Measurement of Through-Assembly Air Leakage and Its Impact on Moisture Performance of Wood-Frame Walls

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Abstract. Air leakage is one of the critical moisture sources that may compromise the structural integrity and air quality of wood-frame buildings. The present study investigates air leakage through typical North American oriented strand board (OSB) sheathing using a one-of-a-kind analytical chamber, the CARWASh, which is designed to generate temperature- and humidity-controlled outdoor and indoor conditions for the evaluation of water management performance and moisture dynamics of exterior wall assemblies. We establish a baseline estimate for air leakage through OSB sheathing in full-scale wood-frame walls by combining moisture content, temperature, and relative humidity measurements and a one-dimensional transient hygrothermal model. The results show large variations in air leakage between the different OSB panels tested and demonstrate that complete airtightness commonly assumed for wall assemblies in hygrothermal simulations as a computational convenience may not be justifiable. We therefore use the measured data to specify a default air change rate (ACH) value for the average air leakage and assess its impact on the moisture performance of several wood-frame wall assemblies across multiple climate zones. The modeling results imply that a typical through-assembly air leakage likely leads to sizable moisture risk for wood-frame walls under elevated moisture load conditions. This work overall contributes to ongoing efforts in developing a quantitative basis for the evaluation of moisture problems in wood-frame buildings.

Keywords: Air Leakage · Moisture Risk · OSB Sheathing · Hygrothermal Model

1 Introduction

Achieving good overall airtightness of the building envelope is essential for energy conservation and sustainability, but also to reduce the risk of moisture damage in buildings [1–4]. Airtightness is generally realized by the installation of an air barrier layer within the wall assembly. While weather-resistive barriers (WRBs), such as housewraps that also function as air barrier materials, would provide adequate airtightness to the building envelope, the execution of its installation is notably a critical factor. Construction

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workmanship defects tend to reduce the performance of WRBs as an air barrier [5]. Consequently, taping the joints of the sheathing panels is often chosen and relied on to achieve airtightness to prevent through-assembly air leakage in wood-frame buildings.

Oriented stand boards (OSB) are commonly used as sheathing panels in the building industry [6] and have an emerging role in the passive house sector as an airtight sheathing material. Recent studies, however, begin to question the airtightness of OSB and the reliability of its manufacturing process affecting air permeability [2, 3, 7]. Langmans et al. [2] have found large variation in the air permeance of commercial OSB brands produced in West-Europe and the resulting through-material air leakage to be significant in terms of the passive house airtightness standards. In addition, OSB is one of the building components that are most prone to moisture-induced damage originating from vapor diffusion, air leakage, and wind-driven rain loads.

The present study has two primary goals. First, we investigate air leakage through a typical North American OSB sheathing using a special temperature- and humidity-controlled analytical chamber. Then we use the results to specify a default air change rate (ACH) value for through-assembly air leakage and assess its impact on the moisture performance of several wood-frame wall assemblies across multiple climate zones.

2 Experimental Methods

2.1 The CARWASh

The present study uses a special temperature- and humidity-controlled laboratory facility—the CARWASh (Chamber for Analytical Research on Wall Assemblies exposed to Simulated weather)—that is large enough to fit a 3 m x 3 m wall assembly between its indoor and outdoor chambers. Details of the CARWASh and the simulated indoor and outdoor conditions are given in Ref. [8].

2.2 Wall Assembly and Sensor Locations

The test wall assembly, framed with 38 mm by 184 mm softwood lumber spaced 406 mm apart on center, consists of six 2.44 m high, 368 mm wide bays. Each bay is covered with a different, 11.1 mm-thick OSB sheathing on the exterior, i.e., cavities A-F. The interior face of the cavity was sealed with 0.15-mm polyethylene vapor barrier taped to the lumber studs to limit exchange with the indoor chamber. The North American OSB is manufactured to a performance-based standard with pMDI binder (polymeric methylene diphenyl diisocyanate) in the face and core layers. Extensive caulking and taping were applied to seal all leaks presented by cracks, etc.

Each cavity had an identical set of sensors installed. Two relative humidity (RH) sensors were mounted on the side of the stud to report the air RH. Four moisture-pin sensors (pairs of uninsulated screws through the full depth of the OSB) and two thermistors were installed to probe the resistance and the temperature of the OSB, respectively. The moisture content of the OSB was calculated from the measured resistance (R) and the associated temperature (T) using the correlation developed in Ref. [9].

The RH of the outdoor chamber in the CARWASh was initially set to 50% for two days, then dropped to 15%, and finally increased back to 50% after another 9 days. The

RH of the indoor chamber was kept constant at 50%. The temperature was constant at 23 °C in both chambers. During the test, data was collected on the RH/T in the wall cavity, the moisture content of the OSB, and the RH/T of the outdoor and indoor chambers.

