Experimental Assessment of Hygrothermal Performance of Wood Frame Wall System in Suzhou's Lake Tai Climate Zone

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A long-term onsite assessment of the hygrothermal performance of a wood frame wall system is presented in this work. The system was applied in a wood demonstration house within the Lake Tai climate zone of Suzhou, China. The hygrothermal performance of the cavity insulation wall was determined from the temperature, relative humidity, and from the temperature of the wood material surface throughout the year. The results clearly indicated the effect of the cavity insulation, cladding cavity ventilation, and air-vapor barrier. Thermal performance was very good due to the wall cavity insulation. Cladding cavity ventilation was effective at low relative humidity of the insulated wall cavities. Condensation and mold growth were not found inside the wall during the test period. The wood frame wall system had good hygrothermal performance and may be widely used in hot summer and cold winter climate zones in China.

Keywords: Hygrothermal performance; Wood frame wall; Insulation; Vapor retarder; Climate

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INTRODUCTION

The city of Suzhou in southeast China has a hot summer and cold winter climate with varying temperature and relative humidity levels. The complicated environment of hot, wet, humid, and cold conditions poses difficulties in the design of building walls when it comes to energy saving and durability.

Wood frame buildings have been constructed in this zone; however, research on the hygrothermal performance of wood frame wall systems in these climatic conditions has not been performed. Thus, there are no useful data for building design and assessment.

Long-term onsite assessment of hygrothermal performance has been used as a reliable method for developing energy-efficient and durable wood frame wall systems. Heat and moisture transfer through a wall have been measured for different materials and climatic conditions (Gatland and Karagiozis 2007; Toman *et al.* 2009; Maref *et al.* 2008; Tichy and Murray 2007). For instance, by comparing three interior vapor control strategies, the experimental results indicated that a 50 μm polyamide film used as an interior vapor retarder in wall systems, common to the Pacific Northwest of the US, would enhance the ability of a wall system to maintain lower relative humidity. Also the on-site experimental hygrothermal performance analysis of an interior thermal insulation system was presented, which was applied during the summer period on a brick-built house from the end of 19th century. The thermal resistance increased approximately two times, and water condensation was never observed inside the envelope.

Dynamic changes in temperature, relative humidity, and moisture content can reveal the function of each material in multilayer walls. Factors such as ventilation, airtightness, insulation, infiltration, and vapor diffusion affect the wall's hygrothermal performance. Experiments and simulation results have been helpful for improving the hygrothermal performance of the exterior wall system (Glass and TenWolde 2007; Karagiozis and Desjarlais 2007; Tariku *et al.* 2009), and professional guidance and recommendations have been provided. Results from these research studies contributed to the building code requirement for a wood house with good performance in different climates.

This study was carried out to develop and implement long-term onsite monitoring of hygrothermal responses of a wall system. We tested one multifamily wood frame wall assembly of a wood demonstration house in a park beside Suzhou's Lake Tai. Both sides of the wall, insulated wall cavity, and ventilation cavity conditions were monitored for the air temperature and relative humidity, and the surface temperature of the wood material in the wall was tested.

EXPERIMENTAL

Tested Building and Wall Configuration

A wood demonstration house was built in a park beside Lake Tai by Suzhou Crownhomes Co., Ltd. (Fig. 1). The house has a post and beam structure with a 125-mm-thick wall fixed within the main structure.

Fig. 1. Demonstration test house

The configuration of the multilayer wall is illustrated in Fig. 2. The exterior walls were framed with 38-mm by 70-mm studs and sheathed with 9.5-mm oriented strand board (OSB). Thermal insulation was achieved by inserting premium loose-fill fiberglass insulation into the cavity between studs. A continuous polyethylene film on the interior surfaces of the cavity insulation was used as an interior vapor retarder. The exterior wall finish was stucco.

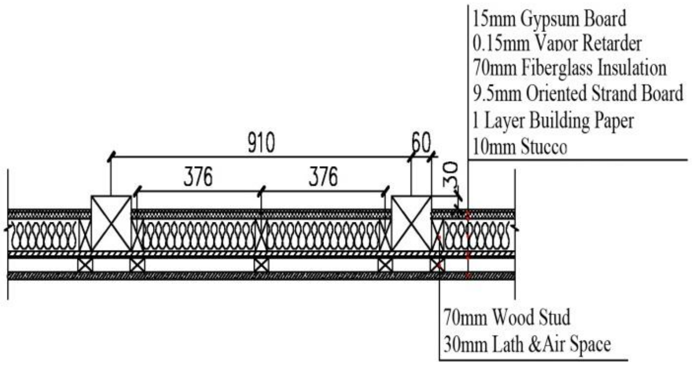

Fig. 2. Configuration of multilayer wall

Instrumentation and Sensor Locations

One profile in the south exterior wall on the first floor was chosen for analysis. Air temperature and relative humidity were monitored with a JWSK-6ACC05 sensor (0.1 ℃ and 0.1 % resolution). Surface temperature was measured using type-T thermocouples calibrated to 0.1 K.

