Adding Air Barrier and Thermal Improvements to Existing Facilities

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ABSTRACT

Many existing buildings were constructed before current energy and building codes required a continuous air and vapor barrier and exterior insulation. In an effort to improve the thermal performance and interior air quality of these facilities, many building owners are looking to upgrade their existing infrastructure. The presenter recently completed evaluations of several existing higher-education facilities with a focus on improving the exterior building enclosures. The presentation will provide an in-depth examination of design considerations with a focus on addressing ongoing air and moisture infiltration caused by the lack of continuous air barriers and thermal insulation. The presentation will discuss unique solutions to improve overall building performance and aesthetics and coordinate construction in an occupied facility.

SPEAKER

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ADDING AIR BARRIER AND THERMAL IMPROVEMENTS TO EXISTING FACILITIES

In the United States, buildings consume about $200 billion in energy costs each year, representing a significant portion of our nation’s energy use and carbon footprint. While the energy efficiency of new buildings has improved dramatically over the last two decades, more than 70% of the building stock in the U.S. is over 20 years old and does not meet current insulation or air infiltration requirements. Any improvements to thermal performance of these buildings will help with overall energy conservation. In addition to conserving energy, retrofitting an existing building is often more cost-effective and a more sustainable approach than constructing a new building. Upgrades can extend the service life of the structure, increase the asset value, and contribute to a healthier, more comfortable environment for occupants. In taking the long view, many leading U.S. corporations and universities, as well as federal, state, and local governments, are committed to reducing energy use across their portfolios by 20% over the next 10 years.¹

Over the past several years, the author has been involved with multiple projects involving the installation of air barriers and thermal insulation over a variety of existing construction types, ranging from solid masonry and concrete to stud-framed buildings. Each building type has its own performance characteristics and concerns that need to be addressed prior to performing building enclosure upgrades.

The first step with any building enclosure modification is to understand the condition of the existing assembly and how it currently performs. It is important to note that no two walls are the same, and their current condition will vary based upon wall design, quality of original installation and materials used, weathering, the function of the space being enclosed, and level of proactive maintenance.

When an air barrier or insulation is added to an existing assembly, the wall’s performance and how it interacts with moisture, air, and temperature will change. Understanding how modifications will affect the existing assembly and whether the existing assembly can manage the new building physics is critical. The condition of the existing building wall will dictate the level of modifications the building can handle and what repairs may need to be performed prior to initiating thermal improvements.

This article will detail the factors that must be taken into account with various types of building wall assemblies, including:

- Masonry
- Precast concrete panels
- Metal stud-framed
- Wood-framed

MASONRY WALLS

Throughout the United States, many older solid masonry structures are being renovated to improve energy efficiency and comfort. The installation of interior thermal insulation is frequently one of the only possible solutions for thermal upgrade of the building envelope when the exterior appearance cannot be changed.

In an effort to study methods of interior insulation retrofits, Gale performed a study for a Boston-area university on three dormitory housing projects. The three dormitories, constructed in the 1920s and 1930s, were of similar architectural styles, massing, construction techniques, and materials. The buildings are composed of load-bearing brick masonry and terra cotta walls with plaster interiors, sloped slate roofs with dormers, and multi-lite double-hung wood windows. In recent years, the original uninsulated masonry wall assemblies at two of the buildings were both renovated, insulation was incorporated into the wall systems, single-pane wood windows were replaced with double-hung insulated wood assemblies, and the roofs were replaced.

Gale performed nondestructive visual survey, an infrared (IR) survey, and a Wärme und Feuchte instationär (WUFI)² analysis to determine whether the renovated wall systems function adequately with respect to dew point location and moisture accumulation over time. Additional analysis was performed to provide a comparative study of the thermal performance of the three in-place wall assemblies.

The following is an overview of the wall assemblies and the results of our WUFI and IR analysis.

