October 14, 2011

CLIENT:

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Re: PS 2011.086 - Town of Barrington Town Office Building

Dear Mr. Lenzi:

This report covers the decision and optimization process for improving the energy efficiency of the Barrington Town Office Building, in Barrington, NH. Details include examination of wall insulation options, best practices for other enclosure retrofit items (roofs, windows), potential mechanical system upgrades, and evaluation and prioritization of options presented by the Turner and SDES Group reports. One goal was to prioritize the most cost-effective items, while simultaneously controlling the overall cost of the renovation project. It is informed by the site visit conducted by BSC on September 6, 2011.

The overall recommendations and prioritizations are presented in the "Conclusions" section.

Two reports were provided to BSC: they were used for background information, and the proposed measures were evaluated, based on BSC's knowledge and field work at the building.

- The New Hampshire Municipal Energy Assistance Program (MEAP) Decision Grade Audit Report SDES Group, LLC February 2010 (referred to as the SDES Group Report)
- Final Report: Barrington Town Offices Study For Remediation, Renovation Or Relocation, H.L. Turner Group, February 2011 (referred to as the Turner Report)

Note that various supporting documents are referenced in this report; links are provided in the final section, Additional Resources.

If you have any questions or comments about this report, please contact Kohta Ueno of Building Science Corporation (kohta@buildingscience.com), or as per contact information shown.

Sincerely,

Kohta Ueno
Senior Associate, Building Science Corporation

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1. Background ... 3
2. Wall Insulation Options ... 3
Exterior Wall Construction ... 3
Interior Retrofit Overview ... 4
Interior Retrofit Site Assessment (Brick Condition) ... 5
Interior Retrofit Negative Aspects ... 7
Exterior Retrofit Overview ... 9
Exterior Insulation: Exterior Rigid Foam ... 10
Exterior Insulation: Exterior Spray Foam ... 13
Exterior Insulation: EIFS ... 16
Exterior Insulation: Panel Overclads ... 17
Exterior Insulation: Cladding Attachment Through Insulation ... 18
Wall Insulation Comparisons ... 19
3. Other Enclosure Upgrades ... 21
Overall Energy Performance ... 21
Airtightness ... 22
Sloped Roof (Vented Attic) ... 22
Flat Roof ... 25
Windows ... 29
Foundation ... 31
Mechanicals ... 34
4. Conclusions and Priorities ... 38
5. Additional Resources ... 39

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1. Background

The Town of Barrington Office Building is a former school building located at 137 Ramsdell Lane, Barrington, NH (DOE Climate Zone 5, at the edge of Zone 6). The easternmost, sloped roof portion of the building is the original wing (circa 1930); the flat roof portion was an addition added in the 1950s (first floor) and 1960s (second level).

The current renovation plan is to improve energy efficiency of the building, while simultaneously keeping project costs under control, and concentrating on those upgrades that have the greatest financial benefit.

Figure 1: Barrington Town Office Building exterior

Figure 2: Barrington Town Office Building overhead

2. Wall Insulation Options

Exterior Wall Construction

Based on the Turner Report, the above-grade wall assembly consists of the following elements, from exterior to interior:

- Single wythe of clay brick (existing brick facade, every 6th course "rowlocked" with CMU backing wall)
- Existing 8" structural CMU (concrete masonry unit) wall
- Brick is tight to CMU, with no air space

The wall is uninsulated masonry: as per the Turner report, heat loss through R-4 uninsulated walls is a significant portion of the total heat loss of the building (see Figure 4). Note that this graph is presented in terms of "Btu/square foot of building area" (i.e., shell area). It appears that it is **not normalized based on the actual areas**, which would require a building takeoff (relative roof/window/wall areas). Given that the glazing ratio is roughly 35%-40%, the overall impact of the uninsulated wall is even greater than shown in Figure 4.

The heat loss through the walls is also corroborated by the SDES Group Report, which shows thermographs where the heat from radiators can be clearly seen through the exterior wall.

As a point of information, insulating the cores of CMU blocks would be both difficult (in a finished building) and have a minimal improvement; adding perlite or vermiculite insulation increase R value from roughly R-1 to R-2 (Figure 3).

Description	Density, lb/ft	Conductivity[b] k, Btu·in/h·ft^2·°F	Resistance R, h·ft^2·°F/Btu	Specific Heat, Btu/lb·°F	Reference[n]
Normal-weight aggregate (sand and gravel)					
8 in., 33 to 36 lb, 126 to 136 lb/ft^3	—	—	1.11 to 0.97	0.22	Van Geem (1985)
concrete, 2 or 3 cores					
with perlite-filled cores	—	—	2.0	—	Van Geem (1985)
with vermiculite-filled cores	—	—	1.92 to 1.37	—	Valore (1988)

Figure 3: R values for 8" concrete block, normal-weight aggregate (sand and gravel) (ASHRAE Fundamentals 2009)

Overall, this shows that significant insulation of the exterior walls would have a major impact on energy use.

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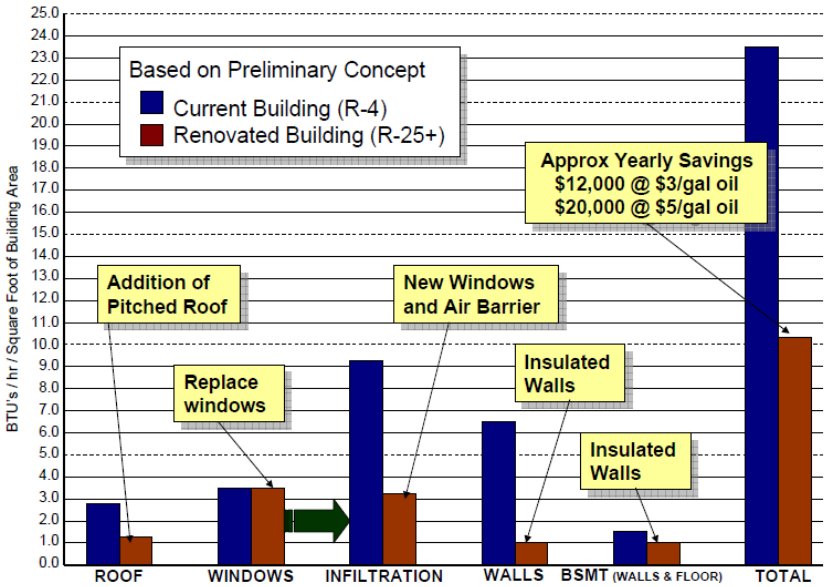

Figure 4: Building component loss Btu/square foot of shell area (Turner Report)

Interior Retrofit Overview

The existing wall is an example of a mass or storage wall system; the categorization of walls can be found in Building Science Digest 013: Rain Control in Buildings. These walls store incident rainfall, and then the water can later evaporate on warmer/drier days, after being safely stored in the masonry material.

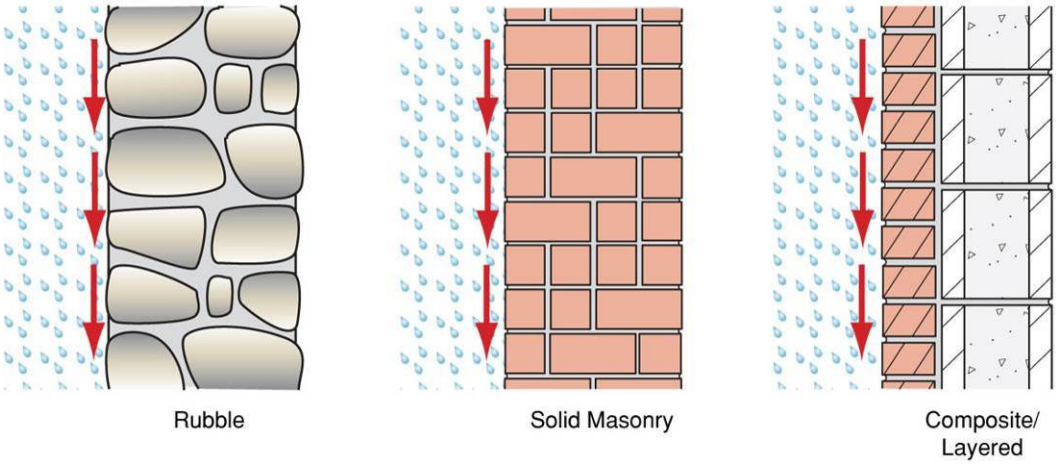

Figure 5: Examples of mass or storage wall systems

These types of assemblies can be insulated on the interior; however, there are a variety of concerns that need to be addressed when detailing insulation, such as freeze-thaw damage, risk of condensation within the assembly, and control of exterior water shedding. This is covered in some detail in Building Science Digest 114: Interior Insulation Retrofits of Load-Bearing Masonry Walls In Cold Climates. In addition, BSC held a full-day workshop on this topic (see Interior Insulation Retrofit of Mass Masonry Wall Assemblies Workshop Westford, MA - July 30, 2011); the opening presentation (Mass Masonry Insulation Retrofits: Fundamentals and Challenges, John Straube) gave an overview of the topic, and what steps should be done to evaluate risk when undertaking these retrofits.

The first step recommended by Dr. Straube was a site assessment of the building, its current condition, signs of existing moisture or freeze-thaw damage, and an indication of the moisture loading that the building currently faces. This type of assessment was included during BSC's site visit.

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Interior Retrofit Site Assessment (Brick Condition)

One common location to find freeze-thaw damage is at the top edge of the building, due to extreme exposure to rainfall (see Figure 59). In addition, the rear of the building faces northeast, which is the worst direction for deposition of driving rain in this location. A close examination of the wall condition (see Figure 6 and Figure 7) showed no indication of freeze-thaw damage.

Figure 6: Rear building brick at roof-wall interface

Figure 7: Rear building brick at roof-wall interface

Another critical detail for handling water control at the exterior face of the building is the window sills: windows concentrate wind-driven rain (because they are not water permeable/have minimal storage); the water should be shed away so that it does not accumulate on the walls underneath windows. No sign of water 'plumes' or stains underneath windows were seen. A closer look revealed that there are excellent water control features in the existing building. All of the windows are placed on concrete sills that are sloped to the exterior, with end dams to prevent "roll off" of water from the ends of the sills. In addition, there is an effective drip edge on the underside; water will tend to drip free from the building, instead of being deposited on the brick face due to surface tension.

Figure 8: Sloped sill with end dam

Figure 9: Drip edge built in to underside of sill

Effective drip edges are a critical detail for water control, as shown in Figure 10.

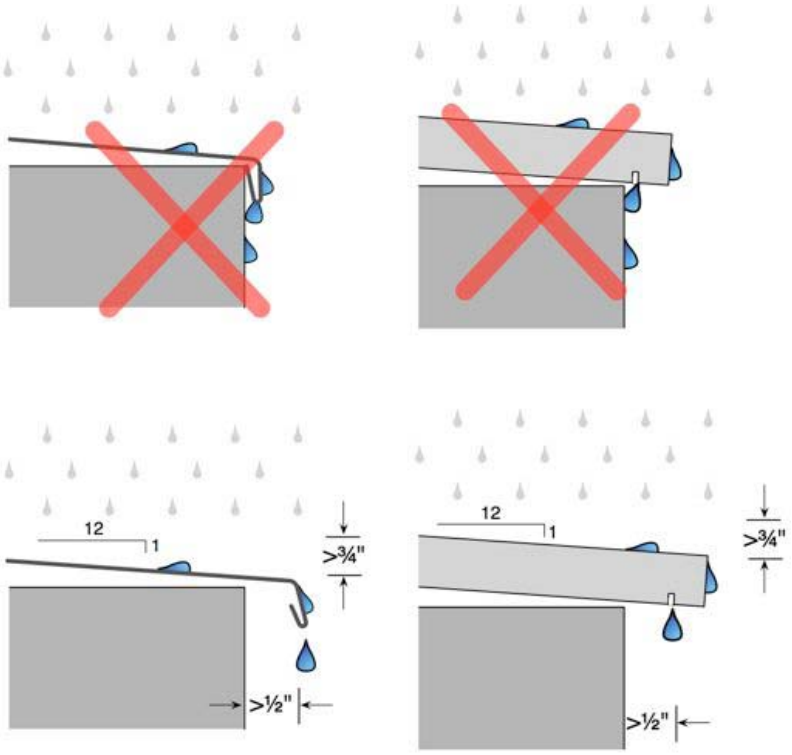

Figure 10. Drip edges and sloped sills are critical deflection elements (Straube 2011)

There is some sign of splashback or water accumulation at the low wall sections are the rear of the building; however, this does not appear to be extensive. In addition, the brick is correctly terminated above grade, transitioning to concrete instead at ground contact. Brick that goes below grade is more likely to "wick" water via capillarity, with resulting moisture problems (as discussed in Building Science Insight 011: Capillarity—Small Sacrifices).

Figure 11: Building rear, showing drainage swale

Figure 12: Rear of building, showing splashback

The roof-to-wall details are either (a) flat roof with no parapet, on the 1950/1960s addition, or (b) sloped asphalt shingle roof with overhang, on the 1930s addition. There is a minimal overhang on the flat roof (see Figure 13), but it does not appear to create an exceptional loading on the top of the building.

There are two locations where the sloped roof terminates at the wall; a kickout flashing is required to avoid concentrated water deposits on the wall (see Figure 14), if interior insulation is being considered. They can be site fabricated from sheet metal; there are also commercially available kickout flashings. Note that we would recommend this upgrade, whether or not the building is insulated on the interior.

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Figure 13: Roof overhang/parapet condition

Figure 14: Roof-wall interface, requires kickout

- DryFlekt ® Kick-Out Diverter Flashing
  http://www.dryflekt.com/

Overall, the existing building has excellent water control features for the most part. There are some small upgrades, such as those listed above, that would be required for interior insulation.

Interior Retrofit Negative Aspects

Although insulating on the interior of the building might be the lowest-cost insulation installation, and preserves the historic appearance of the existing building, there are some negative aspects. Some are covered in more detail under "Exterior Retrofit Overview," which explains the relative benefits of exterior insulation.

One negative aspect of interior insulation is that all mechanical systems that are currently attached to the walls, such as radiators, electrical services, etc., will need to be removed and relocated to the finished location. This is by no means an insurmountable issue, but it is a cost that must be accounted for in the renovation plans. Typically, interior insulation retrofits work very well during gut rehabilitations of buildings (not planned here).

