March 13, 2019

Chris Matejek
Facilities Manager
230C Mountain Rd
Suffield, CT 06078

cmatejek@suffieldct.gov
(860) 668-3890 (o)

PS 2019.014 - Suffield Town Hall Moisture Investigation Report

Dear Mr. Matejek:

The following report covers Building Science Corporation's (BSC) evaluation of the moisture issues occurring at Suffield Town Hall, 83 Mountain Rd, Suffield, CT 06078, in preparation for a major renovation project at the building. The report is based on BSC's site investigation of March 7, 2019.

The report is broken up into sections based on the portion of the building enclosure/shell or phenomenon evaluated:

- Attic Bulk Water and Ventilation Issues
- Attic (Floor/Ceiling Assembly) Air Barrier Issues
- Building Pressure Measurements
- Above-Grade Walls
- Basement
- Summertime Condensation Events
- Mechanical Systems
- Rear One-Story Wing
- Elevator Machine Room

A summary of retrofit recommendations is one of the final sub-heading of each section. In addition, information on possible future work with BSC is included.

Please distribute this report as you see fit to the team members.

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. Executive Summary

Suffield Town Hall, at 83 Mountain Rd, Suffield, CT 06078 is a circa 1960's 3-story mass masonry (brick and CMU block) building used primarily as office space. Building Science Corporation was retained by the client to evaluate the building for potential moisture issues, in preparation for a major renovation project at the building.

Topics and retrofit recommendations are covered in outline form below; action items are called out with priority (**HIGH/MEDIUM/LOW**).

- Attic Bulk Water and Ventilation Issues
  - There are bulk water (rainwater) issues visible on the interior of the attic, at the gable end walls and roof sheathing. However, they do not appear to be active leakage locations. These water control issues should be evaluated over time, to determine whether they are still active, via inspections after severe rain events. If they are active leaks, further investigation is required to determine appropriate retrofit detailing. **PRIORITY: MEDIUM**
  - The cupola leaks wind-blown rain through the louver openings, which is caught by a tarp on the attic floor. Water will continue to get blown in through the cupola louver openings. We recommend continuing to collect blown-in rain, via a catch pan on the floor of the attic, or suspended from the steel structure. **PRIORITY: MEDIUM**
  - There is no provision for "low" attic ventilation, contrary to current practice and code recommendations. However, it is difficult to provide an outside air pathway into the bottom of the attic given existing geometries, so a retrofit is not warranted. **PRIORITY: LOW**
- Attic (Floor/Ceiling Assembly) Air Barrier Issues
  - The fundamental problem at the attic floor/ceiling assembly is catastrophic air leakage through the ceiling. The ceiling assembly consists of lay-in suspended ceiling tile, and foil-faced fiberglass batt insulation, neither of which stop airflow. Interior air is barely contained inside the building's shell/enclosure at the roof; there is no effective "air barrier." The resulting problems include negative effects on energy use (heating and cooling), comfort and temperature control, humidity control (both winter and summer), ice dams (melting snow), and indoor air quality (outdoor pollutants). In addition, there is no effective fire separation between the second floor and the attic, if this is a critical requirement.
  - The moisture problems occurring at the server room are a manifestation of this lack of an air barrier between the attic and the conditioned space. In the summer, the attic (and ceiling space) will be filled with warm, humid outdoor air, which will condense on cool surfaces in the server room.
  - Recommendations are provided for retrofitting an effective air barrier at the ceiling line. Options are provided for gypsum board on the underside of the ceiling joists, or turning the plywood attic floor into the air barrier layer. **PRIORITY: HIGH**
- Building Pressure Measurements
  - Indoor-outdoor pressure measurements were taken to understand building operating conditions. Almost all pressure measurements were "negative" with respect to exterior (i.e., air flowing from outdoors to indoors), which is unexpected behavior for normal building operation. The pressure measurements are all consistent with catastrophic air leakage through the attic ceiling. **PRIORITY: HIGH** (see previous Attic Floor/Ceiling discussion)
- Above-Grade Walls
  - One issue reported by the team was ceiling tile staining throughout the building; based on site observations, they appear to be caused by heating/chilled water piping issues (leakage or condensation). This does not preclude the possibility of through-wall water leaks, but evidence for wall leakage is not strong. **PRIORITY: LOW**
  - The exposed brick above the suspended ceiling has cooler surfaces (has greater heat loss) than the wall below. These areas could be addressed by interior insulation (e.g., spray foam or similar). **PRIORITY: LOW**
  - The team pointed out multiple areas with damaged interior finishes consistent with water leakage, such as the second floor stairwell and the First Selectman's Office. Moisture measurements were consistent with previous water leakage that has not recurred; conditions are currently dry. **PRIORITY: LOW**

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- Basement
  - Issues reported in the basement spaces included musty odors and reported indoor air quality/allergy issues.
  - Unfinished basement areas are bare painted concrete; few issues were noted, besides energy/heat loss at the exposed above-grade portions.
  - The finished basement areas showed inward cold airflow at openings at the interior wall. This airflow is consistent with the negative pressure of the building pulling in cold outdoor air from the basement wall cavity, and has the potential to bring in moisture, musty odors, and contaminants.
  - Finished-area basement interior insulation retrofits (rigid foam or spray foam) can be considered if indoor air quality complaints in these spaces become a priority, and/or a gut renovation is planned in the basement spaces. Insulation retrofits in the unfinished storage areas might be considered as an energy improvement retrofit. **PRIORITY: MEDIUM**
- Summertime Condensation Events
  - The team reported that in the summer of 2018, condensation occurred at the front lobby/foyer floor and at portions of the stairwell from the ground floor to the first floor.
  - No thermal anomalies were seen consistent with these condensation problems. The likely explanation is the cool thermal mass of the building interior results in condensation when hot humid summertime outdoor air is introduced.
  - This problem is made worse by the leakiness of the building. The recommended retrofit measure is to improve building airtightness (roof/ceiling air barrier). If the problems persist after this retrofit, the addition of dehumidifiers is recommended. **PRIORITY: LOW**
- Mechanical Systems
  - There is an exhaust fan installed in the attic, is connected to points throughout the main building. Most of these ventilated rooms are out of service; therefore, the existing exhaust system is ejecting ~880 CFM of air in order to ventilate two ground floor bathrooms (~100 CFM required), unless previous work turned down the fan speed. Of course, massive overventilation is a waste of energy, and hurts humidity control and interior temperature control.
  - Assuming the ground floor bathrooms are being renovated, BSC would recommend either (a) installing a new exhaust system sized for that smaller flow, out through a sidewall, or (b) completely revamping the old existing exhaust system, including capping off all unused duct openings, sealing the system airtight, installing new fan set to the correct flow for 2 bathrooms. **PRIORITY: HIGH**
- Rear One-Story Wing
  - The paint is peeling and "blowing off" of the wood clapboard; possible causes and recommended solutions are provided. **PRIORITY: MEDIUM**
  - The most notable issue was paint bubbling/peeling at an interior wall of the meeting room. The moisture issues observed could not be investigated further without attic access. Suspected causes of the moisture problems include bulk water (rain) penetration, wintertime roof condensation or frosting, summer duct condensation, and/or summertime HVAC condensate leakage. Visual inspection of the roof above the ceiling is recommended. **PRIORITY: HIGH**
  - The mechanical plans show the meeting room HVAC system with 600 CFM intakes and exhausts for outdoor air ventilation. If this ventilation system is active as shown (operating constantly), the meeting room is massively overventilated relative to its typical loads. This will result in excess energy use and poor winter and summer humidity control. The ventilation system for the meeting room should be evaluated more closely, and options such as CFIS control/motorized damper and CO_2 control should be considered. **PRIORITY: HIGH**
  - Thermal stratification, or collection of warm air near the top of the room, and cool air at the bottom, was noted during infrared observations. This stratification contributes to discomfort and higher energy use. This might be addressed by changing the type of ceiling diffuser at the meeting room and offices. **PRIORITY: MEDIUM**

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- Elevator Machine Room
    - A consistent complaint at the elevator machine room is cold temperatures in wintertime; a small electric space heater is located in this room, despite the heat generated by elevator machinery.
    - There is cold air leakage occurring through the ceiling registers, with the associated fan not in operation. At a minimum, the fan system should be inspected, to ensure that motorized dampers are installed, and operating properly with fan operating (opening/closing and sealing tightly). As an alternate system, the elevator machine room could be conditioned with a mini-split heat pump (MSHP) head, which would eliminate this cold air leakage problem. The ductwork would ideally be sealed off in an airtight manner and abandoned in place. **PRIORITY: MEDIUM**

2. Building and Project Overview

Suffield Town Hall, at 83 Mountain Rd, Suffield, CT 06078 is a circa 1960's 3-story mass masonry (brick and CMU block) building used primarily as office space. Building Science Corporation was retained by the client to evaluate the building for potential moisture issues, in preparation for a major renovation project at the building. The report is based on BSC's site investigation of March 7, 2019.

Figure 1: Overview of building from front and east side

Figure 2: Overview of building from rear and east side

Figure 3: Interior lobby/stairwell area, first floor

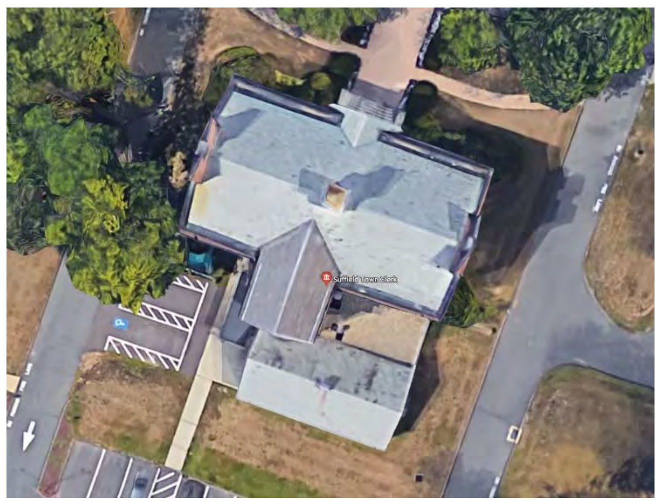

Figure 4: Overhead image, showing orientation

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3. Attic Overview, Bulk Water, and Ventilation Issues

Overview

The building's attic is a vented design, with insulation at the floor/ceiling line below. Overview images are shown in Figure 5 and Figure 6, which show the structural steel reinforcing frame, 2x10 rafters, and roof board sheathing. The floor assembly below is composed of plywood flooring, 2x10 ceiling joists, and foil-faced fiberglass batt insulation in the joist cavities. The attic is used primarily as dry storage of paper records in boxes.

Figure 5: Attic overview, facing west

Figure 6: Attic overview, facing east

This detailing is all consistent with the original 1961 building section (Figure 7).

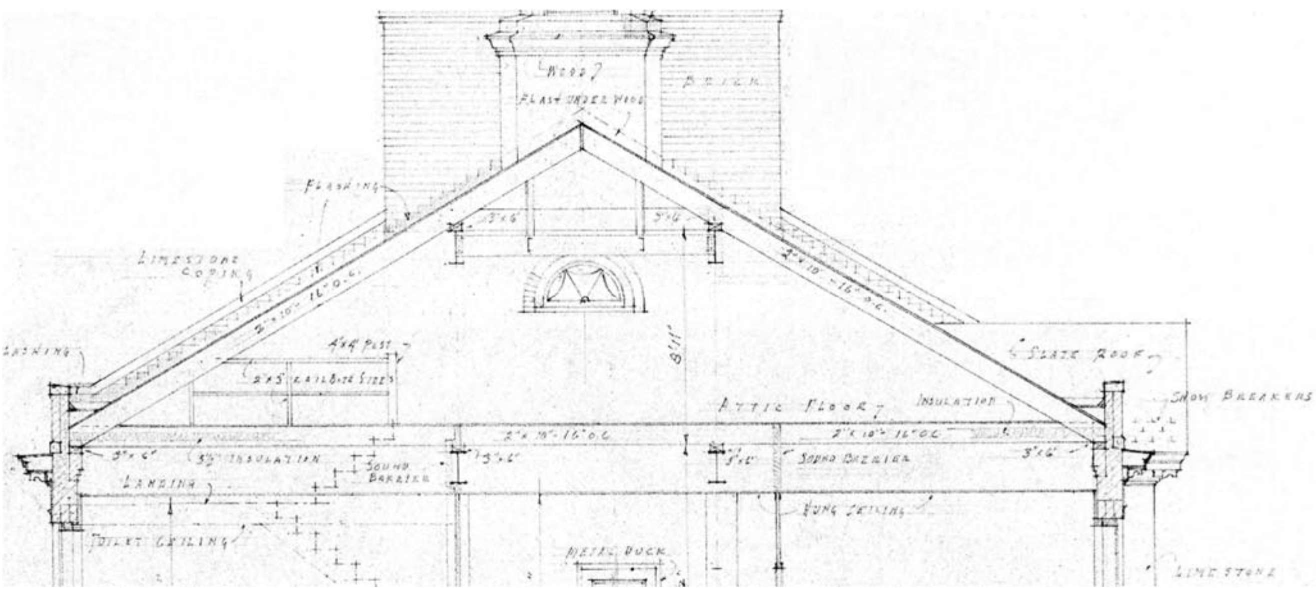

Figure 7: Attic section from 1961 plan set; cupola and brick chimneys beyond

Attic Gable End Water Control

The attic gable end walls are CMU/brick solid mass masonry composite wall (i.e., no water resistive barrier, drainage plane, or system of flashings/weeps). The gable end is detailed with false chimneys on the east side (Figure 8), and one false/one real chimney on the west side. The chimneys appear to be capped with sheet metal covers (Figure 9).

Figure 8: Gable end of attic showing false chimney

Figure 9: Chimney cap and flashing details

Conditions at the west end of the attic are shown in Figure 10 and Figure 11; the interior of the composite CMU block and brick wall is visible.

Figure 10: Interior efflorescence on CMU block wall

Figure 11: Interior efflorescence on CMU block wall

There is substantial efflorescence (white mineral) staining on the interior surface of the CMU wall. This efflorescence means that minerals are being transported by liquid water (rainfall) "wicking" through the wall, and evaporating on the interior. In other words, this is an indication of previous water penetration. However, no signs of active water penetration were obvious.

Further information on efflorescence is covered below.

- Canadian Building Digest 2. Efflorescence
  http://web.mit.edu/parmstr/Public/NRCan/CanBldgDigests/cbd002_e.html

Another water control issue was signs of previous water leakage at the roof sheathing at the base of the chimney; images from the east end of the attic are shown in Figure 12 and Figure 13. There is no clear sign whether these water issues are still active, or solved with previous retrofits.

An unusual geometry occurs at the walls of the false chimney: a steel beam holds the inner wall of the false chimney as shown in Figure 14 and Figure 15 (reference exterior shots, Figure 8 and Figure 9). There is a copper/bitumen flexible

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flashing spanning across the false chimney opening; this flashing is failing, with holes. The flashing is entirely removed at one false chimney on the east end of the building (Figure 16).

Figure 12: Water-stained roof sheathing, SE corner

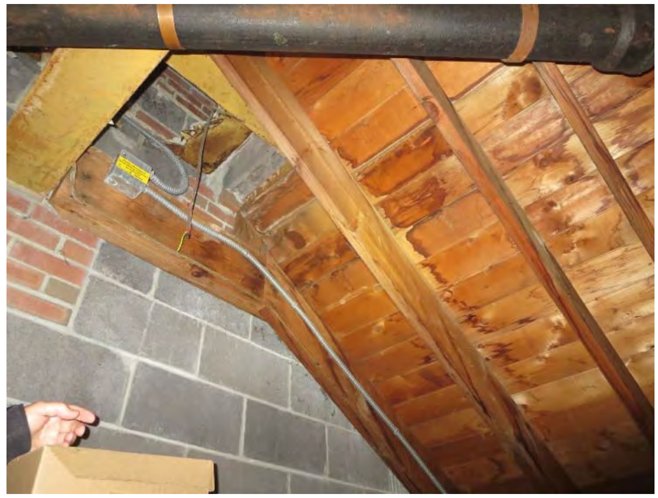

Figure 13: Water-stained roof sheathing, NE corner

Figure 14: Failed flexible flashing at chimney

Figure 15: Failed flexible flashing at chimney

Figure 16: Failed flashing, looking up false chimney

Figure 17: Sheathing staining and daylight

This detailing is consistent with the 1961 plans (Figure 18), which show the flashing spanning over the base of the chimney opening at the steel beam. In addition, the original detailing calls out a limestone or concrete cap at the chimneys; the current metal caps are likely retrofits to address previous water leakage problems. There is no clear indication whether water leakage at the false chimneys is an ongoing issue.

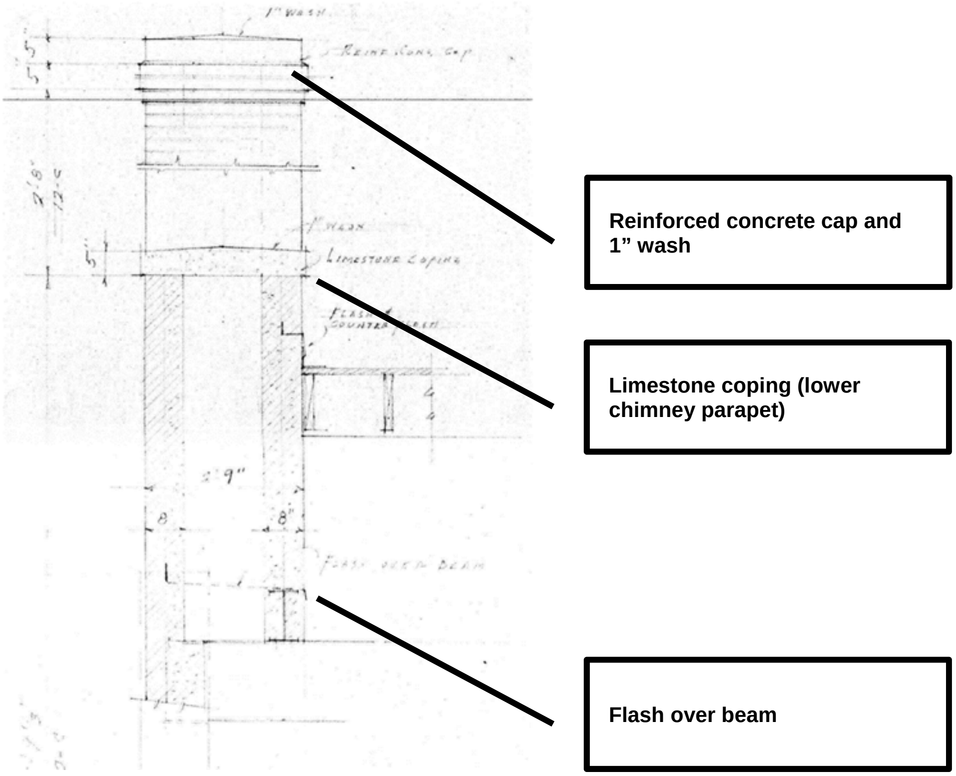

Figure 18: 1961 Plans chimney section detail

Looking upward at the east end of the building, daylight is visible at the flashing detail between the roof and the brickwork (Figure 17), at an area with water staining on the roof sheathing. This might indicate a current or inactive water leak. However, visible daylight does not automatically mean water leakage occurs: a properly shingle lapped flashing/ counterflashing might still have these gaps. However, it does make the detail more vulnerable to wind-blown water penetration.

One advantage of the current unconditioned/vented attic design is that any roof leakage dries readily downward into the attic, minimizing risks of long-term damage to the wood sheathing.

These water control issues should be evaluated over time, to determine whether they are still active, via inspections after severe rain events. If they are active leaks, further investigation is required to determine appropriate retrofit detailing.

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Cupola Water Control

The roof has a decorative vented cupola; it functions as upper attic ventilation, via the open louvers. It also provides the exit point for the exhaust fan ductwork (Figure 20). However, the cupola also appears to be an ongoing water leakage issue: a tarp is spread on the attic floor (Figure 19), likely to catch rainfall blown through the open louvers.

Figure 19: Overview of floor below cupola

Figure 20: Looking up cupola; exhaust fan & ductwork

The cupola is completely exposed as the highest point of the building, per Figure 21 and Figure 22.

