TOOLS AND METHODS OF ANALYSIS:

Insulation Retrofit in Adaptive Reuse of Early 20th-Century Industrial Buildings

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ABSTRACT

Focusing on the building enclosure and analysis tools and methods, this paper presents recent projects in the Boston area where early 20th-century industrial buildings were analyzed to predict future performance and potential distress with the installation of insulation. These case studies illustrate how hygrothermal analysis, close-up investigation, and laboratory testing of enclosure materials have been used to predict the deleterious effects of modifying building interiors with insulation. These projects helped guide design decisions by evaluating potential freeze/thaw damage, the possibility of mold growth at building interiors, potential corrosion of embedded metals, and the effects these conditions have on durability of enclosure materials.

INTRODUCTION

There is an inherent challenge in repurposing buildings to ensure that energy efficiency requirements are met and thermal comfort of new occupants is accommodated. While historic stout and robust structures often demonstrate their durability in the long-term performance of the concrete and masonry materials of which they were constructed, these characteristics often represent challenges when designing for occupant comfort in adaptive reuse projects.

The aging industrial building stock was designed with a focus on meeting structural capacity demands to house the production of materials or storage of goods rather than the thermal comfort of the occupant. Heat-generating activities may have partially alleviated the concern for ensuring that workers were kept comfortable; however, history demonstrates that owners and managers of such facilities generally focused on production and profit rather than occupant comfort. Similarly, one may speculate that maintaining the enclosure of such facilities was a secondary concern to meeting production demands. While typically well-constructed, the original design intent of industrial buildings did not consistently yield enclosures built of high-quality materials. In addition, concern for building energy consumption was not a priority when these buildings were constructed.

The effects that energy performance modifications have on the long-term performance of mass masonry brick and concrete structures are becoming increasingly relevant as more buildings are being retrofitted for office or residential use. Occupant comfort and the condition of exterior enclosures arise as concerns for producing a healthy repurposed building stock. This paper explores some of the tools and methods used in the analysis and design of insulation retrofits to existing enclosures in heating-dominated climate regions for adaptive reuse of such buildings.

THE INSULATION RETROFIT

The change in use of a structure requires that modifications be constructed to comply with current codes, including health, safety, welfare, and energy requirements. Energy codes require a stated amount of R-value for various components of buildings, so why are there no straightforward answers to these questions?

- "What type of insulation should I install?"
- "What is the optimum thickness of new insulation for walls?"

Repurposed buildings present challenges.

While commonalities exist within similar climate zones, a primary challenge with insulation retrofit design includes consideration of the inherent characteristics of the enclosure materials specific to individual buildings. The industry can benefit from evaluating how existing retrofits are performing and learn from successes and failures. The careful consideration and analysis of insulation retrofits can help prevent problems associated with freeze/thaw damage, corrosion, deterioration of metal and wood components embedded within walls, condensation, and mold growth. The presence of one or more of these conditions can cause irreversible damage to the historic fabric of a building, compromise the integrity of concealed anchorage within walls, and subject occupants to potentially toxic interior environments. See *Figure 1*.

- "Is it safe to insulate the interior walls of the building?"

With few exceptions, there are very limited rule-of-thumb answers to these questions within most of North America. Our diverse climate, spanning a large geographic area, represents unique challenges to insulation retrofits. Insulation design is complicated by the wide range of exterior climate conditions experienced across the continent. This includes variations in relative humidity (RH), temperature, and precipitation as it relates to freeze/thaw potential. The type of building construction, use, and geographic location impose vastly different heating and cooling requirements. Therefore, what works to control interior environments within a repurposed building in one climatic region may not be as successfully applied to other regions.

Figures 1A and 1B – Plaster damage occurred after insulation was installed above the domes.

BUILDING SCIENCE 101

Industrial buildings built in the early decades of the 20th century were often constructed with uninsulated mass masonry or composite enclosures. Without a distinct drainage plane, mass masonry walls manage exterior moisture by absorbing moisture during colder and wetter periods and releasing that moisture during dry periods. The porous masonry material safely stores moisture until warmer, drier exterior conditions allow moisture redistribution and transport out of the system. While mass masonry enclosures can provide thermal mass benefits in some locations, in heating-dominated climates like the northeastern U.S., these enclosures should be insulated as part of an overall building rehabilitation.

When considering insulation of mass masonry enclosures, the best solution is to insulate at the exterior. Exterior insulation reduces condensation risks and provides protection to the masonry, thus increasing the overall durability of the enclosure. However, exterior insulation is not an option for all adaptive reuse projects. Constraints such as designer intent or historic preservation concerns often prevent placing the insulation layer on the exterior. In these situations, insulating at the interior is necessary to meet thermal comfort needs and energy code requirements, and to preserve historic appearances.

Introducing interior insulation to a mass masonry enclosure may result in some negative consequences. At the exterior, the outer materials of the façade will experience a greater temperature range. During winter months, the walls that were previously heated from the interior will become colder and wetter, as they are more thermally isolated from the interior. During summer months, the same walls that may have experienced drying through exposure to cool, dry, conditioned air will now be isolated from this drying mechanism. The overall drying efficacy of the insulated moisture management system is affected as colder and wetter masonry reduces exterior evaporation; and at the interior, the presence of vapor-impermeable layers of insulation restricts drying of the interior. The result is a wall system that during the winter experiences colder temperatures and higher moisture content levels. These conditions increase the risks for material damage from freeze/thaw cycles, corrosion of embedded metals, and deterioration of wood members such as timber-frame beam ends that are pocketed into the masonry wall.

Another risk—perhaps of more importance to building occupants—is condensation at the interior that can lead to mold growth and potential health hazards. If the interior insulation layer is not installed to be airtight, then warm air from the interior that comes in contact with the now colder masonry will condense at the interface between these two materials. Generally, interior insulation is concealed behind conventionally framed stud walls that are furred from exterior walls and finished with gypsum wallboard. Therefore, condensation within or behind the new interior cavity wall could go undetected until secondary conditions such as mold or deteriorated interior finishes become visible. To minimize this risk, mitigating interior air circulation between the insulation and the interior face of the wall is essential when insulation is placed at the interior.

