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EVALUATION OF HYGROTHERMAL PROPERTY AND BEHAVIOR OF CLT (CROSS LAMINATED TIMBER) WALL USING DOMESTIC WOOD MATERIAL AND DERIVATION OF OPTIMAL WALL ASSEMBLY

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ABSTRACT

Cross Laminated Timber (CLT) is attracting worldwide attention, due to its durability, usability, and many other advantages. However, since CLT is made of wood, analysis of the hygrothermal performance is essential. In this study, the various conditions that affect the thermal moisture behavior were applied to the simulation for getting stable hygrothermal results. As a result, the standard of Passive house and Domestic wooden house, the climate condition, the presence of breathable water proofing paper, and the insulation alternatives of Expended Polystyrene (EPS) and Extruded Polystyrene (XPS) were applied. It was concluded that breathable waterproofing paper should be installed inside, and the applications of both XPS and EPS made no difference to moisture but the application of Mineral Wool was adversely affect to hygrothermal performance of the CLT wall system. The thickness of insulation should be designed according to the Passive house standard (0.15 W/m^{2}K) rather than the Domestic (Korea) Wooden house standard (0.21 W/m^{2}K).

Keywords: Hygrothermal behavior; CLT; WUFI

1. INTRODUCTION

Cross-laminated timber (CLT) panels have the potential market in North America for building mid-rise or even taller structures, due to their good structural and fire safety performance, carbon storage capacity, light weight, and prefabricated nature [1-3]. CLT is a panel-like wood that is obtained by cross-laminating each material. Since CLTs are formed by crossing and stacking wide aggregate boards together with plywood. However, to be exposed to moisture for a long time during construction and in service is a durability concern for most wood products, including CLT. To ensure the long-term durability of CLT, the hygrothermal performance of CLT needs to be investigated.

The hygrothermal behavior of the wooden wall was analyzed using the Wäme und Feuchte instationär-dynamic heat and moisture (WUFI) program. There have been several worldwide studies that have analyzed the hygrothermal behavior and interaction of walls with the surrounding environment for specific regions [4-9].

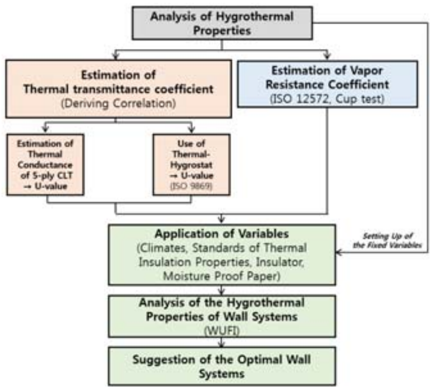

Figure 1. Overall process of the study.

2. MATERIALS AND METHODS

2.1 Methodology

In this study, the basic properties of CLT composed of various wood species and adhesives were measured first. CLT is a cross form of plywood and laminate. Plywood is a kind of composite made of thin plates of wood glued so that the directions of the grain are orthogonal to each other. And the analysis of a building energy of the wooden houses using CLT was conducted. The ultimate goal of this study is to suggest the optimum assembly of the CLT. For this goal, several cases were set and analyzed, and the simulations were carried out with

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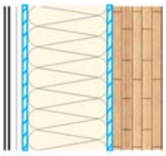
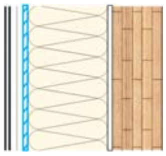
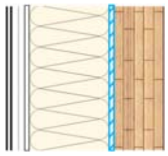
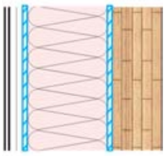
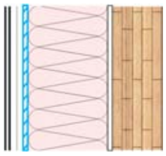
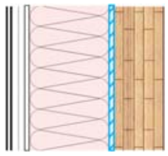
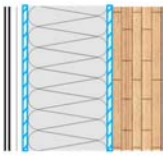
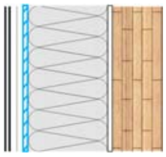
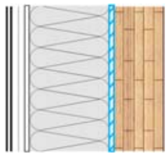
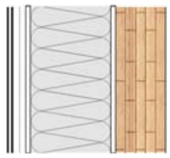
Classifications		Vapor barrier			
Standard	Insulation	O/O	O/X	X/O	X/X
Passive (0.15 W/m²K)	XPS (μ-value: 100)				
	EPS (μ-value: 50)				
	Wool (μ-value: 1.3)				
Korea (0.21 W/m²K)	XPS (μ-value: 100)				
	EPS (μ-value: 50)				
	Wool (μ-value: 1.3)				

Table 1 Wall details for each case (without Incheon & Haenam).

the cases that are the factors affecting the hygrothermal behavior.