Figure 21: Cupola overview from rear (south)

Figure 22: Cupola overview from front (north)

Building exterior areas vulnerable to extreme rainfall and wetting are discussed in Building Science Insight 095: How Buildings Age, and shown in Figure 23:

> *Let’s go back to the water thing. How do buildings get wet? Forget about the condensation thing and air leakage and diffusion. Minor compared to rainwater and groundwater. It is all about “how the building touches the sky” and “how the building touches the ground”. Check out Figure 23 (left). Rainwater does not wet a building uniformly. Neither does groundwater, but groundwater is limited to…wait for it…the ground.*
>
> *The top of the building gets the wettest. The corners at the top next. And the very bottom of the building where rainwater splashes up (“splash back”) and where the building wicks water up from the ground.*
>
> *Then all you have to add are windows (Figure 23 right). The rainwater is not absorbed by glass, runs down and is concentrated at sills – particularly at the corners (“mustaching”). The window-to-wall interface gets more complicated of course because it is typically a hole-in-the-wall rainwater injection system.*

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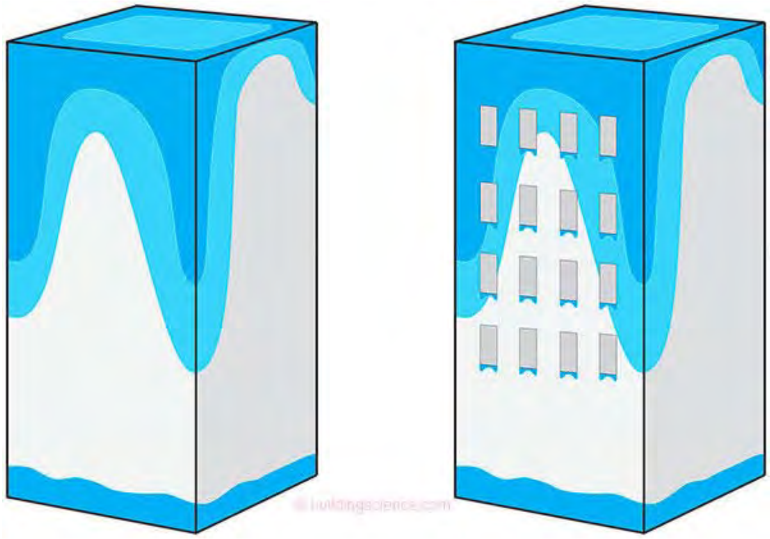

Figure 23: Wetting due to rain and ground contact (left); adding window effects (right)

The cupola is the portion of the building most exposed to wind-blown rain. Water will continue to get blown in through the cupola louver openings. We recommend continuing to collect blown-in rain, via a catch pan on the floor of the attic, or suspended from the steel structure. If a conditioned attic (spray foam at roofline) approach is taken, alternate details will be required at the cupola.

Attic Ventilation

Attic ventilation normally functions by providing a pathway for outdoor air, from low to high. The cupola provides the "high" ventilation. However, examination of the lower edge of the roof (eave) showed no sign of openings for "low" ventilation (Figure 24 and Figure 25).

Figure 24: Close-up of rafter tail and eave condition

Figure 25: Roof sheathing slope-to-horizontal

This is consistent with the exterior detailing (Figure 26) and the 1961 plans (Figure 27): a masonry "parapet" wall forms the base of the sloping roof, to prevent severe snow slide issues. The roof is drained from the horizontal "gutter" inboard of the brick parapet, and from there into exterior downspouts. Therefore, it is difficult to provide an outside air pathway into the bottom of the attic.

Attic ventilation typical practice is to evenly split the high and low openings (50%/50%), however, BSC's recommended approach is to split ventilation 60% at eaves (low) and 40% at ridge (high), per "A Crash Course in Roof Venting."

Overall, retrofitting "low" attic ventilation is a low priority compared to other retrofit action items.

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Figure 26: Exterior view of roof showing parapet

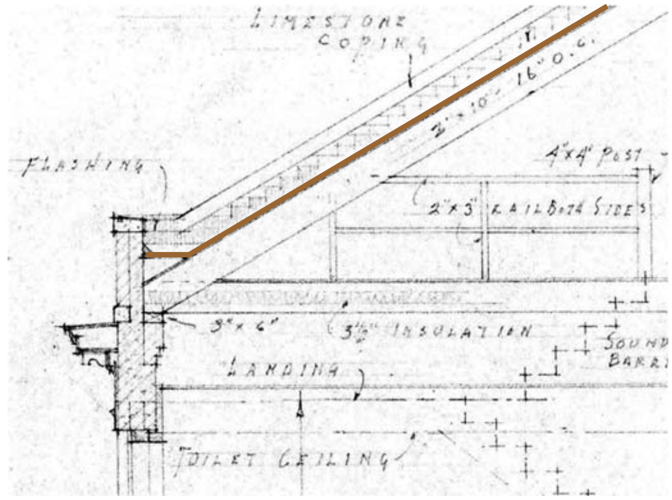

Figure 27: 1961 section; roof sheathing line highlighted

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4. Attic (Floor/Ceiling Assembly) Air Barrier Issues

Floor/Ceiling Assembly (From Above)

The floor of the attic is mostly a plywood deck, with exposed insulation at the perimeter eave conditions (Figure 28 and Figure 29). However, infrared camera observations (covered below) revealed warm thermal anomalies "streaming" up the rafter bays, which typically indicates outward leakage of warm interior air.

Figure 28: Attic floor sheathing, insulation, and eave

Figure 29: Attic floor sheathing, insulation, and eave

Closer examination of these areas revealed sections where the foil-faced fiberglass insulation had fallen or was missing. For instance, Figure 30 shows an area with the batt removed, and a polyethylene air/vapor barrier "patched in" with a large hole. Looking further downward reveals the upper side of the lay-in suspended ceiling tile grid (Figure 31). The 1961 plans (Figure 7) show this geometry: the batt insulation is in line with 2x10 ceiling joists, and the suspended ceiling tile lines up with the "hung ceiling" callout.

Figure 30: Failed insulation and air/vapor barrier

Figure 31: Suspended ceiling tile visible below

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Conditions looking laterally at the cavity between the batt insulation and the ceiling tile are shown in Figure 32, Figure 33, Figure 34, and Figure 35. As shown in the latter two images, many of these batts are failing and have fallen from the ceiling joists. The fiberglass batts are “inset stapled” (stapled to the sides of the joists), with no attempt at air sealing the seams.

Figure 32: Conditions above suspended ceiling

Figure 33: Conditions above suspended ceiling

Figure 34: Failed insulation batts at ceiling

Figure 35: Failed insulation batts at ceiling

Attic Stairwell

The stairwell to the attic is a variation from the main geometry of the attic; it is shown in the 1961 plans in Figure 7. The stairs from the second floor to the attic reach a landing platform lower than the main attic deck, resulting in vertical "kneewall" conditions between the lower platform and the main attic floor deck (Figure 36 and Figure 37).

Figure 36: Stairwell/landing area; exhaust ductwork

Figure 37: Kneewall at stairwell, ceiling height change

This resulting geometry also results in greater heat loss due to air leakage, as demonstrated with an infrared camera. The infrared camera (FLIR ONE Pro, -4°F to 752°F; ±3 °C (5.4 °F) or ±5%, typical percent of the difference between ambient and scene temperature accuracy) shows surface temperatures using a color scale: blue/purple are cooler temperatures, and yellow/orange warmer temperatures. Heat loss from the interior to the attic would appear as warm surfaces.

For instance, the stairs from the second floor to the attic are a significant source of heat loss (Figure 38), both at the door, walls of the stairs, and kneewalls. It is unlikely that the second floor walls between the staircase and the adjacent rooms are insulated.

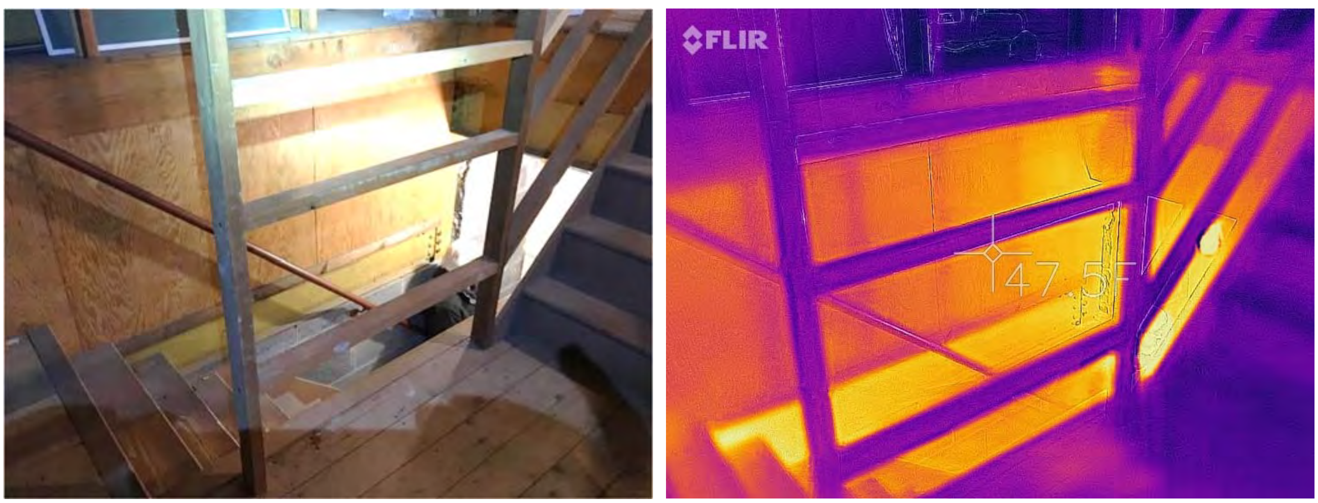

Figure 38: Visual and infrared image of heat loss from stairwell down to second floor

The exhaust ductwork has warm surfaces, consistent with exhausting interior conditioned air (Figure 39). In addition, air leakage is occurring at the top plate of the kneewall. This is shown more closely in Figure 40; the air leak occurs between the kneewall top plate and the ceiling joist.

Figure 39: Visual and infrared image of exhaust ductwork and kneewall air leakage/heat loss

Figure 40: Visual and infrared image of exhaust ductwork and kneewall air leakage/heat loss

Floor/Ceiling Assembly (From Below)

The floor/ceiling assembly between the suspended ceiling tile and ceiling joists/insulation was examined from the second floor rooms below; images are shown in Figure 41, Figure 42, Figure 43, Figure 44, and Figure 45.

Again, the foil-faced batts are inset stapled to the side of the ceiling joists, and no attempts were made to detail it in an airtight manner (taping of seams, etc.). This is particularly evident at the eave condition (Figure 43).

There were multiple cases of the insulation failing and falling down from its installed position, leaving openings in the ceiling plane.

An infrared image of these conditions (Figure 45) shows interior heat “reflected” on the shiny surface of the foil-faced batt insulation. It also demonstrates the greater heat loss (likely air leakage) through the metal gridwork of the suspended ceiling, and cool conditions at the exposed brick walls (discussed later).

Based on these observations, this exposed batt condition (i.e., no “hard ceiling”) occurs throughout the second floor, except at the second floor lobby, and rear addition.

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Figure 41: Conditions over suspended ceiling, IT room

Figure 42: Conditions over suspended ceiling, IT room

Figure 43: Typical stapled batt installation

Figure 44: Failed insulation at conference room

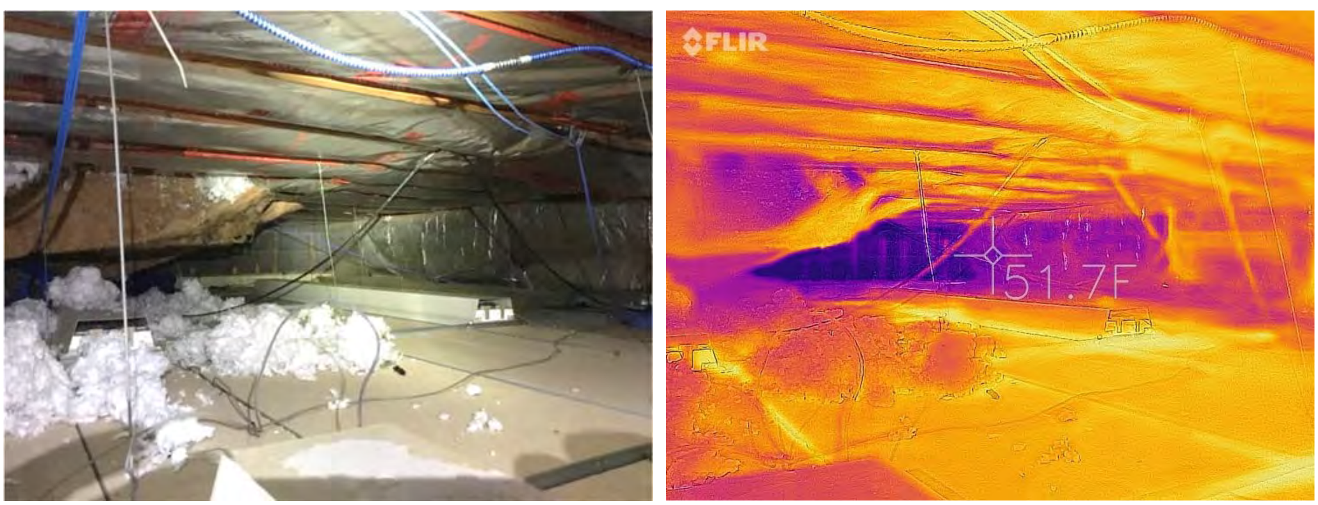

Figure 45: Visual and infrared image of failed insulation at IT room; batt foil facer shows “reflection” of temperature

Server Room Moisture Issues

The server room has reported various moisture and mold issues; although this room is not attic conditions, the issues here are directly related to attic floor/ceiling air barrier problems.

An overview of the server room is shown in Figure 46; it is a “landlocked” (no exterior wall) room on the second floor. An example of moisture issues seen here is apparent mold staining near the ceiling at the east wall (yellow circle in Figure 46 and Figure 47).

Figure 46: Overview of server room, facing east

Figure 47: Apparent mold staining on wall at ceiling

The ceiling space was examined (Figure 48), revealing similar conditions to the remainder of the second floor (Figure 49), with exposed foil-faced batts. Netting was installed to hold the batts in place. There is extensive cabling and electrical conduit throughout this ceiling space.

Figure 48: Suspended ceiling at server room

Figure 49: Server room suspended ceiling conditions

The metal T-bar suspended ceiling grilles have notable corrosion on their surface (Figure 50). There is apparent spotting/mold staining on the upper surface of the light fixture in the ceiling grid (Figure 51).

Another moisture issue is ceiling tile staining at the cooling unit’s supply duct plenum (Figure 52); there is also some rust spotting on the connection band (Figure 53), all consistent with previous condensation and dripping.

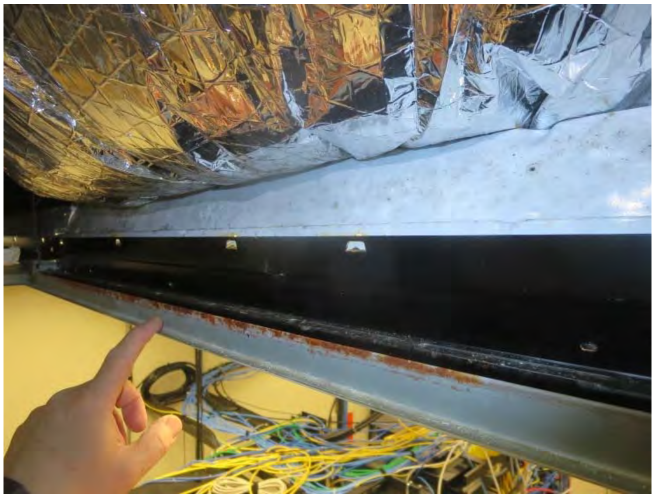

Figure 50: Rust on T-bar suspended ceiling

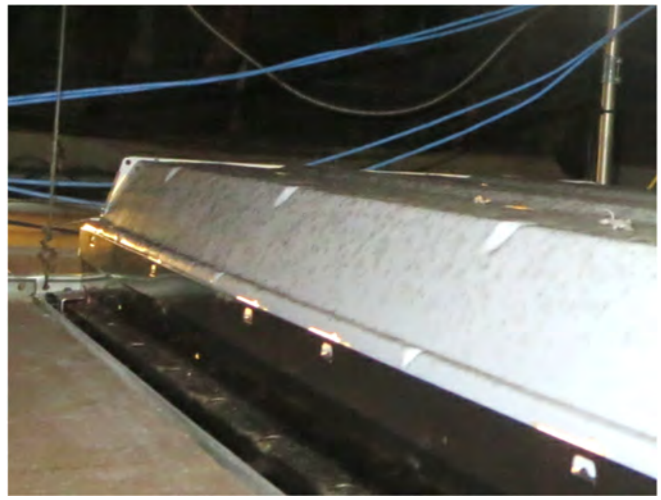

Figure 51: Apparent mold spotting on light fixture

Figure 52: Stained ceiling tile at supply plenum

Figure 53: Air handler supply plenum, corrosion

Cooling is provided in the server room with two ducted HVAC systems: a larger 5-ton unit, and a smaller 1.5 ton unit (Figure 54 and Figure 55).

Figure 54: Large (foreground) and small (rear) AHUs

Figure 55: Ductwork from small AHU

The cooling units are a Trane 5-ton air handler, connected to an American Standard 5 ton outdoor unit, and a smaller Carrier 1-½ ton air handler. The team reported that cooling does not function well in extremely cold weather. Based on Trane literature (e.g., https://www.trane.com/download/equipmentpdfs/ssprc002en_r2.pdf), there are limits on outdoor temperatures for running cooling equipment.

> *Low Ambient Operation: Standard units shall start and operate to approximately 50°F when matched with air handlers and coils. Optional head pressure control accessory permits operation to 0°F*

Problem Assessment

The fundamental problem at the attic floor/ceiling assembly is catastrophic air leakage through the ceiling. Interior air is barely contained inside the building's shell/enclosure at the roof; there is no effective "air barrier." The resulting problems include negative effects on energy use (heating and cooling), comfort and temperature control, humidity control (both winter and summer), ice dams (melting snow), and indoor air quality (outdoor pollutants). In addition, there is no effective fire separation between the second floor and the attic, if this is a critical requirement. The interior-to-attic separation is provided by dropped ceiling tile and paper/foil-faced fiberglass batts (flammable materials).

The moisture problems occurring at the server room are a manifestation of this lack of an air barrier between the attic and the conditioned space. In the summer, the attic (and ceiling space) will be filled with warm, humid outdoor air. Based on pressure measurements, this attic air will tend to be "sucked in" at the server room when the door is closed. When this warm, humid air hits cold surfaces, it can condense, drip, and cause mold growth. This inward airflow occurs at the opening around the electrical conduit (Figure 47, with resulting mold growth), and ceiling T-bar grilles (Figure 50). The lack of an air barrier means the space above the suspended ceiling operates near outdoor conditions, resulting in condensation on cold exposed surfaces, such as light fixtures (Figure 51) and ductwork (Figure 52 and Figure 53).

In case the team believes that the suspended ceiling can function as an air barrier: ceiling tile grids have been measured to be ~10-20 times leakier than typical airtightness targets: therefore, the tile grid does not function as an effective air barrier.

- ***Building Envelope Air Leakage Failure in Small Commercial Buildings Related to the Use of Suspended Tile Ceilings***
  http://www.fsec.ucf.edu/en/publications/html/FSEC-PF-398-00/

- ***Best Practice for the Location of the Air and Thermal Boundaries in Small Commercial Buildings***
  http://www.fsec.ucf.edu/en/publications/html/FSEC-CR-1667-00/index.htm

  Suspended t-bar ceilings are common in commercial buildings. Research has found that these ceilings are very leaky, and several problems arise from this. If the space above the ceiling is vented to outdoors, the entire building becomes leaky. Furthermore, if the insulation is located at the ceiling rather than the roof, then the ceiling space will be hot (summer), and if the ceiling space is also vented to outdoors, then the ceiling space will be hot and humid. The thermal and humidity conditions of the ceiling space have important implications for space conditioning loads, building ventilation rates, and indoor relative humidity. Conductive gains through ductwork add to loads, and various forms of uncontrolled air flow readily move air between the ceiling space and the occupied space. These factors should be considered during design and construction of commercial buildings. Best practice: locate the air and thermal boundaries of the building at the roof deck. This approach has many benefits.

  Based on direct testing of ceiling airtightness in two buildings, it has been found that ***these ceilings have a tightness of approximately 5.0 cfm (2.4 L/s) of air flow per square foot at 0.20 in WC (50 pascals) pressure differential, making them about 10 times more leaky than gypsum board ceilings*** *(Cummings et. al., 1996).*

Lastly, if the server room will be gut renovated, it is worth considering replacing the existing HVAC systems with a specialized computer room air conditioner (CRAC) designed to operate at low ambient temperatures. In addition, the new system should be sized to match the actual server heat load. The current equipment size (5 tons) is equivalent to 18 kW (18,000 W, or 180 100-W light bulbs) continuous electrical draw, which sounds high for a server room of this size. Of course, the cooling load of the server room will decrease once an effective air barrier is in place at the ceiling. This will eliminate the inadvertent conditioning of attic air, as is currently occurring.

