RESEARCH HIGHLIGHT

June 2003 Technical Series 03-111

Comparison of Modeled and Monitored Performance of a Wall Insulation Retrofit in a Solid Masonry Building

INTRODUCTION

In 1996, CMHC assisted in the renovation of a four- storey, solid masonry building located in Prince Albert, Saskatchewan. The renovation included the addition of insulation on the interior of the solid masonry walls. Many architects, renovators and building owners are wary of interior insulation retrofits within solid masonry structures as the practice is thought to increase the likelihood of wall failures due to freeze-thaw cycles, structural stresses and interstitial condensation. Accordingly, CMHC initiated a project to evaluate the impact of the insulation retrofit on the durability of the solid masonry walls over the first year of operation. Temperature, relative humidity, thermal flux, and air pressures were monitored in a multitude of locations through the building envelope in order to provide sufficient data to allow for an assessment of the heat, air and moisture performance of the retrofitted exterior walls. By all indications to date, the walls are performing well with none of the aforementioned concerns realized.

Another motivation of the collection of the wall monitoring data was to use the data in conjunction with computerized hygrothermal models to 1) test the predictive capability of the models, and 2), to use the models to extrapolate the results of the field monitoring. Upon completion of the field monitoring project, CMHC initiated the following project to meet these objectives.

RESEARCH PROGRAM

The project work plan involved the use of a hygrothermal modeling tool to simulate the performance of the retrofitted wall assemblies of the Prince Albert project given the extensive knowledge available concerning boundary conditions and the wall assembly and materials. The cross section of the retrofitted wall assembly is shown in Figure 1.

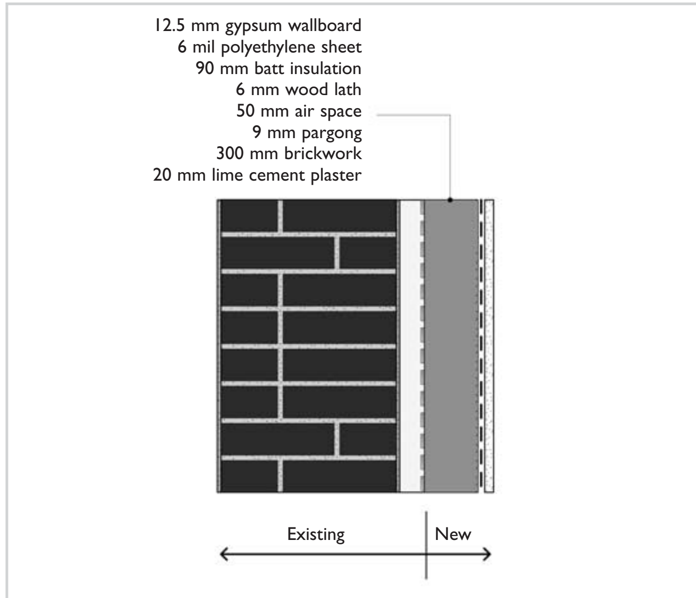

Figure 1 Typical Retrofitted Wall Section

The WUFI hygrothermal simulation tool was used to conduct hour-by-hour calculations that incorporated thermal mass and solar radiation effects and driving rain absorption. Boundary condition files were created from the monitored data for both indoor and outdoor conditions with the data being supplemented by the researcher's best estimate where such data was lacking. The material properties used in the simulations were assembled from available sources for similar materials.

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The default material property data from WUFI was used where possible, although some judgment was usually required in this selection. The exterior lime-cement stucco, brick masonry, spruce, batt and gypsum wallboard were assigned default values. A model was first "built" for a representative monitored location with only the information from the monitoring report as guidance. Comparing the results of this "initial guess" simulation to the measured results prompted some adjustments to a few of the material properties and a closer investigation into the actual assembly of the wall. For example, it became clear that some material properties, such as the permeance values for the parging, and the effective storage and permeance of the wood and lathe, had a great influence on the predicted hygrothermal behavior of the wall system.

