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Hygrothermal performance of highly insulated wood frame walls with air leakage: Field measurements and simulations

KEYWORDS: Highly insulated wood-frame wall assemblies, hygrothermal performance, field test, simulations, durability, air leakage, rain infiltration, energy efficiency

OVERVIEW OF PROJECT

The goal of this project was to develop durable wood-frame building envelope systems for net-zero energy ready buildings. The research was designed to document the moisture performance and durability of exterior insulated and deep cavity walls concurrently in a typical Canadian cold climate with simulated air leakage and water leakage testing.

The impact of increased insulation levels on the hygrothermal performance of wood-based components under different moisture loads (vapour diffusion, simulated air and water leakages) of six types of high thermal resistance (High-RSI) wall assemblies were investigated. These assemblies were installed on both South and North orientations at a building envelope field test facility located in southwestern Ontario. They were allowed to acclimate during a baseline period where climatic moisture responses of the wood-based materials could be assessed prior to simulated moisture loading. Air leakage was simulated by injecting interior air into the central stud bay of each test assembly during the winter of 2013. The moisture content (MC) of wood-based components was monitored using electric moisture content sensors placed in the sheathing and framing plates.

The two main High-RSI wall categories studied in this project were 1) deep-cavity walls with either dense-pack cellulose or closed-cell spray foam; and 2) exterior insulated walls using fibreglass cavity insulation in combination with either low vapour permeable exterior foam or high vapour permeable exterior mineral wool. Through the inclusion of a Part 9 Ontario Building Code compliant datum wall in the study, the risks associated with increased insulation levels was quantified relative to current code compliant practices.

The High-RSI wood-frame walls were assessed by analyzing condensation, mould, and decay risks using the moisture content, temperature, and relative humidity data collected during the field test over a one-year period. These datasets were used to assess condensation risks, drying potential and in-service durability with the intent of developing climate-sensitive design guidelines. Additionally, hygrothermal models (1-D WUFI) of the High-RSI test walls were created to predict their hygrothermal responses to natural climatic conditions and simulated air leakages. Sensitivity analyses were also performed to investigate the influence of material properties and surface transfer coefficients. Simulation results were compared to electrical sensor measurements for model calibration.

KEY RESULTS

The following conclusions are based on observations between October 2012 and June 2013 and do not include summer time moisture responses and results from the water injection tests.

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The analysis of sheathing and plate MC-data indicated that:
1) During the baseline test period:

- The datum and the exterior insulated walls had uniform moisture distribution in contrast to the more complex moisture distribution observed within and between the cellulose-insulated walls.
- The moisture stratification observed in the cellulose-insulated walls had an overall tendency of higher MC-data in the upper portions of the cavity and framing that was most exaggerated in the north facing walls.
- One south facing cellulose-insulated wall showed some promise for the dense-pack approach as its OSB sheathing moisture performance was better than that of the south datum wall. However, while the OSB performed well in this wall, the framing plates still experienced MC-levels of up to 20%.
- The fundamental issue with the deep-cavity wall type is the presence of cold sheathing that provides a condensation plane in cold weather.

2) During the air injection test:

- The warmer OSB sheathing of the exterior insulated walls reduced the risk of moisture related problems especially near the location of the air leak. The sheathing in these wall types performed very well during the test as the OSB MCs were consistently below 16%.
- The moisture content of the upper plates in the walls with exterior foam insulation tended to be higher (relative to the lower plates) with the upper plate in one north-facing wall exceeding 20% MC for two weeks in March 2013.
- The walls insulated with exterior mineral wool outperformed the two foam-based exterior insulations because the mineral wool's high vapour permeability allowed the sheathing and framing to dry to the exterior. This advantage kept the OSB and framing MCs within these walls below 12% MC.
- The deep-cavity cellulose-insulated walls had the highest moisture content levels in both the framing plates and OSB sheathing throughout the duration of the study period. These walls also had the highest number of condensation hours. The deep-cavity cellulose walls were also slower to dry in comparison with the exterior insulated walls.

With properly adjusted material properties and boundary conditions, the simulation results were in a very good agreement with the measured data. These models then provided the tools to investigate the variability of the OSB MC within the test walls as well as the response depths of the electric moisture sensors. The simulation results also indicated that a 1 mm air-change layer within the stud cavity was effective at reproducing the OSB MC observed in the High-RSI walls during the air leakage test.

THESIS

Fox, M. J. 2014. Hygrothermal performance of highly insulated wood frame walls with air leakage: Field measurements and simulations. M.A.Sc Thesis. Ryerson University, Toronto, ON.