Retrofit Recommendations: Vented Attic

Several options are provided for retrofitting an effective air barrier at the attic floor/ceiling plane; the following two options are "vented attics" (unconditioned attic space):

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The most robust solution is to provide a "hard ceiling" (gypsum board) at the underside of the ceiling joists, as shown in Figure 56, which requires the following steps:

- Remove ceiling tile and grid for construction work
- Repair/replace fiberglass batts as required (from below)
- Install gypsum board as air barrier; fire tape and seal all penetrations/joints. Select gypsum board as required by fire rating needs. Details must be developed at perimeter, structural beam penetrations, interior walls, etc.
- OPTIONAL: install closed cell spray foam at exposed brick/CMU wall above ceiling

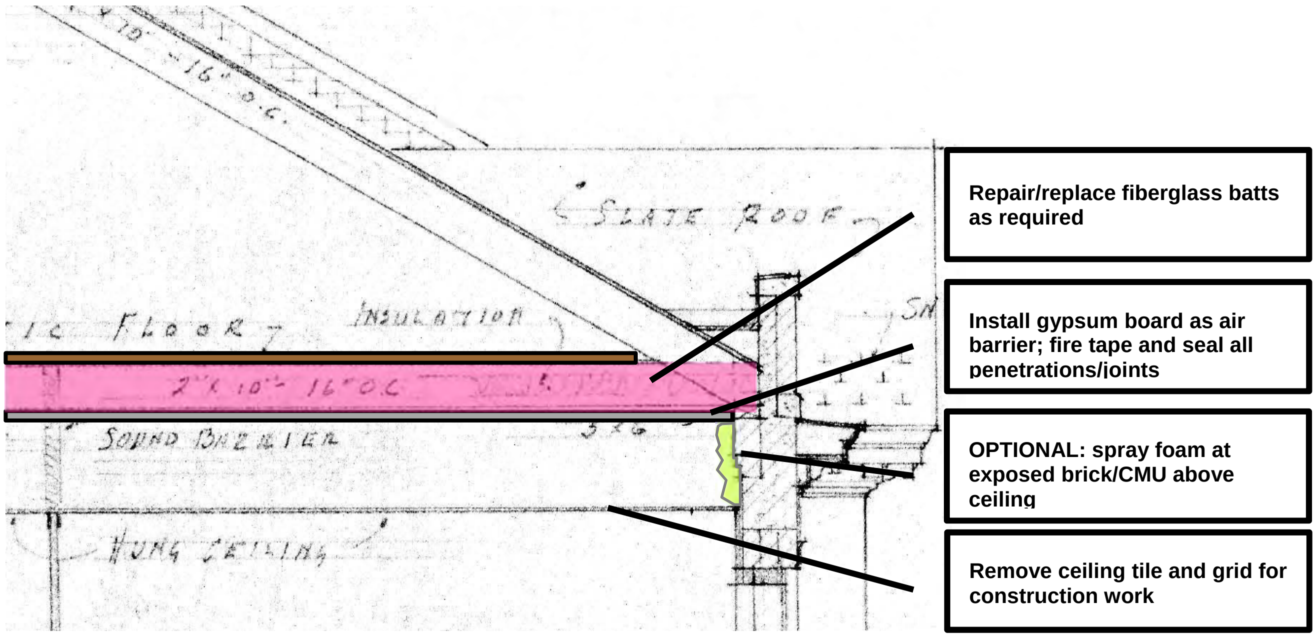


Figure 56: Conceptual design of retrofit with gypsum board ceiling air barrier (vented attic space)

An alternate approach is shown in Figure 57: given that the plywood floor covers most of the attic, it could be leveraged to create an effective air barrier, with some detailing.

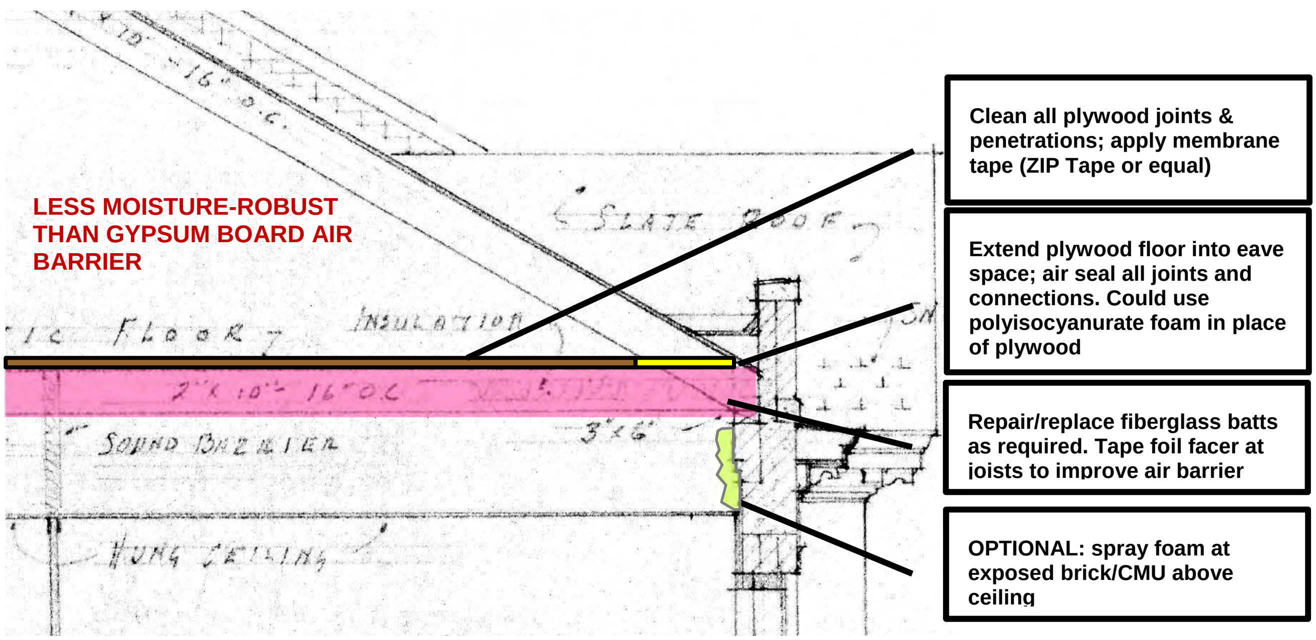


Figure 57: Conceptual design of retrofit with plywood floor ceiling air barrier (vented attic space)

It has the advantage of shifting most of the work to the top side (attic side) of the assembly, minimizing interior disruption (assuming the second floor does not require a gut renovation).

However, this plywood floor approach (Figure 57) is a less moisture-robust assembly than the gypsum board (Figure 56) approach. Making the exterior side of the insulated cavity airtight (rather than the interior side) means that moisture could potentially condense on the underside of the plywood sheathing in winter. In contrast, with the gypsum board approach lets this moisture escape into the attic via air leakage. ***The plywood floor approach should only be done if the airtightness of the foil facers is improved by taping joints on the interior.***

In addition, if the attic ceiling/floor assembly has fire resistance requirements, this does nothing to change the current layering.

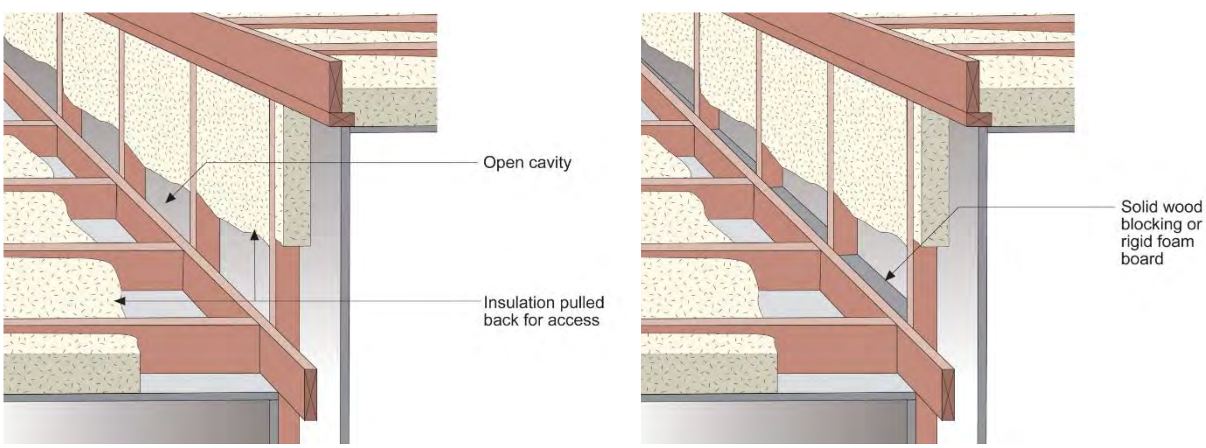
This approach requires the following steps:

- Repair/replace fiberglass batts as required (from below); requires opening ceiling tile grid on a "spot" basis
- Use housewrap tape or similar to seal joints of fiberglass batt foil facers
- Extend the plywood floor into the eave space; air seal all joints and connections. See perimeter conditions of the attic in Figure 58: the board must be "notched" around the rafters. The team could use polyisocyanurate foam in place of plywood; it will function as an effective air barrier
- Clean all plywood joints & penetrations; apply membrane tape (ZIP Tape or equal) and seal all penetrations. For instance, the joint between the CMU gable end wall and plywood (Figure 10) requires an air sealing detail.
- OPTIONAL: install closed cell spray foam at exposed brick/CMU wall above ceiling

Figure 58: Plywood attic floor perimeter condition

The stairwell platform and associated kneewalls will also need air barrier detailing. At the kneewalls, the recommended solution is to provide a solid airtight sheathing (e.g., rigid foam insulation board) on the attic side of the wall cavity, keeping the batt insulation inside a "six-sided box."

Details for retrofitting this condition are shown in Figure 59, taken from BSC's *Attic Air Sealing Guide and Details*. Further guidance can be found in the Building America Solution Center: Attic Knee Walls (https://basc.pnnl.gov/resource-guides/attic-knee-walls#quicktabs-guides=0)



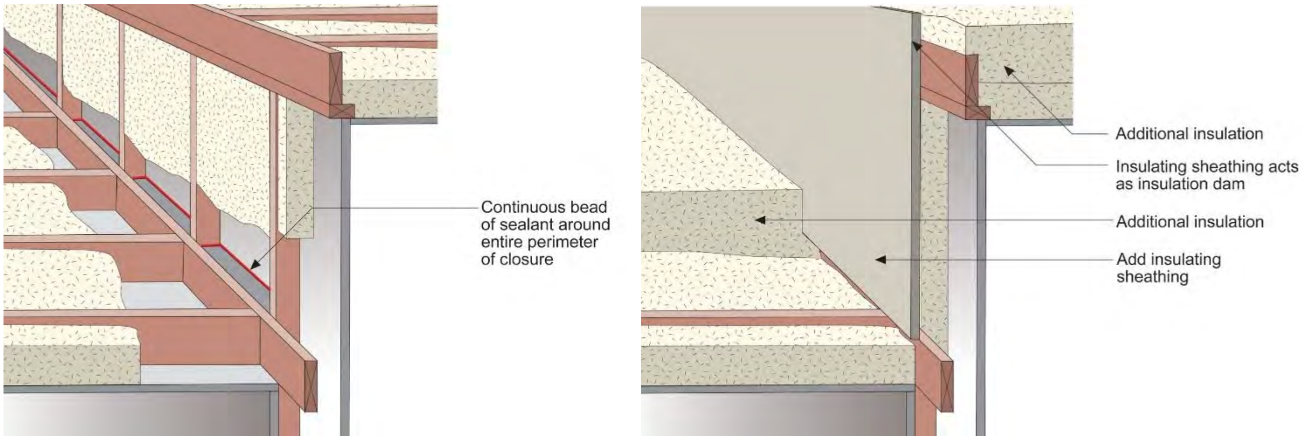


Figure 59: Air sealing and insulation details for two-story kneewall geometry

The stairs to the attic (Figure 38) also require retrofit work; the "cleanest" option is to provide an insulated and airtight cover over the horizontal stairwell opening. This leaves the stairwell "inside," which eliminates the need to insulate the stairwell walls and steps.

Retrofit Recommendations: Unvented Attic

A last approach offered is to turn the attic into a conditioned space, by applying closed cell spray foam to the underside of the roof sheathing.

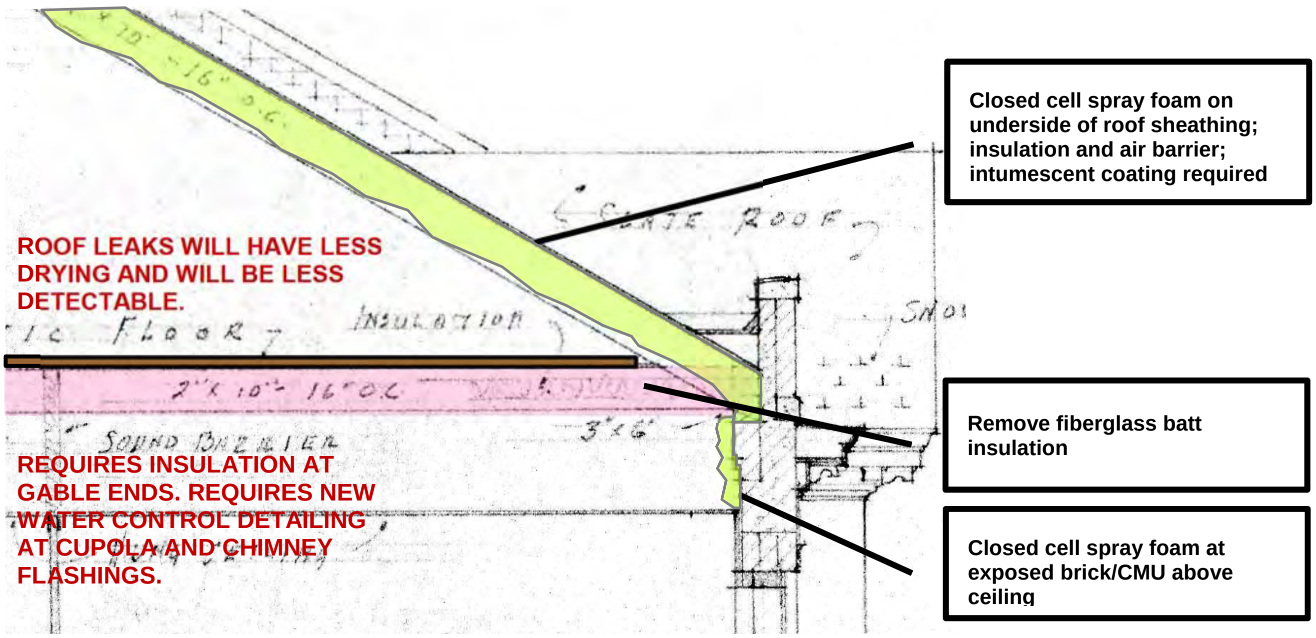


Figure 60: Conceptual design of retrofit with spray foam at roofline (unvented/conditioned attic space)

This "unvented attic" design is discussed in more detail below; it requires the following steps:

- Remove fiberglass batt insulation from below. This ensures that the attic does not operate at cold temperatures, increasing surface condensation risks.
- Closed cell spray foam is applied to the underside of the roof sheathing; this creates an insulation layer and air barrier. An intumescent coating or other type of fire protection is required at this exposed foam.
- Install closed cell spray foam at exposed brick/CMU wall above ceiling

This approach is a higher cost solution and less moisture safe than the previous approaches. Unless there is a strong need to create more conditioned space in the building, it is not a recommended approach (given current constraints). It also does not change the layering of fire protection between the attic and the conditioned space.

Spray Foam Unvented Attic Basics

The basics of unvented roofs are covered in Building Science Digest 102: Understanding Attic Ventilation and "A Crash Course in Roof Venting." Further information on the vented attic vs. unvented attic HVAC trade-off are covered in "Are You Doing Something Stupid? - 3 SPF Topics That Might Have You Rethinking Your Decisions," in section "Systems thinking."

The design for an unvented (or "hot") roof must comply with the IRC §R806.4 Unvented attic assemblies; these requirements are discussed in IRC FAQ: Conditioned Attics. The recommended approach is to insulate entirely with high density (2.0 pounds/cubic foot) closed cell spray foam (ccSPF), sprayed to the underside of the roof deck (Figure 61 and Figure 62).

Spray foam cannot be left exposed in an unfinished attic; it must be covered with an ignition barrier (per IRC §R316.5.3 and §R316.5.4). A common solution is intumescent (fire-resistant ignition barrier) paint, which is commonly applied by the spray foam contractor.

Areas where spray foam is directly covered with an interior finish (e.g., gypsum board) are a non-issue in terms for code compliance.

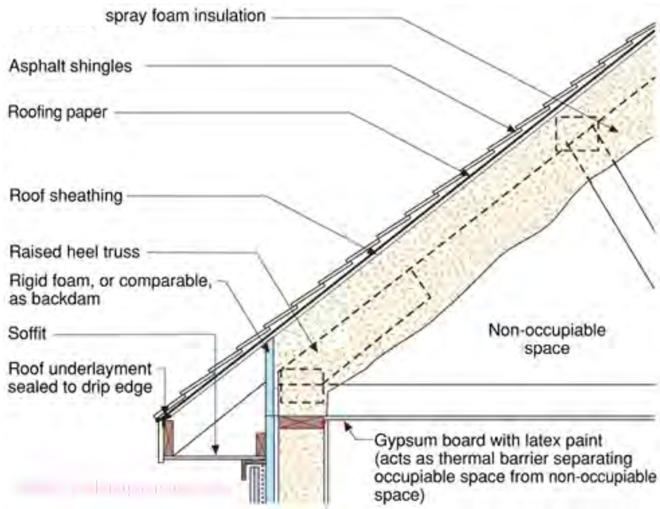


Figure 61: All-spray foam unvented roof design

Figure 62: All-spray foam unvented roof

Spray foam is a material that is essentially "manufactured" when applied at the building site. Given the importance of this material's performance, quality control measures should be set in place. Some key issues include moisture content and temperature of the substrate, applied spray foam layer or "lift" thickness, ratios of the two spray foam components during application, and storage/handling of spray foam components.

5. Building Pressure Measurements

Indoor-Outdoor Pressure Measurements

Patterns of air movement and building conditions can be determined by pressure mapping or pressure measurements. Indoor-outdoor differential pressure measurements were taken using an Energy Conservatory DG-700 manometer at various door and window openings (Figure 63 through Figure 66), and these measurements are shown in a floor plan in Figure 67, and in Table 1. Conditions were measured with the building in “operating” condition (both bathroom exhaust fans running, typical interior doors open).

Measurements were taken using the manometer’s 10-second averaging function; these 3 to 13 measurements were then averaged, as presented in Table 1, with the standard deviation (which gives some indication of the variation, typically due to exterior wind gusts). Pressure measurements are shown in units of Pascals or Pa (250 Pa = 1 inch water column).

Figure 63: Pressure measurement at ground floor door

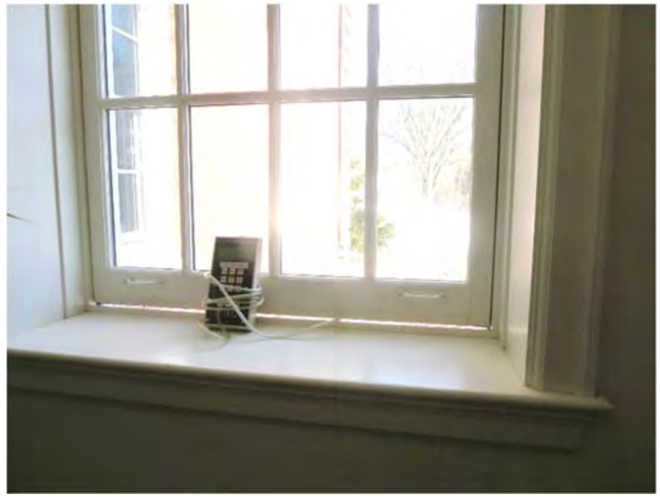


Figure 64: Pressure measurement at 1st floor window

Figure 65: Pressure measurement at 1st floor front door

Figure 66: Pressure measurement at batts/ceiling

Pressure Measurement Results

The pressure measurements are shown in a floor plan in Figure 67, and in Table 1. ***Almost all pressure measurements were "negative" with respect to exterior (i.e., air flowing from outdoors to indoors), as shown by the arrows. As discussed below, this is unexpected behavior for normal building operation.*** The exceptions were pressure measurements through the foil-faced batt facer (slightly outward/positive; +0.1 to +0.3 Pa).