Efforts should be made to specify insulation that minimizes air leakage. An airtight insulation layer will not only reduce the movement of air from warmer interior zones across the insulation but will also minimize the space between the insulation and the masonry where condensation could occur.

INSULATION RETROFIT DESIGN CHALLENGES

Addressing the obvious challenges associated with modification of such buildings lends itself to using available models and simulations to predict problematic conditions. Unlike building energy performance modeling that considers energy consumptions for whole buildings, there are no analogous tools that model and simulate the combined performance of building enclosures with respect to heat, air, and moisture control, and interaction with the surrounding and transient climate. Instead, the industry is predominantly using tools that simulate the moisture and heat transfer response of limited areas and conditions.

Two commonly used simulation soft-

Figures 2A and 2B – Former warehouse rehabilitated for offices (below left); steel column and concrete-encased steel beam located at exterior wall can be thermal bridges (right).

ware programs that perform these functions are Wärme und Feuchte instationär (WUFI), developed by the Fraunhofer Institute for Building Physics (IBP); and THERM, developed at the Lawrence Berkeley National Laboratory. Both of these programs are discussed in the following sections.

The ideal modeling software would provide comparative results of existing and proposed modifications based on a combination of the following:

1. Accepts inputs of location-specific microclimate relative to the subject property (temperature, wind speed and direction, precipitation levels, RH, and horizontal solar radiation)
2. Establishes desired interior environment RH and temperature parameters (summer/winter; occupied/unoccupied)
3. Suggests the physical properties and condition of enclosure materials without extensive testing or knowledge of the materials
4. Considers the configuration of and physical properties of framing systems and members adjacent to enclosures
5. Considers the performance of specific window systems (existing or new)
6. Considers the effects that the ratio of opaque and glazed areas will have on interior conditions and energy costs
7. Compares insulation types and thicknesses as they relate to all of the above factors and considers other inputs such as anticipated occupant load and energy demands
8. At the click of a button, provides simulation results for the anticipated increase in the quantity of freeze/thaw cycles the enclosure will be subject to and includes a clear prediction of mold risk

In other words, we would not be having this discussion if there were simulation tools that enabled a user to accurately and efficiently model a diverse range of conditions that provided meaningful results relative to predicted performance of enclosures. Given the many and varying factors that influence enclosure design and performance in a rehabilitation, it is difficult to establish a singular and reliable approach or tool for this analysis. Until such tools become readily available, practitioners and owners of adaptive reuse projects must rely on a combination of known facts and predictions of available modeling software to resolve design challenges. These conclusions can have a lasting impact on the effects insulation retrofits will have on the performance of the enclosure.

The most readily available and common modeling software used for such evaluation specializes in hygrothermal analysis—the study of moisture storage and heat transport within building materials. Hygrothermal analysis provides information about moisture storage and transport within a system as a function of assumed material properties and climates. The data resulting from this analysis tool can provide predictions on the future performance of modified building enclosures. However, the

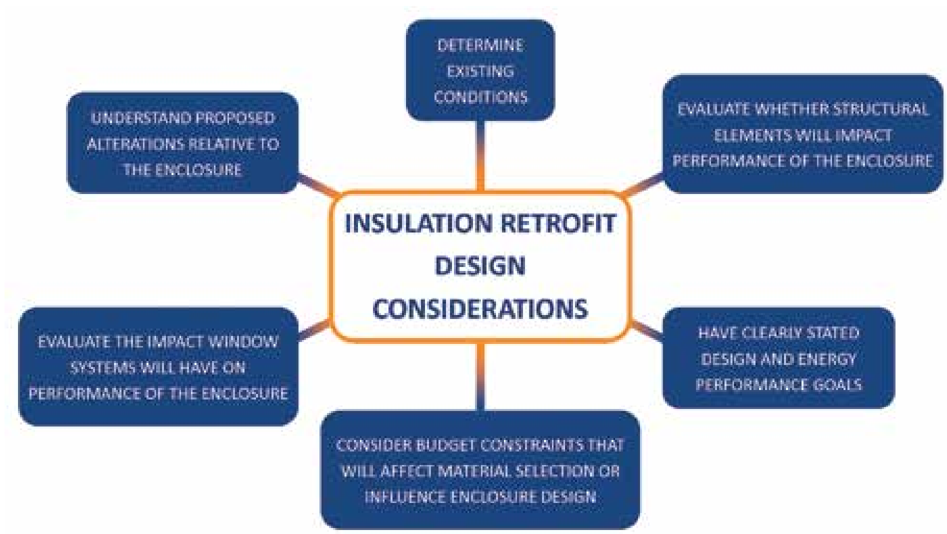


Figure 3 – Many factors must be considered during the course of designing insulation retrofits.

building enclosure consultant and design team must consider several components of the existing structure and proposed modifications so the findings can be appropriately interpreted.

DESIGN CONSIDERATIONS

There are many factors that require careful evaluation in order to produce meaningful conclusions from hygrothermal analysis:

- Perhaps most importantly, the team must have a firm understanding of the structure's existing conditions. Deferred maintenance is a condition typical of many industrial building enclosures. One may find that materials or assemblies have outlived their serviceable lives and require repair or replacement. Deficiencies in the enclosure materials or assemblies should be documented with the severity of conditions noted. The team must determine the extent of repairs required to address problematic conditions that will affect successful performance. The feasibility, cost, and aesthetic impact of executing repairs must be considered. This latter consideration is especially relevant if the property is located within an historic district or is a designated landmark.
- Proposed alterations or modifications to the enclosure must be understood. An example of a factor to consider would be the configuration and design of new window systems. Will they be smaller or larger than the existing windows (*Figure 2A*)? Will new window assemblies be thermally broken and contain energy-efficient glazing? How will the replacement windows be attached to the structure? Will the windows align with the plane of the new thermal barrier? Does the design require opaque glazing, spandrels, or insulated back pans?
- The proposed placement or configuration of existing or new structural elements must also be understood. For example, does the proposed design include installation of interior walls in close proximity to the enclosure? Are there steel elements such as lintels or columns that will act as thermal bridges (*Figure 2B*)?
- Similarly, proposed alterations to the mechanical system must be understood, particularly as they relate to performance of the enclosure. For example, will the ceiling be used as a plenum and affect the detailing required where exterior walls interface with ceilings?
- Lastly, budget limitations and design constraints must be understood to provide the project team with practical advice.
- A graphic representation of insulation retrofit design considerations is shown in *Figure 3*. All of these factors must be considered within clearly stated design goals. Recommendations for the insulation design can be greatly influenced by the omission of one or more of the factors identified above. The building enclosure consultant must have an understanding of project goals so recommendations can be effectively presented.

