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Hygroscopic Properties of Light-Frame Wall with Different Assemblies*[1]

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ABSTRACT

On purpose to reduce accumulated moisture and to prevent moisture condensation in a light-frame wall, thermal characteristics and moisture behaviors were investigated for four different wall assemblies; a) typical wall, b) addition of vapor retarder between the insulation and the gypsum board, c) addition of air gap for natural ventilation behind the siding, d) composition with b) and c). Each wall was tested under two climate conditions; 1) 20°C, 50% RH (indoor) and 30°C, 85% RH (outdoor), 2) 30°C, 85% RH (indoor) and 20°C, 50% RH (outdoor).

The results showed that the typical wall assembly had poor resistance against moisture intrusion from the inside of building. Outdoor and indoor humidity caused the moisture condensations on the inside of the siding and the back surface of the sheathing respectively. The addition of a vapor retarder did not give significant improvement in preventing the moisture intrusion.

Keywords : condensation, permeance, adiabatic performance, light-frame wall, water vapor pressure

1. INTRODUCTION

North American Light-frame wood construction was introduced to Korea in late 1980's. Along with that, the building code of North America has been adopted directly without any considerations of Korean native building practices. And recently, as concerns of energy efficiency results in remarkable improvement of the adiabatic performance of buildings, the advent of high air-tightness and sharp temperature gradient across the exterior wall could easily induce the moisture condensation in the wall. It means that it gives the moisture high chance to stay within the wall and causes deterioration of wood components. Consequently, it threatens the structural safety of the building.

Many factors including climate, humidity, and thermal and permeant properties of materials and assemblies are related with the condensation in the walls (Rousseau, 2003). The effect of these factors on the condensation has been studied by many researchers. In order to represent the severity of the moisture loads from climate, moisture index (MI), which considers both the wetting potential and drying potential of climate,

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Table 1. Materials for wall assemblies

Materials	Specification
Stud	2×4 Lumber
Siding	Western Red Cedar Bevel Siding
Ventilation	Home slicker: Nylon6, vertical channel (2 per inch)
Vapor retarder	Tyvek 1060B
Sheathing	OSB, T: 12 mm
Insulation	Glass wool R-19, width: 15" (Kraft-faced)
Gypsum board	T: 12 mm

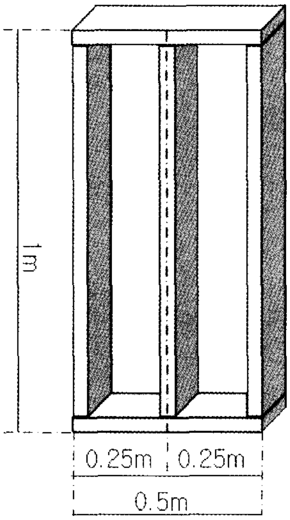

Fig. 1. Size of wall-frame.

was devised by Cornick and Rousseau (2003). Gerald (1985) reported moisture patterns in the walls, which were observed with various composition and direction of the wall in hot, humid summer climate. A similar study focusing on air pressure difference between layers in the wall was done by TenWolde *et al.* (1998).

A long term goal of this study was to decrease the accumulated moisture and to prevent condensation in light-frame walls. To this end, we studied on the transfer of heat and moisture in four types of the wall assemblies and accumulated the knowledge of the mechanism of the moisture condensation.

2. MATERIALS and METHODS

2.1. Materials

The specifications of the materials for the wall assemblies are shown in Table 1. All materials were conditioned under 20°C, 50% RH, for two weeks before the test.

2.2. Fabrication of Wall Assemblies

The size of a wall-fame was 0.5 m×1 m (width×height) (Fig. 1). In order to assess the effects of an additional vapor retarder and an air gap for natural ventilation, four types of the wall assembly were manufactured (Table 2). Type A was considered as a typical wall assembly. An additional vapor retarder was installed for the type B, A 6 mm air gap for the type C, and both an additional vapor retarder and an air gap together for the type D.

2.3. Setup for Monitoring

The sensors were installed at the center of the height of the wall. The gaps around wires were sealed with silicon to prevent air leakage. Fig. 2 shows the detail of wall assemblies and the locations of the sensors.