Figure 67 includes an arrow showing rough wind direction during the day (predominantly from the NW, 5-10 mph). This explains the variation in pressure measurements based on orientation: the wind hitting the west- and north-facing sides of the building resulted in greater inward pressures on those orientations.

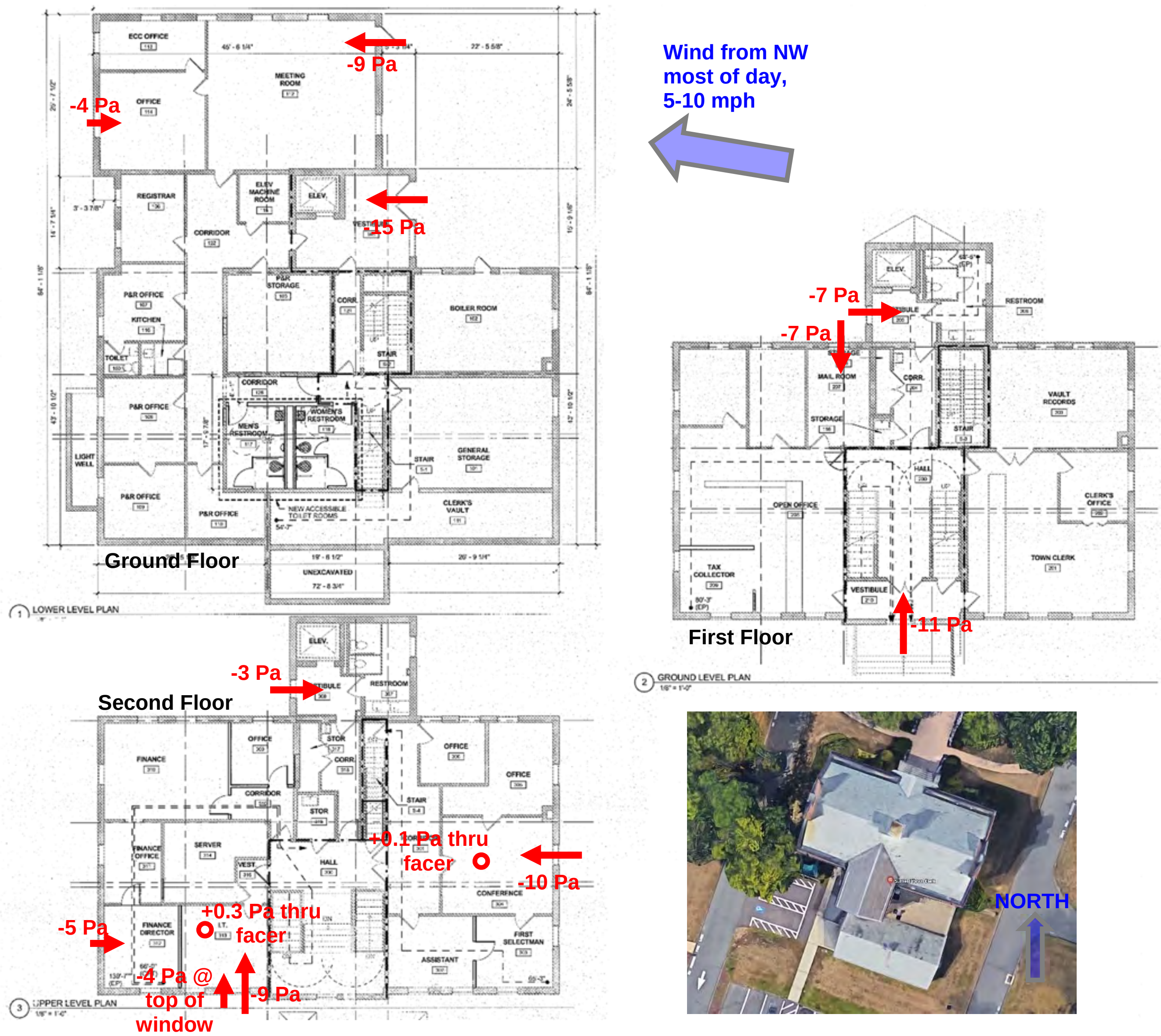


Figure 67: Building plan and pressure measurements, with wind direction noted; overhead view for reference

Table 1: Building pressure measurements; as-found state

Location	Pressure	Floor	Directio	
Meeting Rm West	-9.0 Pa ± 3.1 StdDev	Gnd	W	
Office East	-3.6 Pa ± 0.6 StdDev	Gnd	E	
Gnd Floor Entryway Dbl Door	-15.7 Pa ± 2.0 StdDev	Gnd	W	
1st East @ Flat Roof	-7.2 Pa ± 1.2 StdDev	1st	E	
1st South @ Flat Roof	-7.1 Pa ± 1.6 StdDev	1st	S	
1st Front Door North	-11.4 Pa ± 0.9 StdDev	1st	N	
2nd IT Room Front-North	-9.1 Pa ± 1.2 StdDev	2nd	N	
2nd IT Room Front-Top of Windov	-4.1 Pa ± 1.1 StdDev	2nd	N	
2nd IT Room Front-East	-5.2 Pa ± 1.1 StdDev	2nd	E	
2nd IT Thru Foil Ceiling Facer	0.3 Pa ± 0.1 StdDev	2nd	Up	
2nd Conf Room West	-9.6 Pa ± 1.3 StdDev	2nd	W	
2nd Conf Thru Foil Ceiling Facer	0.1 Pa ± 0.0 StdDev	2nd	Up	
2nd Elev Vestibule East	-3.3 Pa ± 1.4 StdDev	2nd	E	

In addition, an experiment was run turning the attic exhaust fan (Figure 20) on and off, to measure its effect on building pressure, as shown in Table 2. The pressure change is 1 to 3 Pa, or a very small change. The exhaust fan is estimated at roughly 800 CFM (see Table 3). ***Based on these observations, this suggests that the building is very leaky, which is consistent with the lack of a ceiling air barrier.***

Table 2: Building pressure measurements; cycling exhaust fan on and off

Location	Pressure	Floor	Directio	
2nd IT Room Front-Exh ON	-5.2 Pa ± 0.2 StdDev	2nd	N	
2nd IT Room Front-Exh OFF	-4.0 Pa ± 0.8 StdDev	2nd	N	
2nd IT Room Front-Exh ON	-6.7 Pa ± 1.4 StdDev	2nd	N	

Background: Building Pressurization/Depressurization Effects

Building pressures should be understood with seasonal/temperature effects in mind. The mechanisms that drive air leakage are discussed in Building Science Digest 014: Air Flow Control in Buildings and are shown in Figure 68. They are wind, stack effect (warm air rising, leaking outward at the top of the building), and combustion and ventilation (a.k.a. mechanical pressurization/depressurization, or the effect seen by the running of fans). Stack effect will change seasonally: in the winter, it will draw air inward at the bottom of the building; in summer, it will tend to draw air in from the top of the building.

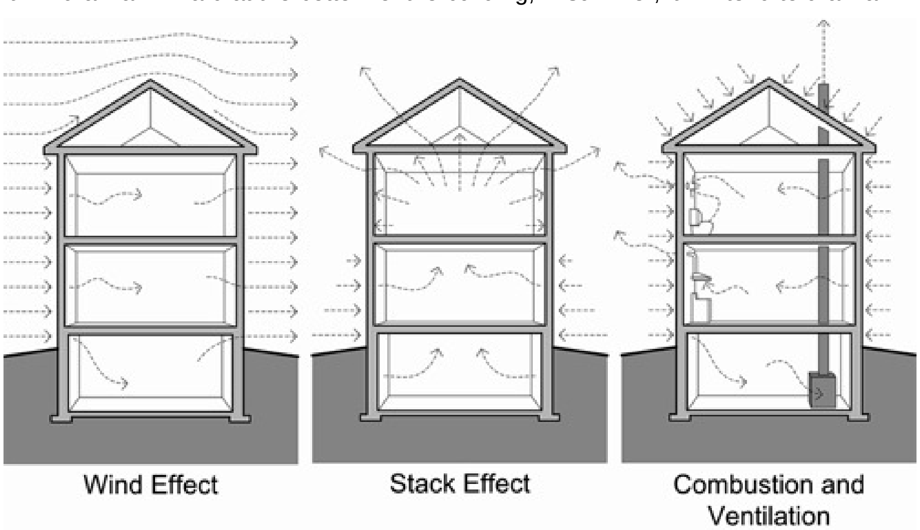


Figure 68: Air leakage mechanisms in buildings (BSD-014)

This is demonstrated in a sketch of stack effect in winter (warm interior conditions in a tube; left portion of Figure 69) and in summer (cold interior conditions in a tube; right portion of Figure 69). The pressure graph shows that in summer, negative pressures occur at the top of the building (air is pulled inward), and positive pressures at the base (air is pushed outward). The term “NPP” stands for “neutral pressure plane,” which is roughly mid-height, where there is no inward or outward pressure (“neutral pressure”).

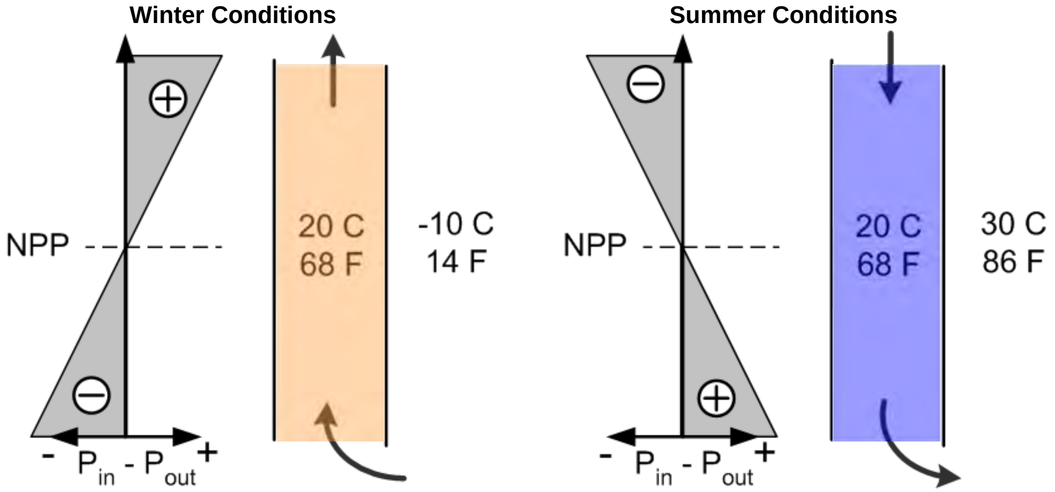


Figure 69: Flow through a heated or cooled cylinder or building (BSD-014)

However, a tube that is closed on one end or the other has a different pressure relationship, as shown in Figure 70. At the “open end” of the tube, the pressure falls to zero (no pressure containment = no pressure difference). As a result, instead of being a “half in-half out” pressure relationship, it is “all in” or “all out.” ***These pressure distributions are analogous to the pressure measurements at the building (Figure 67), suggesting that the roof has catastrophic air leakage, as discussed above.***

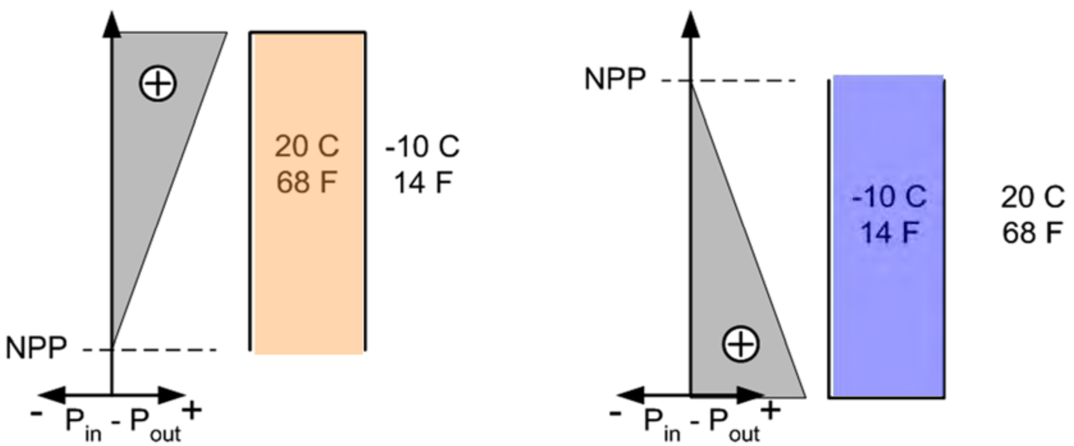


Figure 70: Pressure distribution in simple cylinders with open ends (BSD-014)

This is discussed further in Building Science Digest 014:

> *The pressure at the bottom must be zero since it is connected to the outdoors. The horizontal plane at which the pressure equals the outdoor pressure (i.e., the plane at which the difference is zero) is called the Neutral Pressure Plane (NPP).*
>
> *If there are more openings at the top or bottom of the building (e.g., a mechanical penthouse on the roof or open doors in the bottom), the NPP will be moved closer toward the larger opening. In tall buildings, the NPP has been found to vary from about 30% to 70% of the height of the building.*

Stack effect pressures are proportional to the difference between indoor and outdoor temperature, and the height that it acts over (i.e., open height of the building). Calculations were run for the height of the building (roughly 32 feet from basement to attic floor). With an outdoor temperature 5-10°F (per the site investigation), maximum total stack effect pressure would be roughly 14-15 Pa, which is in line with measured pressures.

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6. Above-Grade Walls

Multiple moisture and thermal issues at the above-grade walls were reported and examined, as covered below.

Ceiling Tile Staining

One issue reported by the team was ceiling tile staining throughout the building; examples in the vault/records room are shown in Figure 71. The left hand stain was examined more closely (Figure 72); there is a cluster of hot/chilled water piping joints at the exterior wall, directly above the stain. Looking more closely at the valve and joint (Figure 73), there is extensive patching (including expanding foam and duct tape) at this joint; this previous repair is consistent with the leakage problem. The repair materials were left in the suspended ceiling near the repair (Figure 74).

Figure 71: Ceiling tile stains, vault/records room

Figure 72: Left-hand stain, vault/records room

Figure 73: Mechanical piping at left-hand stain

Figure 74: Repair materials remaining at left-hand stain

At the right hand stain, there are water stains running down the metal housing for the roll-up window shutter (Figure 75). These drips originate from the concrete slab ceiling, which may be related to the perimeter heating system.

A similar examination was done at the Tax Collector's office (Figure 77); again, drip marks aligned with various insulated piping joints (Figure 78). These drip marks were also visible at the exterior wall finishes, above the suspended ceiling (Figure 79 and Figure 80).

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Figure 75: Drip marks on shutter, right-hand stain

Figure 76: Drip marks at ceiling over shutter

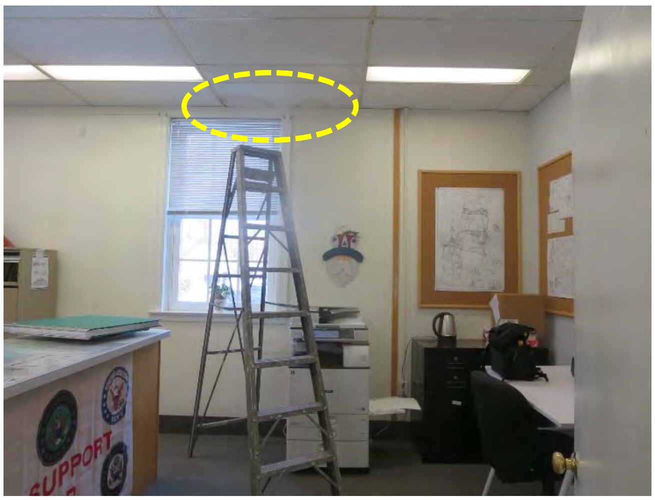

Figure 77: Ceiling tile stains, Tax Collector office

Figure 78: Mechanical piping at Tax Collector office

Figure 79: Stains on wall finishes, Tax Collector office

Figure 80: Stains on wall finishes, Tax Collector office

Overall, it appears that the ceiling tile staining is due to leakage or condensation at the heating/chilled water piping. This does not preclude the possibility of through-wall water leaks, but evidence for wall leakage is not strong.

Uninsulated Ceiling Space

The exterior wall condition above the suspended ceiling is exposed brick or concrete block (Figure 81 and Figure 82); the second floor is supported on top-bearing bar joists.

Figure 81: Ceiling space, Tax Collector office

Figure 82: Ceiling space, vault/records room

The walls below the suspended ceiling are finished with an interior board and a strapped cavity (Figure 83); a foil facer is used to provide some minimal insulating value at this cavity (Figure 84).

Figure 83: Exterior wall furring & board, Tax Collector

Figure 84: Foil facer in strapped cavity

The net effect of this strapped cavity is shown in the infrared image in Figure 85: the strapped cavities are warmer (have a higher R-value) than the wood vertical strapping.

The exposed brick above the suspended ceiling is cooler (has greater heat loss) than the wall below, as shown in Figure 86.

Figure 85: Visual and infrared image of east-facing wall, Tax Collector office

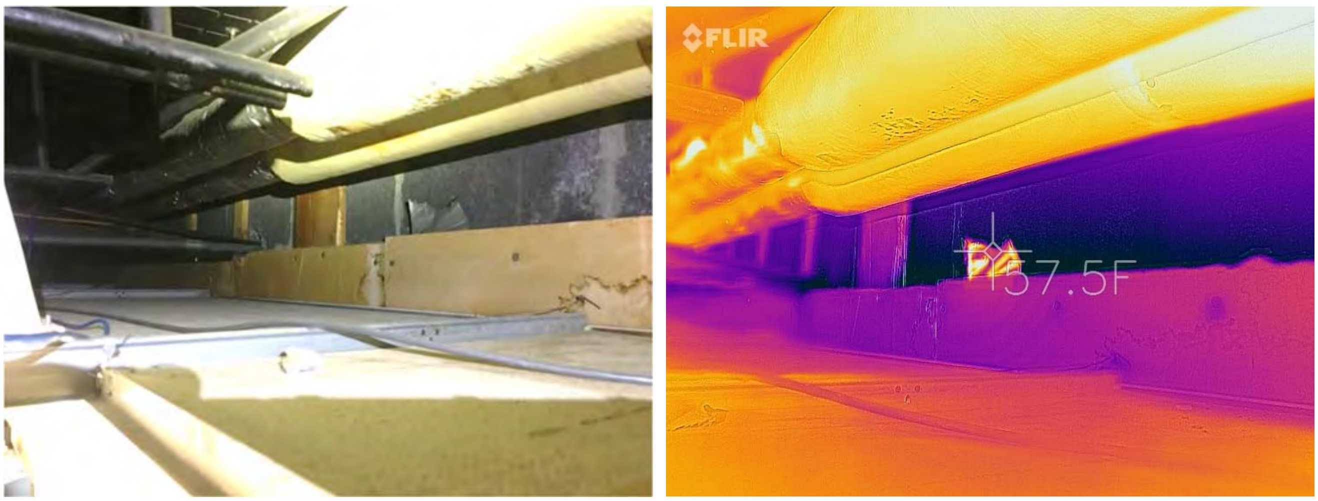

Figure 86: Visual and infrared image over suspended ceiling, Tax Collector office

The net effect of these two conditions can be seen from the exterior (Figure 87): there are warmer surface temperatures at the wall heating units, and at the uninsulated ceiling cavity.

Figure 87: Visual and infrared image of east wall of building; thermal anomalies at 1st-2nd ceiling line

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Similar behavior was seen on the second floor: Figure 88 shows conditions at the IT room, where the surface temperatures of the wall above and below the suspended ceiling can be contrasted.