Figure 15: Interior office space, showing radiator

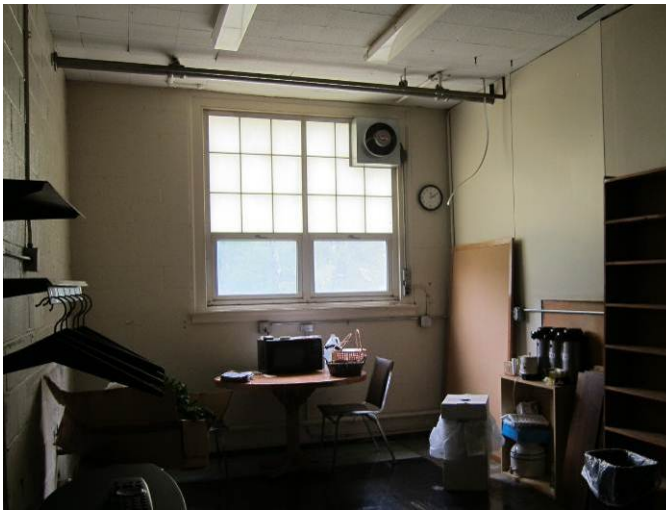

Figure 16: Interior basement level space

The use of interior wall insulation results in thermal bridges at interruptions of the wall insulation; examples include masonry "tee" wall intersections, and cast floor slabs that are connected to the masonry bearing wall (see Figure 17). Note that the small area of the uninsulated wall can have a disproportionate effect on overall heat loss.

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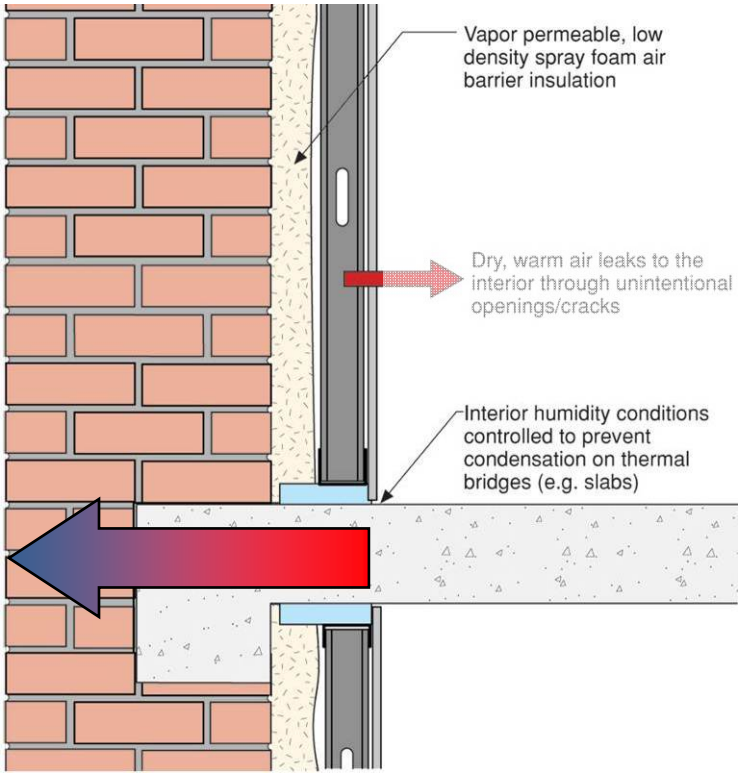

Figure 17: Heat loss after interior insulation at thermal bridge of embedded slab edge

Tee walls were examined in more detail using two-dimensional thermal simulations. Figure 18 shows a party wall (e.g., two side-by-side townhomes), with a masonry party wall. It shows that insulating on only the interior of the wall results in a thermal bridge (heat loss location), with greater heat loss at the corner of the party wall (red circle in Figure 18).

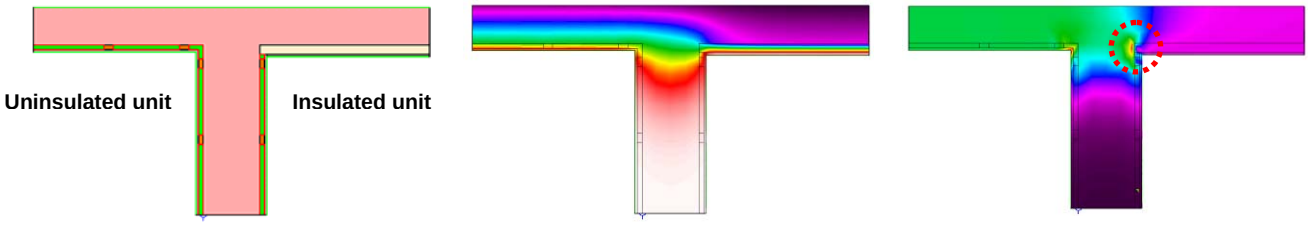

Figure 18: Two-dimensional heat flow model of party wall (assembly, temperatures, heat flux); no "wing" insulation

This can be addressed by continuing the insulation onto the party wall by roughly a foot, which greatly reduces the heat loss (heat flux, right hand illustration) at the corner. This is a detail that should be implemented if interior insulation is done.

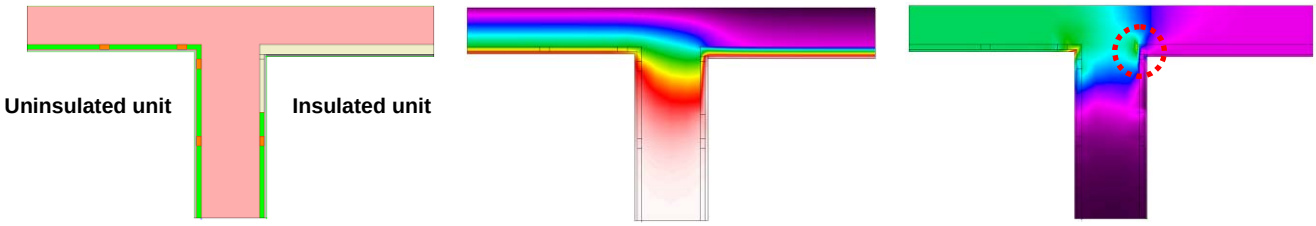

Figure 19: Two-dimensional heat flow model of party wall (assembly, temperatures, heat flux); 1' "wing" insulation

The flat roof to wall connection will also be a thermal bridge: insulation on the interior of the wall is not directly connected to the rigid board insulation on the flat roof (see BSI-001, Figure 5: "The Roof-Wall Connection").

Finally, wood members that are embedded into a masonry wall become more vulnerable to moisture damage after the application of interior insulation: they run at a colder (and therefore wetter) state in winter, and their ability to dry is reduced.

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The 1950s/1960s wing was examined; the framing of the first floor ceiling is dimensional lumber wood joists, embedded in the CMU wall, at roughly 12" o.c. Overall, insulating on the interior results in a higher risk than the uninsulated case.

Figure 20: Embedded floor joists in 1950's wing

Figure 21: Embedded floor joists in 1950's wing

Exterior Retrofit Overview

Overall, insulating on the exterior of a structure has significant benefits for building durability and performance. The benefits are covered in more detail in Building Science Insight 001: The Perfect Wall: this type of assembly (with insulation outboard of the structure) would be what would result from an exterior retrofit:

> *"The Perfect Wall"—In concept the perfect wall has the rainwater control layer, the air control layer, the vapor control layer and the thermal control layer on the exterior of the structure. The claddings function is principally to act an ultra-violet screen.*
>
> *…*
>
> *But where to put the insulation? If we put the insulation on the inside of the structure the insulation does not protect the structure from heat and cold. Remember we really do want to protect that darn structure—especially for the sake of making the structural engineers life more happy. Expansion, contraction, corrosion, decay, ultra violet radiation, and almost all bad things all are functions of temperature. So all the control layers go on the outside. Keep the structure from going through temperature extremes and protect it from water in its various forms and ultra violet radiation and life is good.*

Examples of this assembly in new construction (on CMU backup walls) are shown in Figure 22 and Figure 23.

Secondary benefits of exterior insulation are described in Research Report 1012: Residential Exterior Wall Superinsulation Retrofit Details and Analysis:

> *… the interior is still habitable during this retrofit; in fact, two of the following case studies were conducted on occupied houses. Increasing the thickness of the wall at the interior will result in a loss of habitable square footage. In exterior retrofits where the existing cladding is first removed, it provides an opportunity to inspect the condition of the building, including finding and repairing previously undetected leakage or moisture damage. More limited insulation techniques might not find these issues, resulting in long term moisture damage consequences, which would be exacerbated by the reduction in heat flow (and thus drying potential) due to insulation retrofits. The exterior insulation technique described here places non-moisture sensitive insulation outboard of the existing structure, thus providing a layer of protection*
>
> *Finally, applying insulation on the exterior can successfully handle details such as stairwells on exterior walls and intersecting tee walls, which have limited options when insulating from the interior.*

The use of an exterior overclad allows the selection of a new aesthetic choice for the façade appearance, if desired.

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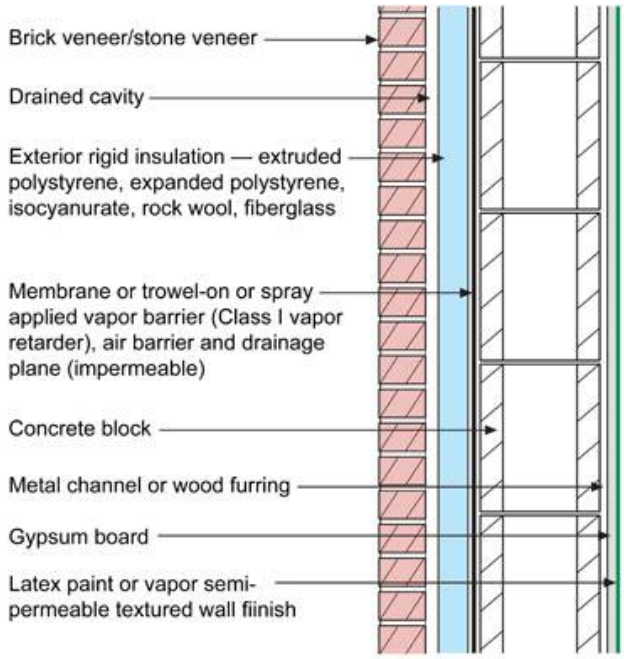

Figure 22: "Perfect wall," rigid exterior insulation on CMU backup (from BSI-001)

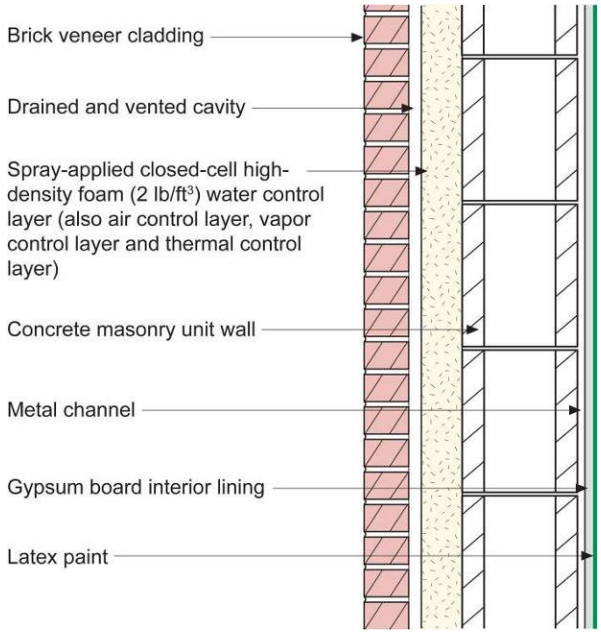

Figure 23: "Perfect wall," exterior spray foam insulation on CMU backup (from BSI-048)

The Turner Report also makes a recommendation for exterior insulation, which we concur with.

> *Meanwhile the exterior of the building shall be fitted with a new skin. This shall consist of an external air barrier, a drainage plane, and a minimum of 3-inches of rigid foam, an air space, and new siding. Several options are being considered for new siding including "Hardiplank" cement board siding, vinyl siding, and metal siding. As of the writing of this report, a final decision has not been made. A sketch, SK-A1, of the proposed wall construction is included at the end of this section.*

Their proposed wall (SK-A1) shows both interior and exterior insulation; although this results in a greater overall R value, it involves the disruption of both interior and exterior portions of the building.

Exterior Insulation: Exterior Rigid Foam

Several examples of assemblies and details that have been used on previous projects are shown in the sections below.

The first example is commonly used on wood frame buildings; it includes a housewrap (as an air control layer and secondary drainage plane) 4" (2x 2" layers) of foil-faced polyisocyanurate rigid board, 1x3 furring attached back to the structure with 6" screws, and new cladding attached over the drained and ventilated rainscreen created by the 1x3 furring. If this were implemented on a mass masonry building, the housewrap would be replaced with a liquid-applied membrane.

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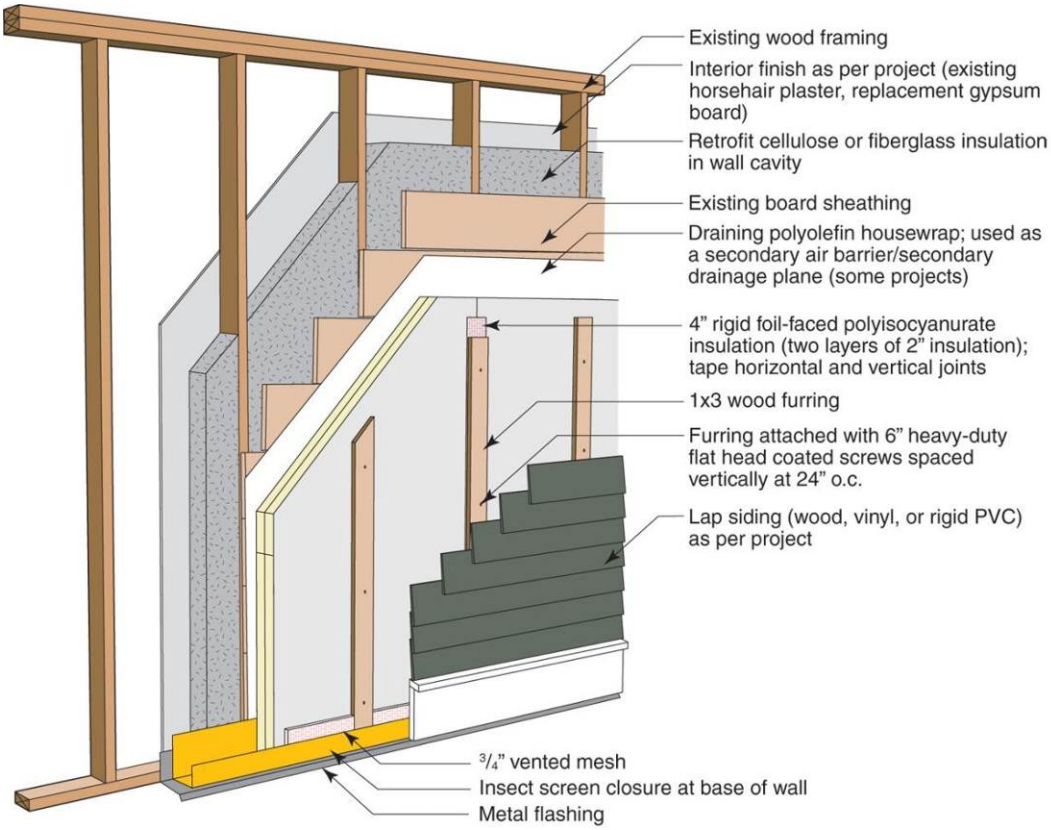

Figure 24: Schematic of exterior rigid foam overclad retrofit

Examples of this overclad being assembled are shown in Figure 25 through Figure 28. This type of assembly is also described in Building Science Digest 139: Deep Energy Retrofit of a Sears Roebuck House—A Home for the Next 100 Years.