All sensor locations are shown in Fig. 3. Air temperature and relative humidity sensors (RHT1–RHT10) were placed in each layer from the inside to the outside of the wall. These sensors were installed 300 mm from the top and bottom of the test wall. Surface temperature (T1 toT6) sensors of studs and OSB were positioned in the cavity insulation. T1 and T5 were located at the centers of the top and bottom wood plates, and T2 and T4 were in the exterior sheathing board and were 300 mm from the top and bottom wood plates. T3 and T6 were situated in studs and the exterior sheathing board, respectively, and were centered vertically between the top and bottom plates.

Sensors were connected to the data collection equipment. Data were recorded in a computer every minute and could be flexibly extracted every 30 min or every hour for analysis by the operating software. The monitoring process began in June 2010, and testing has been continuous for over two years.

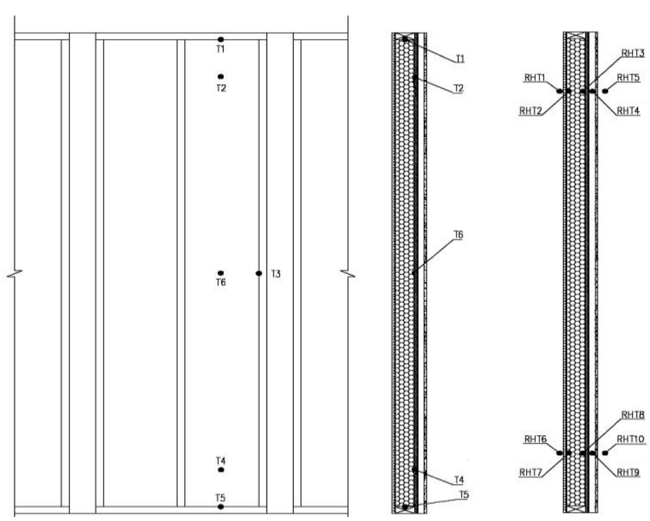

Fig. 3. Sensor locations in the tested wall

RESULTS AND DISCUSSION

Changes of Interface Temperatures and Relative Humidity

The trend was basically similar between RHT1–RHT5 and RHT6–RHT10, as described in a previous research report (Wang 2011). Thus, Figs. 4 and 5 only show air temperature and relative humidity changes for RHT1–RHT5 throughout the year (except for August, in which there were missing data). The air temperature variance of each interface of the wall from April to October was less than that from November to March of the next year. The air temperature of the medial wall was similar to that at the interface between the gypsum board and vapor retarder. The change of air temperature at the interface between the insulation layer and OSB sheathing board was closer to that of the lateral wall, which confirmed the effective function of the insulation layer. On the coldest day in January, despite the lateral wall air temperature being near −3.0 °C, the temperature of the medial wall remained over 11 °C. On the hottest day in July, despite the lateral wall air temperature reaching 37.0 °C, the temperature of the medial wall was only 25 °C. It is thus clear that the temperature difference between the medial wall and lateral wall maintained the ideal level from spring to autumn.