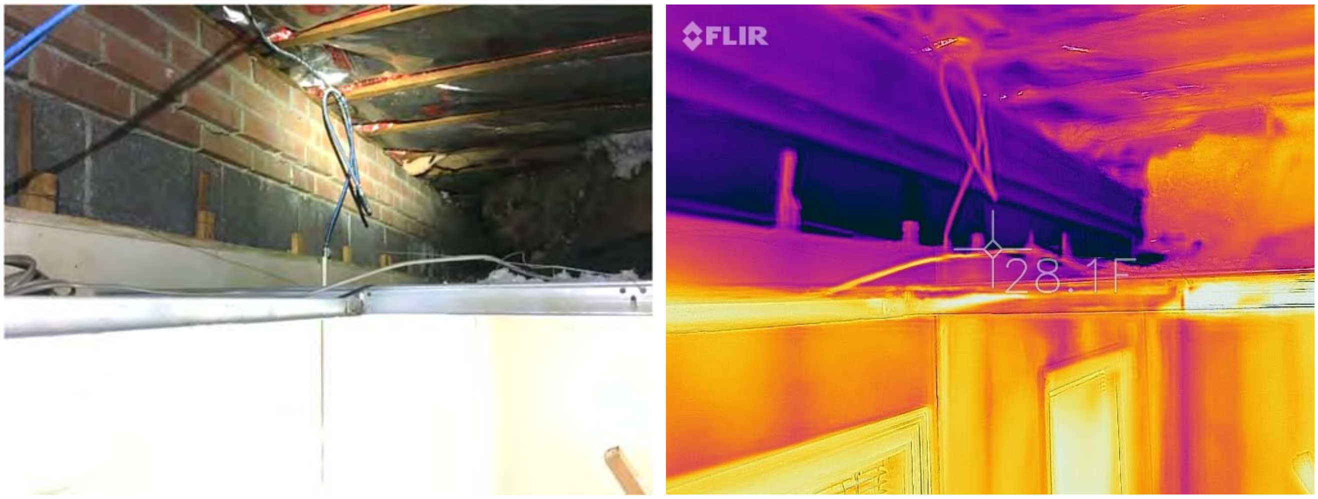

Figure 88: Visual and infrared image over suspended ceiling, second floor IT room

These exposed brick and CMU wall areas above the suspended ceiling could be addressed by interior insulation (e.g., spray foam or similar), as discussed below.

Wall Bulk Water Issues

The team also pointed out multiple areas with damaged interior finishes consistent with water leakage. An example was found at the second floor stairwell, around the heating/cooling fancoil unit (Figure 89), where the interior plaster and paint had bubbled and cracked.

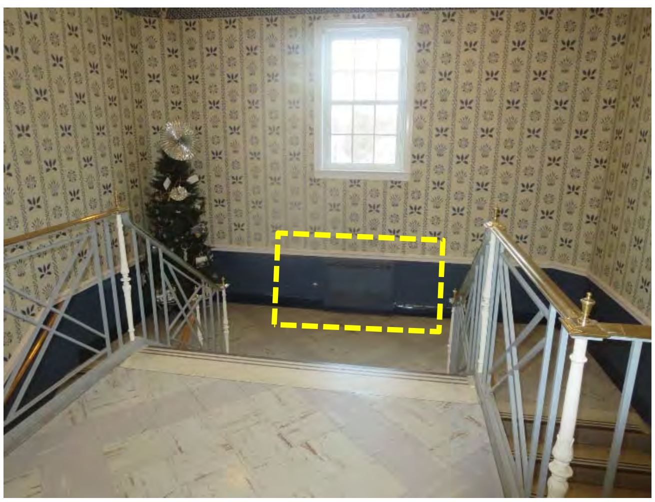

Figure 89: Second floor stairwell; staining at fancoil

Figure 90: Moisture measurement at damaged plaster

Surface moisture levels were measured on a spot basis using a handheld Tramex Moisture Encounter capacitance-type moisture meter, set on the Plaster/Brick scale, which provides qualitative results on a 0-100 scale (Figure 90). No evidence was seen of current moisture problems (all readings 0), which is consistent with previous water leakage that has not recurred.

A similar issue of bubbling paint and plaster was seen at the northwest corner of the building, in the First Selectman's office (Figure 91). Again, Tramex measurements read 0, indicating that whatever moisture issues (likely roof leakage) caused this problem, they are not currently active. This was corroborated by infrared observations (Figure 93): the only visible pattern was thermal bridging through the wood strapping between cavities, rather than latent moisture issues.

Figure 91: First Selectman office NW corner damage

Figure 92: Moisture measurement at plaster

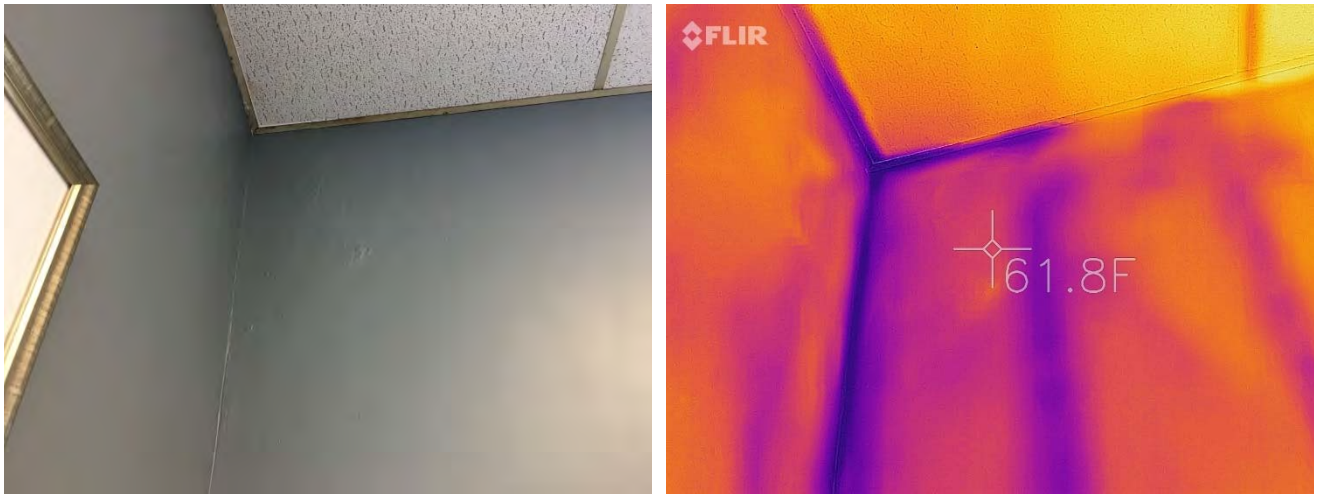

Figure 93: Visual and infrared image of First Selectman office NW corner damage

Lastly, at the west side of the vault/records room, the wall above the suspended ceiling had significant efflorescence staining, consistent with previous water leakage (Figure 94); the location is shown on the exterior in Figure 95.

Figure 94: Efflorescence on brick, vault/records room

Figure 95: Location of efflorescence on west exterior

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This water issue was not currently active, so no further investigation was conducted. The water leakage pattern is consistent with failed water control features at the corner of the building (e.g., clogged/overflowing gutters).

Wall Thermal Bridging

As discussed previously, the wall cavity (with a foil facer) has a higher R-value than the solid wood vertical strapping. This is demonstrated by infrared images of the walls (Figure 96 and Figure 97), showing the thermal bridging through the wood members (cooler surface temperatures).

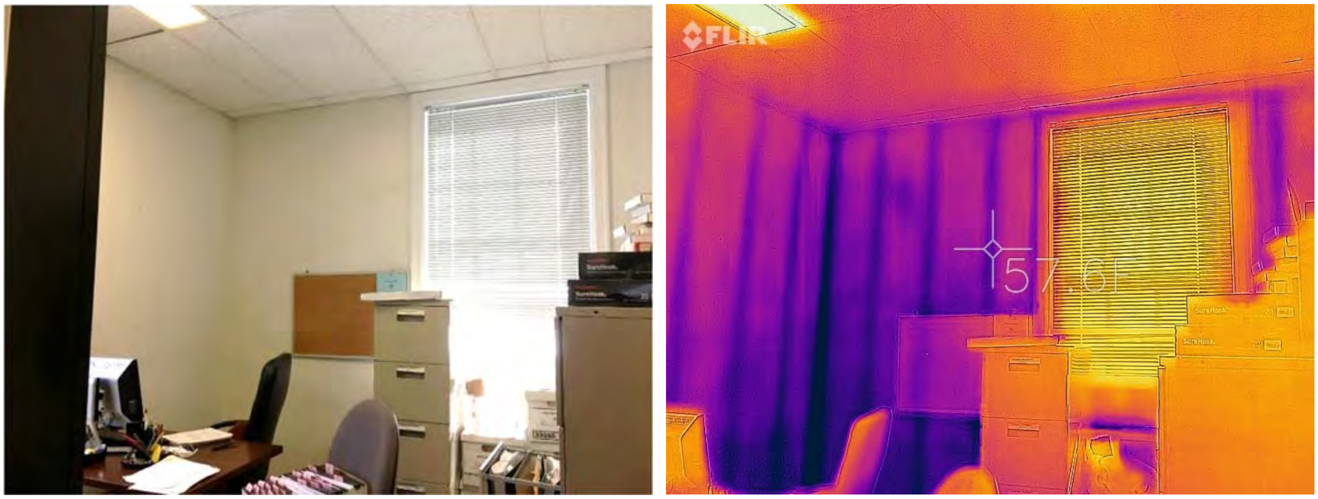

Figure 96: Visual and infrared image of tax collector rear (south and east) office walls, showing thermal bridging

Figure 97: Visual and infrared image of second floor stairwell walls, showing thermal bridging

Addressing this is a much lower priority than other retrofits. Changing this condition would require a gut retrofit of the interior, and detailing similar to the basement walls (Figure 108 and Figure 109).

7. Basement

Issues reported in the basement spaces included musty odors and reported indoor air quality/allergy issues.

Exterior Observations

Exterior grade changes around the building perimeter; the one-story wing (former garage) is at slab on grade conditions, but grade rises towards the front of the building. This results in partially-buried walls at the sides of the main building, and full basement conditions at the front of the building (Figure 98 and Figure 99).

Figure 98: Exterior of east side, showing sloping grade (buried basement at front/sides)

Figure 99: Visual and infrared image of west wall, showing boiler chimney and heat loss at basement

The exterior infrared image shows heat loss at the boiler chimney, the uninsulated wall between the first and second floors, and at the solid concrete basement wall.

Unfinished Basement Areas

Most of the basement perimeter has unfinished walls (painted solid concrete), as shown in the general storage room (Figure 100). Few issues were noted; one issue was a foundation crack (Figure 101), but it did not appear to be an active source of water leakage.

Infrared images of the general storage room (Figure 102) and the clerk's vault (Figure 103) show cooler temperatures at the above-grade portions of the basement walls, showing greater heat loss where the wall is exposed above the ground. No other problematic thermal anomalies were noted.

Figure 100: Overview of general storage room

Figure 101: Concrete crack at window, general storage

Figure 102: Visual and infrared image of general storage room west wall; heat loss at above-grade exposed portion

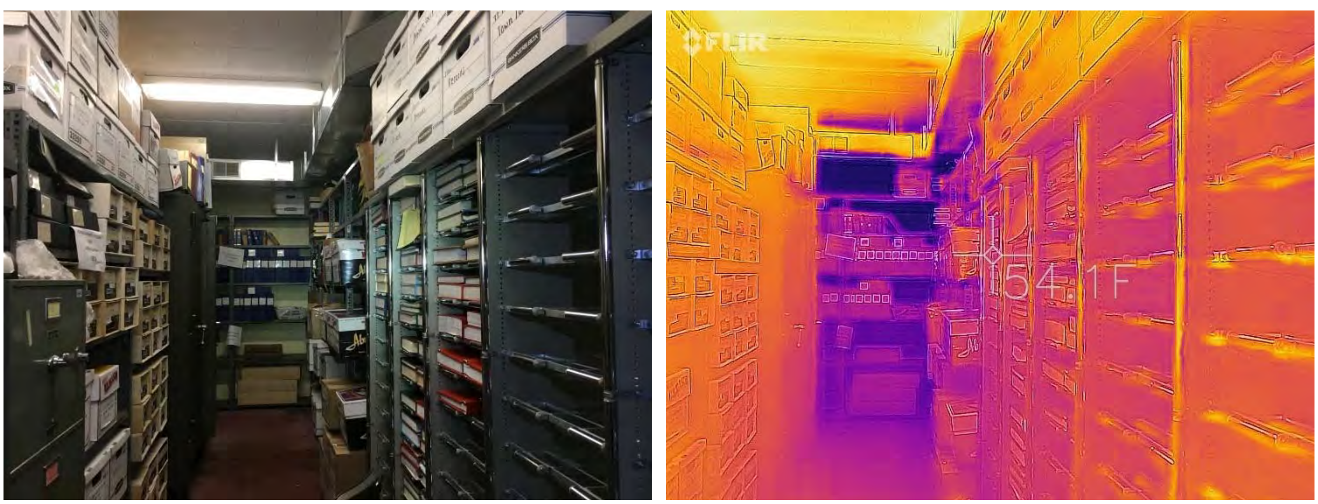

Figure 103: Visual and infrared image of clerk's vault west wall; heat loss at above-grade exposed portion

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Finished Basement Areas

The east walls of the basement are finished office spaces; infrared images of these spaces show apparent thermal bridging at the framing, and what appears to be inward cold air leakage at openings such as electrical receptacles (Figure 104 and Figure 105).

Figure 104: Visual and infrared image of P&R office east wall, thermal bridging and air leakage

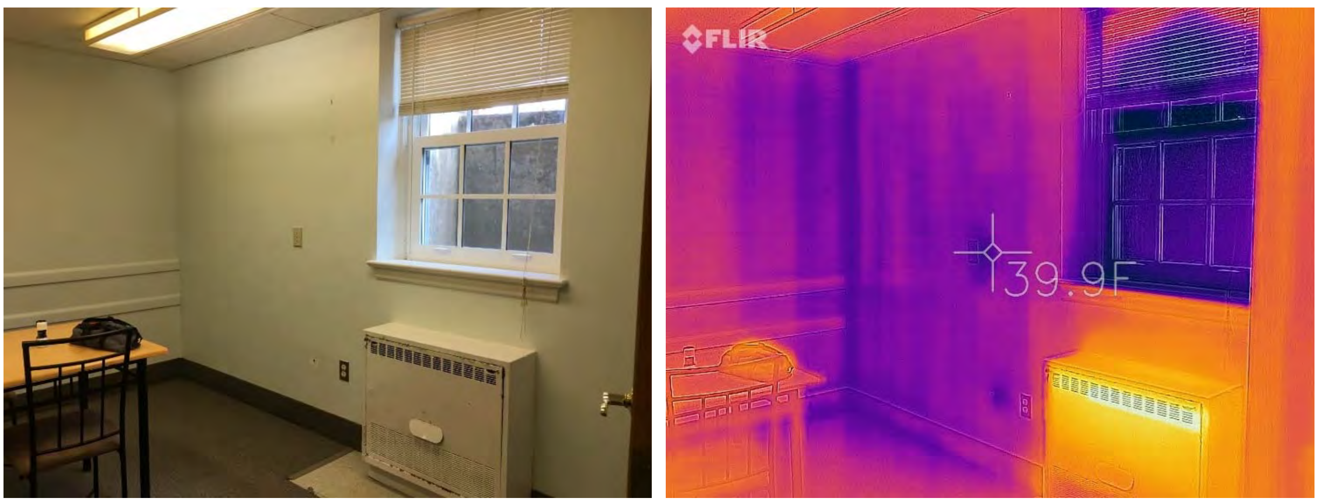

Figure 105: Visual and infrared image of P&R office east wall, thermal bridging and air leakage

Wall build-out was examined more closely: based on probing with a saw (Figure 106), the framing cavity is empty (no insulation), with a ~4-½ inch airspace. The interior finish appears to be a cementitious plaster, which is a far more moisture-resistant and durable finish for a below-grade space than paper-faced gypsum board.

The presence of airflow at the openings in the interior plaster was confirmed with air velocity measurements, using a Fieldpiece STA2 In Duct Hot-wire Anemometer (Figure 107). Measurements are shown in feet per minute (FPM) velocity; conditions at the opening were 50-140 FPM of ~50°F inward airflow. ***This airflow is consistent with the negative pressure of the building pulling in cold outdoor air from the basement wall cavity, and has the potential to bring in moisture, musty odors, and contaminants.***

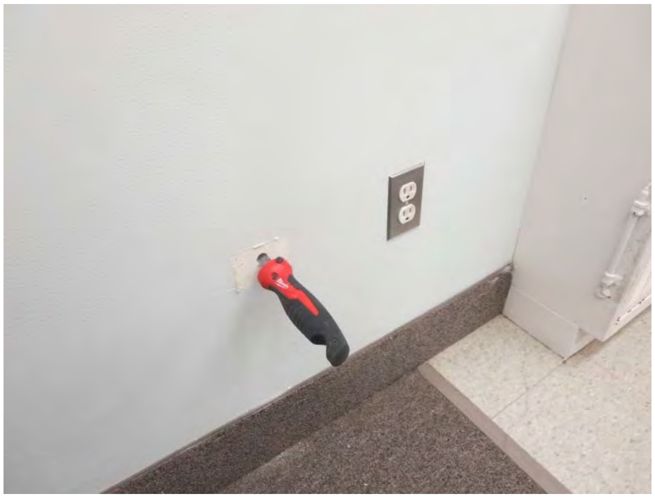

Figure 106: Measuring depth of cavity behind finish

Figure 107: Air velocity measurement at opening

Retrofit Recommendations

Foundation insulation details that have greater moisture safety are covered in Building Science Digest 103: Understanding Basements. Some recommended assembly options are shown in Figure 108 and Figure 109. They show the options of rigid foam (extruded polystyrene/XPS) or closed cell (2 pounds/cubic foot) polyurethane spray foam, applied to the interior side of the foundation wall. All these materials have the advantage of being air impermeable (unlike fiberglass insulation), keeping interior air away from cold surfaces (avoiding condensation risks). The materials are also somewhat tolerant of moisture intrusion: they can take incidental, periodic wetting without damage.

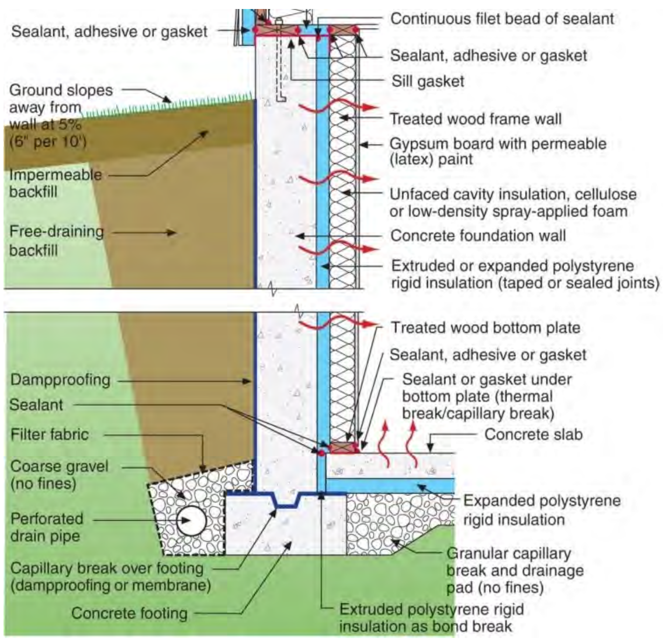

Figure 108: Interior basement insulation with insulated wood frame wall and gypsum board

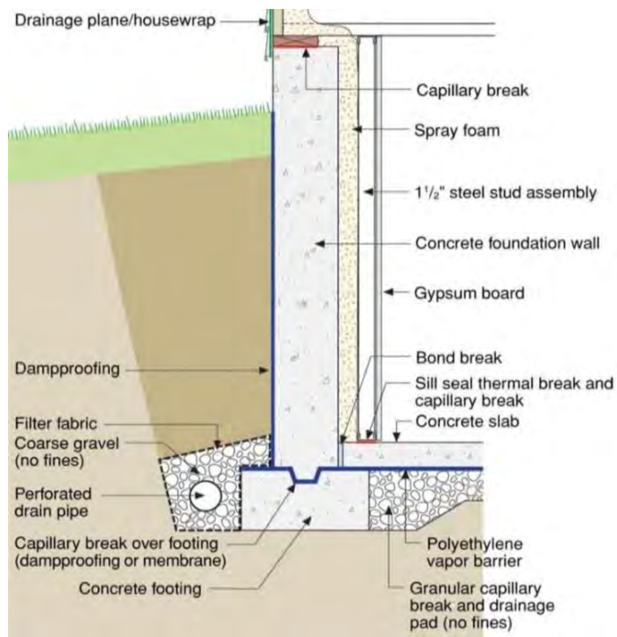

Figure 109: Basement interior spray foam application, with steel stud frame and gypsum board

Figure 108 shows the use of rigid foam board insulation (e.g., XPS) on the interior, attached either with adhesive or mechanical fasteners. Note that the rigid foam must be detailed as an air barrier (taped seams, caulk details at top, bottom, and window penetrations), to prevent interior air leaking into the air space behind the foam, and condensing on the hidden surface. A stud frame wall can be built inboard of the XPS foam, and filled with insulation (e.g., fiberglass), if additional R value is required. However, if only R-10 is required (e.g., typical code value), a 2" layer of XPS foam would be sufficient insulation.