2.2 WUFI

In this study, WUFI Pro 5.3 program was used. The CLT used in this test is a system which in configured by Larch made as laminate (Lar-lam) (2-plies), and Larch made as plywood (Lar-ply) (3-plies). The plies were attached to each other by phenol resin. The materials were all domestic. Since there is no standard wooden wall in Korea, a wooden wall was constructed based on the standard wooden houses' design proposed by the Korea Rural Community Corporation [5]. The hygrothermal behavior of the wooden wall was analyzed by using the WUFI to solve the moisture problem at the design stage, and to find the optimal condition of the CLT wall system. The water content of the CLT wall system, as well as the mold growth risk, was obtained and analyzed, respectively [10]. The simulation setup to investigate the drying and wetting behavior of CLT considered the hygrothermal performance of CLT panels made of the same species with different methods of manufacture, plywood and laminate. 24 different wall assemblies were monitored over three years under the climatic conditions of Incheon and Haenam, Korea [11]. In general, the configuration of each wall included a structural CLT panel on the interior, followed by the breathable waterproofing paper, exterior insulation, Extruded Polystyrene (XPS) or Expended Polystyrene (EPS), and a 38 mm air cavity behind the cladding created by 9 mm Western Red Cedar. The type of Water Resistance Barrier (WRB) is a vapor permeable (VP) layer.

2.3.1 Hygrothermal properties of each material to conduct the simulation

There are fundamental properties that need to be earned to analyze the hygrothermal performance of materials in WUFI. Specifically, they are the bulk density, porosity, specific heat capacity, thermal conductivity, and water vapor resistance factor of each material. The porosity is the ratio of voids to total volume, and generally has big values, as the sizes of the particles are even. It can be measured by the mercury absorption method. The specific heat capacity is the thermal energy required to raise the mass temperature of a unit mass by 1 °C. Differential Scanning Calorimeter (DSC) measuring equipment is used to measure the temperature of the test sample and the reference sample at a constant heating rate. The calorie value of the reference sample can be determined according to the phase change of the sample. The thermal conductivity is the energy transferred from the hot side to the cold side per unit of time. The TCi measuring equipment is used to dry the material in a dry condition at a temperature of 60 °C for 48 hours, and measure the thermal conductivity. The water vapor resistance factor (μ) of a building material is the value obtained by comparing the moisture permeation amount through the material per unit area and unit time with the permeation amount of the floating air layer at the same temperature. The value is obtained when the water vapor pressure is different on both sides of the material, and they should be kept constant. That is, the water vapor resistance factor is a coefficient that can indicate how resistant the material is to vapor permeability. This can be obtained through a dry-cup test. In this study, the bulk density, porosity, and specific heat capacity were obtained from the results of previous test analysis, and the thermal conductivity and vapor permeability resistance factor were directly measured in this study.

2.3.2 Cases of simulation

Table 1 below shows the number of wall systems applied to the simulation. The thickness of insulation of wall systems is set according to the Domestic wooden house standard (Korea) and Passive house standard (Passive), respectively. The types of insulation were classified into three types, XPS, EPS, and Mineral Wool. The applied cases were divided into four types, depending on whether breathable waterproofing paper was applied to either the exterior or interior side, or to both sides. The climate conditions of Incheon and Haenam were applied.