CASE 1: ORIGINAL 1930S CONSTRUCTION

The unrenovated wall assembly consisted of solid load-bearing masonry composed of an exterior wythe of brick masonry (Figure 1), an approximately 7-in.-thick terra cotta infill, and interior plaster walls.³ The construction represents a fairly common transitional-period, load-bearing wall system that undergoes consistent wetting and drying cycles. As there were no vapor barriers in the system, the wall was able to seasonally adapt and dry from the interior or exterior of the assembly (depending on which side was heated), limiting the potential of condensation and frost inside the walls. The WUFI simulation indicated that the overall water content of the system was undergoing a consistent wetting and drying cycle. Over the five-year analysis period, the water content of each of the materials, as well as the overall water content of the assembly, decreased. While this type of wall system is not optimal in terms of energy efficiency, it performs well hygrothermally over

[Figure 1 – Typical solid masonry wall dormitory.]
time and has a good track record when maintained.

**CASE 2: RENOVATED ASSEMBLY WITH SPF**

The renovated wall assembly consisted of solid load-bearing masonry, comprised of an exterior wythe of brick masonry, an approximately 7-in.-thick terra cotta infill, a 1-in.-thick application of closed-cell spray polyurethane foam (SPF), a 1½-in. metal stud wall, and gypsum interior sheathing. The WUFI simulation indicates the dew point occurred within the SPF layer. The water content of the overall assembly showed an adequate performance, with the overall water content of the system undergoing a consistent wetting and drying cycle with minor accumulation of moisture over the five-year cycle in the brick masonry and terra cotta. Provided that there are no vapor barriers on the outside face of the insulation (only an air barrier was reported), these conditions will allow for the insulation to dry out to the exterior.

The addition of an air barrier in a solid masonry wall system (to which insulation is added) is recommended to minimize the water vapor transport through exfiltration air through the wall. Although closed-cell SPF insulation can act as a vapor barrier, the thickness of SPF applied in this case was not sufficient for it to function as a complete vapor barrier, allowing some inward drying potential (Figure 2).

As WUFI is only capable of accounting for a “perfect” continuous wall system, it does not account for areas where insulation may not have been continuously applied, particularly at transitions, such as around floor joists/slabs, window perimeters, etc., which could result in air exfiltration and moisture infiltration at these areas (Figure 3). Furthermore, WUFI “assumes” that the masonry/terra cotta wall to which the SPF was applied is in “perfect” condition and any defects such as cracked or spalled brick, mortar deterioration, etc., have been repaired. The integrity of the exterior masonry wall system is important, as the lack thereof could increase the bulk-water accumulation within the masonry wall and potential for freeze-thaw damage due to the change in the temperature gradient as a result of the added insulation.

**MASONRY WALL SUMMARY**

The addition of insulation within a solid masonry assembly results in a shift in the temperature gradient and the natural wetting and drying cycles of the wall. Without the correct placement and correct physical characteristics of the air barrier, insulation, and vapor-permeable layers, newly insulated walls can experience moisture accumulation through condensation that results in frost within the wall and leads to deterioration of the new interior wall components and original wall assembly. As can be illustrated with the three dormitories, the original construction exhibited superior hygrothermal performance compared to the two renovated structures but lacked an air barrier and thermal efficiency.

The thermographic analysis indicated that the renovated buildings experienced less heat loss than the uninsulated building. It is important to note that some areas—such as at building corners and primarily at changes in plane of building elevations (i.e., areas adjacent to stairwells) and around floor slabs—can be difficult to thermally isolate from the interior, causing thermal bridging through the newly installed insulation. This project and other similar projects indicated that SPF insulation provides the best thermal break to the exterior wall assembly while also controlling the movement of water vapor via air transport. The use of 1 in. of closed-cell SPF insulation is preferred over the batt insulation with a vapor barrier, as it will still allow drying to the interior. Unlike batt insulation, closed-cell SPF is an air barrier and will reduce the possibility for moisture from contacting or infiltrating into occupied space.

It is important to note that a hygrothermal analysis must be performed on
each individual wall system to determine the appropriate insulation thickness and determine what types of barriers should be considered. Evaluating the exterior masonry surfaces to identify all masonry defects (cracked or spalled masonry and open or cracked mortar joints) is necessary so that repairs can be performed prior to performing interior energy upgrades.