To measure temperature and relative humidity in a wall, J-type thermal couples (accuracy: ± 2°C at 20°C) and capacitive sensors (±3% at 20°C)

Table 2. Composition of wall assemblies

	Type	Additional vapor retarder	Air gap	Temp.& RH	
				Indoors	Outdoors
A	Forward	×	×	20°C, 50%	30°C, 85%
B	Forward	○	×	20°C, 50%	30°C, 85%
	Reverse	○	×	30°C, 85%	20°C, 50%
C	Forward	×	○	20°C, 50%	30°C, 85%
	Reverse	×	○	30°C, 85%	20°C, 50%
D	Forward	○	○	20°C, 50%	30°C, 85%
	Reverse	○	○	30°C, 85%	20°C, 50%

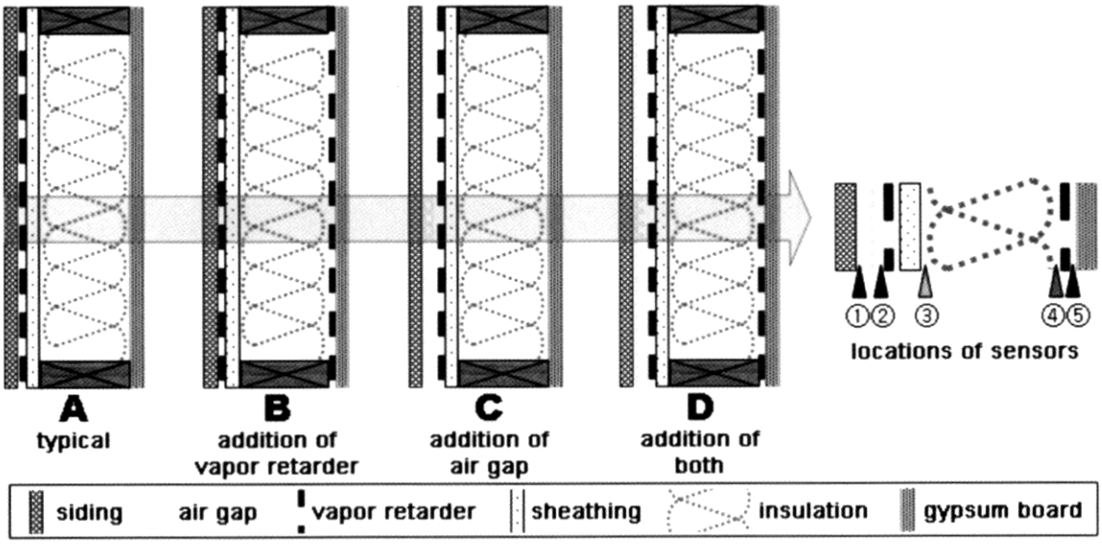

Fig. 2. Details of wall assemblies and the locations of the sensors.

were used respectively.

The exterior climate condition was simulated in the 30°C-85% RH reading chamber (Hanbaek Scientific Co., Korea) which was confined in the conditioning room, and the interior one, 20°C -50% RH reading conditioning room (Fig. 3). Each wall was attached to the opening of the chamber. Then the gaps between the walls and the opening were filled up with silicon. To examine the moisture intrusion from the interior, the wall was installed reversely in the cases of B, C and D (Table 2). The period of the monitoring was two weeks after the installation.

2.4. Calculation of Vapor Pressure and Vapor Saturation Pressure

The vapor saturation pressure over liquid water for the temperature range of 0 to 200°C can be calculated from the following equation 1 (Hyland and Wexler, 1983b).

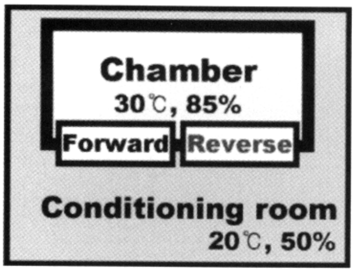

Fig. 3. Schematic diagram of installation and environmental conditions.

$$\ln p_{ws} = C_1/T + C_2 + C_3T + C_4T^2 + C_5T^3 + C_6\ln T \qquad \text{(Eq. 1)}$$

where

ln = natural logarithm

p_{ws} = saturation pressure, Pa

T = absolute temperature

K = $^{\circ}$C+273.15

C_1 = -5.8002206×10^{3}

C_2 = 1.3914993×10^{0}

C_3 = -4.8640239×10^{-2}

C_4 = 4.1764768×10^{-5}

C_5 = -1.4452093×10^{-8}

C_6 = 6.5459673×10^{0}

Relative humidity can be expressed as the ratio of water vapor pressure p_w in the moist air to water vapor pressure p_{ws} in the air saturated at the same temperature and pressure

$$\Phi = \frac{p_w}{p_{ws}} \Big|_{t,p} \qquad \text{(Eq. 2)}$$

where

Φ = relative humidity

p_w = water vapor pressure

p_{ws} = water vapor saturation pressure

Using equation 1 and 2, the water vapor pressure can be calculated from the measured temperature and the relative humidity. Because water vapor pressure is linearly proportional to the quantity of moisture in the air, it is able to predict the condensation in a wall with verifying the distribution of water vapor pressure.