Figures 4A and 4B – Samples of each material comprising the exterior wall construction are prepared for the critical degree of saturation (S_{crit}) testing in a laboratory.

ANALYSIS TOOLS

When considering a design to insulate an existing load-bearing masonry wall, there are several pieces of information that can be gathered to inform decisions. Depending on the effort that can be expended, these methods or tools may be used singularly or together in some fashion. The choice of method or tool is dependent on the questions one is trying to answer. Interested in knowing if the exterior building materials will be damaged from increased freeze/thaw cycles when insulation is added to the interior? How much insulation can be added with minimal deleterious effects? Is the concern about the potential for condensation at the interior or risk of damage to metals embedded in the enclosure? The following is a discussion of the available tools often used to analyze insulation retrofits and how the results could be used to inform design decisions.

Existing Condition Assessment

An on-site assessment will provide information about the existing condition of uninsulated building materials and could inform predictions about material performance with the addition of interior insulation. At locations like parapet walls where the masonry material would have experienced more extreme temperature ranges similar to interior insulated conditions, assumptions could be made about the quality of the material. For example, a parapet constructed of brick masonry that exhibits significant freeze/thaw damage could indicate that brick in the body of the façade is at risk for similar distress after insulation is added to the interior. Evidence of water intrusion, eroded mortar, damaged or missing flashings, sealant failure, efflorescence, and corrosion of steel elements are conditions that indicate existing moisture management issues. These are conditions that would need thorough evaluation and should be remedied before interior insulation is considered.

Laboratory Material Property Testing

The objective with material sampling and laboratory testing is to assess the risks associated with applied interior insulation to existing masonry wall construction. Material properties derived from laboratory assessment of samples taken from the actual building can be used as inputs for computer-modeled simulations. Using project-specific material properties improves confidence in the simulation results, thus allowing for a better estimation of the impacts of adding interior insulation. It is useful to conduct tests to determine material properties such as dry mass, saturated mass, water absorption coefficient, and the critical degree of saturation (S_{crit}).

CRITICAL DEGREE OF SATURATION

The S_{crit} is derived from a test procedure known as frost dilatometry, where samples of materials removed from wall assemblies undergo laboratory-based freeze/thaw cycles (*Figure 4*). The S_{crit} provides information about the saturation of masonry materials at freezing temperatures and is

Figure 5 – WUFI simulation of an uninsulated wall assembly.

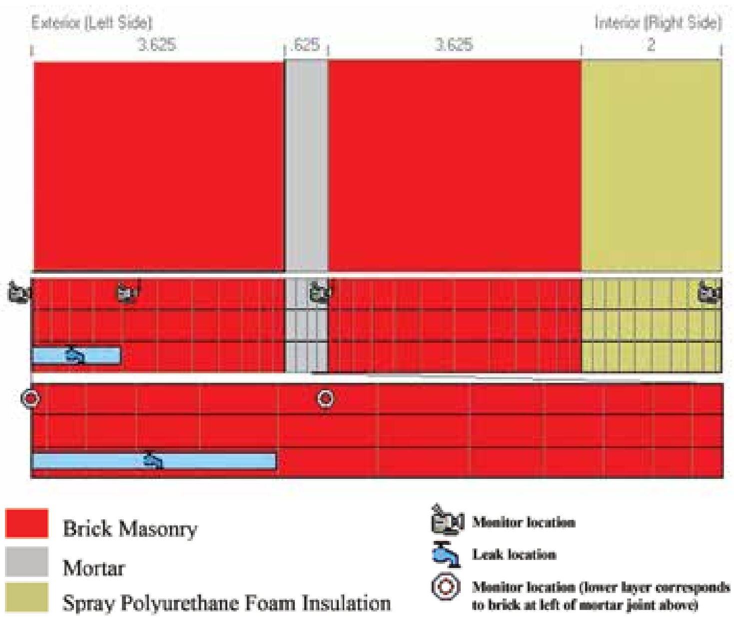


Figure 6 – WUFI simulation of a brick masonry wall assembly with 2-in. closed-cell SPF insulation.

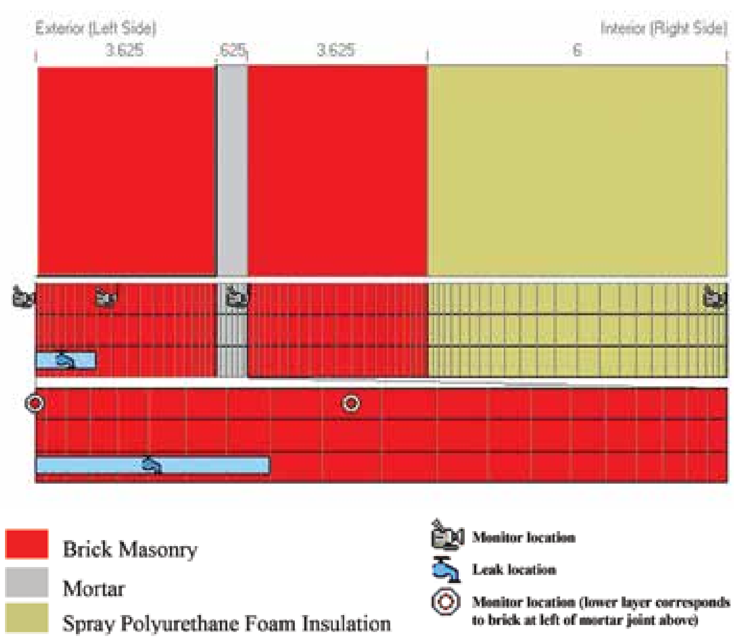


Figure 7 – WUFI simulation of a brick masonry wall assembly with 6-in. closed-cell SPF insulation.

a material characteristic that represents a threshold moisture content above which the material will be seriously damaged by freezing. At moisture content levels below S_{crit}, it is expected that even after repeated freeze/thaw cycles, no damage will occur to the material.