**PRECAST CONCRETE PANELS**

In January 2014, a Boston hospital retained Gale to investigate significant interior condensation occurring in and around patient suites. This 16-story concrete structure, comprised of exterior precast concrete wall panels with punched aluminum window openings, was constructed in 1979. The original installation included 1 in. of expanded polystyrene (EPS) insulation installed against the interior face of the precast concrete panels. Subsequent interior modifications include removal of this insulation and the installation of 2 in. of mineral wool insulation. This noncontinuous insulation layer is interrupted by metal hat channels secured to the backside of the precast panels to support the gypsum wallboard. A reinforced polyethylene sheet product was installed between the furring and the interior gypsum sheathing.

Test cuts performed at the exterior walls revealed the mineral wool to be damp, with moisture condensing and running down the inside face of the precast concrete panel. Further test cuts showed that the interior polyethylene vapor barrier was not installed in a continuous manner, seams were not taped, and large openings were left around mechanical and plumbing penetrations. Like most hospitals, the interior was slightly pressurized, driving warm, humidified air through gaps and voids into direct contact with the precast concrete wall panels. This resulted in the development of excessive amounts of condensation.

With the assistance of single-point data loggers, the interior conditions were found to range from 67.8°F to 71°F, with RH ranging between 42% and 55%. Exterior temperatures ranged from 14°F to 24°F. The data logger analysis was performed using a battery-powered digital thermometer data logger meter. These meters display and store temperature readings from the thermocouple temperature probes that are attached to various surfaces and exterior wall components. Figure 5 shows where the thermal probes were placed:

1. Interior surface of the precast concrete panel
2. Interior surface of the interior gypsum wall board
3. Surface of the steel support angle for the precast panels at the floor above

*Figure 5 – Locations of thermal data logger probes.*

Figures 6 and 7 chart out the temperatures logged. As shown in these graphs, the temperature readings of each of the probes fluctuated along the same ranges as the exterior temperatures. Note that the exterior temperatures are taken from the Logan International Airport Weather Station, approximately five miles from the site. The graphs clearly show that the temperature of the interior surfaces of the precast concrete panels exhibited temperature readings that followed closely to those of the exterior temperatures. The difference in temperature between the exterior and the interior side of the precast panels ranged from approximately 20°F down to only a 5°F temperature difference. It is worth mentioning that the most significant condensation was occurring in a suite on the north side of building but the temperature data loggers were performed from a suite on the south side due to room usage. On March 6, 7, and 8, the temperature peaks recorded are due to solar heat gain experienced on the south elevation.

Based on information presented by the building facility staff and documented during multiple site visits, condensation typically occurs in the building when there are back-to-back days where the exterior temperatures are below 30°F. Due to the exterior wall construction and lack of insulation, the concrete wall temperature is cooled below the interior dew point during prolonged periods of cold temperature. Gaps and voids in the interior air barrier allow warm interior humidified air to come in contact with these cold surfaces, resulting in water vapor condensation. Similarly, the existing windows, which were nonthermally broken, incurred similar condensate issues.

Several interior and exterior insulation
options were considered, but the client preferred an interior retrofit that would allow thermal modifications to be performed at each floor over an extended period of time. Gale performed thermal and hygrothermal modeling analysis utilizing THERM Finite Element Simulator, Version 7.3, developed at Lawrence Berkley National Laboratories with support by the U.S. Department of Energy, and WUFI to perform one-dimensional hygrothermal analyses by transient modeling.

Since the existing window systems were considered in poor condition and beyond their serviceable life, new thermally improved aluminum curtain wall assemblies, suitable for high-rise building applications, were recommended. The proposed interior-glazed curtain wall system will have thermal separators and insulated glazing for increased thermal performance. More importantly, the window opening will be slightly reduced to allow for thermal isolation of the window from the surrounding concrete panels, contributing to cold conductivity and resultant condensation.

Currently, the existing aluminum window frame is in direct contact with the uninsulated concrete panels. By reducing the window dimensions, a thermal break and insulation will separate the window frame from the concrete panel to achieve higher thermal performance.