3. RESULTS AND DISCUSSION

3.1 Analysis of results using WUFI

3.1.1 Water content (WC) of the insulation

In WUFI, water content can be known in certain material that was selected by users in the set period. So, in this study, the insulation was chosen to be analyzed based on the assumption that the insulation is the most vulnerable material to moisture. Figure 3 shows the maximum value for comparing the water content in each case on the Passive standard basis, while Table 6 shows the average of each. In terms of the insulation, the water contents of XPS, EPS, and Mineral Wool are (1.79, 1.80, and 2.40) kg/m^3, respectively, which are highly likely to cause mold in the order XPS < EPS < Mineral Wool. Since Mineral Wool has too much effect on the water content, the averages of water content are obtained without the Mineral Wool when analyzing the influence of breathable waterproofing paper on the water content. When calculated as such, the water contents of O/O, O/X, X/O, and X/X are (1.79, 1.81, 1.79, and 1.79) kg/m^3, respectively. Therefore, the water content increases in the order of O/O = X/O = X/X < O/X. When the average of the water content is calculated by region, the water contents of Incheon and Haenam are (1.98 and 2.03) kg/m^3, respectively. So the water content in Haenam is higher than that in Incheon. Figure 4 shows the maximum water content of the insulation according to the 'Korea' standard. Table 7 shows the average of the water content according to the presence of breathable waterproofing paper. The results of analysis through the graph are as follows. Insulation material has high water content in the order of XPS < EPS < Mineral Wool, with (1.800, 1.826, and 2.948) kg/m^3, respectively. Since Mineral Wool has too much effect on the water content, averages of water content by O/O, O/X, X/X, and X/O are obtained without the Mineral Wool, to analyze the influence of the breathable waterproofing paper. When calculated as such, the water contents of O/O, O/X, X/O, and X/X are (1.80, 1.83, 1.80, and 1.81) kg/m^3, respectively. Therefore, the water content increases in the order O/O = X/O < X/X < O/X. The water contents of O/O, O/X, X/O, and X/X are ((2.20 and 2.30), (1.8 and 1.8), (2.2 and 2.3), and (1.8 and 3.0)) kg/m^3, respectively. Therefore, the water contents of O/X and X/X are larger than those of O/O and X/O. The water contents in Incheon and Haenam are (2.00 and 2.35) kg/m^3. So the hygrothermal condition of the climate condition of Haenam is worse than for Incheon. Comparing the 'Passive' standard and the 'Korea' standard, the water contents are larger in the 'Korea' Standard house. In other words, when adjusting the Passive house standard, the water contents are more stable, than adjusting the Domestic wooden house standard.

3.1.2 Total Water Content (TWC) of the Wall system

The Total Water content (TWC) is an indicator of water stability for a long period. Therefore, if it shows a decrease with time, it is considered that there is no water accumulation in the wall systems. Also, it is possible to judge that the wall system is stable in the hygrothermal condition when the value decreases as time goes on. Since the period in the simulation is set to 3 years, the average values of the 1st, 2nd, and 3rd years are obtained respectively, and the difference between the 1st and the 3rd year is obtained and described in Table 8. In the table, the values are all minus, which means the values all decrease as time goes by. The larger the obtained values, the better in terms of water accumulation. Looking at the difference between the 1st and 3rd year, the water contents of the insulation, XPS and EPS, are low overall, and the insulation of Mineral Wool has larger water content than them. The averages of total water content difference between the 1st and 3rd year of standard were obtained. The differences of the 'Korea' and 'Passive' standard were (0.94 and 0.90) kg/m^3. In the 'Korea' standard, the water content is not stable as time goes by. In order to see the influence by the presence of the breathable waterproofing paper, the averaged values of total water content difference between the 1st and 3rd year of O/O, O/X, X/O, and X/X were obtained, except for the values of Mineral Wool. This was because Mineral Wool has larger water content than the other insulation materials. The results are as follows. The values of the O/O, O/X, X/O. and X/X are (9.62, 9.31, 9.62, and 9.54) kg/m^3. This means that the decrease in the total water content from the 1st to 3rd year is big in the order O/X < X/X < O/O = X/O. The differences in water contents between the 1st and 3rd year of O/O and X/O are larger than those of O/X and X/X, which means the water contents are stable. To get the regional total water content interpretation, the averages of total water content difference between the 1st and 3rd years of Incheon and Haenam were obtained. The values of Incheon and Haenam are (1.01 and 0.83) kg/m^3. Because the difference of total water content between the 1st and 3rd year is bigger in Incheon than that in Haenam, the water stability in Haenam is worse than in Incheon.