Figure 109 shows the use of closed-cell spray foam directly against the concrete foundation wall. Closed cell spray foam is moisture-tolerant, provides sufficient water vapor control, and will provide an excellent air barrier. It must be protected from interior ignition sources (i.e., gypsum board or equivalent). ***If a steel stud wall is used, the studs should ideally be installed completely inboard (or just touching) the spray foam.*** This eliminates any thermal bridging problems (loss of insulation value; see BSI-005: A Bridge Too Far), and provides a space for running services.

The recommended interior finish is a fiberglass-faced (non-paper faced) gypsum board, such as GP DensArmor Plus, USG AquaTough, or Temple Inland GreenGlass. However, mold-resistant paper faced gypsum board is an acceptable (albeit lower performance) substitution.

Lastly, at the unfinished storage spaces, heat loss could be reduced by applying insulation to the exposed concrete walls. A lower cost insulation detail is to use Dow THERMAX insulation on the foundation wall, which can be left exposed (Figure 110 and Figure 111).

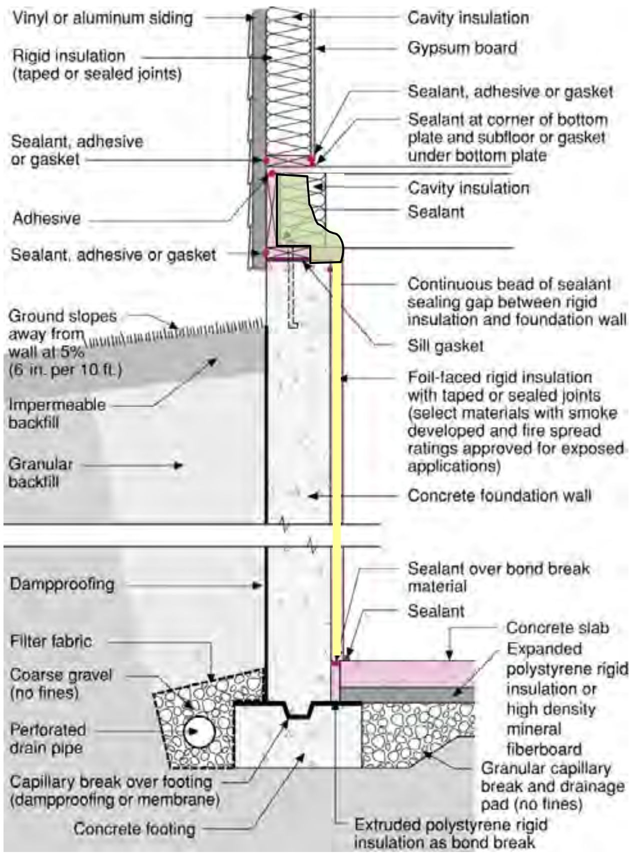

Figure 110: Interior basement insulation with rigid polyisocyanurate foam (THERMAX) left exposed

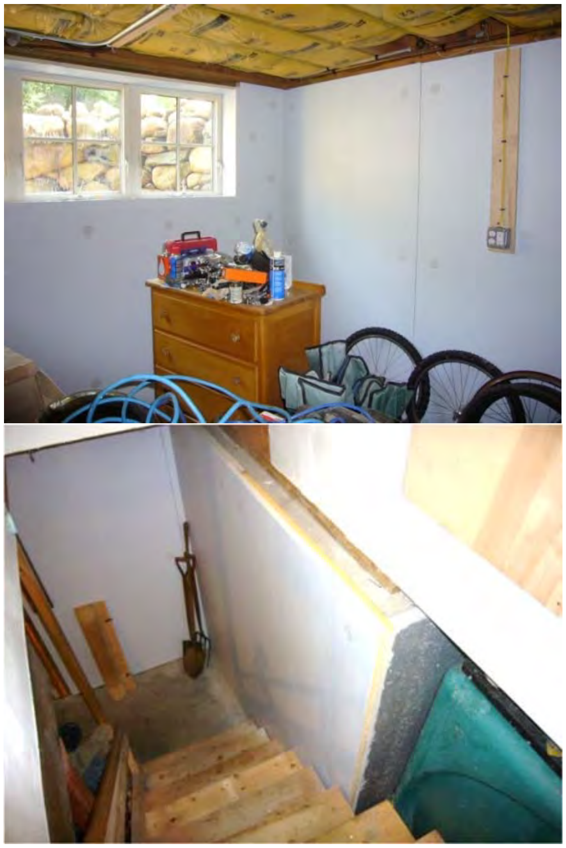

Figure 111: Basement interior with rigid polyisocyanurate foam (Rosenbaum 2011)

This solution was used by Marc Rosenbaum (a colleague and building science practitioner); images of the process and the finished results can be found on his blog:

- Basement insulation, part 3
  http://blog.energysmiths.com/2011/08/basement-insulation-part-3.html

The finished-area basement interior insulation retrofits can be considered if indoor air quality complaints in these spaces become a priority, and/or a gut renovation is planned in the basement spaces. Insulation retrofits in the unfinished storage areas might be considered as an energy improvement retrofit.

8. Summertime Condensation Events

Background

The team reported that in the summer of 2018, condensation occurred at several locations in the building. They included condensation at the front lobby/foyer floor, and at portions of the stairwell from the ground floor to the first floor (Figure 112 and Figure 113).

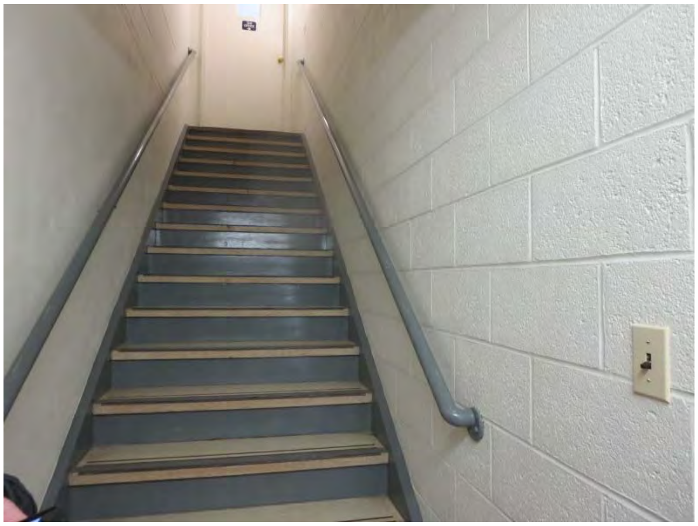

Figure 112: Ground-to-first floor stairway

Figure 113: Summertime mold on stair edge

Field Observations

Finding a summertime problem during winter conditions will always be difficult and problematic; however, infrared observations were taken to determine if any thermal anomalies could be linked to the summertime condensation issues.

The first floor lobby (Figure 114) shows suspected air leakage around the door, and warm interior conditions (past the exterior foyer). No notable thermal anomalies are seen.

Figure 114: Visual and infrared image of front entryway and front door (first floor)

The stairwell from the first floor to the basement was also examined (Figure 115 and Figure 116); the only notable thermal anomaly is warm areas behind the stairwell wall. The thermal anomalies are consistent with the wall mounted fancoil and piping in the Ground Floor Women's Room. The thermal anomaly does not match pattern of condensation and mold growth. Therefore, again, the condensation/mold problems are likely a thermal mass/outdoor air problem.

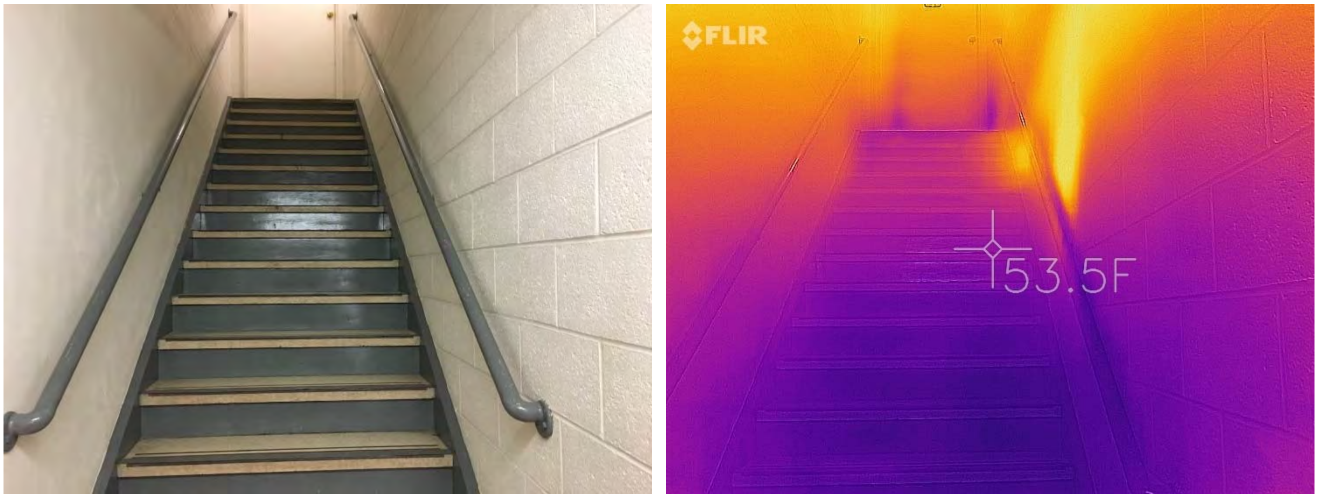

Figure 115: Visual and infrared image of ground-to-first floor stairway; thermal anomaly at wall

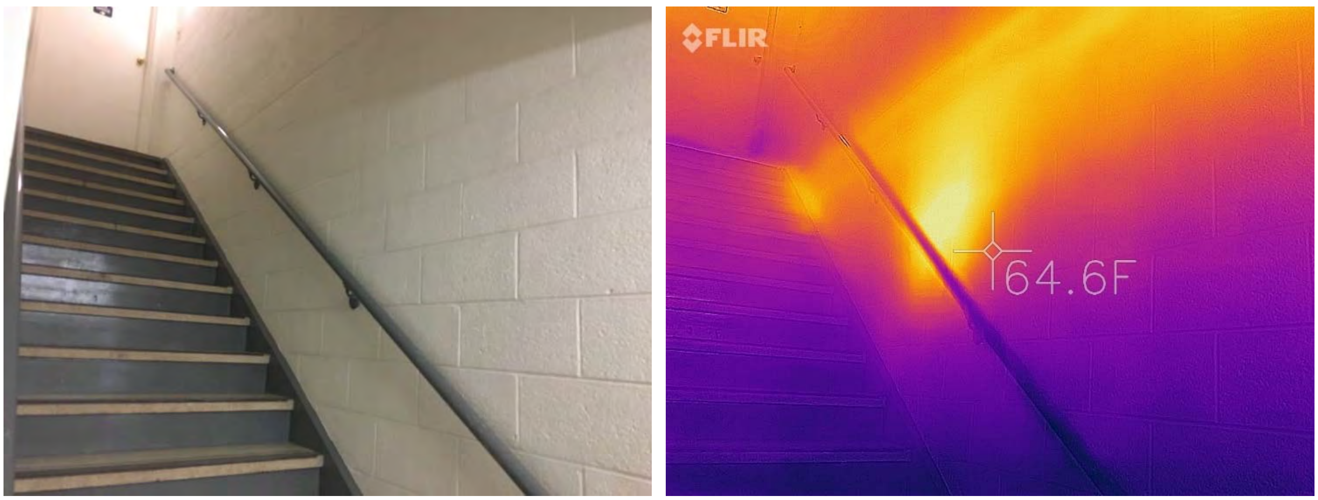

Figure 116: Visual and infrared image of ground-to-first floor stairway; thermal anomaly at wall

Problem Assessment and Retrofit Recommendations

The likely explanation for the summertime condensation issues is:

- The interior is cooled in summer, resulting in cool, non-porous interior surfaces such as the floor and stairwell metal hardware.
- Opening the door in service results in intake of warm, humid air
- Roof/ceiling air barrier deficiencies result in high interior dewpoints (air moisture levels) due to outdoor air leakage, increasing risks of interior condensation
- Warm, humid outside air then condenses on the cool interior surfaces

This problem was worsened by Summer 2018 conditions: outdoor dewpoints throughout the East Coast were elevated compared to normal conditions.

The recommended retrofit measure is to improve building airtightness (roof/ceiling air barrier). If the problems persist after this retrofit, the addition of dehumidifiers is recommended. However, this is a lower priority project, assuming that this condensation issue was a "one-summer" event.

9. Mechanical Systems

Heating/Cooling

Heating and cooling throughout the building is provided by unit fancoils/cabinet heaters in occupied rooms. The units are individually thermostatically controlled. The fancoil unit is shown in operation at the IT room in Figure 117.

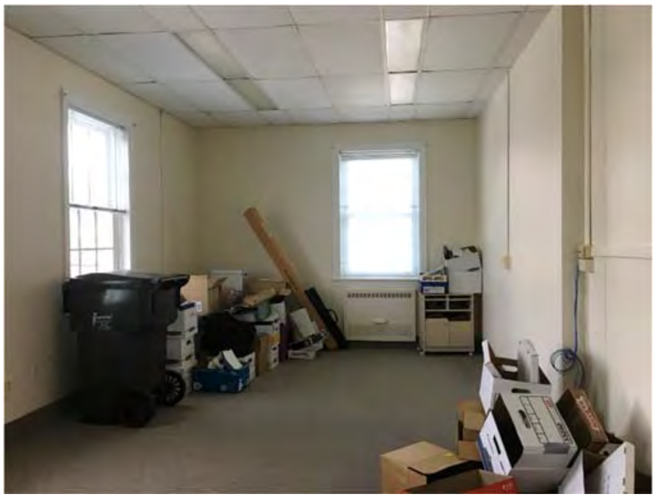

Figure 117: Visual and infrared image of second floor IT room, showing running fancoil/cabinet heater

These fancoil units are fed in turn by a boiler and screw chiller on the ground floor level (Figure 118). There are current issues with near-boiler piping leakage (Figure 119).

Figure 118: Overview of boiler room

Figure 119: Boiler piping (leakage issues)

The existing heating/chilled water piping system appears to be a 2-pipe system, based on previous plans (Figure 120) and observations of piping in the suspended ceiling (Figure 121).

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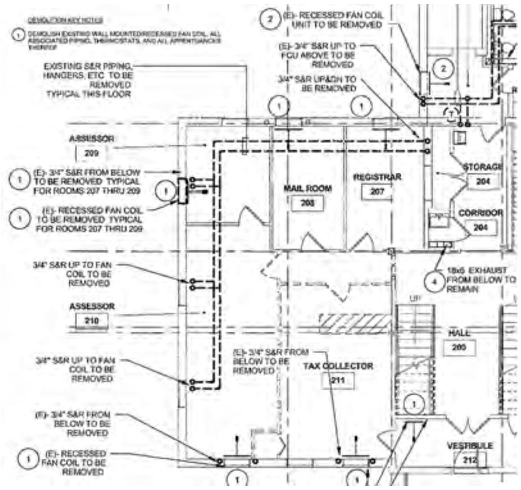

Figure 120: M011 Piping demolition plan, 2-pipe


Figure 121: Boiler piping (insulated 2-pipe system)

Exhaust Ventilation System

There is an exhaust fan installed in the attic, venting out of the cupola (Figure 122); it is connected to sheet metal ductwork that runs through the conditioned space (Figure 123).


Figure 122: Exhaust fan in attic, routed thru cupola


Figure 123: Attic exhaust fan ductwork

Based on the 1961 plan set, the exhaust riser is connected to points throughout the main building, including the second floor janitor's closet (now used as storage), per Figure 124 and Figure 125.

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Figure 124: Second floor Janitor's Closet

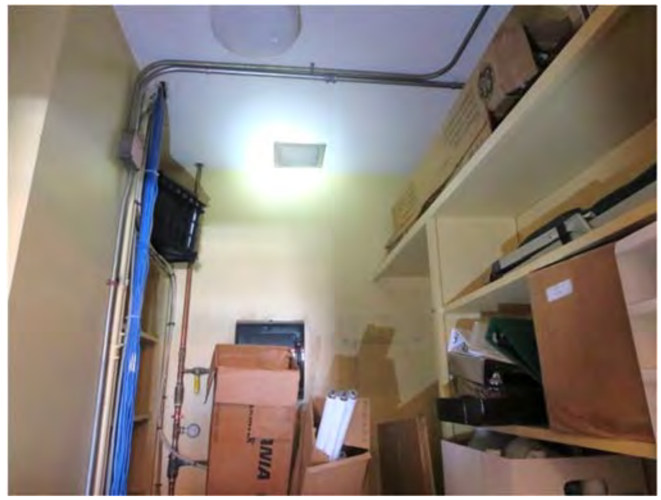

Figure 125: Second floor Janitor's Closet (storage)

The exhaust ductwork system can be traced on the 1961 plans, as shown in Figure 126. ***Almost all of these exhaust flows are to rooms that no longer have (or need) functional exhausts***, including the jail cells (150 CFM total), 3 lavatories (300 CFM), first floor Men's Room (150 CFM), second floor Women's Room (200 CFM) and the janitor's closet (80 CFM). The ground floor pistol range (250 CFM) was on a separate exhaust fan.

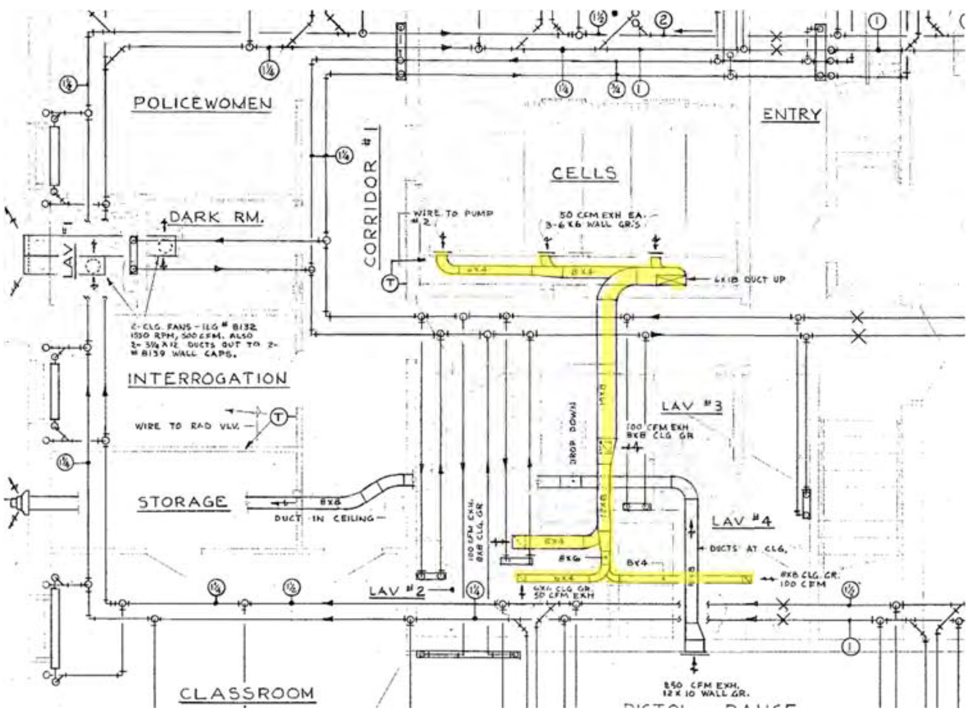

Figure 126: H&V1 Ground floor HVAC plan, exhaust ductwork highlighted

The airflows for this exhaust system are totaled in Table 3, adding up to ~900 CFM:

Table 3: Design airflows for 1961 exhaust system

Cells, 50 CFM x3	150
Lav #2, #3, #4 (2 lavs in use)	300
1st Floor Men	150
2nd Floor Women	200
Janitor	80
Total	**880**

Given that most of these ventilated rooms are out of service, the existing exhaust system is ejecting ~880 CFM of air in order to ventilate two ground floor bathrooms (~100 CFM required), unless previous work turned down the fan speed. The fan in the attic does not provide exhausts for the new ADA bathrooms; they are ventilated via a system in the ceiling of the elevator vestibule on the second floor (~300 CFM). ***Of course, massive overventilation is a waste of energy, and hurts humidity control and interior temperature control.***

Retrofit Recommendations

Assuming the ground floor bathrooms are being renovated, BSC would recommend either (a) installing a new exhaust system sized for that smaller flow, out through a sidewall, or (b) completely revamping the old existing exhaust system, including capping off all unused duct openings, sealing the system airtight, installing new fan set to the correct flow for 2 bathrooms.

10. Rear One-Story Wing

The rear one-story wing of the building is a former slab-on-grade garage, which now operates as a meeting room and offices.