Figure 25: Overclad; air barrier housewrap layer

Figure 26: Foam, furring strips, and cladding

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Figure 27: Foam, furring strips, and cladding

Figure 28: Foam, furring strips, and cladding

One common concern raised when attaching cladding over rigid foam is deflection ("sagging") of the strapping/cladding. This system has been demonstrated to have excellent performance over hundreds of projects and decades of service. However, a quick explanation of its performance is shown below (more detail is provided in Research Report 1012: Residential Exterior Wall Superinsulation Retrofit Details and Analysis).

A test rig was constructed to measure deflection of a furring strip assembly over foam (see Figure 29); initial application of weights showed no measurable deflection. After the application of a 250 lb load (7.8 pounds per square foot), a deflection of under 0.003" was measured. For comparison, the weights of typical claddings are shown below:

- Wood siding ~2 psf
- Fiber cement 2-3 psf
- Stucco 8-10 psf

Therefore, wall cladding loads are much lower than any level that would cause appreciable deflection. In addition, a short-term demonstration of three construction workers hanging from one screw attachment through foam is shown in Figure 30 (c/o Petersen Engineering, Portsmouth, NH).

Figure 29: Deflection testing of 1x3 strapping on foam

Figure 30: Field test of foam deflection/strength

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Exterior Insulation: Exterior Spray Foam

Another retrofit assembly is to apply spray foam to the exterior of the existing structure, which creates a layer of insulation, a very effective air barrier, and a water control layer (drainage plane). 2x3 framing members are temporarily held in place with gutter spikes, and then locked in place with the application of high density (closed cell) spray foam.

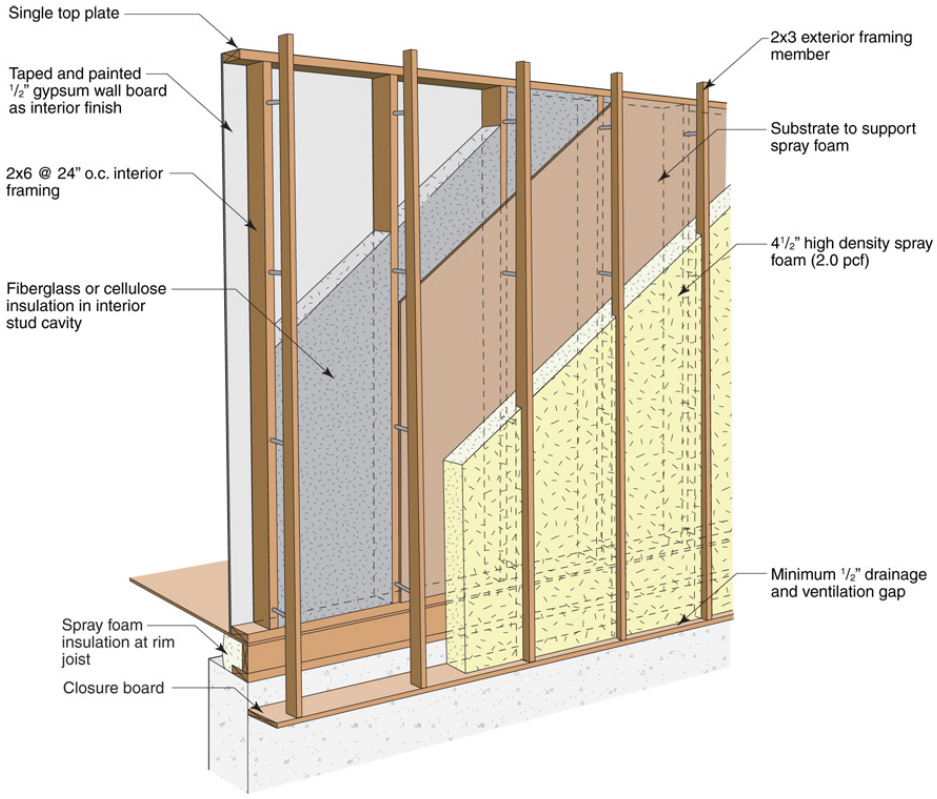

Figure 31: Schematic of exterior spray foam overclad retrofit

This retrofit is covered in more detail in NESEA 2008 “What Would John Straube Do?”; several details are shown below in Figure 32 through Figure 35.

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Figure 32: Installation of 2x3 framing

Figure 33: Window installation and extension "box"

Figure 34: Application of exterior spray foam

Figure 35: Completed retrofit showing spray foam

Note that this retrofit technique is not limited to wood-frame walls; this same technique is shown over a mass masonry (concrete block) building in Figure 36 and Figure 37. It is discussed in more detail in Building Science Insight 048: Exterior Spray Foam. In a similar manner, wood furring is built out as cladding attachment, and locked into place with the spray foam (see Figure 36 and Figure 37).

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Figure 36: Exterior SPF retrofit on masonry (BSI-048)

Figure 37: Exterior SPF retrofit on masonry (BSI-048)

Building Science Insight 048: Exterior Spray Foam has a further explanation of how cladding attached to wood embedded in spray foam behaves structurally:

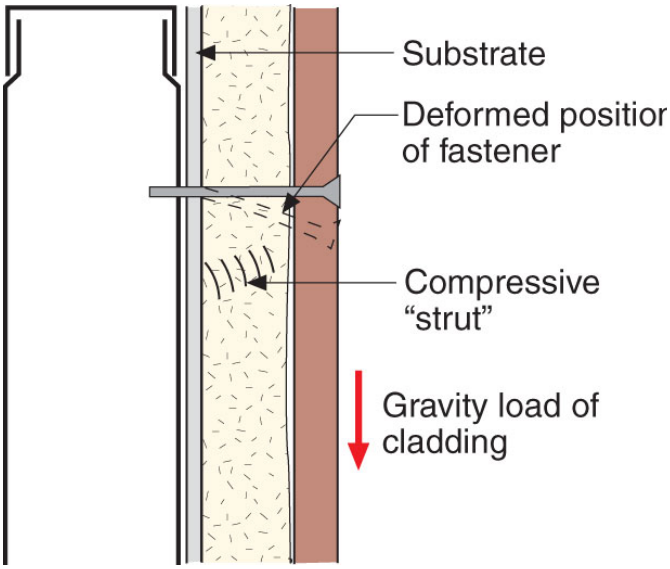

Figure 38: Mechanics of furring strip gravity loading (BSI-048)

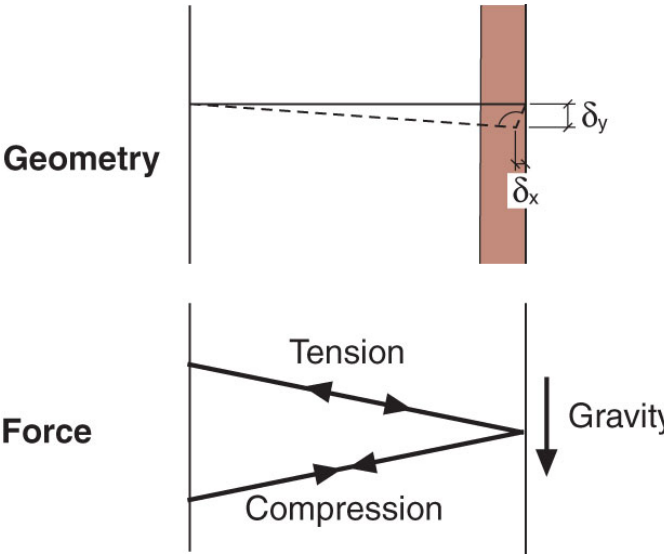

Figure 39: Mechanics of furring strip gravity loading (BSI-048)

*The "freak-out" part is the structural strength of the cladding attachment. How can you hang those "thingies" so far away from the wall on long screws? The compressive strength of the SPF makes it work. The issue is screw bending—the "bending moment" of the screw. Here comes the obvious part. For the screw to bend it has to rotate inward into the wall. For it to rotate inward into the wall, the "thingy" has to rotate with it. The "thingy" pushes against the SPF and the SPF pushes back. The compressive strength of the SPF resists the rotation inward of the "thingy." Structurally, this can easily be calculated** as a "truss." The "thingy" frames*

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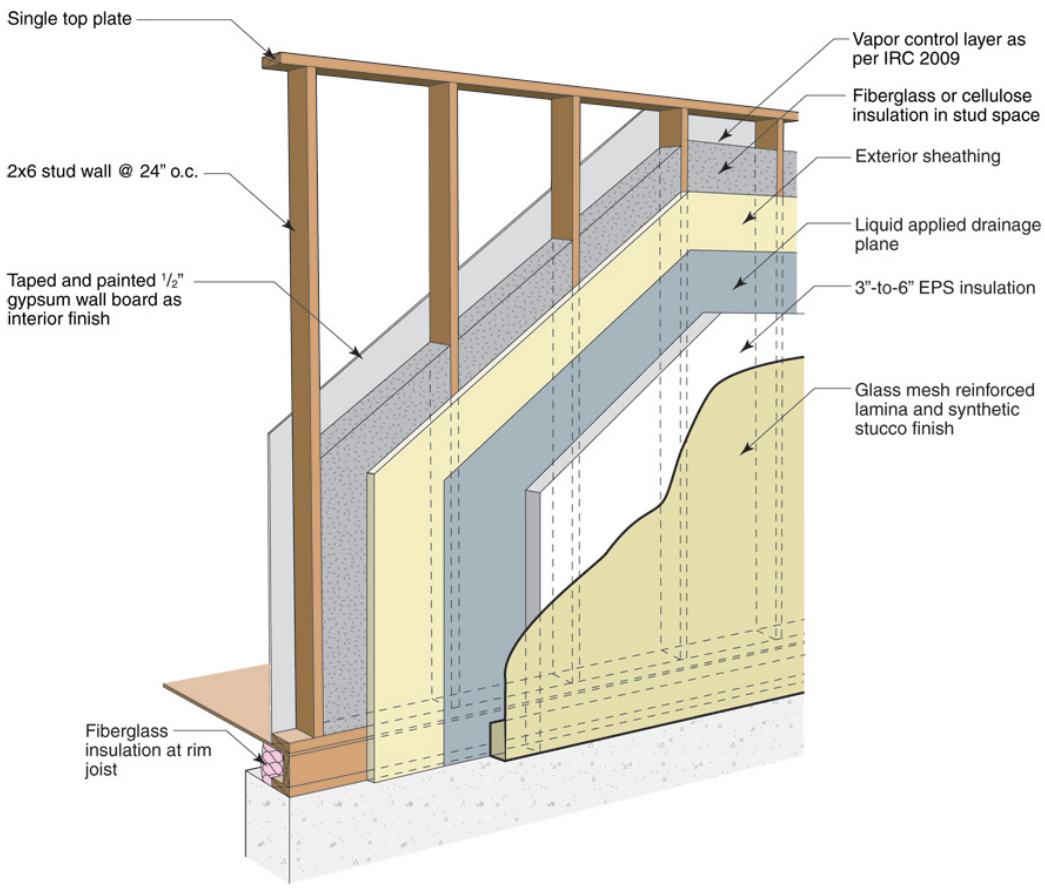
are real flimsy until the SPF is applied. The foam expands outward and bonds to the frames. Then things are unbelievably stiff. Now, despite the ease of calculation, structural engineers, and engineers in general, like "tests." We have done lots of tests. We have found that you can pretty much hang an SUV off the wall using screw stand-offs and SPF. In fact, we have found the same thing with extruded polystyrene board insulation and isocyanurate board insulation. The short answer is that a "truss analogy," as a basis for calculation, provides a conservative result for all of these insulations. If you want a less conservative answer, use finite element analysis or do your own tests. I bet that conservative wins.

Exterior Insulation: EIFS

Another common commercially-available overclad option is EIFS (exterior insulation and finishing system): it involves a drainage plane (e.g., liquid applied membrane) on the existing structure, followed by expanded polystyrene (EPS) insulation and a glass mesh reinforced stucco lamina. This is discussed in more detail in Building Science Digest 146: EIFS - Problems and Solutions. Note that historically, EIFS has been linked to major problem; this was due to the use of a face-sealed (non-drained) EIFS system:

Drained EIFS are significantly different from face-sealed systems in that, by definition, they have a provision for drainage. Unlike face-sealed perfect barrier systems such systems can be successfully used as an exterior cladding system in essentially all climates and exposures. Drainable EIFS are not subject to the same limitations of use as face-sealed or barrier systems. In fact, drainable EIFS are among the most robust and advanced moisture control assemblies available.



Examples of EIFS overclads being applied and completed are shown in Figure 40 and Figure 41.

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Figure 40: Drained EIFS overclad of brick building

Figure 41: Completed EIFS overclad

Exterior Insulation: Panel Overclads

Another overclad example is the use of stressed-skin insulated metal panels (filled with polyisocyanurate foam). This is shown as an overclad over an existing uninsulated brick wall (see Figure 42). The project is described in more detail at the web site below. This retrofit is being conducted on an occupied building; the residents are not being relocated during this work.

- Castle Square Apartments Deep Energy Retrofit
  http://www.castledeepenergy.com/
  http://www.castledeepenergy.com/?page_id=24

Figure 42: Insulated panel overclad wall

Figure 43: Insulated panel overclad roof-wall detail

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Exterior Insulation: Cladding Attachment Through Insulation

Another approach is to attach non-insulating exterior cladding (e.g., fiber cement panels, metal panels, lap siding, etc.) onto metal Z-girts attached back to the structure, with insulation between the Z-girts (see Figure 44 and Figure 45). However, this approach results in significant thermal bridging, thus reducing the effectiveness of the insulation substantially—e.g., loss of over half of the nominal insulating value is common.

Figure 44: Metal panel cladding on Z-girts

Figure 45: Z-girts bypassing "perfect wall" insulation

If this approach is taken, we would recommend the use of a non-thermally conductive spacer (e.g., a commercial off the shelf option such as the Cascadia fiberglass spacer system), which prevents these thermal bridging issues.