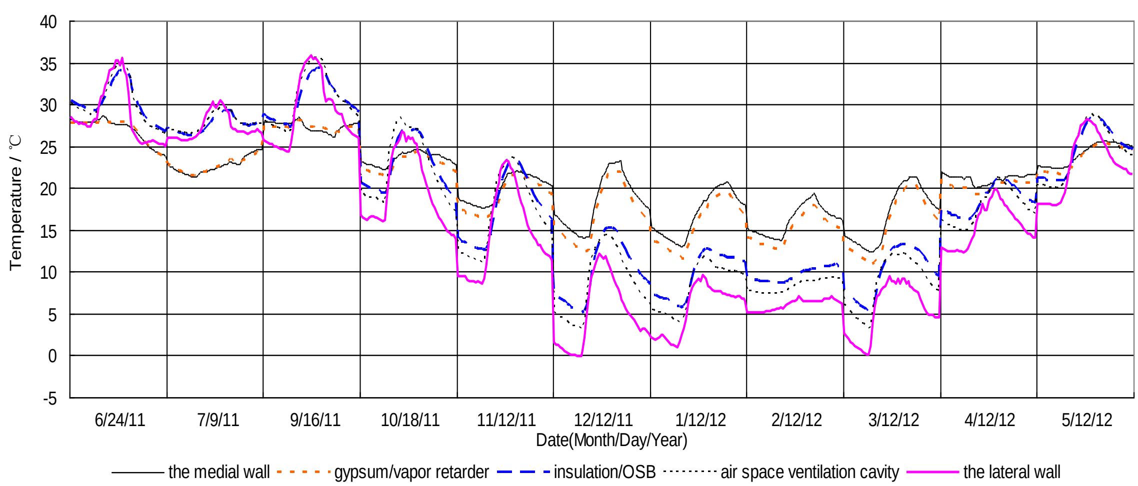

Fig. 4. Changes in interface temperatures throughout the year

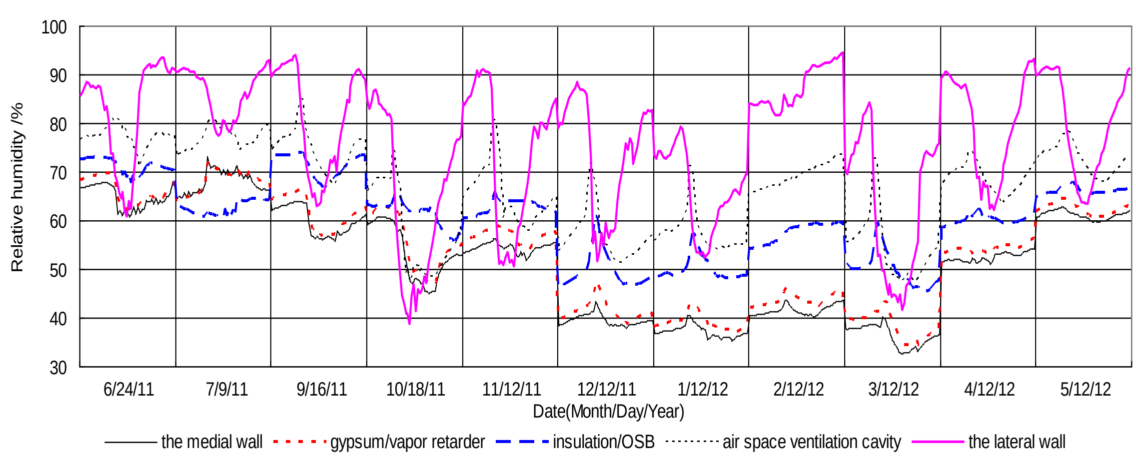

Fig. 5. Changes in interface relative humidity throughout the year

Relative humidity changes were directly related to temperature because increasing temperature could lead to increasing steam partial pressure. The relative humidity variance of the lateral wall ranged from 30% to 99%, and that of the medial wall was smaller and steadier. The relative humidity of the medial wall, that of the interface between the gypsum board and vapor retarder, that of the interface between the insulation and OSB sheathing board, and that of the air space ventilation cavity showed similar trends. The differences among each interface from December through the following March were larger than for other months because of the low indoor temperature in the winter. In addition, the peak temperature and relative humidity on each interface clearly showed a hysteresis behavior from the medial to the lateral wall. There is thus an absorption and release process to heat and water vapor for the materials of the wall. However, the delay time for the wood wall was shorter than that for concrete or masonry construction walls because wood wall is of lightweight construction.

Effect on Hygrothermal Performance for Materials and Construction of Wall

Insulation layer

The temperature was measured monthly on the coldest day outdoors from October through the following March and was used to analyze heat transfer through the multilayer wall. Temperature gradients through the tested wall profile are shown in Fig. 6. It is clear that temperature obviously decreased from the medial to the lateral wall, and the temperature difference was greatest between the gypsum board and OSB sheathing board in the heat transfer process from the medial to the lateral wall. The greatest temperature difference value was 8 °C in December. The effect of insulation is very significant and kept the interior of the house relatively warm.