Exterior Observations

The most notable exterior observation is the poor condition of the paint on clapboard at the gable ends (Figure 127 and Figure 128). The paint is peeling and “blowing off” of the wood clapboard.

Figure 127: West gable end of rear one-story wing

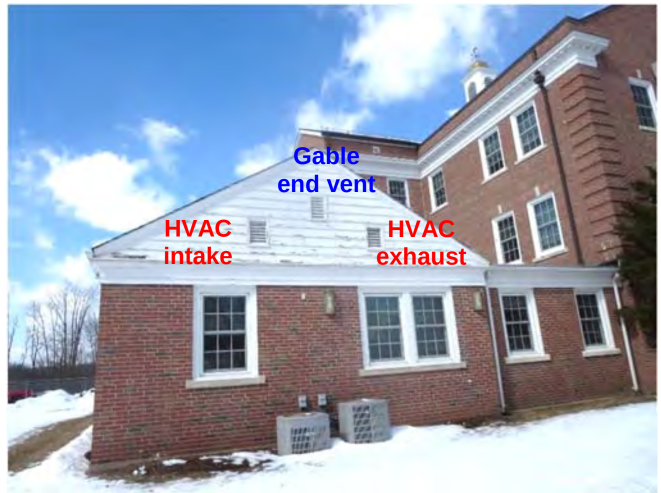

Figure 128: East gable end of rear one-story wing

There are many possible causes for these paint issues, including (a) paint reaching end of service life, (b) repeated applications of oil paint, resulting in low vapor permeance and inhibited outward drying, and/or (c) possible moisture issues in the attic. The recommended solution is to strip the paint down to bare wood, and repaint with a “breathable” (vapor permeable) latex exterior primer and paint. Alternately, replacement with a non-moisture sensitive cladding (e.g., fiber cement clapboard) is a good long-term solution. The attic might be investigated for moisture issues (as discussed below).

The attic ventilation appears to only have gable end vents; there was no clear sign of low eave ventilation.

Interior Ceiling and Water Leak

The most notable issue was paint bubbling/peeling at an interior wall of the meeting room, per Figure 129 and Figure 130.

Figure 129: Meeting room, with water leak highlighted

Figure 130: Bubbled paint at interior wall at meeting rm

Examination of this interior partition wall above the suspended ceiling revealed water staining of the gypsum board, demolished gypsum board, and suspected mold (Figure 131 and Figure 132). The location of this water issue was compared with the exterior elevation (Figure 133) and the floor plan (Figure 134); no obvious correlations for water leakage risks were noted.

Figure 131: Damaged sheetrock, interior wall

Figure 132: Damaged sheetrock, interior wall

Figure 133: Line of water stain relative to exterior

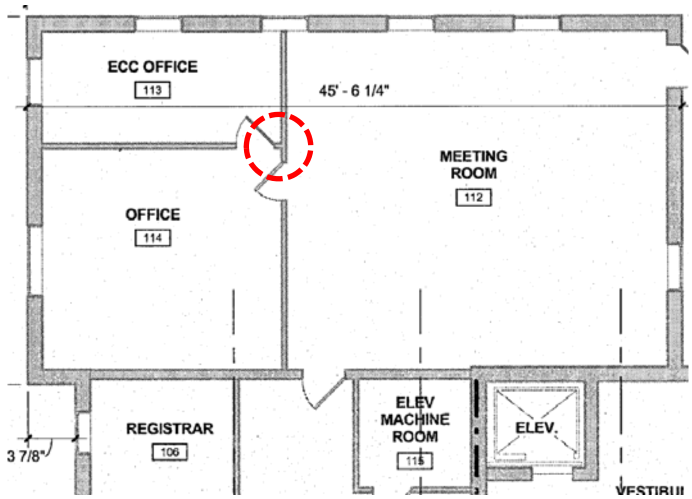

Figure 134: Location of water stain relative to plan

The ceiling construction above the suspended ceiling was unusual: it appears to be fiberglass foil-faced semi-rigid duct board insulation, pinned to the ceiling above (Figure 135). The ductwork is fed through this duct board insulation. Construction was probed with a screwdriver (Figure 136); there is a solid substrate behind the insulation board.

These observations are consistent with the plans: the original 1961 (police garage) plans show a plaster ceiling and a wood truss roof (Figure 137).

The 1997 plans show the conversion of the garage into occupied space. The retrofit work calls out 1-½ inch rigid insulation mechanically fastened to the existing plaster ceiling (Figure 138), which matches field observations.

Figure 135: Ductwork through hard ceiling

Figure 136: Solid substrate at duct board insulation

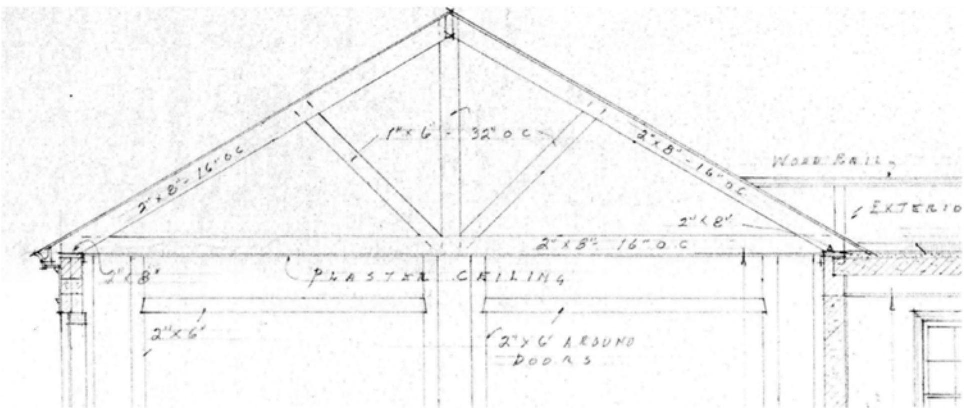

Figure 137: One-story wing (former garage) attic 1961 plans, showing plaster ceiling and truss roof

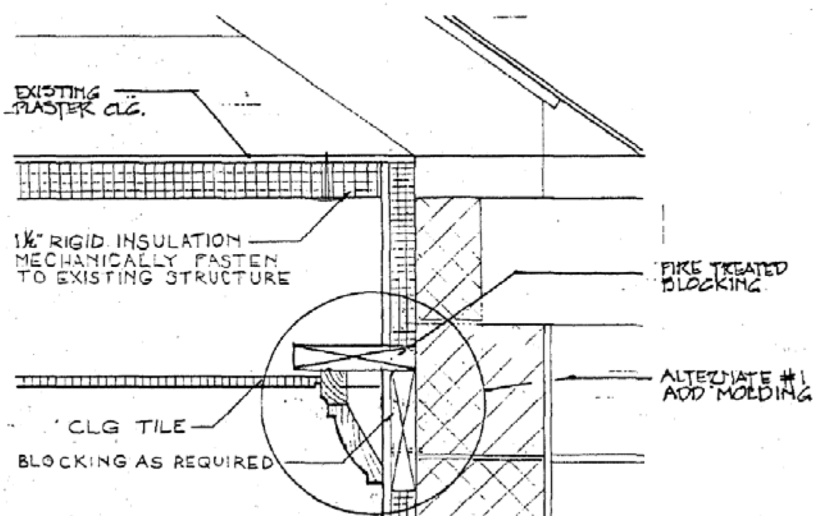

Figure 138: 1997 Meeting room renovation plans, showing ceiling and wall insulation

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The moisture issues observed could not be investigated further without attic access. The attic access hatch location was unknown during the investigation, but the 1997 renovation plans indicate that the hatch is located in the corner office (Figure 139). Suspected causes of the moisture problems include bulk water (rain) penetration, wintertime roof condensation or frosting, summer duct condensation, and/or summertime HVAC condensate leakage.

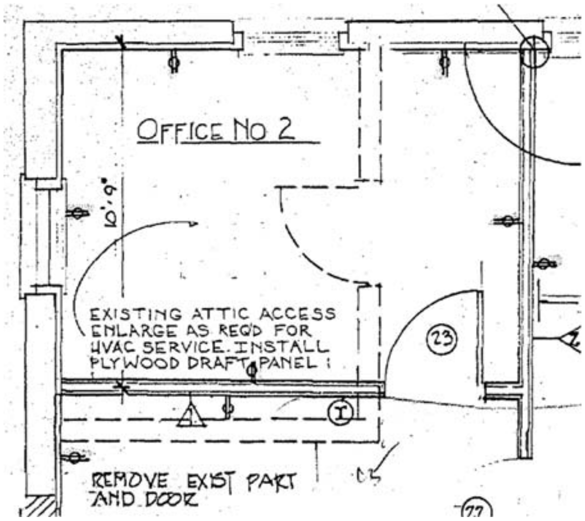


Figure 139: 1997 Meeting room renovation plans, showing attic access location in corner office

Mechanical System

The 1997 renovation plan (Figure 140) shows the existing mechanical system: there are two air handlers/furnaces: a large one for the meeting room (HVAC 1), and a smaller unit for the offices (HVAC 2).

These plans show HVAC 1 connected to the outdoor air louvers on the east gable end (Figure 128); based on the plans, they are 600 CFM intakes and exhausts. ***If this ventilation system is active as shown (operating constantly), the meeting room is massively overventilated relative to its typical loads.*** This will result in excess energy use and poor winter and summer humidity control.

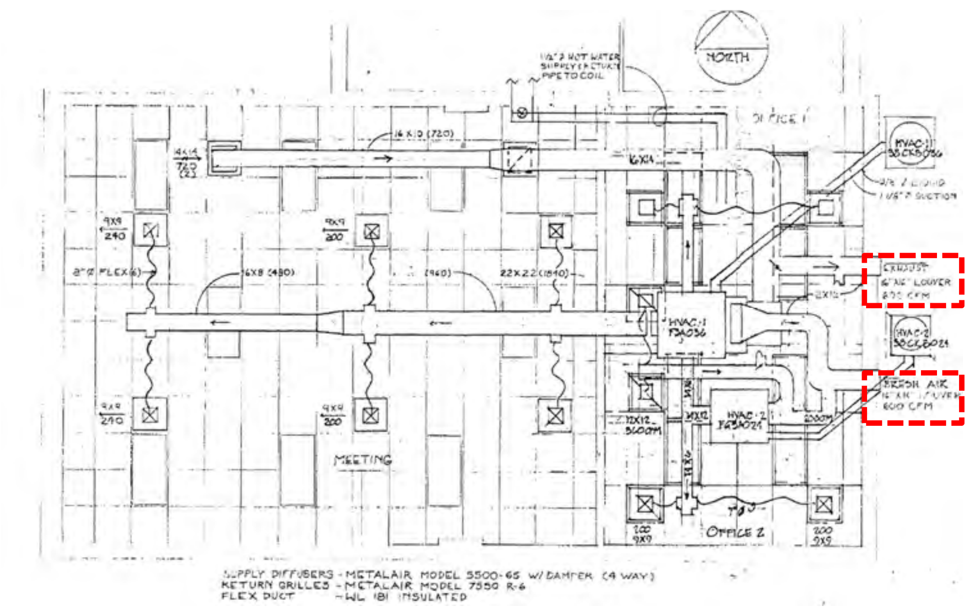


Figure 140: 1997 Meeting room renovation plans, HVAC schematic, with outside air intake/exhaust highlighted

The 2014 plans show mechanical system renovations that were not apparently executed; for instance, they show a new condensing boiler. The demolition plans from the 2014 set show the current state of mechanical systems in a slightly clearer form; the two duct systems are highlighted for reference (Figure 141).

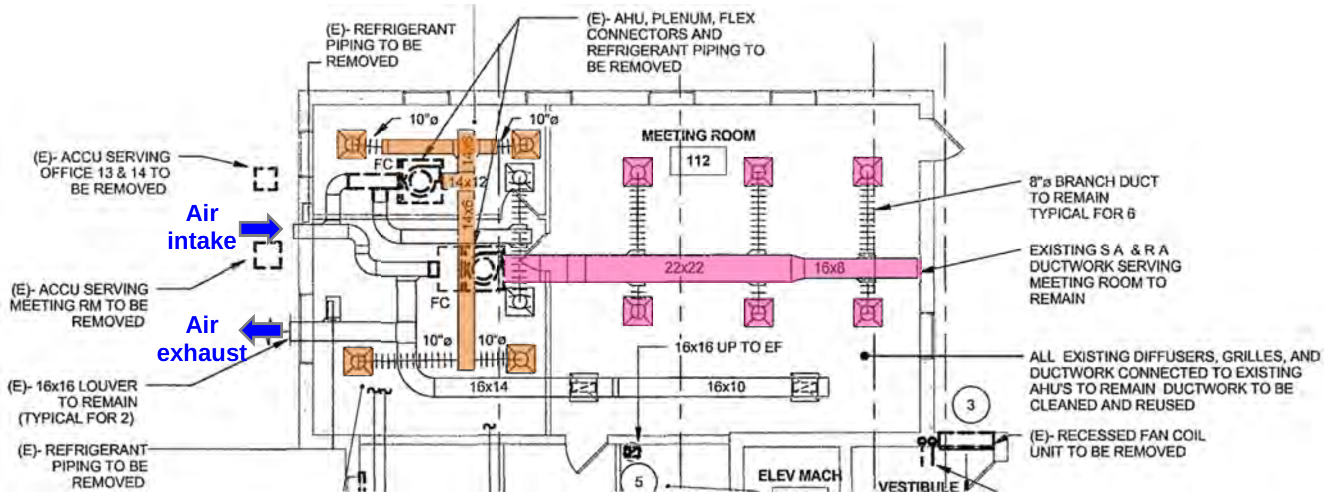


Figure 141: M010 Ground floor meeting room demolition plan (2014 plans)

Meeting Room Ventilation System

As stated previously, if the meeting room HVAC system (HVAC 1) operates with the large outdoor louvers at the design rates (600 CFM), the meeting room is massively overventilated in most conditions. Although a meeting room has substantial peak loads (high occupancy), it was empty for most of the day of the investigation. The interior RH in the meeting room was 14%, compared to ~20% in the remainder of the building, which is consistent with overventilation.

Modern ventilation systems are often controlled by a carbon dioxide (CO_2) sensor; they use CO_2 as an indicator of human occupancy, and runs the ventilation system based on an indoor setpoint level.

A simpler improvement to the existing system is to convert it to a Central Fan Integrated Supply (CFIS) system, which is a supply-only ventilation system (see Figure 142). These systems can be installed with a motorized damper in the outside air duct, to prevent overventilation.

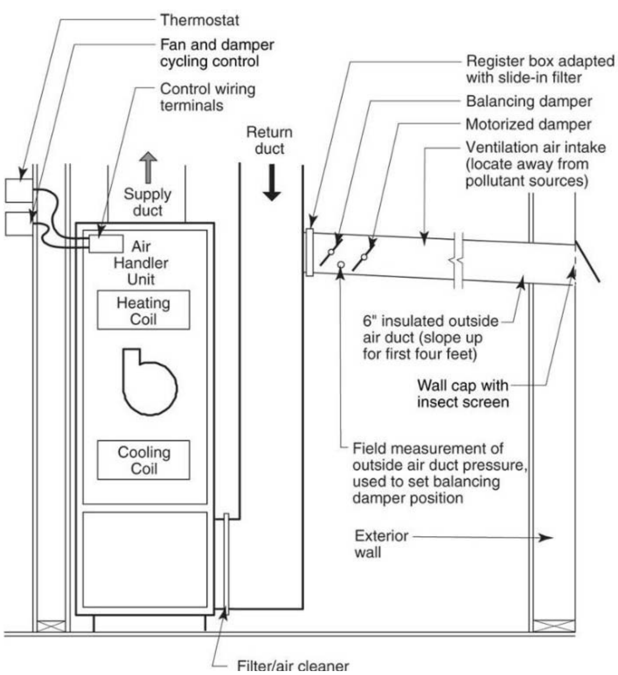


Figure 142: Schematic of central fan integrated supply ventilation

Figure 143 shows an installed CFIS system; the outside air duct (from the return side of the air handler to the exterior) is highlighted in yellow, and the motorized damper (shutting off excess ventilation) is circled in red. A Honeywell CFIS system is shown installed on a furnace/air handler in Figure 144.

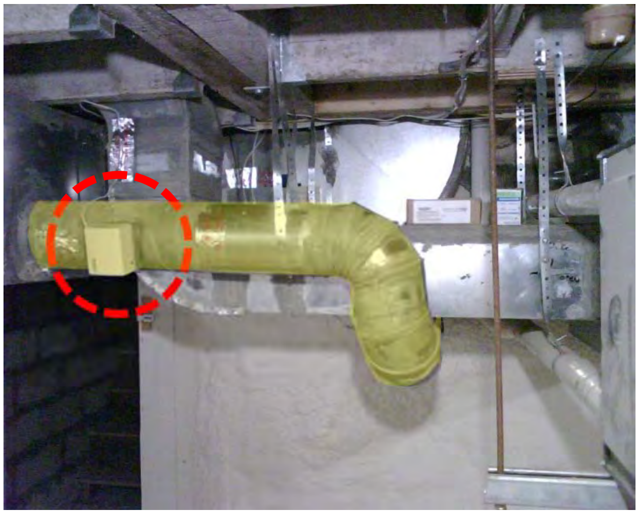


Figure 143: CFIS system, motorized damper highlighted

Figure 144: Honeywell CFIS system at furnace return

Further information on this system can be found in Information Sheets 610: Central Fan Integrated Ventilation, and “Central Fan Integrated Supply Ventilation—The Basics.” This system requires a specialized controller which needs to interrupt the wire between the thermostat and the furnace; good options include following:

- AirCycler FR-V
  http://www.aircycler.com/pages/aircycler-frv
- Aprilaire Ventilation Control System - Model 8126X
  https://www.aprilaire.com/whole-house-products/ventilation/model-8126X
- Honeywell Fresh Air Ventilation System, Y8150
  http://yourhome.honeywell.com/en/products/ventilation/fresh-air-ventilation-system-y8150

The ventilation system for the meeting room should be evaluated more closely, and options such as CFIS control/motorized damper and CO_2 control should be considered.

Infrared Observations (Thermal Stratification)

Interior infrared observations were taken at the meeting room, as shown in Figure 145 and Figure 146.

Figure 145: Visual and infrared image of meeting room; thermal bridging at furring, and thermal stratification

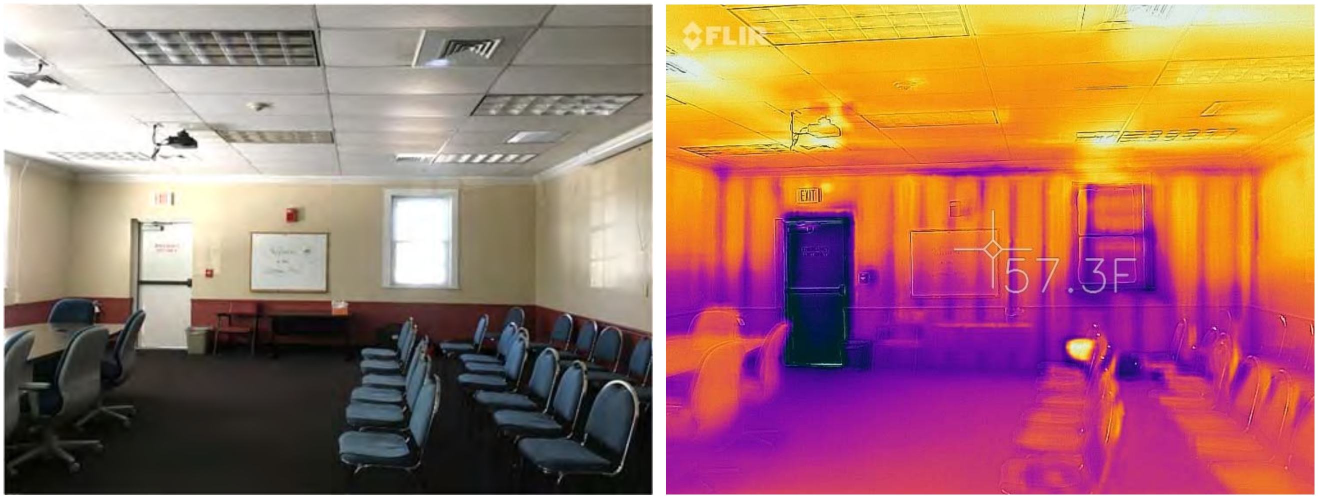
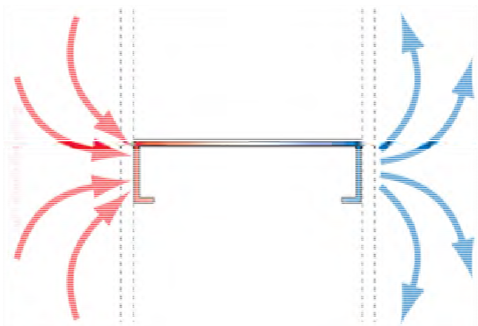


Figure 146: Visual and infrared image of meeting room; thermal bridging at furring, and thermal stratification

One clear observation from the infrared images is thermal bridging through framing; further information on thermal bridging, or steel bypass of the insulation is provided in Figure 147, and covered in Building Science Insight 005: A Bridge Too Far:



Steel studs are designed to provide the maximum possible conductive energy transfer across a wall using the minimum amount of material—a thin web with cleverly designed heat transfer fins (flanges) on both sides to efficiently absorb heat on one side and reject it on the other (Figure 1). It gets even worse when steel studs are used with a steel frame (Photograph 4). It is pointless to insulate the cavity to fight this efficiency of heat transfer. Of course if it is pointless, we do it. ***The lunacy has progressed to the point where we are using higher and higher thermal resistance cavity insulations like expensive spray foams. Why waste money on cheap insulation when we can waste even more on expensive insulation?***

Figure 147: Heat transfer through steel studs (BSI-005)

The reason for this thermal bridging is shown in the 1997 renovation plans (Figure 148): the 1-½ inch rigid insulation is interrupted with 1-½ inch metal Z channels, which bypasses the insulation, creating the "cold lines."