Once calculated, S_{crit} can be compared to moisture content levels generated from simulated materials and conditions. For example, a WUFI analysis provides moisture content levels over time and at various temperatures. The S_{crit} of the existing material could be compared to the simulated moisture content of the modeled material under insulated conditions. If the moisture content of the simulated material is below the measured S_{crit} at freezing temperatures, then one could infer that the addition of interior insulation is not significantly increasing the potential for freeze/thaw damage to the material.

WUFI PRO 5.1

WUFI is an advanced hygrothermal computer-based modeling and simulation program that can assess the response of a multilayered enclosure system in terms of one-dimensional simultaneous heat and moisture transport. The program was jointly developed and validated by the Oak Ridge National Laboratory (ORNL) and the Fraunhofer Institute's Building Physics division. A PC-based program, WUFI is dependent on the user providing assumptions about the following key factors:

- Building material properties, including but not limited to thermal conductivity, moisture storage, and transport coefficients
- Wall construction makeup and orientation
- Indoor ambient temperature and RH
- Historical climate data, including assumptions with respect to wind-driven rain.

WUFI's standard material database includes material properties for a broad assortment of the most typical construction materials. The program also includes a database of 30-year-averaged daily weather data for over 60 North American cities. Both of these databases can be used to make reasonable assumptions in lieu of actual material and climate data.

WUFI provides a useful tool for the relative comparison of the various modified masonry wall assemblies by analyzing

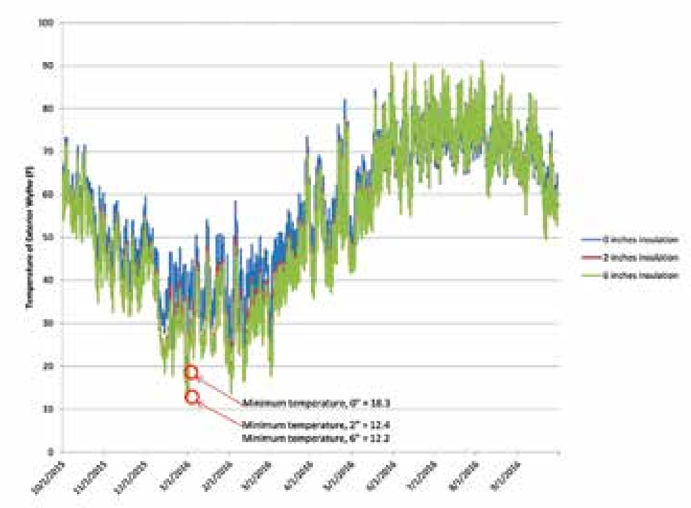


Figure 8 – Temperature of the exterior wythe of brick for 0 in., 2 in., and 6 in. of insulation.

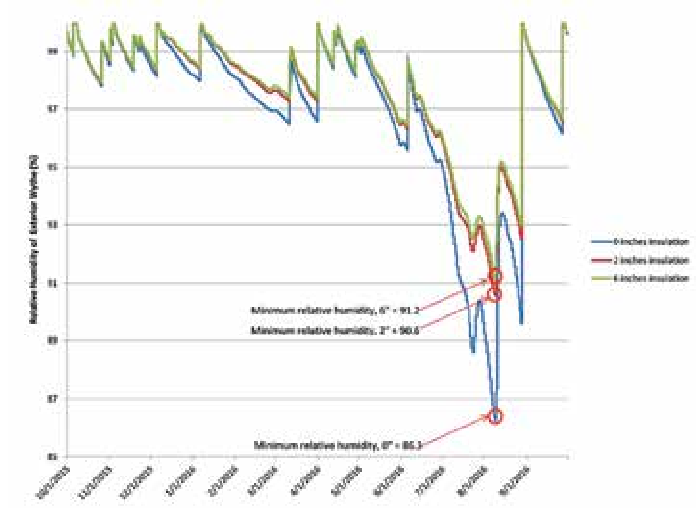


Figure 9 – RH of the exterior wythe of brick for 0 in., 2 in., and 6 in. of insulation.

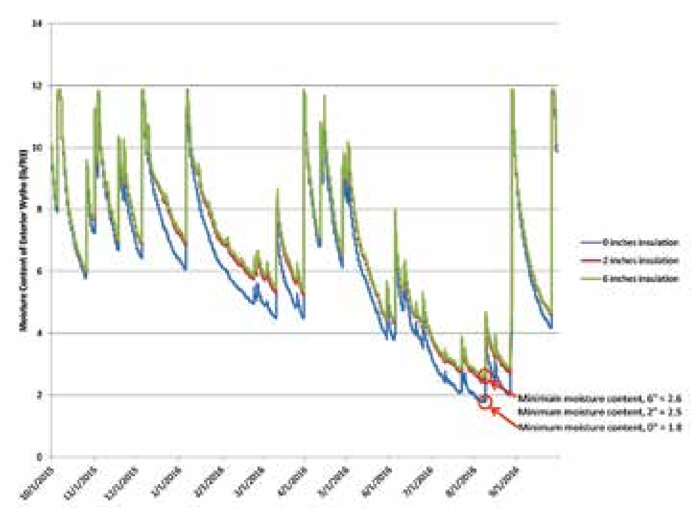


Figure 10 – Moisture content of the exterior wythe of brick for 0 in., 2 in., and 6 in. of insulation.