3. RESULTS and DISCUSSION

3.1. Experimental Results

In Fig. 4 and 5, the progresses of temperature and relative humidity for type D wall are shown. Equilibrium of temperature was reached within 24 hours in the all wall assemblies. As shown in Fig. 5, equilibrium of relative humidity

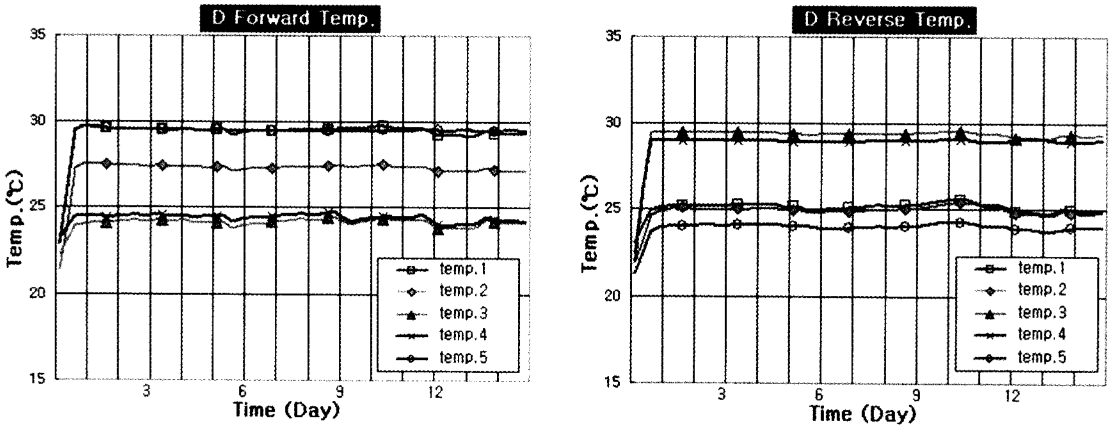

Fig. 4. Progress of temperature.

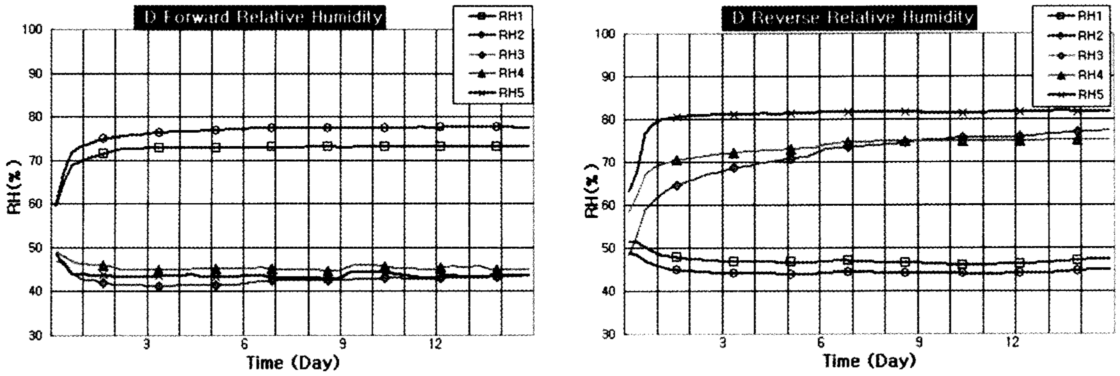

Fig. 5. Progress of relative humidity.

