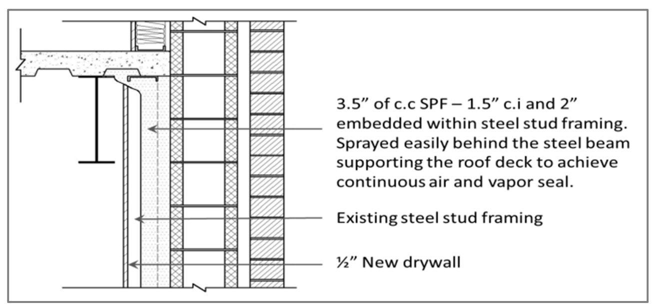


Figure 8: Roof-to-wall junction behind the steel beam sealed effectively with spray foam.

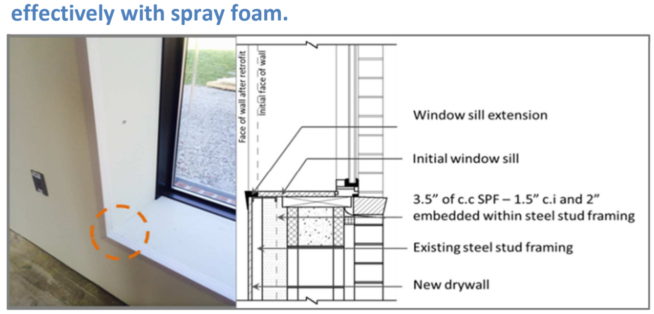


Figure 9: Extended window sill over additional retrofit components

Junction Details

[4] Mould Index:
0 – No mould; 1-3 – small amounts of mould; 4 - moderate growth; 5-6 plenty of mould growth.