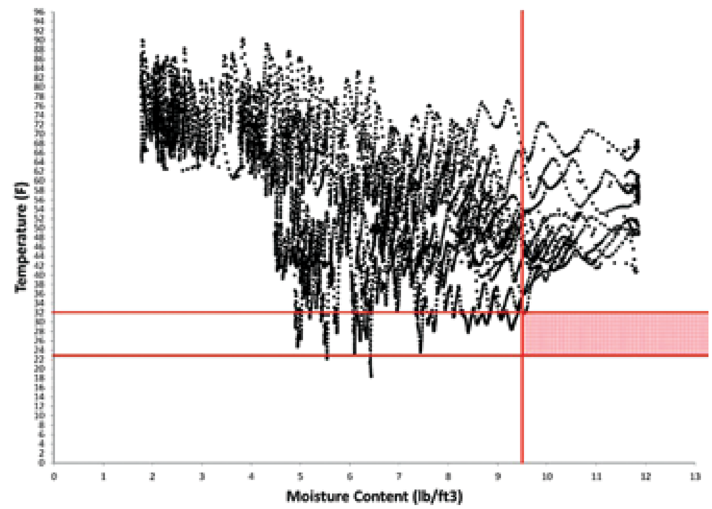


Figure 11 – Temperature versus moisture content for the original wall construction.

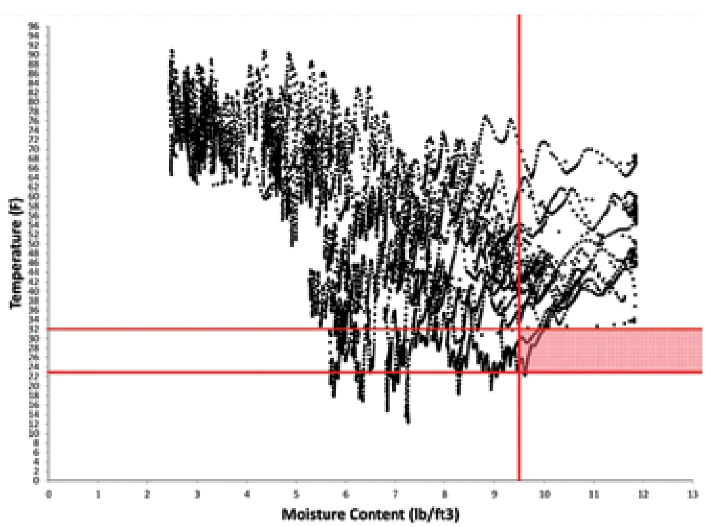


Figure 12 – Temperature versus moisture content for the wall section with 2 in. of insulation.

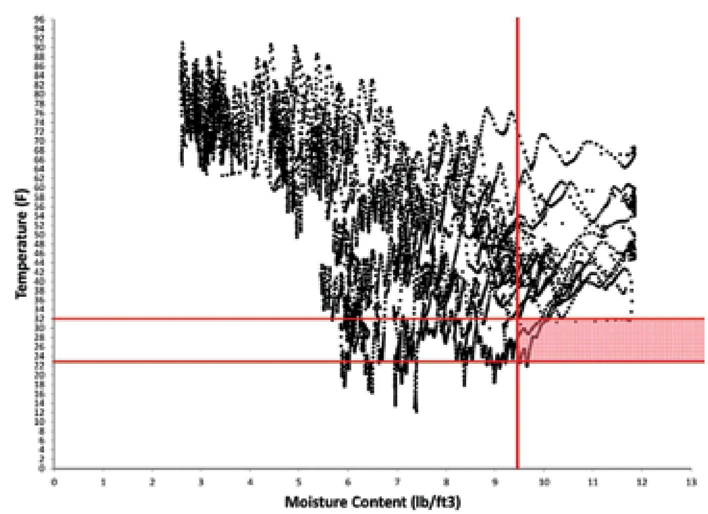


Figure 13 – Temperature versus moisture content for the wall section with 6 in. of insulation.