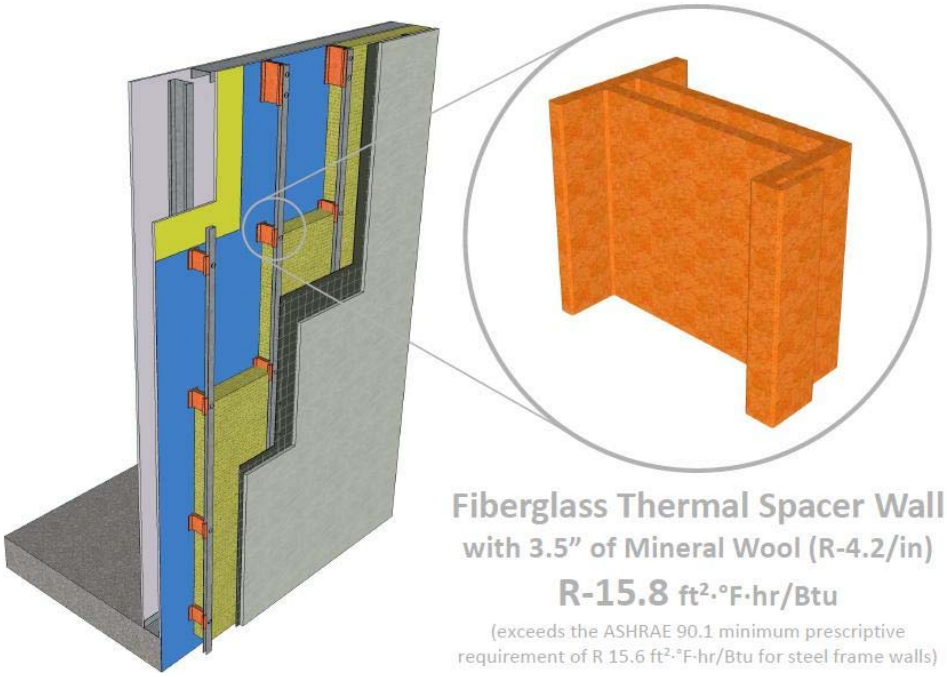

Figure 46: Cascadia Windows Ltd. Fiberglass Girt Spacer System

- Fiberglass Thermal Spacers
  http://www.cascadiawindows.com/products/series53.php

However, the systems discussed in previous sections (spray foam, rigid foam) have thermal performance as high as this option, and likely at lower cost.

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Wall Insulation Comparisons

Overall, if we were required to use interior insulation, based on our field observations, we would consider this building a good candidate: the exterior water control detailing is good, there are no signs of exterior brick damage (freeze-thaw), and there are no signs of extensive or systematic bulk water leakage through the brick. Further testing would be recommended before proceeding, though.

However, the fundamental issue is that interior insulation intrinsically increases risk to the existing structure. In addition, there are secondary issues that suggest that exterior insulation should be considered as an option.

Characteristic	Interior Insulation	Exterior Insulation
Aesthetics	Change/upgrade interior appearance	Change/upgrade exterior façade
Square footage impacts	Reduced; exterior stairwells become more narrow	Unchanged (but exterior footprint increases)
Moisture/durability risks	Risks to building enclosure increase (freeze-thaw, embedded beams, condensation on interstitial surfaces)	Risks to building enclosure are reduced (minimal to no interstitial condensation risks; see BSI-001)
Thermal performance	Thermal bridging risks at slab floors, tee wall intersections, roof-wall interface at flat roof	If detailed in a continuous manner (see BSI-001), superior thermal performance
Water control	Dependent on exterior brick water shedding features and updates	Can be completely designed from scratch; ventilated rainscreen detail is common, which provides high performance/protection
Required steps ([1])	• Removal of interior mechanical systems (radiators, electrical) • Interior stud out of walls (note: metal framing should be kept clear of insulation to avoid thermal bridging issues) • Insulation (high density spray foam or rigid plastic foam insulation installed in an airtight manner) • Insulation of details (tee walls, etc.) • Mechanical rough-in • Gypsum board, mud, tape, paint • Mechanical replacement (radiators, electrical) • Window returns for thickened wall made from gypsum board • Brick bulk water deposition measures (kickout flashing, improved parapet)	• Exterior air barrier/water resistive barrier on brick (liquid applied) • Installation of insulation (rigid foam insulation, mineral fiber, or high density closed cell 2 PCF spray foam; liquid applied WRB may be omitted with high density spray foam) • Installation of cladding supports (may be before previous step, depending on selected system) • Installation of cladding (higher cost than interior gypsum finish) • Window returns for thickened wall must be exterior materials (fiber cement, PVC trim, etc.)—higher cost • Connections to roof details required (thicker wall matching up to flat roof parapet and sloped roof overhang)

([1]): This is meant as an exercise to roughly approximate the relative costs of these two systems; a complete or detailed cost estimate is beyond the scope of this report.

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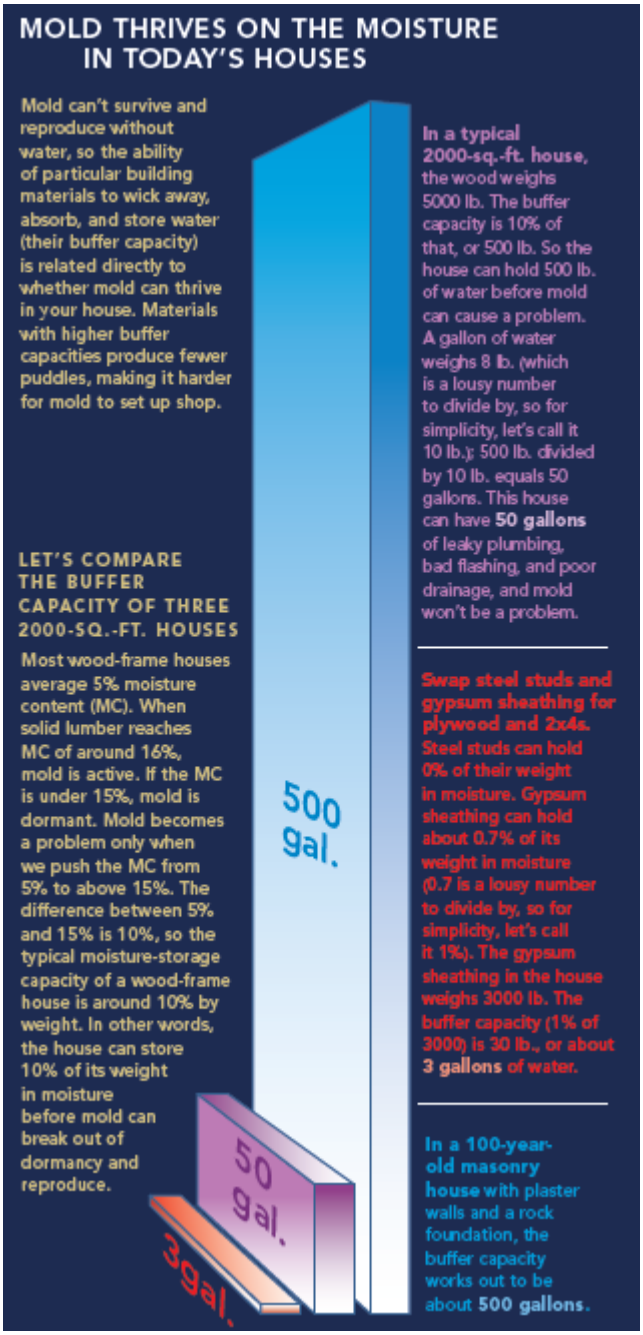

Figure 47: Relative storage capacity of various constructions (Lstiburek 2006)

Another aspect that warrants further discussion is the relative risks of mold and other related indoor air quality concerns with these retrofit methods. As noted in other reports and sources, mold growth occurs in when mold spores are present in a location with an acceptable substrate (food), an acceptable temperature range, and sufficient moisture to cause microbial amplification. Given that mold spores are everywhere, control of moisture is the only real method available to avoid mold issues.

Overall, mass masonry walls are one of the less risky assemblies for mold growth, due to its large storage capacity, compared to residential wood frame construction, or commercial-style steel stud/gypsum board construction. This is covered in more detail in "The Mold Explosion: Why Now?" (*Fine Homebuilding*, December 2006/January 2007) by Joseph Lstiburek, and is excerpted in Figure 47. Typically, mass masonry walls have little food value to mold. However, other items that are contained within the building, such as paper-faced gypsum wall board, framing (wood), finishes and furnishings such as ceiling tile and carpet, and stored materials such as paper all provide excellent food sources for mold, if they become wet.

Insulating on the interior of the masonry structure has some risk in that the interface between the masonry and the insulation will be at high relative humidity levels throughout the winter. Interstitial (within the wall) condensation and mold growth could be associated with an incorrectly assembled system. However, a correctly detailed assembly, which has a robust and complete air barrier (such as the spray foam installation described above) has a higher margin of safety.

Also, interior insulation would be done typically with closed cell spray foam; there have been some cases of incorrect formations or poorly applied products resulting in odor and indoor air quality complaints. These problems should be addressed with a quality control system, and they appear to be a very rare occurrence. However, this does have some risk of becoming an IAQ concern if these issues arise.

On the other hand, insulating on the exterior of the structure greatly reduces the risks of condensation. By placing the entire structure within an insulated shell, there is no "cold condensing surface" to be found—we have effectively eliminated this "third rail" source of moisture. In addition, the monolithic bulk water control layer (i.e., drainage plane) on the outside of the building greatly reduces risks of bulk water entering the wall (compared to the interior insulation approach, which allows the wall to get wet and then dry). Overall, an exterior insulation ("Perfect Wall") approach has the greatest margin of safety in terms of any moisture (and therefore mold) issues.

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3. Other Enclosure Upgrades

Overall Energy Performance

There are several pieces of useful information that were gleaned from previous reports. For instance, the SDES Report put the Town Office Building's energy consumption in context with the remaining portfolio, showing that it is by far the worst performer, both on a total cost and square footage normalized (Energy Use Intensity, kBtu/sf·year) basis (see Figure 48).

Facility Name	Baseline Total Site Energy Use (kBtu)	Total Floor Space (Sq. Ft.)	Current Site Energy Intensity (kBtu/Sq. Ft.)	Annual Energy Cost (US Dollars ($))
Community Center	697,854	12,000	65.7	$18,889
Highway Complex	251,928	3,200	85.2	$7,181
Public Safety Building	677,123	13,000	58.4	$17,467
Recycling Center	87,993	1,300	78.1	$2,595
Town Hall	1,497,380	14,000	100.1	$27,464

Figure 48: Energy use figures for Town Hall and other municipal buildings (SDES Report)

In addition, the monthly electrical consumption was graphed, along with cooling degree days (i.e., monthly cooling load) for Concord, NH. This is useful because it can partially disaggregate the loads associated with cooling space conditioning compared to "base loads" (domestic hot water, computer and lighting use, etc.). It is assumed that in the months with no cooling loads, there is no significant cooling system operation, and that the "peaks" during the summer months can be measured.

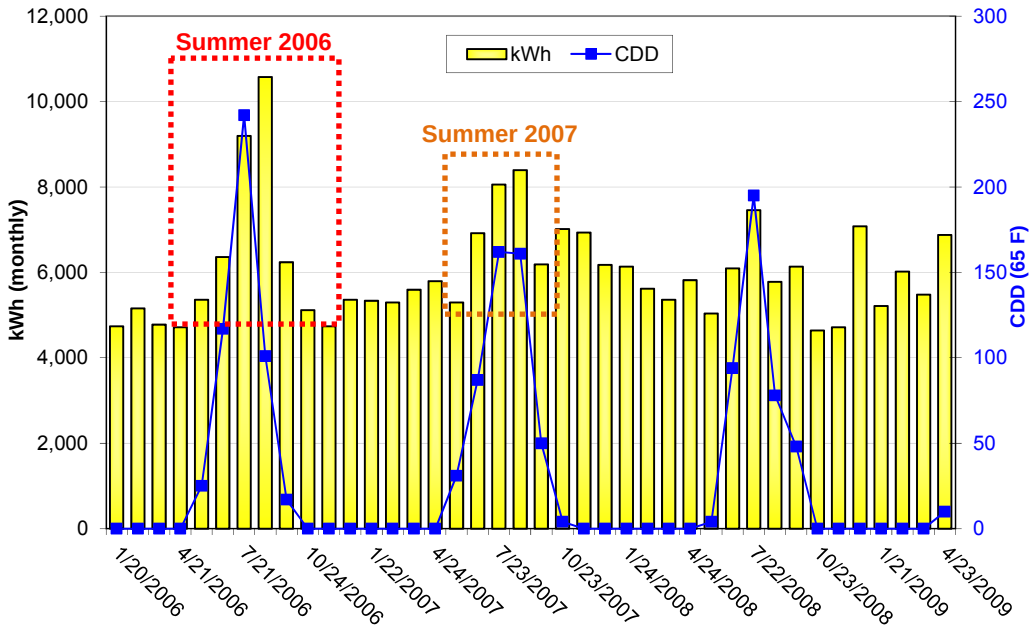

Figure 49: Monthly electricity use with cooling degree days (CDD Base 65) for Concord, NH

This analysis demonstrates that the cooling load is only a small proportion of the overall electrical use. For instance, the "peak" in 2006 was roughly 15,000 kWh, or $2,400, and the summer of 2007 in roughly 12,000 kWh, or $1900. In contrast, the "base load" (monthly year-round load) is roughly 56,000 kWh/year, or ~$9000. We would conclude that it is definitely not a bad thing to reduce cooling loads, but to put in perspective, **major** reductions in cooling loads (i.e., cutting them in half) would yield savings of roughly ~$1000-1200/year at most. So, for instance, the use of exterior overhangs and shading devices is not likely to be a cost-effective option, unless they can be installed at a very low cost.

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Airtightness

In a heating-based (cold) climate, improving airtightness is commonly the most effective (overall) and the most cost-effective way to reduce space conditioning energy use. The Turner Report provides measurements that they took on the building, showing that there are substantial improvements that can be made (i.e., "low-hanging fruit"), due to the high air leakage in the existing building (0.8 air changes per hour, vs. 0.3 to 0.5 typical; as a point of reference, BSC residential buildings that were particularly airtight commonly achieve levels of 0.1 nACH).