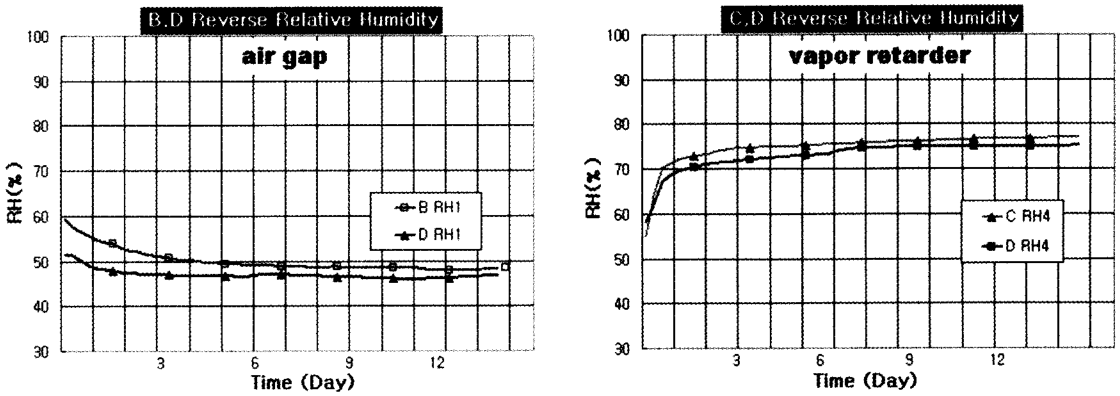

Fig. 6. Effect of additional vapor retarder and air gap.

was reached within 48 hours in the case of the forward direction (humid exterior). In the other case (humid interior), the equilibrium of relative humidity could not be attained in two weeks and moisture was accumulated in the wall continuously. It was assumed that difference between the two cases was resulted from that of the vapor permeance between OSB and gypsum board. While the intrusion of moisture from the exterior was restrained by OSB which had lower vapor permeance than a gypsum board, the gypsum board could not retard the intrusion of moisture from the interior efficiently. This was confirmed through the additional test for the permeance of the respective material.

3.2. Effect of Additional Vapor Retarder and Air Gap

Two test results from type B and type C were compared with type B to evaluate the effect of the additional vapor retarder and those from type B and D to evaluate the effect of the air gap. Fig. 6 shows that the additional vapor retarder and the air gap could not reduce the intrusion of moisture significantly. This may be contributed to non-convective room test condition. Further studies on the effect of an air gap would be needed.

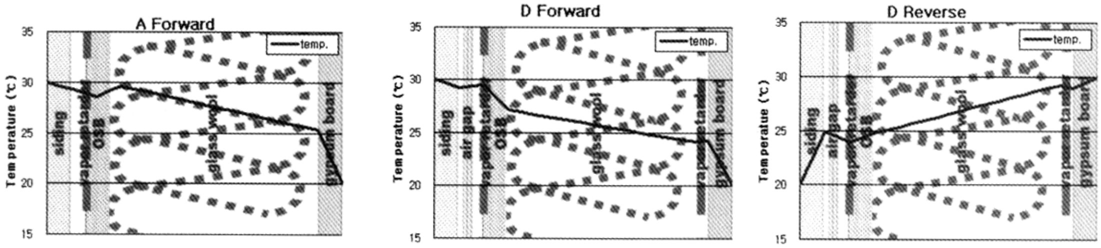

Fig. 7. Distribution of temperature.

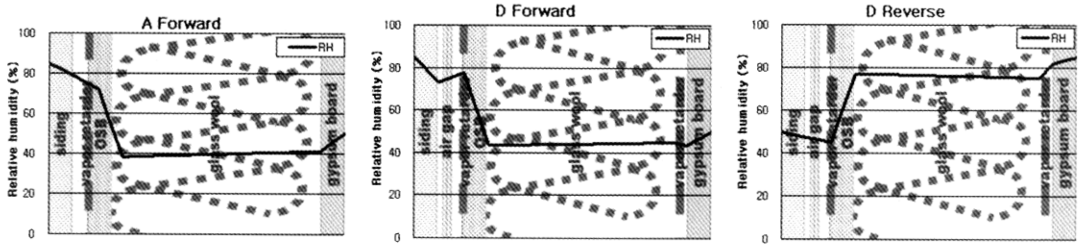

Fig. 8. Distribution of relative humidity.

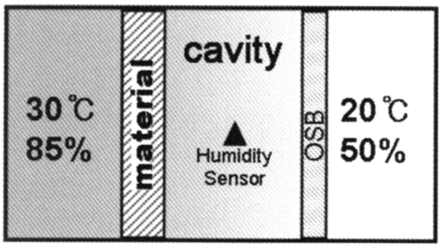

Fig. 9. Test for permeance of each material.

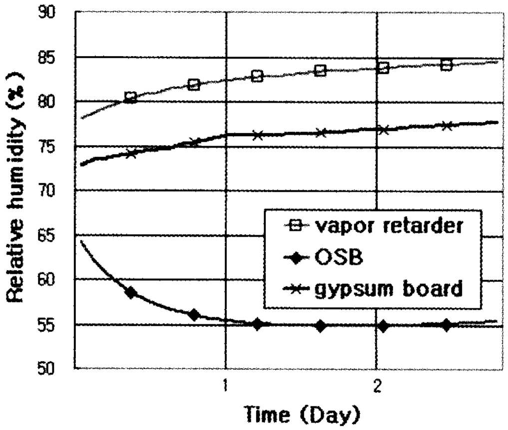

Fig. 10. permeance of materials.