It should be noted that the installation of insulation upgrades to the exterior of the façade would provide the best thermal performance, as thermal bridging through the existing cladding and structural elements can be significantly reduced. Similar to the masonry buildings previously discussed, the increased cost and change in building appearance can make this option infeasible. Instead, an internal spray-applied insulation option is often the most cost-effective option. In this case, installing spray-applied insulation over the existing precast concrete panels was the best option. The main advantage of using SPF is that it creates a continuous and seamless air- and vapor-impermeable thermal barrier between the interior and exteriors of the building envelope, with a high level of reliability.
MODELING

As part of the design phase for the high-rise, precast concrete wall panel construction, several hygrothermal models and two-dimensional modeling were performed for the exterior wall. The following is an overview of the wall assemblies and the results of our WUFI and thermal analyses.

Assembly 1:
The wall assembly modeled in this case is based on the existing nonthermally broken aluminum windows within the original exterior wall construction, consisting of the following components, listed from the exterior:

- 8-in.-thick precast concrete panels
- 1-in. EPS, with periodic vertical furring strips
- Vapor barrier (noted to be noncontinuous and open at penetrations)
- 5/8-in. gypsum wall board, painted

At the interior face of the insulation, the RH passes 80% briefly (Figure 8). Typically, if the humidity surpasses 80% for prolonged period of times, corrosion of metal framing can occur. While the model did not indicate this being an issue, it was in close proximity to a dangerous range where risk could be increased if the vapor barrier was not completely continuous and allowed additional moisture within the system. Figure 9 indicates the interior gypsum wallboard surpassed 70% RH, a trigger point for mold growth during the summer months.

The key performance of this wall is dependent on the vapor barrier remaining in good condition. While the insulation maintains the interior wall surface at a higher temperature, it also reduces the temperature of the interior surface of the concrete. Should moist interior air hit these colder surfaces, condensation could occur. The thermal conductivity of the precast concrete panels is also virtually unchanged around the window opening.

Assembly 2:
The wall assembly modeled in Figure 10 had the existing nonthermally broken aluminum windows within the existing exterior wall construction with prior interior modifications. The assembly consisted of the following components, listed from the exterior:

- 8-in.-thick precast concrete panels
- 2-in. mineral wool insulation, with periodic vertical furring strips
- Vapor barrier (noted to be noncontinuous and open at penetrations)
- 5/8-in. gypsum wall board, painted

The modeling indicates the thermal performance occurs on the interior at the insulation layer. The continuity of the interior vapor barrier is critical to the success of this wall assembly. The interior face of the concrete wall is significantly cooler than the interior temperature. When a six-air-change-per-hour air leak was introduced through the interior finishes and vapor barrier, the wall assembly collected significant moisture content each winter (Figure 11). Figure 12 indicates a significant period of time that condensation can occur (areas indicated by 100% RH each winter) at the interior concrete surface. This includes potential condensation within the mineral wool and metal framing layer.
Assembly 3:

The wall assembly modeled in Figure 13 has a new thermally broken aluminum curtain wall system with the wall construction consisting of the following components, listed from the exterior:

- 8-in.-thick precast concrete panels
- 2\(\frac{1}{4}\) in. SPF
- 5/8 in. gypsum wall board (painted) on 2-in. metal studs, set minimum 1\(\frac{1}{2}\) in. off face of precast

The new SPF insulation installed to the interior surface of the precast concrete panels provided a thermal barrier between the conditioned interior and the concrete wall panels. Since the product was spray-applied, it could be installed continuously around existing objects and uneven surfaces. One item of concern was the depth of the metal studs. The greater the offset, the less thermal bridging was caused. While modeling the SPF assembly in Figure 14, at ¾ in. of thickness, there was still the potential for RH above 80%, which could cause corrosion of metal items. At a depth of 1\(\frac{1}{2}\) in., the chance for corrosion was reduced (Figure 15). Therefore, we recommended an offset of 1\(\frac{1}{2}\) in. for the metal studs. The humidity continued to moderate moving towards the interior surface of the room (Figures 16 and 17).