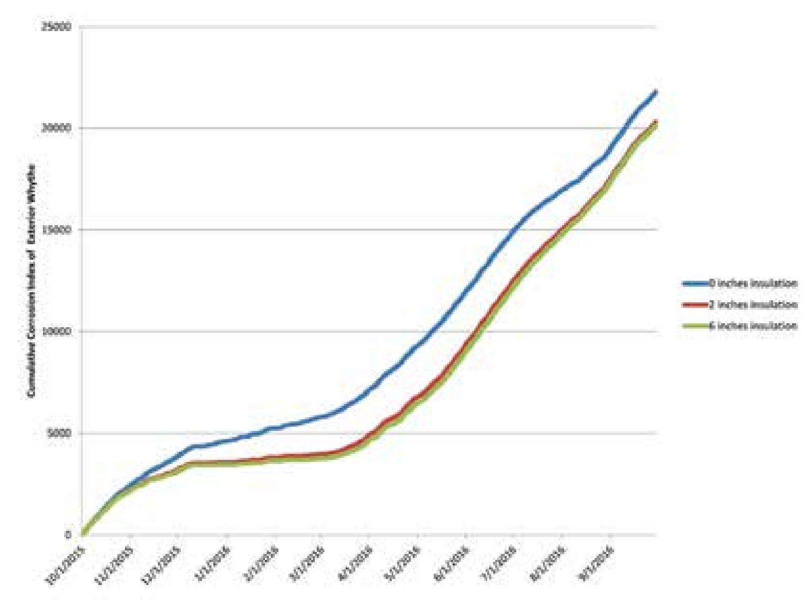
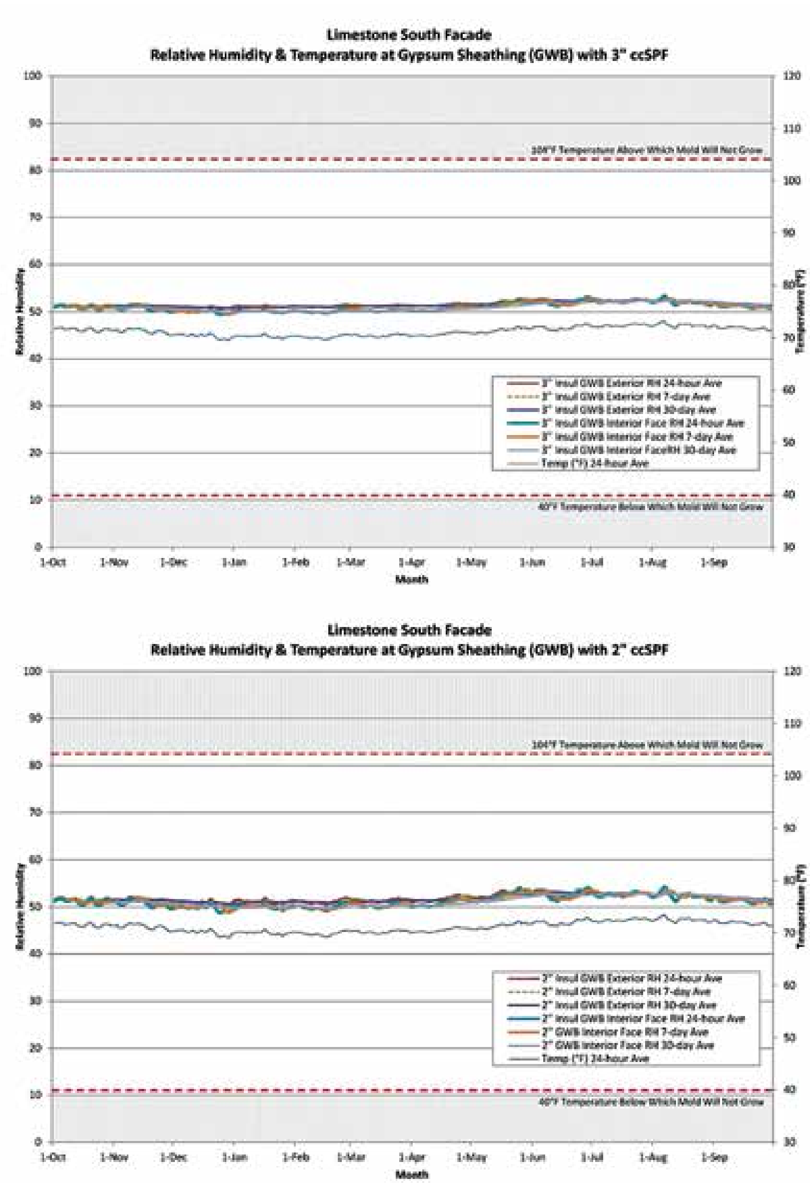


Figure 14 – The cumulative corrosion index for 0, 2, and 6 in. of insulation.



moisture transport and heat transfer through these assemblies.

However, WUFI only analyzes a one-dimensional "cut" through an assembly and cannot assess the effects of two-dimensional or three-dimensional interface details; variations in materials; or existing conditions such as deteriorated mortar, cracked brick, or failed sealant. In addition, WUFI cannot effectively assess the effects of air leakage or thermal bridging that may be present in the existing construction. WUFI should not be considered a precise prediction of in-service performance but a tool for comparing various design scenarios. WUFI results are only as reliable as the input data and are heavily dependent on the knowledge of the modeler—"garbage in, garbage out."

A WUFI analysis generates information about temperature, RH, and moisture content that can be comparatively analyzed. For example, an existing wall assembly can be modeled as uninsulated and compared to a model with two and six inches of spray polyurethane foam (SPF) insulation to understand how the added insulation affects the thermal and moisture transport properties of the modified assembly (*Figures 5-7*).

The program generates results over a specified period of time that can easily be compared to better understand how these assemblies perform in relation to each other (*Figures 8-13*).

To understand potential effects of frequency of freeze/thaw cycles and potential corrosion of embedded metals, the data from WUFI can be postprocessed, compared to known values such as S_{crit}, and used to generate comparative indices for corrosion (*Figure 14*) and freeze/thaw cycles.[1] A corrosion index (CI) for each simulated section indicates the relative frequency that conditions supporting corrosion exist. For each project, the CI is based on set values for temperature and RH. The CI increases nonlinearly with changes in either RH or temperature and provides a good relative indicator of corrosion potential to embedded metals.

Exploring the potential for mold growth with added interior insulation, temperature, and RH data from the WUFI simulation can be analyzed following ANSI/ASHRAE Standard 160-2009, *Criteria for Moisture-Control Design Analysis for Buildings.* This standard establishes criteria for conditions to minimize condensation and resulting mold growth. The criteria defined by this standard indicate that all of the following conditions must be met to minimize risk of mold growth:

- 30-day running average surface RH <80% when the 30-day running average surface temperature is between 41°F and 104°F.
- 7-day running average surface RH <98% when the seven-day running average surface temperature is between 41°F and 104°F.
- 24-hour running average surface RH <100%

Figure 15 – ANSI/ASHRAE Standard 160-2009, analysis for two simulated wall assemblies with varying thickness of insulation.

when the 24-hour running average surface temperature is 41°F and 104°F.

The charts in *Figure 15* are an example of this type of analysis. In this example, the WUFI-simulated section does not show a potential for mold growth based on this standard.

THERM

THERM allows the modeling of two-dimensional heat transfer effects in building components. Originally developed as a standardized tool for the window industry, THERM requires the user to provide the following inputs:

- Geometry of the wall section
- Materials and material properties
- Boundary conditions, including temperature and film coefficient, which is the amount of heat transfer due to air moving along a surface

THERM is commonly used to provide a basic study of thermal bridging in construction assemblies. Through analysis of temperature patterns (isotherms) and dew point, however, THERM can also be used to identify potential problems with condensation within modified wall assemblies. The THERM model in *Figure 16* is showing the thermal bridging effect of embedded steel framing that not only connects to the exterior via a steel shelf angle but also is transferring heat to the exterior brick masonry.