3.3. Distribution of Temperature, Relative Humidity and Water Vapor Pressure in Wall

Fig. 7 and 8 show the distributions of temperature and relative humidity in a wall at the end of the test. It was found that the glass wool and the gypsum board were major adiabatic layers in the wall assembly (Fig. 7). The union of vapor retarder and OSB was a main resistant layer against moisture intrusion (Fig. 8). However, the additional vapor retarder showed poor performance against the moisture intrusion from the interior. This led to do an additional test about the permeance of each material was performed. Fig. 9 illustrates the scheme of the test where vapor retarder, OSB, and gypsum board were involved. As shown in Fig. 10, a vapor retarder allowed the most moisture movement. From this result, it is presumed that the permeance of current vapor retarder used for the exterior wall is not proper for preventing moisture intrusion from the interior.

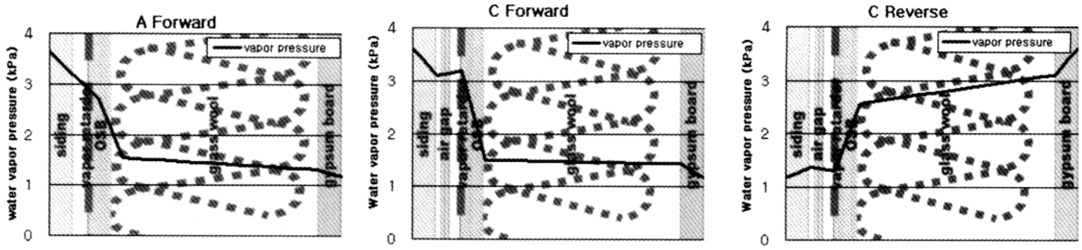

Fig. 11. Distribution of water vapor pressure.

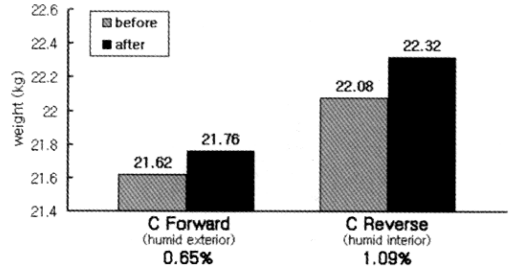

Fig. 12. Change of weight.

The distribution of water vapor pressure was shown in Fig. 11. The area below the curve of the vapor pressure was proportional to the quantity of accumulated moisture in a wall. Moisture from the interior intruded into the wall much more than the exterior. This was confirmed by comparing the weight of a wall before and after experiment (Fig. 12).

3.4. Estimation of Condensation

It was found that the moisture gradient was relatively sharp while the thermal gradient was gentle. For a moist air from the interior passing the glass wool, it approached to the dew point because of good adiabatic performance and poor resistance against moisture intrusion of the glass wool. Thereby, it was thought that the inside surface of the sheathing was subjected to the condensation. Also, high permeance of the gypsum board might cause condensation.

In this study, the case of an additional vapor retarder showed large vapor permeance. If it serves in extreme humidity such as kitchen and bathroom, it would not be able to function properly as a vapor barrier. Accordingly, to restrain condensation originated from the indoor humidity, it was recommended that a vapor retarder with low permeance should be used and the appropriate solutions for the removal of accumulated moisture in a wall must be provided.

4. CONCLUSIONS

In order to improve the hygroscopic performance of light frame wall, four types of wall assembly were fabricated. Temperature and humidity of each wall were measured in hot and humid condition. To estimate the permeance of an additional vapor retarder, the test for permeance of vapor retarder, OSB and gypsum board was conducted. Then, we obtained the following conclusions.

1) All types of wall assemblies showed poor performance against the moisture intrusion from the interior. The equilibrium of the relative humidity was reached in a short period in the case of humid exterior. However, in the case of humid interior, a lot of moisture intruded into the wall because of high vapor permeance of gypsum board. Consequently, it was liable to the condensation.

2) The effect of an additional vapor retarder was very weak. From the test for material permeance, vapor transmission of the vapor retarder for the exterior wall was found to be

large in extreme humid conditions. It was suggested that current vapor retarder have to be replaced with lower-permeant one for better performance against indoor humidity intrusion.

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