The use of new thermally efficient fenestration and the...
SPF insulation provided a thermal barrier that maintained a continuous barrier around the interior. The new curtain wall frames were held off the concrete to reduce thermal bridging. While they were warmer than the old windows, they were still the weak location in the assembly. As indicated in Figure 11, when it is below 10ºF outside, the window frames could be expected to be in the low 40s, requiring the interior temperature and humidity to be reduced to 68°F and 30% RH to eliminate any risk for condensation to occur on the aluminum frames.

Assembly 4:
The wall assembly modeled in Figure 18 had a new thermally broken aluminum curtain wall system with the wall construction consisting of the following components, from the exterior:

- 3-in. exterior insulated finish system (EIFS)
- 8-in.-thick precast concrete panels
- Periodic vertical furring strips
- 5/8 in. gypsum wall board, painted

Figure 18 represents a new thermally efficient curtain wall assembly installed within the existing punched opening of the precast concrete panel construction. Additionally, a new EIFS had been installed on the exterior surface of the precast concrete panels, and finishes installed on the interiors. EIFS was modeled due to lack of complexity, but a similarly exterior insulated cladding system would be expected to perform similarly. Note the thermal conductivity and temperature differentials are now moved towards the exteriors instead of the interiors (Figure 19). When installing an exterior insulating system, the thermal and moisture issues are shifted out to the exterior insulation layer, which is outboard of the drainage plane and structural members. Over the long term, this would provide the longest-lasting assembly. While it may require periodic maintenance to maintain the new exterior cladding, the structure and the interior environment would be isolated from the exterior weather and could be expected to last longer than with an interior option.
METAL-STUD FRAMED WALLS

Unlike masonry and concrete walls, metal stud-framed walls have less moisture storage capacity than wood-framed or masonry walls, so the margin for error is drastically smaller. In this case, the addition or omission of a vapor retarder is more critical. Continuous exterior insulation is preferred to reduce thermal bridging caused by metal studs (Figure 20). Older metal-stud buildings typically have minimal exterior continuous insulation. For instance, continuous insulation was not a code requirement until the adoption of the 2006 International Energy Conservation Code. Older walls experience significant overall insulation R-value loss due to the thermal bridging caused by the metal studs, reducing effective R-values to 55% of the stated value on the label.6

For instance, an R-15 batt installed within a 3.5-in. stud wall results in an effective R-value of only R-6.4, while an R-21 batt installed within a 6-in. stud has an effective R-value of R-7.4.6 By increasing the exterior insulation, the thermal barrier shifts outward, as does the potential dew point. Depending on the new cladding being utilized, you can move to an assembly closer to those now used in new construction. These assemblies consist of an exterior cladding and air space, continuous insulation, an air and vapor barrier, exterior sheathing, metal stud walls, and existing interior finish. The removal and replacement of the exterior sheathing allows the engineer to review the condition of the metal studs and removal of the existing batt insulation. The moisture-damaged insulation and deteriorated studs will likely require replacement. If the existing stud cavity insulation is not removed, a thermal analysis should be performed to confirm that the dew point will remain outside of the air and vapor barrier. A vapor-permeable barrier is another consideration.

On a recent project involving an international corporation’s headquarters, the exterior siding was found to be in poor condition and near the end of its useful life. During the design phase, an infrared (IR) survey indicated significant air leakage and thermal bridging (Figure 21). To address these issues, the proposed wall assembly included a vapor-permeable air barrier, exterior continuous insulation, and a fiber cement wallboard to replicate the traditional New England clapboard style of the original building (Figure 22).

Since the project maintained the existing interior finishes and exterior sheathing, the existing batt insulation remained in place. This required using a vapor-permeable air barrier to allow drying potential inwards and outwards. A continuous layer of rigid insulation was installed outboard of the new air barrier. Vertical furring was added to provide a venting cavity behind the siding. When insulating the exterior in this manner, it is important to provide additional blocking around the windows to accommodate the thickness of the insulation. Additional considerations are needed with regard to the fastening of the furring and siding to comply with wind loading.