The project documented the data used for input into the models, the results of the simulations compared to the results of the monitoring, a comparison of the output of the two models, a detailed explanation of the differences between monitored and modeled results, and a discussion of the input variables that had the greatest effect on the results. The likely long-term performance of the retrofitted wall assemblies of the Prince Albert building was discussed. Finally, recommendations regarding future monitoring, and modeling, of heat, air and moisture conditions in wall assemblies were developed.

FINDINGS

It was found that the modeling results generally agreed with the trends and magnitudes of the various parameters recorded during the field monitoring project. For instance, the predicted and monitored temperatures were compared for two points in the wall assembly: at the exterior surface and at the back of the masonry wall. Generally, it was found that the modeled results closely tracked the monitored temperatures for both locations.

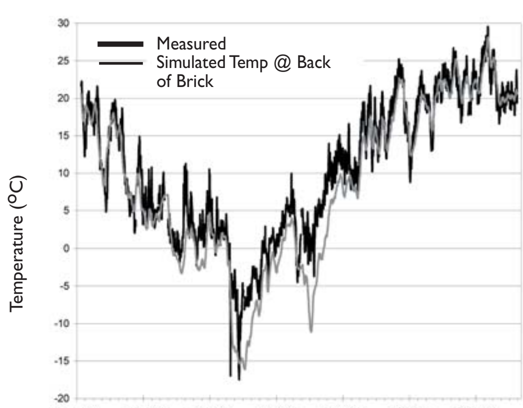

Figure 2 Comparison of Modeled vs. Monitored Surface Temperature of the Masonry Walls

Figure 2 shows the results of the modeling and the monitoring of temperatures on the interior face of the exterior masonry wall.

The relative humidity (RH) of the air space between the masonry and the interior retrofit wall was used to compare predicted to measured moisture performance. The monitored RH in this location was found to vary much more quickly and dramatically than the modeling predicted, and the deviations from measured data become large at some points during the year (for example, end of December and middle of June). It was suspected that the differences might have been due to sorption isotherm for wood, wood's unique short-term hysteresis or the influence of air leakage.

In general, reasonable agreement between the modeled and the monitored results was reached by accounting for air movement through the wall. In the cases considered, the results of the modeling suggested that the moisture in the walls was trending towards an annual equilibrium (that is there was no net gain or loss in moisture over the course of a year). These trends were confirmed by the results of the monitoring. In those cases where the wall was subjected to brief wetting periods, it dried out and hence no long-term moisture accumulation is predicted.

Parametric Investigation of Hygrothermal Modeling Sensitivity:

The variables that had significant impact on the modeling results included airtightness, the starting moisture content of the assembly, the vapor permeance of the parging and the vapour barrier. Additionally, the method of modeling the interstitial lath space was important to the results. The climate assumed for the simulations also played a role. Some of the more significant influences are discussed below.

Influence of Starting Moisture Content: The wall assembly modeled had both a high level of hygric mass and relatively low exterior and interior permeance. As a result, the estimated starting moisture content used in the modeling was found to influence the performance of the wall for a long period of time. Simulations started at higher moisture content were found to undergo fewer short-term changes because a large amount of moisture had to be added, or removed, before the RH of the assembly was affected.

Influence of Parging Permeance: The default permeance value for lime plaster 10 mm thick was 2,600 ng/Pa/s/m^2. Three other parging permeance values were considered and it was found that while parging permeance did not significantly affect the results, it was noted that the less permeable the parging, the more accurately the simulations compared with the measured results.

Influence of Wood Mass: The total volume of the wood in the wall (50 x 50 mm strapping @400 mm, 38 x 89 mm studs @400 mm, and 6 x 19 mm @25 mm) contained the equivalent of about 19 mm of solid wood. A parametric study was conducted to assess the impact of the equivalent wood thickness on the results. It was found that increasing the thickness of wood in the system increases the moisture storage capacity and modifies the behavior of the assembly. These results encouraged the use of 19 mm of wood for all of the simulations however because the wood is not installed in the wall in a single, continuous layer, the permeance of the wood was artificially increased to 9,700 metric perms to reflect the fact that air and water vapour can freely move around the lath and framing