> *Another key issue with the existing building envelope is air infiltration, particularly around the window frames. As part of the building evaluation we performed a blower door test to get an idea of the air leakage rate for the building. The test was conducted with the exterior doors closed and all interior doors open, including the corridor doors to large office spaces and the corridor doors at the stairwells. The average of the readings from the blower door test indicated an air exchange rate of .76 air changes per hour. For comparison, a well-constructed, new building would have an air infiltration rate of .3 to .5 air changes per hour. This difference can represent as much as 5 to 6 BTU's per hour, per square foot in heating cost for the Town Office Building. This represents about a 50% savings in energy costs. This is illustrated on the energy savings graph at the end of this section. So even though new windows would have a small increase in terms of the R-value or thermal resistance, with proper installation, flashing, and sealing around the rough opening, they would make an appreciable difference in terms of cutting down on air infiltration. Furthermore, new windows would fix the condensation issue.*

We concur with the Turner Report observation that increasing airtightness is a vital strategy for reducing overall energy use. The actual airtightening measures that we would recommend are covered within the enclosure element sections below. **But any retrofit plan must include a comprehensive air barrier strategy, which identifies the air control layer (i.e., air barrier), and ensures that there are details to connect it to the air barrier on other components (roof-to-wall, wall-to-foundation, etc.).** For instance, if the interior retrofit is chosen, the wall spray foam (air barrier layer) must be connected to the windows, to the roof air barrier layer, and from floor-to-floor (i.e., through the floor framing). If the exterior retrofit is chosen, it becomes a simpler detailing exercise, as the air barrier is a uniform layer (e.g., liquid applied WRB on face of brick) across the entire wall, which can be identified and connected to other components.

Air barriers are covered in more detail in Building Science Digest 014: Air Flow Control in Buildings and Building Science Digest 104: Understanding Air Barriers.

Blower door testing can be a very useful tool for quantifying overall leakage, and if combined with infrared observation (during cold weather) it can reveal air leakage locations. Turner had several recommendations which should be addressed, including weatherstripping of doors, exhaust fan louvers stuck in the open position.

It may be worthwhile to implement some of the measures discussed below, and then perform a follow-up blower door test, in order to quantify the improvements, and locate any remaining leakage locations that were not addressed during the main remediation. This type of work is often done at the stage where the air barrier is deemed "substantially complete," but before installation of finishes, to allow touch-up of any remaining problem areas.

Sloped Roof (Vented Attic)

One location for major upgrades is the vented (sloped) attic over the 1930s wing of the building. Although it is insulated with fiberglass batts, it could easily be upgraded by (a) improving the airtightness of the flat ceiling plane which separates interior space from the unconditioned attic, and (b) increasing insulation thickness with low-cost batt or loose-fill insulation.

The ceiling itself is cement-based plaster on an expanded metal lath backing: this material very airtight. However, at discontinuities and penetrations of the ceiling, there are penetrations which results in a lack of air barrier continuity. For instance, the Turner Report noted during their infrared observations:

> *Thermal images taken in the attic of the 1930's wing show air leakage at the intersection of the wall and ceiling. [i.e., exterior perimeter]*

In addition, there are an excellent set of images showing thermal bypasses (air leaks) at attic in SDES Report, including unsealed block mechanical shafts. Some examples are shown in Figure 50 (wiring penetrations through the ceiling) and Figure 51 (open CMU block wall cores). In addition, every duct penetration should be air sealed: there was daylight visible around the duct opening (see Figure 85 and Figure 86).

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Figure 50: Wiring penetrations through ceiling

Figure 51: CMU wall cores left unsealed

One approach to remediation is to apply a skim coat of spray foam on the entire attic floor, as per Figure 52, and then to top the foam with cellulose insulation (Figure 53).

Figure 52: Skim coat of spray foam on attic floor

Figure 53: Cellulose insulation installed over spray foam

Another approach is to find selective locations where air leakage is occurring, and to seal them with spray foam, caulk, rigid foam, or other materials. Examples of selective air sealing are shown in Figure 54 and Figure 55.

This procedure will involve the removal of all batt insulation from attic (or move it to another portion of the attic), and removal of the walking surface deck/catwalks. The spray foam contractor would then selectively air seal all penetrations, ceiling top plates, joints between sections of cemetitious plaster ceiling, and the ceiling-to-exterior wall detail (including the block cores).

Other locations were highlighted in the SDES Group Report, including the perimeter of the chimney penetration, and the concrete block duct chase. Their report also shows substantial heat loss from cupola, indicating leakage of warm interior air into the attic, and then to the exterior. The penetrations around ductwork should be sealed by peeling back the insulation jacket and insulation, and then either using spray foam or matsic to create continuous air barrier (joining inside liner to plaster ceiling).

Following air sealing, the attic insulation should be upgraded. The code minimum (2009 IECC for commercial buildings) is R-38; this could easily be made thicker (e.g., R-50) at a relatively small delta in cost, if a loose-fill insulation contractor is selected. Note that the catwalks might need to be raised in order to be above this insulation level (R-50 ~14” of cellulose). Also, ventilation chutes may be required to prevent clogging of roof ventilation at the eaves.

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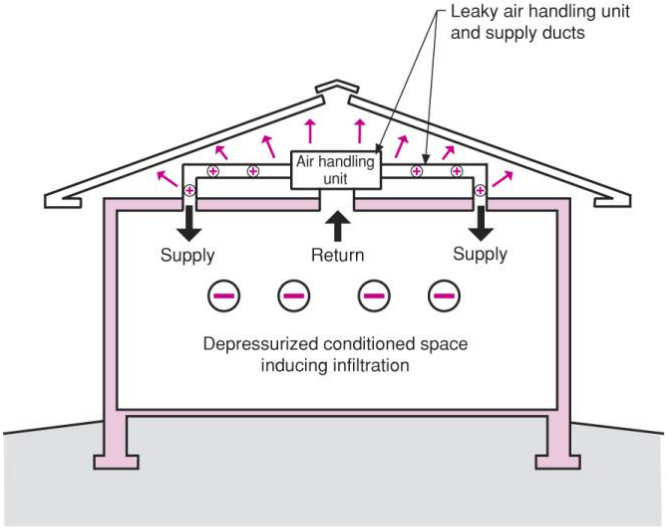
Figure 54: Cellulose insulation removed from top plates

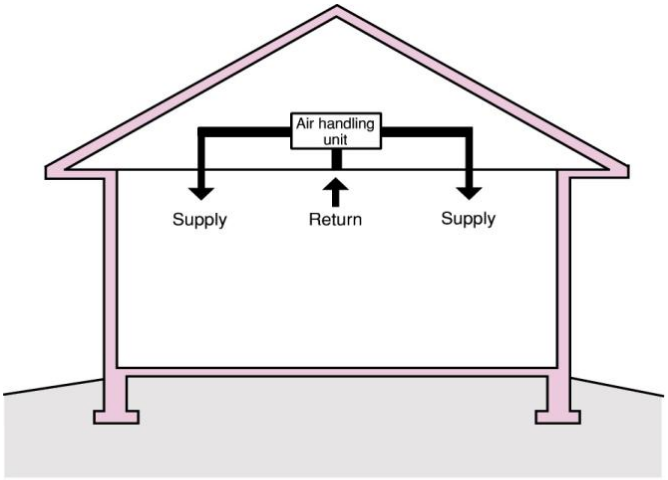
Figure 55: Spray foam at air barrier deficiencies

One option that is sometimes considered in cases like this is to convert the attic into an unvented attic, with the air barrier and insulation at the roofline, instead of the floor of the attic. This has particular benefits when mechanical equipment (i.e., air handlers) is located in the attic, because it eliminates duct leakage (and thus forced infiltration/building air leakage) issues (see Figure 56 and Figure 57). This would eliminate the need to remove the floor insulation, air seal the attic floor, and deal with any duct leakage issues.



Note: Colored shading depicts the building's thermal barrier and pressure boundary. The thermal barrier and pressure boundary enclose the conditioned space.

Figure 56: Vented roof with leaky air handler in attic



Note: Colored shading depicts the building's thermal barrier and pressure boundary. The thermal barrier and pressure boundary enclose the conditioned space.

Figure 57: Unvented roof, with air handler inside

However, there are several reasons to leave this system as a vented attic (insulated at the ceiling plane):

- There are several historic water leak stains visible on the roof framing; these would need to be addressed before implementing this system. Chimney flashing issues would need to be addressed as well.
- An unvented roof would give less advance warning of roof leakage, as it would be concealed by the roof plane insulation.
- The cupola would need to be isolated from the interior (unvented attic space) and air sealed if an unvented roof is selected.
- The air handlers in the attic are cooling-only, so they only operate for a relatively small portion of the year, compared to a heating/cooling system, which would cause air leakage throughout the year.

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Flat Roof

One recommendation from the Turner Report is to overbuild a new sloped roof on the flat roof (1950/1960s wing) of the building; this is recommended to improve thermal performance (new insulation ~R-40), to protect the face of the building from bulk water, and to provide a tempered space for the mechanical equipment:

> *We are proposing that the insulation for the new pitched roof be located at the roof plane providing a tempered attic space for mechanical equipment, as well as a better thermal rating for the roof system. With a new roof and new insulation, a rating of R-35 to R-40 could be achieved. It is anticipated that the new pitched roof would be constructed of wood trusses spaced at 24-inches on center. The trusses would run north to south and be configured to overhang the face of the building by about 18 to 24 inches. The overhang will help to keep water away from the face of the building.*

It is true that increasing roof projection/overhang provides protection from incident rainfall: a survey of Vancouver buildings shows that problems with wall water leakage can be related to overhang length (see BSD 013: Rain Control in Buildings).

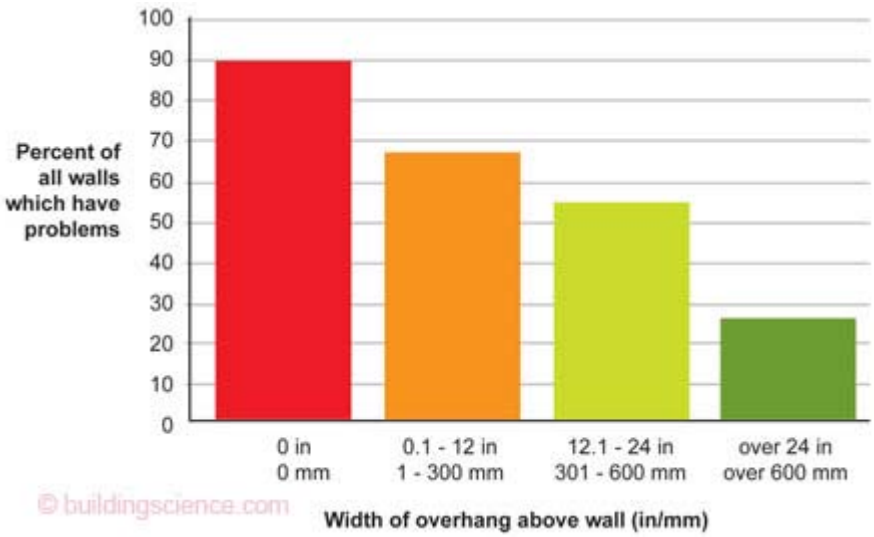
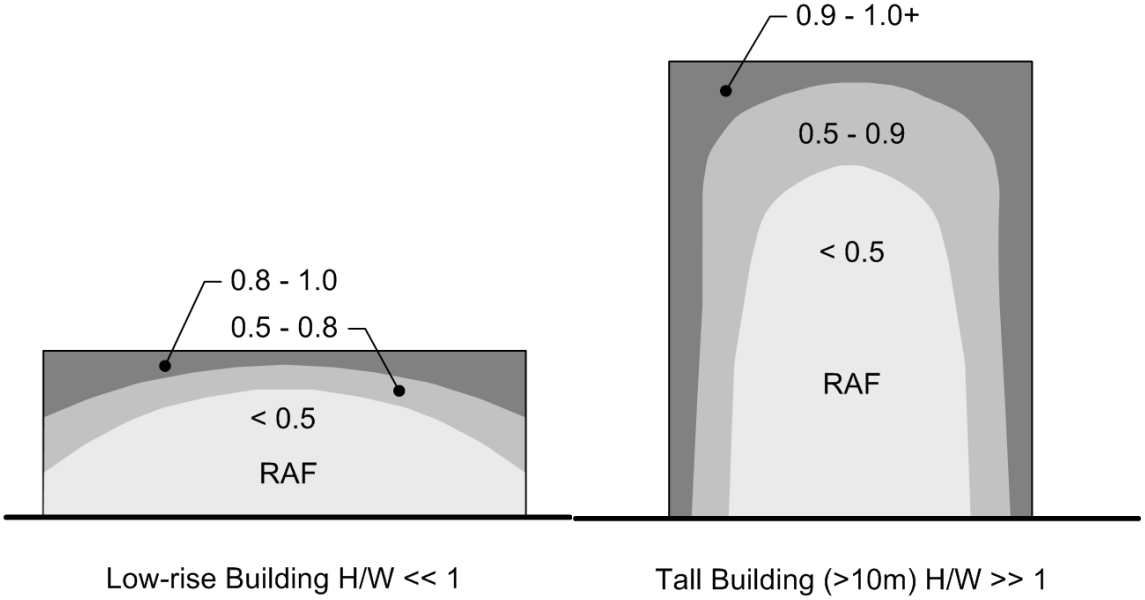


Figure 58: Wall problems as a function of the overhang size from a field survey (BSD 013: Rain Control in Buildings)

In addition, rainfall concentrates at the top and corners of rectangular-shaped buildings; a roof overhang reduces wind-driven rain deposition on the walls.



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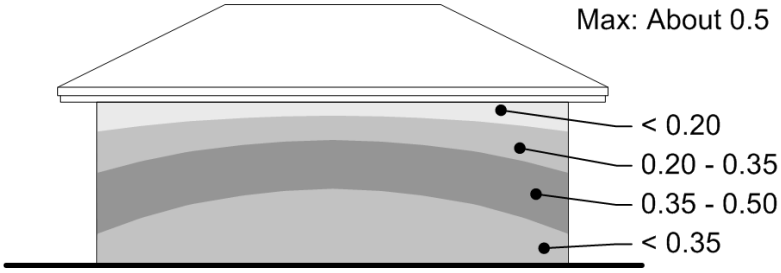

Figure 59: Rain deposition factor (RDF) showing relative rain deposition on various building shapes

However, of course, note that there are limits to how much of the wall is protected by overhangs in two-story buildings, as shown by the weathering patterns in Figure 60. Overall, the decision on whether the overhang is a worthwhile addition should be based on the vulnerability of the wall to water damage (i.e., interior vs. exterior insulation, the retrofit of a rainscreen onto the wall, etc.) and the cost of the upgrade.

Figure 60: Weathering patterns showing degree of roof overhang protection (Salem, MA)

The existing roof edge detail at the flat roof (1950/1960s wing) is shown in Figure 61 and Figure 62. It provides some projection (and thus protection) from rainfall deposition/drips at the roof-wall interface, but no substantial overhang.

Figure 61: Existing flat roof edge detail

Figure 62: Existing flat roof edge detail

This detail could be slightly improved, if rebuilt, by adding some minimal framing to push the drip edge detail further off the wall, as shown in Figure 64. The existing roof is roughly 12 years old; this might be done at the next replacement cycle. This would dovetail especially well into an exterior insulation retrofit, which would require rebuilding of the parapet/roof-wall interface to account for the greater thickness of the exterior wall.