Beyond WUFI and THERM, there are more sophisticated three-dimensional modeling programs that include heat transfer and computational fluid dynamics (CFD) that can estimate the effects of air leakage on an insulated wall assembly. However, these tools are not readily accessible to the vast majority of practitioners.

IN-SITU MONITORING AND MOCK-UPS

Project-specific conditions related to interior and exterior climate are important factors that also impact the outcome of a one-dimensional hygrothermal modeling and simulation. WUFI makes available several standard weather files that are based on 30-year-average data. While the appropriate use of WUFI's standard weather files provides a reasonable assumption for basic simulations, the standard weather files may not closely reflect climatic differences for the specific site and can impact confidence in the results. For this reason, it is beneficial to undertake project-specific model validation if possible.

Data gathered from project-specific climate conditions for an extended period of time can be input directly into WUFI in order to provide more realistic simulation results. These include measurement and recording of exterior temperature, rainfall, wind speed and direction, horizontal solar radiation, and interior temperature and RH. Additionally, it can be beneficial to measure vertical solar radiation (solar radiation striking vertical wall surfaces, including incident and reflected solar radiation) and driving rain. These types of data are typically gathered from a weather station installed on the roof of the subject property.

Equally important to the validation process are measurement of temperature, RH, and moisture content within strategically selected representative wall sections that will be modeled so that this information can

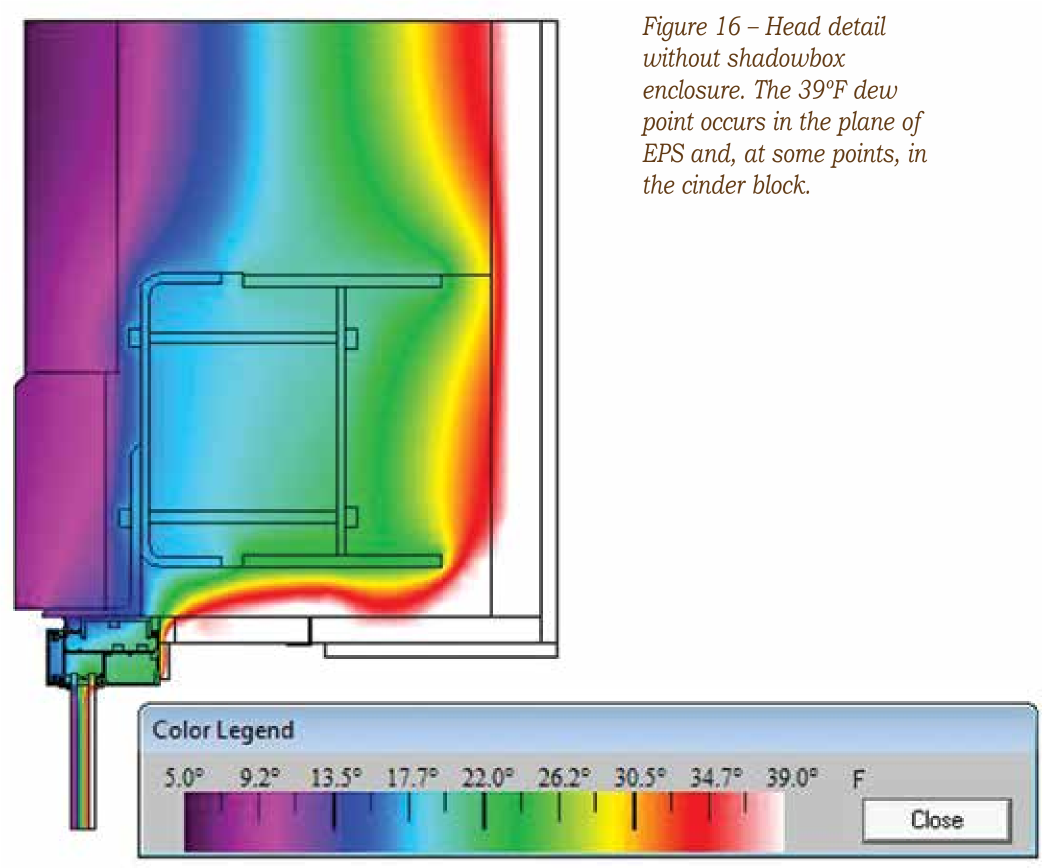


Figure 16 – Head detail without shadowbox enclosure. The 39°F dew point occurs in the plane of EPS and, at some points, in the cinder block.

be compared to the simulated results using the collected climate data.

Monitors can also be used to evaluate performance of wall assemblies following installation of an insulation mock-up. If mock-ups are feasible, data should be gathered for a minimum period of one year. The purpose of the monitoring is to evaluate how the wall is responding to the presence of insulation. Data gathered from monitors can be interpreted to determine whether wall areas are subject to increased frequencies of freeze/thaw cycles or if conditions arise that support corrosion and mold growth. While completing such mock-ups is generally not practical due to budget and time constraints, findings from this type of study will produce the most realistic prediction of future performance of the exterior walls.

APPLYING FINDINGS

The data resulting from the various analysis tools can be powerful and overwhelming, depending on how it is presented. For example, once the simulated model is created in WUFI, the program can quickly generate temperature, RH, and moisture content values for a particular location in the wall assembly. If the simulated model is run for a projected three-year period, the information for temperature alone would generate 26,280 results—one for every hour over the three-year time period. WUFI has built-in functionality to plot these data, but examining raw data representing one aspect of the model can be misleading and should not be considered a precise prediction.

In practice, results from the various analysis tools are most effective when studied comparatively. It is important to inspect and model existing conditions so that this information can be compared to less-tangible simulated conditions. For example, the charts in *Figures 8-13* represent data from WUFI simulations for three wall assemblies: uninsulated, 2 in. of insulation, and 6 in. of insulation. The data generated by WUFI for each assembly have been exported to and plotted in comparison to the other simulated models. Examining these charts, one can quickly understand how adding insulation at the interior lowers the temperature of the exterior wythe during winter months and increases the RH and moisture content during other seasons. *Figures 11-13* show how adding insulation at the interior increases the moisture content during the critical freeze/thaw temperature range of 23°F to 32°F of the wall section.