2.3 Hygrothermal Modeling

The RH in the wall cavity was simulated using WUFI Pro software, version 6.7, which is a hygrothermal simulation tool commonly used for building design. It calculates transient coupled heat and moisture transport in wall assemblies. The measured RH/T of the outdoor and indoor chambers provided inputs for the boundary conditions of the hygrothermal model. The WUFI cross section of the wall assembly is shown in Fig. 1. OSB was modeled as three layers to resolve differences in moisture content through the depth and facilitate comparison with the measured values since the uninsulated full-depth pin-type sensor pairs register the highest MC. The material properties of OSB used here have been validated through modeling of cold-climate field data [10].

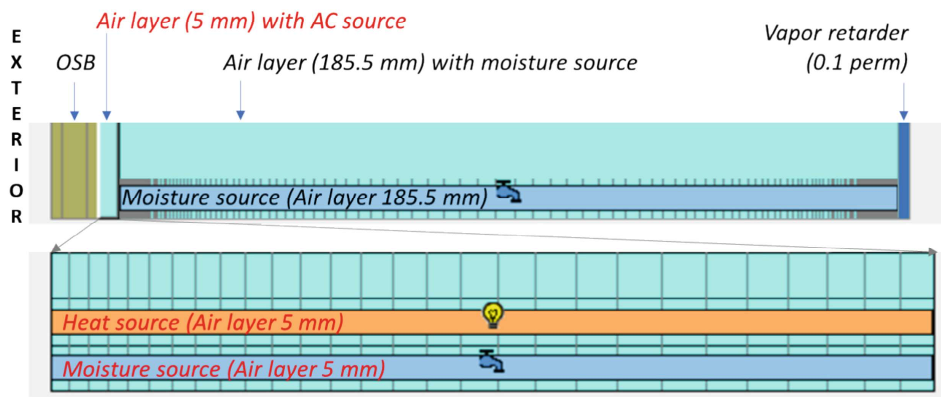

Fig. 1. WUFI cross section of the test wall assembly.

We also use WUFI to simulate the moisture performance of several wood-frame wall assemblies across multiple climate zones.

3 Results and Discussion

3.1 Through-Assembly Air Leakage

For each cavity, we compare the simulated and measured RH values. Figure 2a shows that the hygrothermal model significantly underestimates the RH measurements. When the outdoor RH was reduced to 15%, the simulated RH in the wall cavity drops at a significantly faster rate than measured.

Given the low volume of the OSB-air cavity system, a plausible explanation of the observed discrepancy is that the relatively large mass of wood surrounding each cavity acts as a source for moisture. To represent such desorption in the one-dimensional simulation, we add a moisture source to the air layer of the cavity (Fig. 1). The shape of the moisture source function was estimated as the inverse of the average moisture content measured for the wood components within the cavities and its amplitude was identical in the simulations for all six cavities. The moisture source function is shown in black at the lower part of Fig. 2b with a secondary vertical axis to the right.

Despite the extensive air sealing efforts, we observe large variations in the measured RH values between the cavities. Even if the variations could still be due to sealing imperfections, they could also originate from differences in the air permeance of the OSB panels tested. To account for this through-assembly air leakage in the simulation, we follow the work of Lstiburek et al. [11] and use the airflow model within the current version of WUFI. Specifically, a 5-mm air layer with a constant ACH is inserted at the interior interface of the OSB (Fig. 1). The air layer is coupled to the outdoor chamber simulating air change between the cavity and the outdoor. The ACH values are then optimized to achieve the best fit between simulation results and measurements.

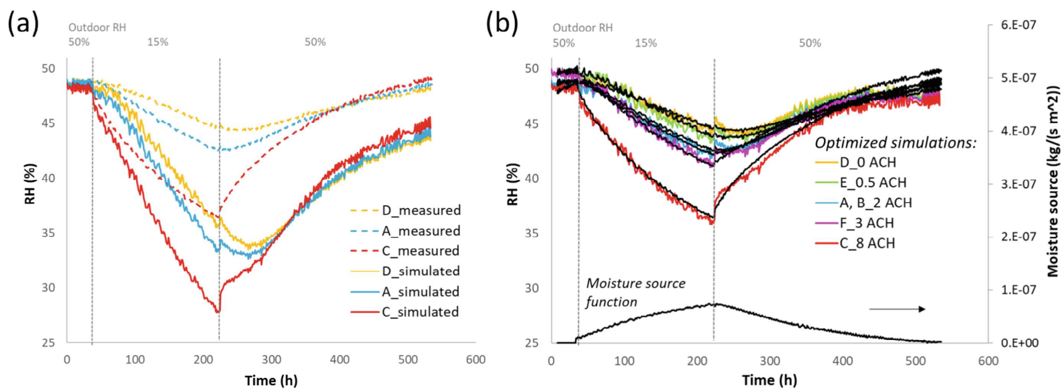

Fig. 2. (a) Measured (dash lines) and simulated (solid lines) RH in cavities A, C, and D of the wall assembly. (b) Measured (black lines) and simulated (color lines) RH in cavities A-F after optimization of the simulation. The moisture source that was added to the cavity air is shown at the bottom of the graph with a secondary vertical axis on the right. (Color figure online)

The results of the optimized simulations are compared to the measured data in Fig. 2b. They clearly demonstrate that including the aforesaid moisture and heat 'sources' in the hygrothermal simulation—to accurately describe moisture redistribution and airflow within the wall assembly—results in a good agreement between the measured and predicted RH values for all six cavities. The estimates for the air change rate of the most and least airtight cavities, i.e., D and C, are 0 ACH and 8 ACH, respectively. The simulated ACH values show large variations between the wall cavities in agreement with the findings by Langmans et al. [2]. The results suggest that complete airtightness frequently assumed for wall assemblies in hygrothermal simulations as a computational convenience should be reassessed.