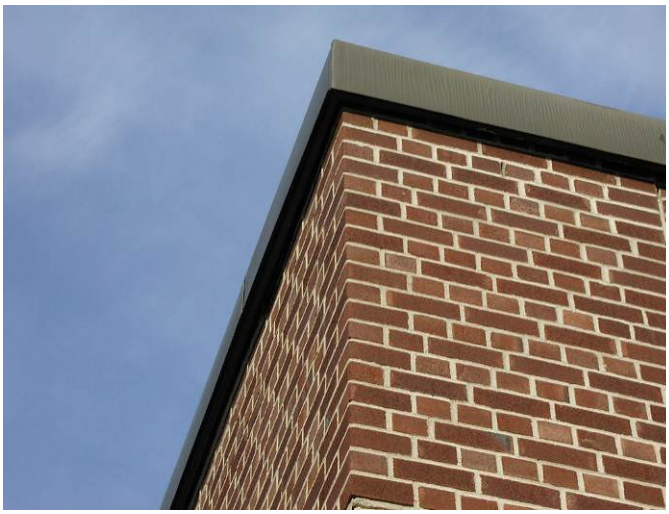

Figure 63: Parapet overhang/drip edge detail

Figure 64: Improved drip edge overhang

The existing roof R value is unknown; however, it can also be upgraded simply with increased thickness of rigid insulation at the next replacement cycle of roofing. The code requirement (2009 IECC) is a minimum of R-20 continuous insulation in Zone 5; it is also R-20 in Zone 6. Assuming R-6 per inch (typical for glass fiber faced polyisocyanurate), that would be a thickness of 3-½" of insulation. Of course, this upgrade will also require modifications to the existing sheet metal roof-wall detail, to account for the added thickness. Additional thickness (e.g., up to R-30 or higher) would be a reasonable step, if added thickness can be accepted.

Note that **minimum** thickness of rigid roof insulation (e.g., at roof drains) is critical, as a lack of insulation at those locations can cause disproportionate loss relative to their area—especially for higher R value roofs (see SWA Party Walls, April/May 2009):

> *A highly simplified example illustrating this point is this: in a 100 square foot wall, R- 10, an R-2 window occupies 10 square feet, or only 10%. However, because lower R-values dominate the assembly thermally, the window represents 35% of the heat loss. Big difference!*
>
> *What this means for roof insulation is that you get the most bang for your buck with the first few inches of thickness, after which we see diminishing returns. So given infield installation methods, the minimum thickness becomes priority; all else is highly variable depending on the shape of the roof. We find it helpful to recommend a minimum insulation value, such as 4 inches of polyisocyanurate (see attached graphic). That way, the entire roof will be at least R-26, but the average will be somewhat higher. Checking the roof slope plan carefully for minimum insulation values will aid in making sure you get the most energy-efficient roof for your money.*

Therefore, we would recommend a roof insulation specification for a minimum insulation thickness, as opposed to trying to have exceptionally thick insulation to make up for the thinned portion. We would also recommend a minimum slope of ¼" per foot for the tapered roof insulation, to ensure positive drainage to the roof drain.

The air barrier also needs to be addressed at the flat roof. We would recommend an air barrier layer within the roof assembly **below the layers of rigid foam**, as per Building Science Insight 036: Complex Three Dimensional Airflow Networks. Air leakage into the "roof sandwich" (layers of rigid foam) can result in condensation within the assembly. Therefore, we would recommend that the concrete structural planks (see Figure 65 and Figure 66) be sealed at their seams (e.g., self-adhered membrane flashing, liquid applied mastic), and at the roof-to-wall interface. In addition, edge wrapping of the roof insulation further improves airflow control (see Figure 67).

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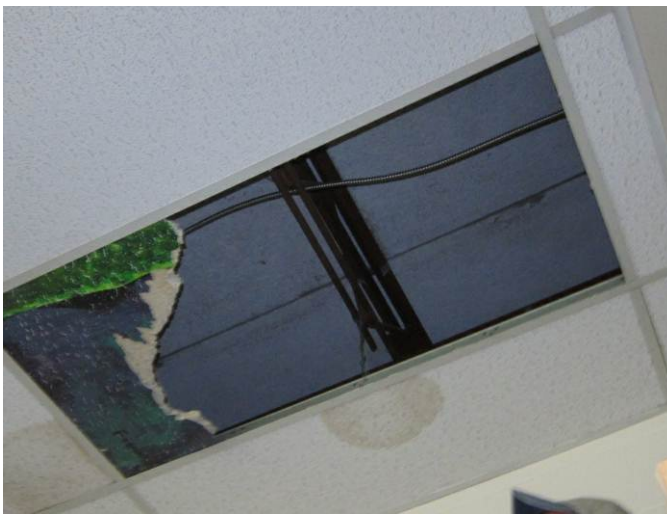

Figure 65: Interior of flat roof assembly

Figure 66: Interior of flat roof showing bar joist

Some details to address the differential movement of the roof-wall interface (i.e., "stretching" of the roof membrane at the edge) are covered in BSI-050: Parapets—Where Roofs Meet Walls. They include the use of rigid blocking at the edge to restrain the roofing, or a perimeter backer rod detail, which allows for differential movement:

> *Large backer rod supporting a bunch of extra membrane that lets things move when they have to move. The "Zen" approach to membrane movement. Use a more dimensionally stable membrane and then let things move when they have to. Again, notice the continuity of the control layers.*

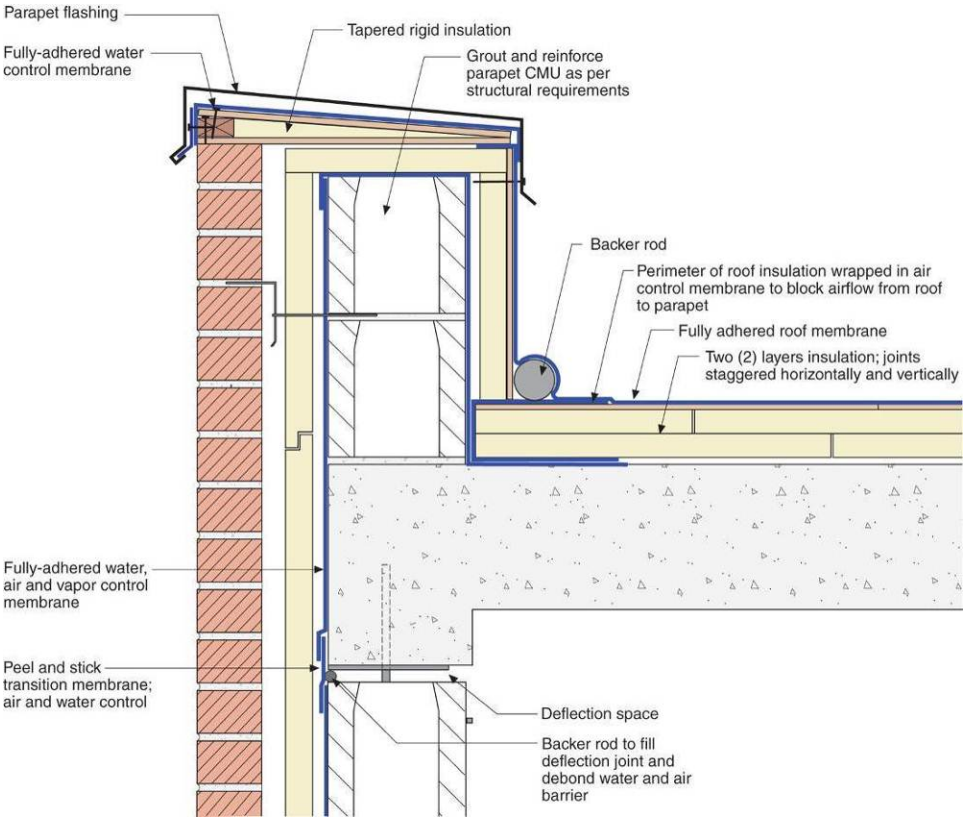

Figure 67: Masonry parapet example detail (from BSI-050: Parapets—Where Roofs Meet Walls)

The use of an overbuilt attic over the flat roof as semi-conditioned mechanical space is also discussed under the Mechanicals section.

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Windows

As an overview of windows in building enclosures, the following are the basic problems associated with their thermal performance:

- They are the single worst performing component of the building enclosure (shell). A typical double-glazed, non-metal frame window has U≈0.5 (R-2); adding a low E coating (typical current technology) raises it to U≈0.35 (R-2.9); see Figure 71. In comparison, wall opaque values are R-13, R-19, or higher, and roof have even higher R values. The physics behind this problem are discussed in BSI-006: Can Highly Glazed Building Façades Be Green? (see sidebar at the end, dealing with the disproportionate effect of glazing ratios on overall R values).
- At the same time, windows are the most expensive component, especially to upgrade (i.e., replace). For instance, upgrading from a U≈0.35 (R-2.9) to a U≈0.20 (R-5) triple glazed window might be a cost difference of $20/square foot, for the benefit of an added R-2. In comparison, a building insulation overclad (not counting finish materials) could be something in the range of an R-20 increase for $10-15/sf.

An overview of the current state of the windows at the Town Office Building is stated in the SDES Report:

> *The windows were replaced in the early 1980's with an atypical construct consisting of 2 layers of milky white translucent fiberglass sheet separated by an air gap and held together with divided-light aluminum frames. Most of the window units also have two lower open-able sections providing limited ventilation. A significant number of the open-able units no longer provide a view to the outside as in many cases are now supporting air conditioning units year round. Air sealing and insulation around and within the AC units is less than ideal.*

Examples of window conditions are shown in Figure 68 and Figure 69 below.

Figure 68: Windows exterior view

Figure 69: Windows interior view

The SDES report continues:

> *Although the pure fiberglass portions of the window units are thermally slightly superior to their glass counterparts, the aluminum frames sandwiched in between the fiberglass panels are a large source of heat loss. Note the high temperatures (orange, red and white) indicated in the thermal images.*

Although we cannot eliminate the possibility that elevated temperatures are due to solar gain of dark frames, the higher temperatures of the adjacent white frames (showing heat flow) indicates that the SDES explanation is correct.

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Figure 70: Window and translucent panel infrared (SDES Group Report)

There are some failed IGUs, but they do not appear to be endemic to the entire building. In addition, air leakage around and through the windows appears to be an issue, based on the Turner Report observations:

> *Another key issue with the existing building envelope is air infiltration, particularly around the window frames. … So even though new windows would have a small increase in terms of the R-value or thermal resistance, with proper installation, flashing, and sealing around the rough opening, they would make an appreciable difference in terms of cutting down on air infiltration. Furthermore, new windows would fix the condensation issue.*

A typical technology for upgrading double-glazed or single-glazed windows in acceptable condition is the application of exterior storm windows. They are relatively low cost ($8-10/sf); the current generation of low-E storm windows adds benefits over clear glass storm windows (see Figure 71). However, given the use of outward-swinging awning windows, exterior storms are not an available option.

Existing Window Types	U-factor	SHGC
Single-pane clear window (metal frame)	1.18	0.78
Single-pane clear window (non-metal frame)	0.86	0.68
Double-pane clear window (metal frame)	0.80	0.70
Double-pane clear window (non-metal frame)	0.49	0.60

New Window Options	U-factor	SHGC
Highly-insulating window	0.22	0.30
ENERGY STAR window for northern climates	0.30	0.30
Double-pane low-E window (non-metal frame)	0.35	0.35
Double-pane clear window (non-metal frame)	0.49	0.60

Storm Window Options	Primary Window Types	U-factor	SHGC
Low-E Storm Window	Single-pane clear window (metal frame)	0.70	0.61
	Single-pane clear window (non-metal frame)	0.40	0.52
	Double-pane clear window (metal frame)	0.63	0.57
	Double-pane clear window (non-metal frame)	0.34	0.48
Clear Glass Storm Window	Single-pane clear window (metal frame)	0.79	0.70
	Single-pane clear window (non-metal frame)	0.49	0.60
	Double-pane clear window (metal frame)	0.67	0.64
	Double-pane clear window (non-metal frame)	0.38	0.55

Figure 71: Generic thermal performance (U value/SHGC) of various existing window and storm technologies

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Further research was done on the translucent fiberglass panels; it appears that an equivalent current product is Kalwall; their website states the following performance range.

> *Translucent insulation is available in various densities with insulating U-value options from .53 to .05 [R-1.9 to R-20]. The Standard System is 2 ¾" thick and can be up to 4" thick. Solar Heat Gain coefficients from 1.0 to under .04 … U = .05 with Kalwall+ Nanogel® [R-20]*

Their lowest-end (U=0.53) product is no better than double glazed windows (clear glass); however, their high end U=0.05 product uses nanogel (a.k.a. aerogel-type product), which would be exceptionally expensive. They might have an "in-between" product that has better performance than double glazed windows at a reasonable price. It is unknown what the current performance of the translucent panel is, if the thermal bridging through the aluminum spacers is included, but it appears to be slightly better than the awning windows, based on the infrared thermography from the SDES Group report. This has the substantial benefit of reducing the surface area of the building with an exceptionally low (U≈0.5 or R-2) insulating value.

Overall, we have the following recommendations in terms of windows and fenestration:

- Replacement of the windows for purely energy reasons will be difficult to justify, given that the existing windows are likely ~R-2, and would be upgraded to ~R-2.9 units, at substantial cost.
- Replacing the windows is indicated to have airtightness benefits (as per the Turner Group report); if the air leakage is due to window-to-wall or window-to-frame interface issues, this could be addressed as an upgrade in place (i.e., removal of trim and application of low expansion foam or caulk). However, if the air leakage is through the window itself, the application of gaskets is possible, but might have a low chance of success.
- The removal of the air conditioner units during the heating season would be beneficial for airtightness. If central cooling is to be implemented in the 1950/1960s wing, this issue could be eliminated.
- We would recommend retaining the translucent panels, given their apparent better performance (assuming that these aesthetics are acceptable). If anything, replacing them with higher performance translucent panels might be considered; however, there is no information on their current performance level, including the thermal bridging through the aluminum. This makes the calculation of the benefits of replacement difficult.
- Exterior awnings, as recommended by the SDES report, are unlikely to have a worthwhile benefit, as discussed in the section "Overall Energy Performance," in terms of the cooling loads/costs.

Foundation

Basements account for up to one quarter of the typical energy consumption in a house (Canadian Building Digests, Crocker 1974). Therefore, insulating foundations is a critical measure for achieving high performance buildings—this becomes more and more true as the above-grade portion of the building is improved. Figure 72 and Figure 73 show that the above-grade and the shallow portions of the basement wall have the greatest heat loss, and thus the most benefit to being insulated.