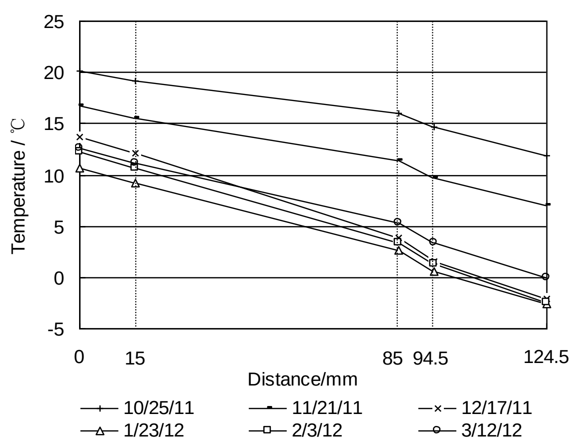

Fig. 6. Temperature gradients through the test wall profile

Vapor retarder of polyethylene film

Relative humidity was measured monthly on the coldest day outdoors from October through the following March and was used to analyze moisture transfer through the multilayer wall. Relative humidity gradients through the tested wall profile are shown in Fig. 7. It is clear that relative humidity increased from the medial to the lateral wall, and the difference was great between the gypsum board and OSB sheathing board. The greatest relative humidity difference value was 15% in January. Therefore, the polyethylene film is a good barrier material to stop air and vapor movement.

From the differences in the relative humidity seen in Fig. 5, it is clear that the polyethylene film in the wall assembly was able to stop the movement of moisture into or out of the conditioned space. Thus, the relative humidity in the insulation cavity was always lowest when the outside air was humid or the indoor air was hot-humid in the summer. However, the lower relative humidity indoors might lead to drying and cracking of the wood elements because of dry air conditions indoors during the winter.

Otherwise, the relative humidity of the OSB cavity-side was not more than 70% throughout the year, so not only are there no risks of mold growth and condensation, but the relative humidity indoors can be improved in the winter without the polyethylene film layer.

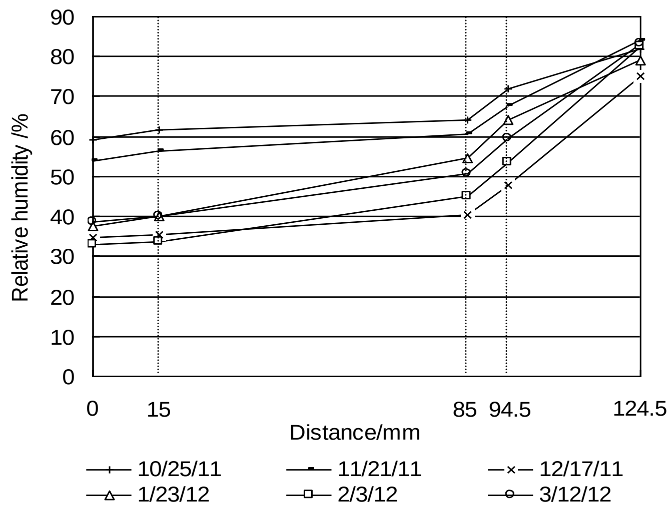

Fig. 7. Relative humidity gradients through the test wall profile

Waterproof and moisture-permeable building paper

The relative humidity at the interface between the insulation layer and OSB sheathing board was comparatively stable (Fig. 5) and was lower than that inside the ventilation cavity, with differences between 7% and 10% (Fig. 7). These results imply that it is more effective to use waterproof and moisture-permeable building paper under conditions of high outdoor relative humidity. Moisture penetration was impeded from the wall ventilation cavity into the interior of the house.

Stucco and air space ventilation cavity

Relative humidity gradients were largest in the interface between the ventilated cavity and the lateral wall (Fig. 7). The maximum gradient was 34% in December. Both the stucco and air space ventilation cavity were clearly effective in preventing moisture and rain. Data showed that relative humidity inside the cladding cavity was always lower than that of the lateral wall before it reached maximum, and the relative humidity peak inside that cavity confirmed hysteresis behavior (Fig. 5).

The temperature difference between the ventilated cavity and the lateral wall was about 4 °C. This confirmed that heat loss was reduced due to the thermal resistance of the air space.

Wood frame and board

The surface temperatures of SPF frame dimension lumber and OSB sheathing board are shown in Fig. 8. Surface temperatures of the OSB sheathing board at T2, T4, and T6 developed continuously with changes in lateral wall temperatures and were influenced by the outdoor temperature conditions. The wood frame surface temperatures at T1, T3, and T5 became smaller than those of the OSB sheathing. There was a certain heat barrier due to both the wood frame and insulation material.