3.2 Moisture Performance Simulations

Inclusion of a realistic air leakage in the hygrothermal simulations is necessary to improve the predicting power of the modeling results. We define the default through-assembly air leakage as the average ACH value plus one standard deviation of the six

OSB measurements, i.e., 5.5 ACH. We use this default ACH value then to investigate the impact of air leakage on the moisture performance of several wood-frame wall structures in different climatic conditions. Using the airflow model [11], two 5-mm air layers with the default ACH value are inserted at the interior side of the OSB sheathing. These air layer simulate air leakage from the interior and exterior into the cavity of the wall assembly.

Figure 3 shows representative examples of the moisture performance of typical wood-frame wall assemblies in different climates with no air leakage, with a minor air leakage represented by our default 5.5 ACH value, and with air leakage typical for imperfect assemblies as proposed by Lstiburek et al. in Ref. [11]. The test walls consist of a vinyl or stucco cladding, WRB, OSB sheathing, fiber glass insulation, vapor retarder, and a gypsum board interior finish.

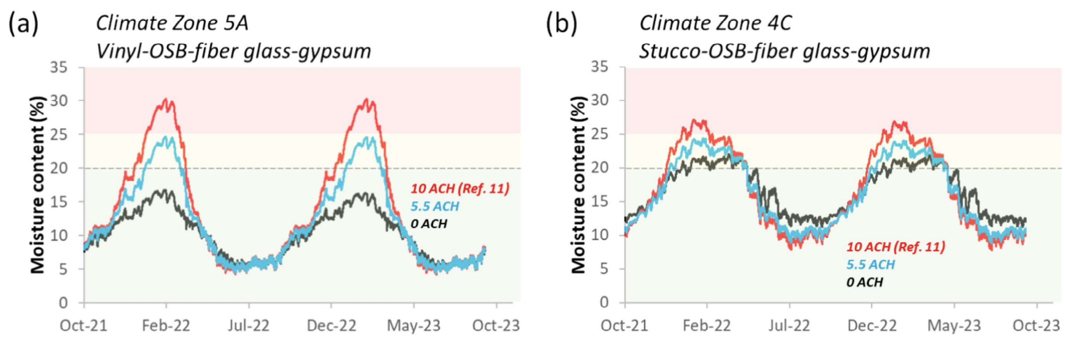

Fig. 3. Moisture content of the OSB sheathing material (interior side) in Climate Zone (a) 5A and (b) 4C. The moisture performance is categorized by red/yellow/green traffic light colors in terms of potential moisture risk for the OSB sheathing. The simulations were run on a north-facing wall with interior temperature and RH of 75°F ± 2°F and 45% ± 15%, respectively.

The results in Fig. 3 show that through-assembly air leakage significantly affects the moisture performance of the test walls. Assuming complete airtightness for these wall assemblies under-predicts the moisture content of the OSB sheathing material, which is highest during the winter months in these examples. When the moisture load conditions are elevated, increased air leakage raises the risk for mold growth and decay. In line with empirical expectations, we identify the cold and marine climates as the most challenging climates in terms of moisture problems for the OSB sheathing that are directly related to air leakage. The simulations also reveal that the air-leakage-induced burden on the OSB becomes marginal as the indoor and/or outdoor climatic moisture load lessens.

4 Conclusion

We studied the air leakage through six full-scale OSB sheathing panels by combining measured moisture content, temperature, and RH data with hygrothermal simulations. Incorporating moisture and heat ‘sources’ in the simulations to accurately model vapor redistribution and air convection within the wall assembly was key in achieving reliable ACH value estimates for each cavity. The results showed large variations in air leakage between the different OSB panels tested and implied that the assumption of complete airtightness often used in hygrothermal simulations as a computational convenience may not be justifiable for typical wood-frame wall assemblies.

The measured average ACH value was used then as input parameter in the simulation to investigate the effect of air leakage on the moisture performance of several wood-frame wall assemblies across multiple climate zones. The modeling results clearly showed the risk of moisture damage, even minor through-assembly air leakage presents for the OSB sheathing under elevated moisture load conditions.

In summary, this work demonstrated the critical role model inputs and assumptions play in improving the predicting power of hygrothermal simulations for the assessment of wall assembly moisture performance. The results also inform ongoing efforts in developing a quantitative basis for the evaluation of moisture problems in wood-frame buildings related to vapor diffusion, air leakage, and wind-driven rain.

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