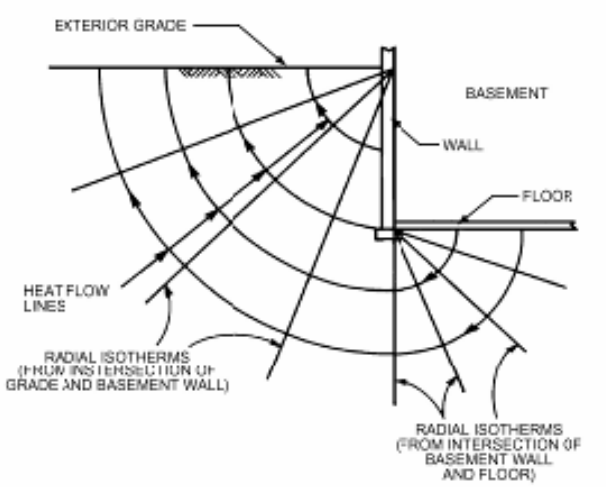

Figure 72: Heat flow from below-grade surfaces (ASHRAE 2005)—earth acts as insulation, less heat loss at deeper portions

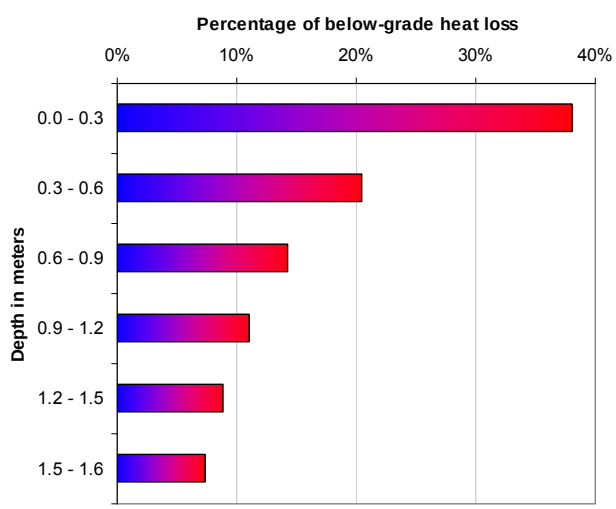

Figure 73: Fraction of basement heat loss vs. depth in meters; greatest heat loss from shallow portions (from Boileau and Latta 1968)

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It appears that substantial grading and drainage work was done on the exterior of the building already. An excellent detail for exterior water control (reducing leakage into basements) that adds insulation is shown below in Figure 74. That time would have been an ideal opportunity to do this retrofit; I am assuming that it is unlikely this would be feasible at this point.

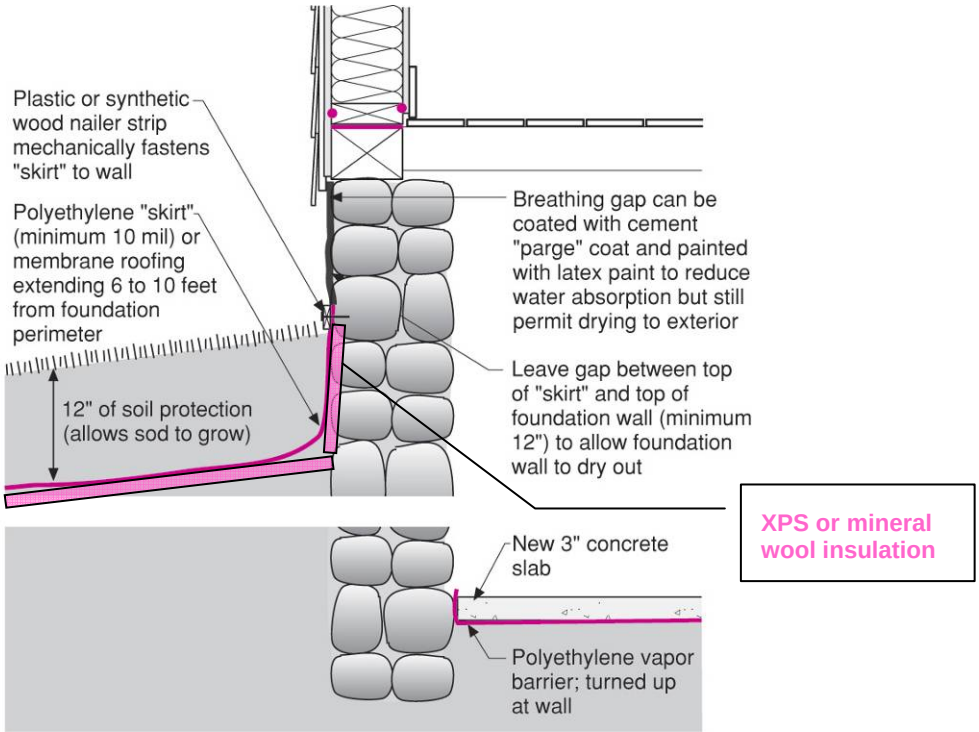

Figure 74: Ground "skirt" foundation water control (with recommended addition of insulation)

A more robust drainage detail can be constructed by sloping the edge of the “ground roof” detail into a subsoil French drain and drained to daylight or a storm sewer, as shown in Figure 75 and Figure 76.

Figure 75: Retrofit of “ground roof” detail (Petersen Engineering)

Figure 76: Backfilling of “ground roof” with peastone (Petersen Engineering)

This type of insulation would also be consistent with the exterior insulation overclad discussed earlier.

Alternately, interior insulation could be applied to the interior of the foundation wall. Acceptable details are shown below; a full discussion of foundation insulation is covered in Building Science Digest 103: Understanding Basements. Interior insulation assemblies need to prevent condensation of interior moisture on the cold foundation wall surfaces (in wintertime and summertime), and they should ideally be made of materials that are tolerant to incidental wetting (e.g., plastic foam products). Several assemblies that meet these requirements are shown in Figure 77 and Figure 78.

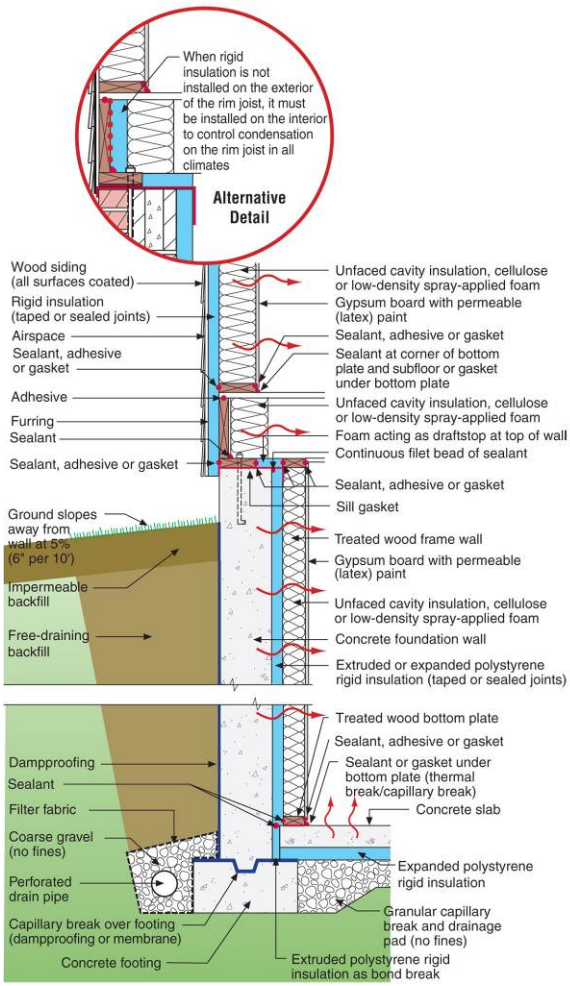

Figure 77: Interior foundation insulation retrofit with XPS and fiberglass batt insulation

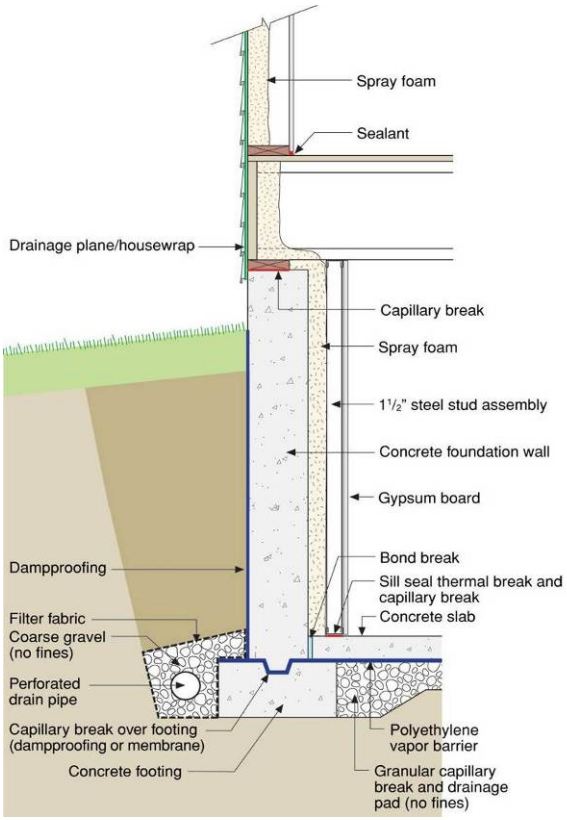

Figure 78: Interior foundation insulation retrofit with high density spray foam insulation

Another item that needs to be addressed is the mechanical spaces located underneath the front and rear concrete porches (Figure 79 and Figure 80). It would be difficult to insulate this space from the exterior, as it would change the height of the exterior porch/step, and require major excavation. Two options include:

- Insulate walls and ceiling of spaces with rigid insulation rated to be left exposed (Dow THERMAX), or high density (closed cell, 2 pound/cubic foot) spray foam with an intumescent coating for fire protection (superior solution for energy performance), OR
- Insulate wall between porch space and basement interior. Door will need to be replaced with a weatherstripped and insulated door (or insulation added to the door). Under-porch space will operate at colder conditions, which might result in problems for the stored oil and/or mechanical equipment at the front (lower cost but less effective solution).

Condensation issues were noticed on the walls and ceiling of the front mechanical space during the site visit (on 9/6/2011); this was likely due to high moisture levels inside the space (standing water). The interior insulation retrofit would prevent this condensation from occurring. However, bulk water issues should be solved (such as standing water on the floor) before undertaking any interior insulation measures.

Figure 79: Rear oil storage at basement level

Figure 80: Exterior porch/oil storage area

Mechanicals

The mechanical systems are described in the Turner Report as follows:

> *The existing boiler plant consists of two relatively new Buderus cast iron hydronic boilers. The boilers are fired by No. 2 oil fired burners. The oil tanks are located in a below grade enclosed space, below the main entrance at the rear or north side of the building. Both boilers are identical size with a capacity of approximately 100,000 BTU's each. The building is fitted with hot water piping and independent hot water system zone pumps. With having recently been replaced they are in very good condition, and thus it is recommended that they will be included as part of the new heating plant.*
>
> *Two new cast iron hydronic boilers with #2 oil fired burners. Equal sizing. Building zoned by independent HWS zone pumps. Fuel storage tank buried.*

The SDES Group Report adds:

> *The building is heated by forced hot water supplied by two oil-fired boilers installed in late 2007 feeding wall-mounted cast iron radiators along the exterior the building. The building is divided into 6 heating zones. The units are functioning properly and are in good working condition.*

We concur with the observations made in the Turner and SDES report, to retain these boilers; other measures, such as the addition of a boiler reset control and insulation of distribution piping, would definitely be beneficial. Note that the boiler "reset curve" (i.e., change of boiler loop temperature with outside temperature) will be different before and after the renovations (addition of insulation and airtightening). It appears that thermostatic radiator valves are already used on radiators (thus preventing the waste of overheating in certain spaces).

The Turner Report recommends the replacement of the existing distribution with radiant floor heating:

> *The rooms are heated by wall-mounted, cast-iron radiators. As part of the new heating system it is recommended that these be removed and replaced with a radiant floor heating system. The radiant floor heating system can be installed directly over the existing concrete slabs at the lower levels. It is recommended that rigid insulation be placed over the slab with the radiant heat tubing over that. Everything would then be encapsulated with a lightweight concrete topping. A similar procedure could be accomplished on the second level without the need for the insulation.*

This would be an expensive installation, and the measurements I have seen to date do not indicate any actual energy savings associated with these types of systems. They are definitely a premium/high comfort system, and allows the use of low-temperature water to reduce the efficiency of condensing boilers. However, it is likely that the lowest boiler temperature is based on condensation risks (i.e., non-condensing oil boilers used here). The installation of insulation over the buried slab would be beneficial for energy reasons, but is a lower priority than insulation of the basement walls (see Figure 72).

The water heating is provided by electric resistance heating (see Figure 82); however, given the program of the building (primarily office use), there would probably be minimal benefit to upgrades of this system. However, if domestic hot water use is greater than the presumed level, this issue might be worth further examination. Addition of a timer (to lower tank temperature during evenings and weekends, assuming no occupancy) would be a quick, low-cost energy upgrade, but will require attention to ensure that the timer does not "shift" during power outages.

Figure 81: Existing Buderus oil boilers

Figure 82: Electric resistance water heating

The 1930s wing is cooled by two 5-ton split system air conditioners, located in the vented attic (see Figure 83 and Figure 84). These are cooling-only systems; space heating is provided by boiler/radiator system. It is unknown how leaky the duct system is, but elimination of duct leakage is critical in an unconditioned space such as this attic. Flex duct is typically relatively airtight; however, the connections (and sheet metal systems) are notoriously leaky, and should be sealed with mastic (not duct tape, which has poor longevity in this application). In addition, there would be some benefit to increasing duct insulation levels: the current ductwork is R-4.2; code calls for R-8 duct insulation in unconditioned spaces such as this attic. The air handler itself often is a source of substantial air leakage: some limited sealing can be done (e.g., wiring penetrations, etc.); however, this is limited by the need to provide access to the units for maintenance.

Figure 83: Air handler and ductwork in attic

Figure 84: Air handler and ductwork in attic

In addition, there is an aerosol-based duct sealing method (Aeroseal: http://www.aeroseal.com/); they have an excellent product, but their distribution in the Northeast is currently limited (although they are attempting to increase their number of distributors).

The penetrations of the ducts through the ceiling plane must be sealed: daylight was visible at the penetration (see Figure 85). Further recommendations can be found in the section Sloped Roof (Vented Attic).

Figure 85: Duct penetration through ceiling

Figure 86: Daylight visible at duct penetration

The ventilation system in the 1950/1960s wing is a continuously running rooftop exhaust fan, as noted in the SDES report:

> *On the SAU side of the building a large rooftop blower runs 24/7 also removing warm air from the conditioned spaces regardless of need for fresh air and without any form of heat exchange. Note warm air leaving the vent dome on the SAU-side roof.*

Eliminating or limiting the airflow in this system would have major energy benefits: overventilation (as is now likely occurring) will largely negate many of the benefits of air tightening discussed previously in this report. Ideally, the ventilation system should be re-designed to meet ASHRAE 62.1 rates (or other code-mandated levels), and kept to a minimum flow if possible (demand controlled, timer switch, etc.).