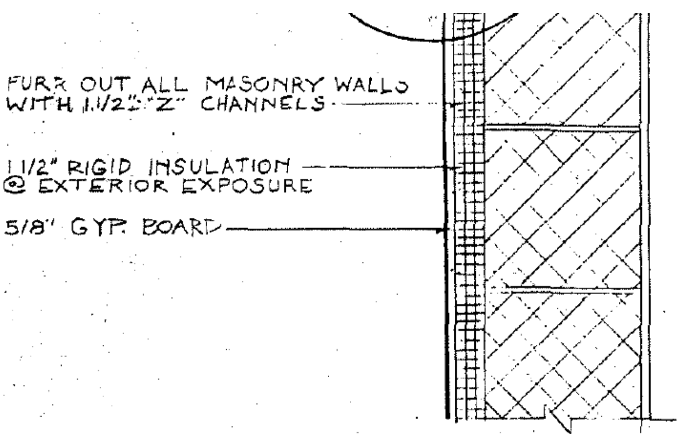


Figure 148: 1997 Meeting room renovation plans, showing interior wall insulation

A second notable issue was thermal stratification, or collection of warm air near the top of the room, and cool air at the bottom. This was particularly noticeable when climbing a ladder; there were noticeably warm temperatures near the ceiling. This stratification contributes to discomfort and higher energy use, and is discussed further below.

Background: Stratification Due to HVAC Design (ACCA Manual T)

ACCA Manual T (Air Distribution Basics) provides useful background information on temperature stratification and HVAC design. First, it classifies ceiling diffusers into horizontal and vertical "throw" models.

> *Ceiling diffusers are available in models which are designed to either discharge the air **horizontally, parallel to the ceiling**, or **vertically toward the floor**.*

The diffusers used at the meeting room ceiling are horizontal throw. This is shown in the infrared images of the first floor (Figure 145 and Figure 146), where the ceiling diffusers create x-shaped warm patterns across ceiling

Manual T also notes that buildings or spaces with poor thermal performance (airtightness and insulation) have larger vertical temperature gradients/stratification, and that supply systems that mix air reduce temperature gradients.

> *Larger vertical temperature differences (gradients) are associated with poorly constructed and/or poorly insulated homes (or rooms) and smaller gradients are associated with tight, well insulated homes (or rooms). Larger gradients are associated with supply outlets that do a poor job of mixing and diffusing the supply air with the room air and smaller gradients are associated with supply outlets which thoroughly mix the supply air with the room air.*

As a result, *Manual T* shows that if a space is heated with ceiling ductwork with a horizontal (parallel to ceiling) flow, there will be stratification of warm air near the ceiling (Figure 149). This is exactly the pattern seen at the meeting room.

> *During heating, the total air pattern that is associated with horizontal discharge diffusers tends to cling to the ceiling and a large stagnant region develops below. This can cause a very noticeable temperature differential between the floor and the ceiling. In cold climates the combination of slab construction and ceiling terminals may result in unsatisfactory comfort at the foot/ankle level.*

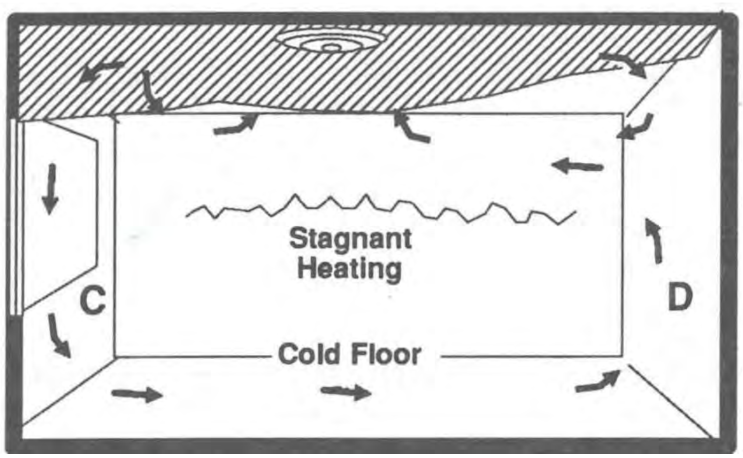


Figure 149: Horizontal ceiling discharge effect on heating pattern and stratification (ACCA Manual T)

In contrast, using vertical throw ceiling diffusers can break up the stratification pattern, mixing the air. However, the velocity of the air hitting occupants can result in comfort complaints:

> *During heating, round or square diffusers located in the interior of the room can provide a desirable total air pattern but drafty conditions will occur if the jet of primary air penetrates into the occupied zone. Therefore, the benefit of using higher jet velocities to get the air down to the floor is offset by the tendency of the higher velocities to create drafts. For this reason, these types of diffusers are only recommended when comfort considerations are not of primary concern, such as a warehouse heating application.*

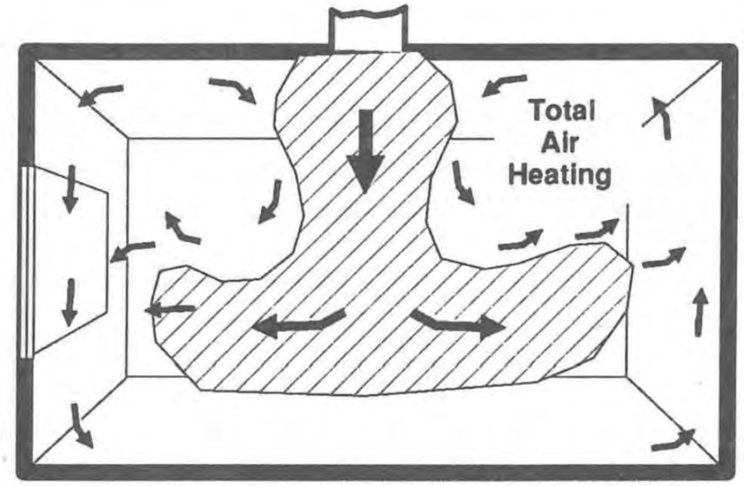


Figure 150: Vertical ceiling discharge effect on heating pattern and stratification (ACCA Manual T)

If the one-story wing ceiling diffusers are changed to vertical discharge diffusers, the vanes should be directed to “throw” air downward and towards the exterior walls. This will hopefully direct air away from directly landing on occupants. In addition, if the airflow pattern “adheres” to the exterior wall, it will have a longer throw, and will therefore be more likely to break up the stratification pattern:

Takeaway: switching the ceiling registers from horizontal to vertical throw units will help break up thermal stratification. Downsides include some risk of comfort issues (if the “jet” of air lands on occupants), and impaired cooling performance. Improving thermal performance (e.g., reducing air leakage) will reduce stratification.

Retrofit Recommendations

Action items recommended at the one-story rear wing include:

- Examine the attic for indications of the source of the water issues seen at the interior partition wall
- Consider a retrofit of HVAC-1, to reduce outside airflow in proportion to occupancy. Options include a CO_2 sensor (occupancy-based) or a CFIS controller and motorized damper (timer-based).
- Replace the ceiling diffusers at the meeting room, switching from horizontal “throw” to vertical “throw” units, in order to break up stratification.

11. Elevator Machine Room

Initial Observations

A consistent complaint at the elevator machine room (Figure 151) is cold temperatures in wintertime; a small electric space heater is located in this room, despite the heat generated by elevator machinery.

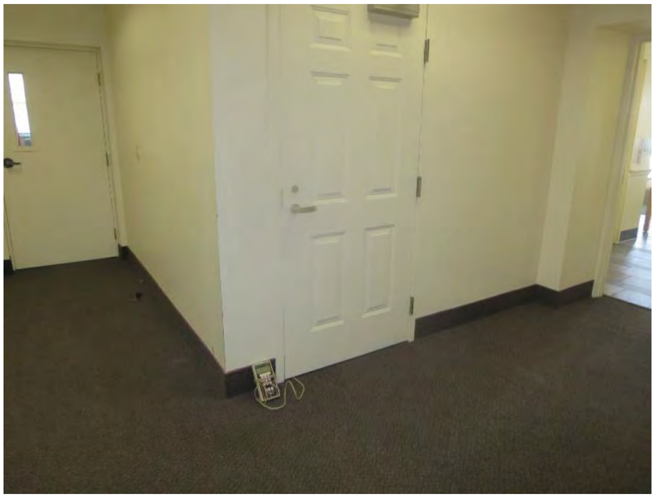


Figure 151: Elevator machine room from hallway

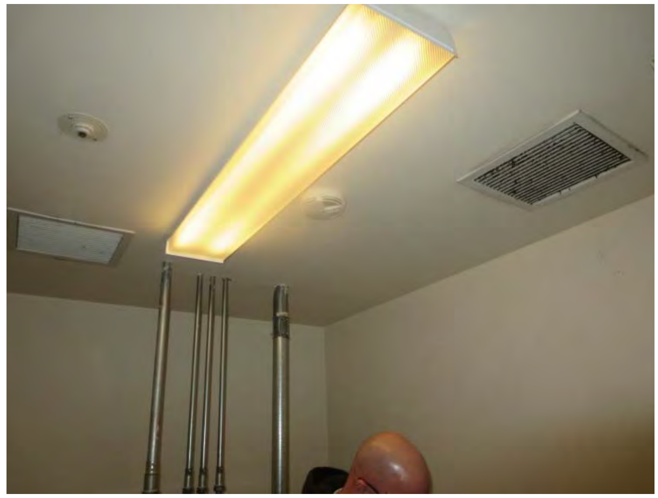


Figure 152: Elevator machine room ceiling registers

The ceiling of the elevator machine room has two ceiling registers (Figure 152). Based on the 2001 mechanical plans (Figure 154), the elevator machine room is ventilated by a rooftop exhaust fan and a relief duct with a motorized damper (Figure 153). The exhaust fan is controlled by a wall-mounted thermostat: when the elevator machine room exceeds a certain temperature, the fan runs to cool the space with outdoor/ambient air.

Figure 153: Rooftop fan and exhaust opening

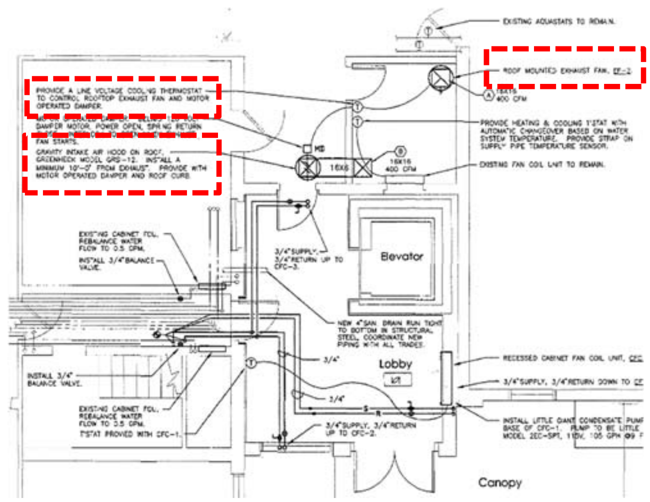


Figure 154: 2001 Mechanical plan; fans highlighted

Pressure and Infrared Observations

An infrared observation of the elevator room ceiling revealed cold conditions at both of the ceiling registers (Figure 155), with the exhaust fan not in operation.

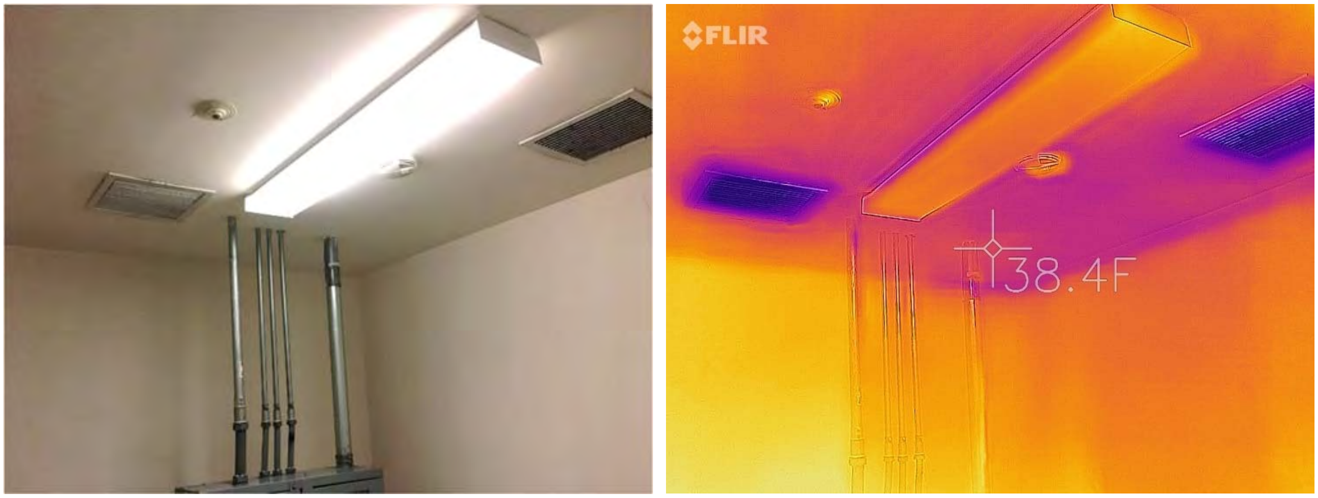


Figure 155: Visual and infrared image of elevator machine room ceiling; inward airflow at both ceiling registers

Conditions at these registers were examined more closely with the hot-wire anemometer (Figure 156). Airflow was below the meter's detection limit (40 FPM), but cool air was distinctly felt "falling" from these ceiling registers, at 50°F or colder. This is consistent with outside air being pulled into the machine room, due to building negative pressures. It also suggests that the motorized dampers are ineffective at sealing against outdoor air.

The pressure of the elevator machine room relative to the hallway was measured with the fan on and off (Figure 157). Surprisingly, the room was positively pressurized (+4 Pa) with the fan on, compared to +2 Pa fan off. This suggests that the rooftop fan is configured to supply air rather than exhaust air.

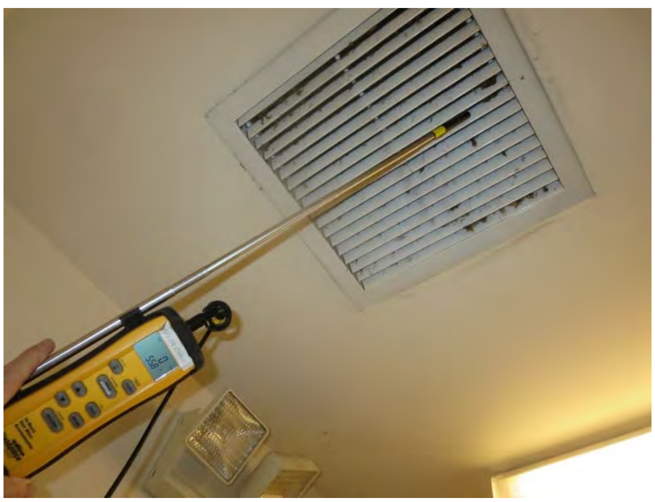


Figure 156: Air velocity measurement at ceiling grille

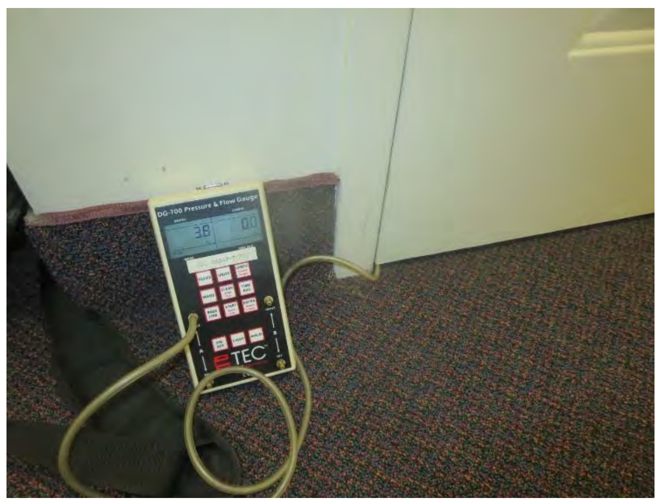


Figure 157: Pressure measurement. elevator mach. rm

Retrofit Recommendations

At a minimum, the fan system should be inspected, to ensure that motorized dampers are installed, and operating properly with fan operating (opening/closing and sealing tightly).

As an alternate system, the elevator machine room could be conditioned with a mini-split heat pump (MSHP) head, which would eliminate this cold air leakage problem. The ductwork would ideally be sealed off in an airtight manner and abandoned in place.

12. Follow-On Work

Meeting Participation

Building Science Corporation could participate in further discussions with the Town of Suffield, if our input is warranted. For instance, discussing this report with the Permanent Building Committee might be useful. However, extended meetings move beyond the original proposed scope of services. Additional services could be contracted using the hourly billing clause in the original agreement (cited below). Kohta Ueno is a Senior Associate I.

> *Any additional or follow up work will be billed at the hourly rates listed below, separate from the fixed fee. Hourly rates are valid through to the end of the 2019 calendar year, after which the rates may be subject to change. Expenses are separate from the hourly rates listed below.*

2019 BSC Hourly Rate Schedule	*$300/hour (Principals)* *$225/hour (Senior Associate I)* *$200/hour (Senior Associate II)* *$150/hour (Associates)*

Participation in a meeting on site will require budgeting of travel time (roughly 3.5 hours) plus the actual meeting time and associated follow-up; scheduling may also be an issue. As an alternate plan, BSC could participate in a screen sharing GoToMeeting, thus eliminating travel time while still allowing presentation of visuals. This assumes that the team can assemble and gather at a speakerphone, with a networked computer and large screen.

Architectural Plan Review

BSC commonly provides architectural plan review services for owners, architects, builders, and other clients. This is typically a review and markup of an architectural plan set, with recommendations on improving details to avoid durability and moisture problems. Further description of this type of consulting is here:

- Building Performance and Enclosure Consulting
  https://www.buildingscience.com/service/building-performance-and-enclosure-consulting

BSC would typically budget $4000-5000 for a plan review, depending on the scope of the project. If the review requirements are more limited, we could likely provide some review services under the hourly agreement described above.

13. Additional Resources

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

- 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 102: Understanding Attic Ventilation
  http://www.buildingscience.com/documents/digests/bsd-102-understanding-attic-ventilation/
- Building Science Digest 103: Understanding Basements
  http://www.buildingscience.com/documents/digests/bsd-103-understanding-basements
- Building Science Insight 005: A Bridge Too Far
  http://www.buildingscience.com/documents/insights/bsi-005-a-bridge-too-far/
- Building Science Insight 095: How Buildings Age
  http://buildingscience.com/documents/building-science-insights/bsi-095-how-buildings-age
- IRC FAQ: Conditioned Attics
  http://www.buildingscience.com/documents/guides-and-manuals/irc-faqs/irc-faq-conditioned-attics
- Attic Air Sealing Guide and Details
  http://www.buildingscience.com/documents/guides-and-manuals/gm-attic-air-sealing-guide/view
- A Crash Course in Roof Venting
  http://www.buildingscience.com/documents/published-articles/pa-crash-course-in-roof-venting/view
- Information Sheet 610: Central Fan Integrated Ventilation Systems
  http://www.buildingscience.com/documents/information-sheets/information-sheet-ventilation-system