Figure 9 shows that the surface temperature was lower because of the stud thermal bridge, especially the temperature of the corner of the wood frame in the roof, which was the lowest at only 10 °C. Therefore, a detailed structure and construction technique is most important to prevent energy consumption due to air leakage.

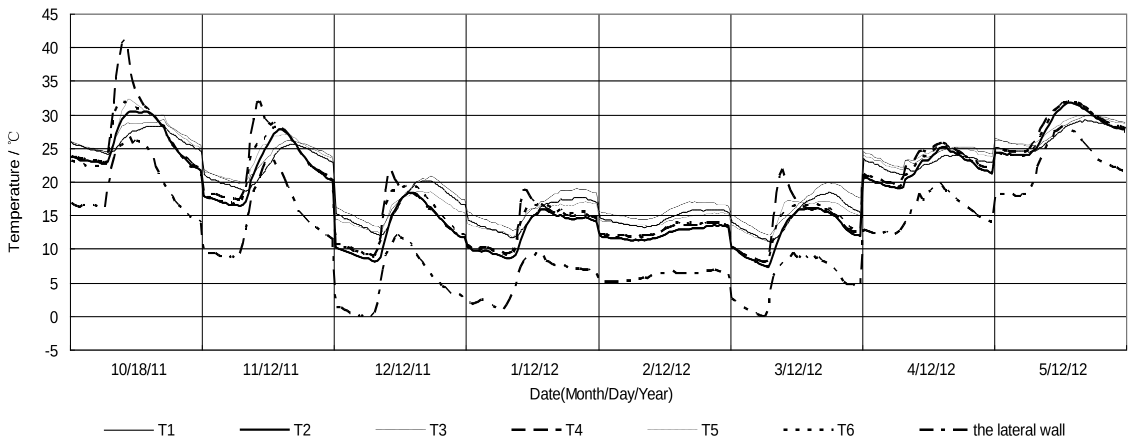

Fig. 8. Surface temperature of wood materials of SPF and OSB

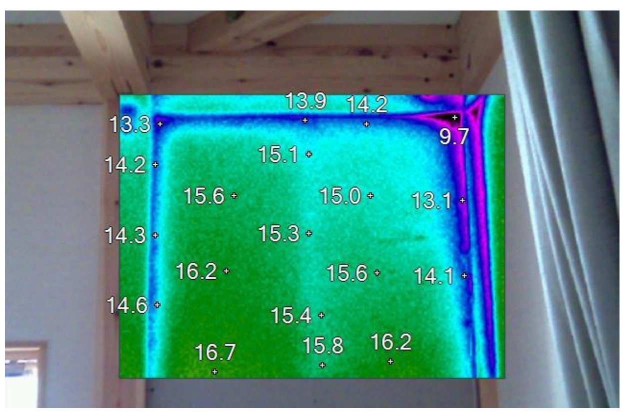

Fig. 9. Infrared spectra of the inner surface of the wall

Durability

Durability is closely related to hygrothermal performance. In particular, humidity can lead to destruction of wood components of a house. Wood durability is likely affected by mold growth on the surface in cases where the relative humidity remains above 80% for a long time. During the test period, the temperature of the ventilated cavity reached 37 °C with the highest relative humidity of 84% in July, but the duration of high temperatures and relative humidity was not continued at length. Consequently, there was no mold growth (Li 2009).

When the relative humidity of both the medial and lateral walls was high in summer, the relative humidity of the OSB cavity-side was the lowest. All temperatures were above 0 °C in winter, and the relative humidity was less than 80% under the rainy and humid weather. Therefore, water condensation in the wall was not found.

CONCLUSIONS

1. The wood frame wall system demonstrated good hygrothermal performance, and the temperature and relative humidity were stable in the climate conditions of Suzhou's Lake Tai, with a hot summer and cold winter.

2. The good thermal performance of the wall is attributed to the cavity wall insulation within it, according to temperature gradients through the tested wall profile.

3. The water control strategy of using polyethylene film and building paper provides a high level of moisture resistance to reduce air relative humidity in the test wall and interior.

4. Cladding and a ventilation cavity can greatly enhance moisture tolerance and reduce moisture-related risks for a multilayer wall. There was no mold growth or water condensation inside the wall during the test period.

5. The test wall system can be widely used for environmentally-friendly buildings in the hot summer and cold winter climate zone of China.

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