Figure 87: Addition rooftop exhaust fan

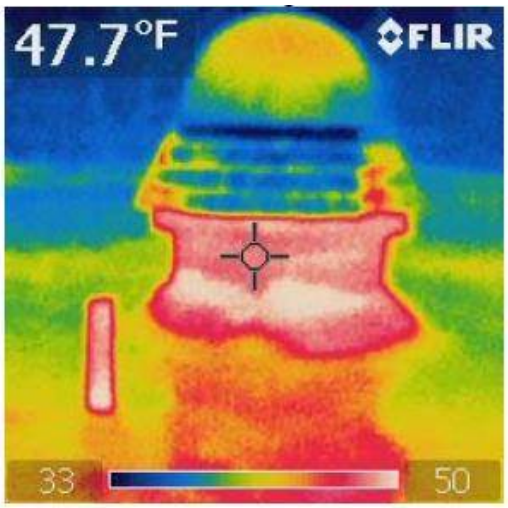

Figure 88: Exhaust fan infrared (SDES Report)

As a possibility, the existing ductwork system might be usable if combined with CAR (Constant Airflow Regulator) dampers, as shown in Figure 89. These devices allow the flow of a limited/fixed amount of air over a wide pressure range, thus limiting airflows to the code-mandated requirements in a given space. In addition, multistory building ventilation systems suffer from the superimposition of stack leakage (warm interior air rising out the top: see Building Science Digest 014: Air Flow Control in Buildings). This results in the overventilation of some spaces, and underventilation of others.

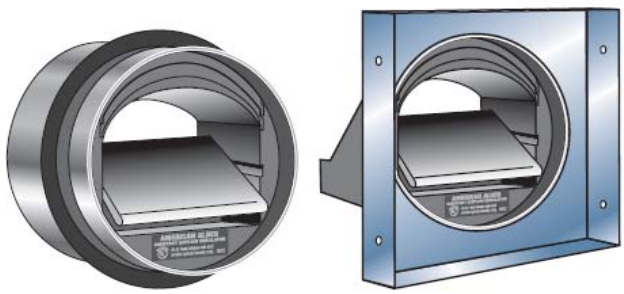

Figure 89: Aldes CAR Constant Airflow Regulator

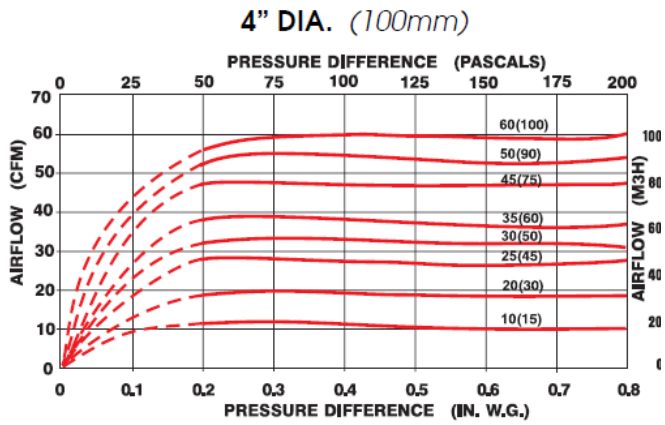

Figure 90: Aldes CAR pressure-flow response curve

If it is an option to completely revamp the ventilation system in this building, the use of one or several heat recovery ventilators (HRVs) would reduce the heating load associated with ventilation, which can be substantial in commercial buildings. This could be done with a large central system (requiring ductwork for distribution), or multiple smaller system (reduced ductwork requirements, but needs local penetrations to the exterior).

The SDES Report also noted exhaust fan louvers stuck in the open position; this is another item to be remedied.

The Turner Report recommended the use of an unvented sloped roof overbuild on the 1950/1960s wing, in order to provide a tempered space for mechanical equipment. However, there is significant space in the dropped ceiling above both the first and second floor spaces that is available for mechanical equipment.

If the goal is simply to add ventilation and mechanical cooling to this wing, it might be reasonable to use a VRF (variable refrigerant flow) system. These systems involve a larger rooftop unit (Figure 92) connected to multiple indoor units (Figure 91) via pairs of insulated copper refrigerant lines.

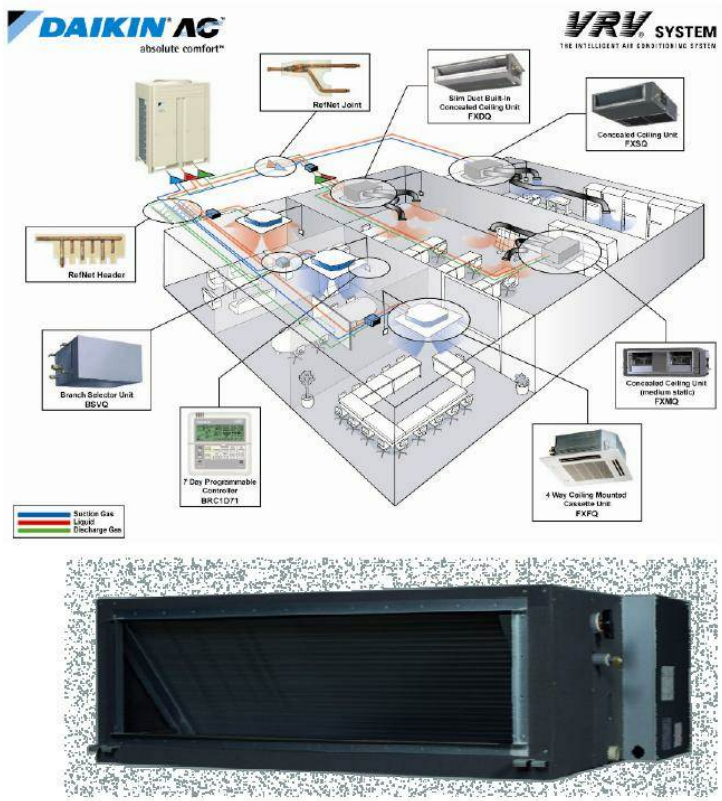

Figure 91: Daikin VRV conceptual diagram

Figure 92: Daikin VRV outdoor unit (~66" high)

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There is no need to add significant ductwork to distribute cooling, which makes them a good match in a retrofit application with limited space such as this. In addition, each indoor unit operates as its own zone, allowing zoned cooling throughout the building. Elimination of the window air conditioners will improve airtightness throughout the year.

Note that VRF systems have a higher cost per unit of cooling ("dollars per ton"), compared to conventional ducted systems. However, if the savings of eliminating the roof overbuild can be recouped with the installation of this type of a system, it might be a worthwhile choice.

Other incidental items from the SDES Report (such as the retrofit of T8 fluorescent light fixtures with occupancy sensors and/or dimming/daylight controls) are likely to be beneficial as well.

We would recommend that the upgraded mechanical system be selected after completion (or at least selection) of enclosure renovations; the space conditioning unit can be smaller (and therefore more economical) by taking advantage of upgrades to the building shell (insulation and airtightness), which reduces cooling loads.

4. Conclusions and Priorities

Based on the discussions above, we would put the renovation items into some of these high, medium, and low priorities, based on a general assessment of their benefit and an estimate of their cost. However, these priorities are likely to change, based on construction sequencing issues, bond issue procedures, etc.

High Priorities:

- Insulation and air sealing of the 1930s wing vented attic (flat ceiling plane): this is a relatively small and self-contained project, and has substantial benefits to overall airtightness.
- With this attic air sealing project, the ductwork system should be sealed, including penetrations through the ceiling; possibly replace R-4.2 flex ductwork with R-8 insulated ductwork.
- General air tightening improvements, such as door weatherstripping, gross leakage through open louvers, etc. (as per SDES and Turner reports).
- Window air leakage should be addressed, if a systemic installation detail can be developed (e.g., air leakage at the frame-to-opening intersection, etc.)
- The overventilating exhaust system in the 1950/1960s wing should be either substantially revamped or replaced. Limiting ventilation to rates specified in ASHRAE 62.1 would be a necessary first step. The flow rates can be limited with flow limiters (CARs), if the existing ductwork system provides sufficient distribution of ventilation air; the use of controls (timers, occupancy sensors, etc.) would also be beneficial for reducing ventilation rates to reasonable levels. Alternately, replacement of the existing ventilation with either a central or distributed heat recovery ventilators would have additional energy benefits.
- Exterior wall insulation retrofit: regardless of whether an interior or exterior insulation strategy is selected, the fact that a large portion of the building is insulated at R-4 results in substantial heat loss. The installation of wall insulation would be a major project, but with substantial associated benefits. If interior insulation is chosen, some water control measures discussed in the report should be undertaken, and perhaps testing of the brick for freeze-thaw resistance. Note that exterior insulation will require detailing at the roof-wall intersection and window openings, to account for the thicker wall.
- Addition of a boiler reset control should reduce fuel use and short-cycling of the boilers. Note that the boiler "reset curve" (i.e., change of the boiler loop temperature with outside temperature) will be different before and after the renovations (addition of insulation and airtightening).

Medium Priorities:

- Consider the use of a blower door test after major air tightening and ventilation renovations, to measure current air leakage, and identify remaining worst air leakage points (wintertime test for infrared use).
- Flat roof insulation and air barrier can be upgraded when roof replacement occurs (likely within 10 year range). The use of a sloped roof overbuild does not seem to have benefits in line with its cost. Various details such as roof-wall air barrier connections and improved drip edges should be addressed at this time.
- If cooling is required in the 1950/1960s wing, consider the installation of a variable refrigerant volume (VRF) system; this would not require the roof overbuild described in the Turner report.
- Windows might be replaced to address the failed IGU issues; this can be done on a unit-by-unit basis. Also, replacement of window air conditioner units will require their replacement with windows. Replacement windows should be at least low E coated, and preferably Energy Star (U=0.30 or less) windows.

- Foundation insulation would reduce energy consumption; however, the implementation is likely to be more difficult than exterior wall insulation. Interior insulation would require new interior finishes and services; exterior insulation would require excavation of the surrounding soil. However, if there are continuing bulk moisture issues at the basement level, exterior insulation would be an excellent measure to undertake to provide water control.

Low Priorities:

- The addition of renewable energy (as per the SDES Report) is a relatively low priority, until other measures undertaken, unless there are particular incentives available to municipalities.
- The replacement of the translucent panels with higher performance units might have energy benefits; however, there is no information on their current performance level, including the thermal bridging through the aluminum. This makes the calculation of the benefits of replacement difficult.

5. Additional Resources

Several documents are referenced over the course of this report; they can be located at the following locations:

- Building Science Digest 013: Rain Control in Buildings
  http://www.buildingscience.com/documents/digests/bsd-013-rain-control-in-buildings/
- Building Science Digest 014: Air Flow Control in Buildings
  http://www.buildingscience.com/documents/digests/bsd-014-air-flow-control-in-buildings
- Building Science Digest 103: Understanding Basements
  http://www.buildingscience.com/documents/digests/bsd-103-understanding-basements
- Building Science Digest 104: Understanding Air Barriers
  http://www.buildingscience.com/documents/digests/bsd-104-understanding-air-barriers
- Building Science Digest 114: Interior Insulation Retrofits of Load-Bearing Masonry Walls In Cold Climates
  http://www.buildingscience.com/documents/digests/bsd-114-interior-insulation-retrofits-of-load-bearing-masonry-walls-in-cold-climates
- Building Science Digest 139: Deep Energy Retrofit of a Sears Roebuck House—A Home for the Next 100 Years
  http://www.buildingscience.com/documents/digests/bsd-139-deep-energy-retrofit-of-a-sears-roebuck-house-a-home-for-the-next-100-years
- Building Science Digest 146: EIFS - Problems and Solutions
  http://www.buildingscience.com/documents/digests/bsd-146-eifs-problems-and-solutions/?searchterm=eifs

- Building Science Insight 001: The Perfect Wall
  http://www.buildingscience.com/documents/insights/bsi-001-the-perfect-wall
- Building Science Insight 006: Can Highly Glazed Building Façades Be Green?
  http://www.buildingscience.com/documents/insights/bsi-006-can-fully-glazed-curtainwalls-be-green/
- Building Science Insight 011: Capillarity—Small Sacrifices
  http://www.buildingscience.com/documents/insights/bsi-011-capillarity2014small-sacrifices/?topic=/doctypes/building-science-insights
- Building Science Insight 036: Complex Three Dimensional Airflow Networks
  http://www.buildingscience.com/documents/insights/bsi-036-complex-three-dimensional-air-flow-networks/
- Building Science Insight 047: Thick as a Brick
  http://www.buildingscience.com/documents/insights/bsi-047-thick-as-brick/
- Building Science Insight 050: Parapets—Where Roofs Meet Walls
  http://www.buildingscience.com/documents/insights/bsi-050-parapets-where-roofs-meet-walls
- Building Science Insight 048: Exterior Spray Foam
  http://www.buildingscience.com/documents/insights/bsi-048-exterior-spray-foam/

- Research Report 1012: Residential Exterior Wall Superinsulation Retrofit Details and Analysis
  http://www.buildingscience.com/documents/reports/rr-1012-residential-exterior-wall-superinsulation-retrofit/
- Guides and Manuals: Attic Air Sealing Guide and Details
  http://www.buildingscience.com/documents/guides-and-manuals/gm-attic-air-sealing-guide/view

- Interior Insulation Retrofit of Mass Masonry Wall Assemblies Workshop Westford, MA - July 30, 2011
  http://www.buildingscienceconsulting.com/services/building-america-expert-meetings.aspx
- Mass Masonry Insulation Retrofits: Fundamentals and Challenges John Straube
  http://www.buildingscienceconsulting.com/services/documents/file/2011-07-30%20%20BA%20Straube%20Masonry%20Retrofit_s.pdf
- NESEA 2008 "What Would John Straube Do?"
  http://www.buildingscienceconsulting.com/presentations/documents/Straube-WWJSD.pdf
- EEBA Las Vegas, NV - September 14-16, 2011
  Massachusetts Deep Energy Retrofit Program: Lessons Learned
  http://www.buildingscienceconsulting.com/presentations/documents/2011_EEBA_MA_DER%20Lessons_Learned_Ueno.pdf
- Mold Explosion: Why Now? *Fine Homebuilding*, December 2006/January 2007, pages 70-75.
  http://www.buildingscience.com/documents/published-articles/pa-mold-explosion-why-now/
- SWA Party Walls, Volume 5, Issue 2 March—April 2009, "Raising the Roof—Part 1"
  http://www.swinter.com/partywalls/PWMar-Apr09.pdf