Assessing the potential for mold growth is another example of the value of comparative analysis and post-processing data. Exporting the results data from the simulated WUFI models and calculating running averages for surface temperature and RH over time can illustrate the potential risk for mold growth at a particular location in the wall assembly.

For example, the charts in *Figure 15* represent two simulated wall assemblies—one with 2 in. of closed-cell spray polyurethane foam (ccSPF) insulation and one with 3 in. of ccSPF. These data represent the RH and surface temperature at simulated-model interior gypsum wallboard over a model year. Based on ANSI/ASHRAE Standard 160-2009, in order for mold growth to occur, the temperature must be between 40°F and 104°F, and the RH must be equal to or greater than 80%. By defining the mold growth temperature range (dashed lines) and plotting the running averages for surface temperature and RH, this analysis demonstrates that there is a relatively minor shift in risk for potential mold growth for this wall assembly between 2 and 3 in. of ccSPF insulation. In neither scenario does the RH equal or exceed 80%.

When assessing the potential for corrosion of embedded metals, a comparative analysis is essential. There are many factors influencing when and where corrosion of embedded metals might occur, such as moisture content, temperature, condition of the existing metal, and its location in the wall assembly. A CI calculated from moisture content and temperature values from simulated models allows for a comparison of the CI for each wall assembly (*Figure 14*). Although the values have little quantitative meaning, they provide a good relative indicator of corrosion potential.

Another index that is useful when assessing the effects on exterior materials of adding insulation to a wall assembly is the freeze/thaw index. Derived from moisture content and temperature values at critical locations within the simulated wall sections, the freeze/thaw index is the potential frequency of freeze-thaw cycles found in *Table 1*.

Similar to the CI index, the freeze/thaw index does not have quantitative meaning. However, correlating the number of freeze/

thaw cycles with observed conditions of materials can provide a relative indicator of potential material damage from adding insulation and lowering the exterior wall temperature.

Material	Uninsulated	2-in. Closed-cell SPF	3-in. Closed-cell SPF
Limestone (East)	6	15	14
Limestone (South)	7	16	16
Beige Brick	0	1	1
Dark Brick	0	0	0

Table 1 – Freeze/thaw index.

Despite the varied and complex analysis methods available to investigate potential effects of retrofitting a mass masonry building with interior insulation, applying findings often comes down to experience and common sense. It is accepted that installing insulation at the interior will result in an exterior wall that experiences a wider range of temperatures, holds more moisture and increases the potential for corrosion and deterioration of embedded metals and wood, and that the potential for condensation-related hazards for building occupants increases. Therefore, the application of findings from analysis often comes down to risk assessment and mitigation.

CONCLUSION

The tools presented here offer potential resources to help guide decisions for insulation retrofits of industrial buildings. There are a growing number of evaluation tools available to predict the effects that modifications will have on enclosure materials. However, there are no standardized industry tests or evaluation tools that can holistically predict the outcome of proposed alterations. The inherent variability of existing conditions and influence this variability has on subsequent recommendations/analyses underscore the importance of having a standardized approach to hygrothermal analysis for insulation retrofit design of industrial buildings.

The tools presented are intended to provide a potential approach for resolving critical issues that can significantly influence the success of an insulation retrofit. In addition to evaluating the design considerations discussed, the analysis should include:

- Completion of an existing condition assessment of the enclosure
- Determining the critical degree of saturation (S_{crit}) of each material that comprises the wall assembly
- Completion of a comparative WUFI

study to evaluate frequency of freeze/thaw cycles, create a CI, and simulate conditions that foster mold growth

If feasible, data gathered from in-situ monitoring of the uninsulated enclosure will greatly inform the analysis. Monitoring project-specific climate conditions for an extended period of time is beneficial to validate hygrothermal models and simulations. In addition, data from strategically placed monitors can provide information on how exterior wall assemblies respond to seasonal changes. Implementing mock-ups of installed insulation and monitoring performance for a designated period will provide the most realistic results possible. This approach is rarely used due to the time and expense involved.

The concepts presented here can also be applied to nonindustrial buildings. Owners, contractors, and designers will benefit from the creation of a standardized approach to performing and interpreting hygrothermal analysis. Finding safe and effective approaches to insulating mass masonry buildings will continue to demand attention as the building industry continues to require higher-performing, more energy-efficient, and more comfortable buildings.

Editor's Note: This article was originally published in the Proceedings of RCI's 29th International Convention and Trade Show *in March 2014.*

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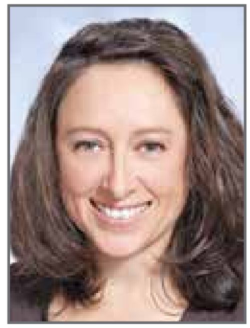
Tara Ikenouye holds master's degrees in architecture and historic preservation. Prior to joining Wiss, Janney, Elstner (WJE), she interned with the National Park Service and participated in several preservation field schools rehabilitating deteriorated historical windows and wood and stone building elements. Ikenouye is a Certified Passive House Consultant through the Passive House Institute of the United States (PHIUS). At WJE, she has done condition assessments and investigations of materials and assemblies, deterioration, and water infiltration of brick masonry and concrete structures, and has performed hygrothermal modeling and studies for the rehabilitation and insulation of mass masonry structures and historic preservation projects.



Anita Simon, AIA

Anita Simon, AIA, has bachelor's and master's degrees in architecture. Her work at WJE involves condition assessment and evaluation of assemblies or material failures followed by the development of repair recommendations. Her expertise includes field observation during construction or repair of materials such as terra cotta, brick, stone, stucco, and sealant; cleaning studies of various masonry materials; and monitoring of cleaning procedures. She performs investigations of hurricane-, fire-, and water-damaged structures and also has experience in litigation support services for multifamily residential properties.