Influence of Permeance of Inner Layer: The permeance of the interior layer is well known polyethylene has a permeance of around 3.7 metric perms. However, the role of the permeance of the interior wall layers was investigated because of its potential influence on the performance of the wall assembly. The permeance of the interior layers of the wall used for most simulations was increased in three steps from 3.7 metric perms (0.15 mm thick poly) to 37 perms (typical of a heavy oil paint), to 370 (a high estimate for latex paint on drywall) to 3,700 (a value essentially equal to little or no vapour resistance). In a very cold, dry, climate such as Prince Albert, the resultant interior wall RH is predicted to be much lower with little or no interior vapour resistance. This is due to the combination of low interior relative humidity (due to low occupancy and high ventilation), the insulating value of the masonry, and its moisture storage capacity. It is important to emphasize that these results are only valid for the very dry interior conditions of this particular building.

Simulations in Different Climates: One point in the wall assembly was simulated for an exposed east-facing location in Toronto (this orientation was chosen since it is known to result in the worst performance). The results show that the wall design which performed well in Prince Albert could become much wetter in Toronto. In fact, the RH within the wall assembly continued to climb for the first two years. The impact of removing the polyethylene vapour barrier was also investigated. Removing the poly did not reduce the RH in the airspace within the wall or change the moisture content of the masonry.

RECOMMENDATIONS FOR MONITORING

Several specific recommendations for future field monitoring projects were developed based on the experience gained through the reconciliation of the modeling with the monitored results. These include the need for detailed physical description of the subject building and its surroundings, knowledge sensor location, and the need for wall specific solar radiation and driving rain data. Measurements of wind speed and direction, and ideally some measure of air pressure across the assembly would also be useful for the assessment of driving rain and air leakage potential. In assemblies that contain a significant amount of moisture storage capacity, at least one set of gravimetrically determined moisture content values would help avoid the need to estimate the starting moisture content.

RECOMMENDATIONS FOR MODELING

At this stage in the development of hygrothermal modeling, the quality of the predictions is highly dependent on the experience and expertise of the analysts. This project, for example, required certain derived material properties, the generation of detailed exterior boundary conditions, an understanding of interior conditions and a practical appreciation of the effects of building flaws (such as air leakage and rain penetration).

To aid in the accuracy of modeling projects, an assessment of the climate data of the site is important. The role of driving rain can be especially important, and differences between standard weather years and monitored data can play a significant role for exposed assemblies with absorbent cladding materials. Parametric studies should be used to identify those variables that are important and those that have little influence on the results. The starting moisture contents must be chosen based on measured values (if available) or the model must be calibrated to the measured data for any hope of matching results in systems that store appreciable amounts of water (such as masonry and wood systems). The actual materials in the monitored building should be carefully identified and the basic material properties measured if possible. Basic material property data includes colour, density, and, for cladding, rate of water uptake. The role of air and rain leakage must always be considered as they will often overwhelm the influence of heat conduction and vapour diffusion on hygrothermal behaviour. If hygrothermal enclosure simulation is used as an analysis tool in the design process, the absolute accuracy is less important since design decisions are based on discrete variations in assembly and materials. Hence, for design, more emphasis should be made on comparisons of predicted performance between different assemblies and climate zones, and less on absolute values of performance.

IMPLICATIONS FOR THE HOUSING INDUSTRY

This research project served to demonstrate the strengths and weaknesses of hygrothermal modeling in the assessment of wall performance. Hygrothermal modeling can be a cost-effective method to assess wall performance but the accuracy of the analysis is heavily dependant upon the availability of data on boundary conditions, material properties and the actual construction of the assembly. The knowledge of the user regarding building physics and the sensitivities of the specific hygrothermal modeling tool is also critical. With respect to the performance of insulated solid masonry walls, both the monitoring and modeling seem to indicate that, for the case study building, the installation of interior insulation within a properly detailed assembly did not have an adverse impact on the durability of the retrofitted wall system.

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Research Report: *Comparison of Modeled and Monitored Performance of a Wall Insulation Retrofit in a Solid Masonry Building, March 2003*

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Housing Research at CMHC

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Printed in Canada
Produced by CMHC 09-11-06
Revised: 2006

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