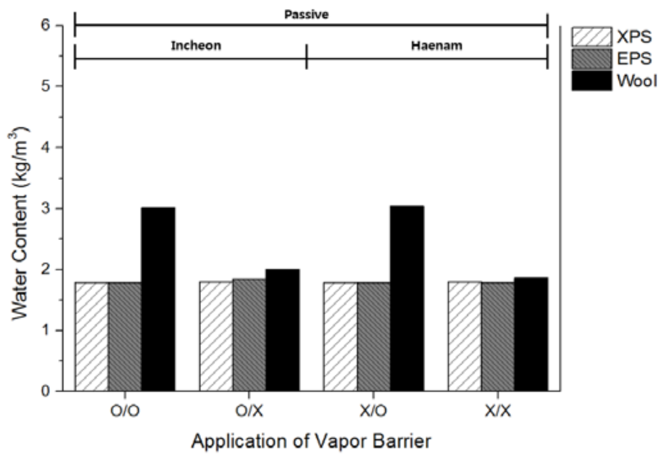


Figure 3. Graph of Water Content (Passive standard).

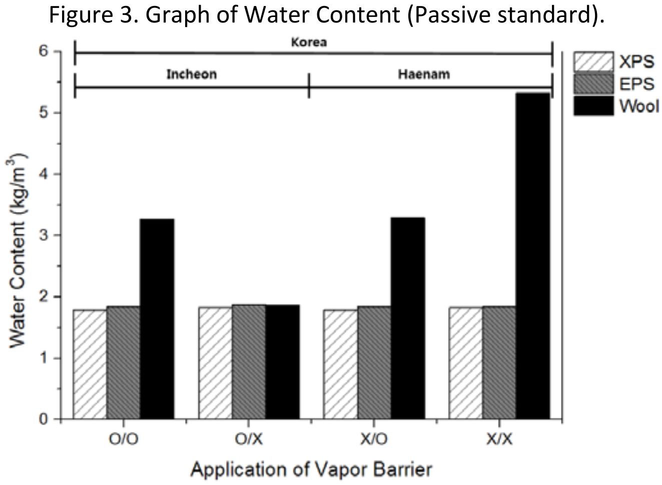


Figure 4. Graph of Water Content (Korea standard).

3.1.3 Lowest Isopleth for Mold growth (LIM) Total Water of the Wall system

If the relative humidity exceeds the boundary that is made by the equation described in Table 9, it is judged that there is a risk of mold growth. In this study, the sums of time over the boundary line in the LIM graph were compared for each case. The results of Figure 3 are as follows. For insulation, the hours of having a risk of mold growth for XPS, EPS, and Mineral Wool are (323.38, 823.25, and 2,568.25) h, respectively. They are likely to occur in the order XPS < EPS < Mineral Wool. Table 10 shows the possible time to grow mold by calculating the averages of the risk hours by the presence of breathable waterproofing paper. The times to be able to grow mold for O/O, O/X, X/O and X/X are (0, 252.25, 252.25. and 507.15) h, respectively. So, the likelihood of growing mold is higher in the order O/O < O/X = X/O < X/X. Also, the risk hours to grow mold in Incheon and Haenam are (891.83 and 1,203.73) h, respectively, so mold is more likely to grow in Haenam than in Incheon. The Lar_Lar_p was applied to WUFI to determine the stability of thermal moisture through the water content;

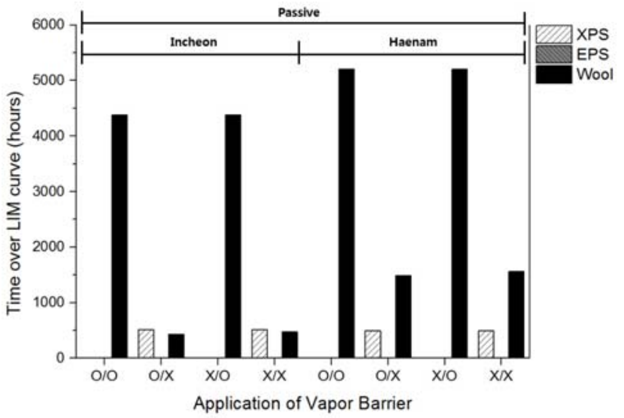


Figure 5. Hours of likely to grow mold (Passive standard).

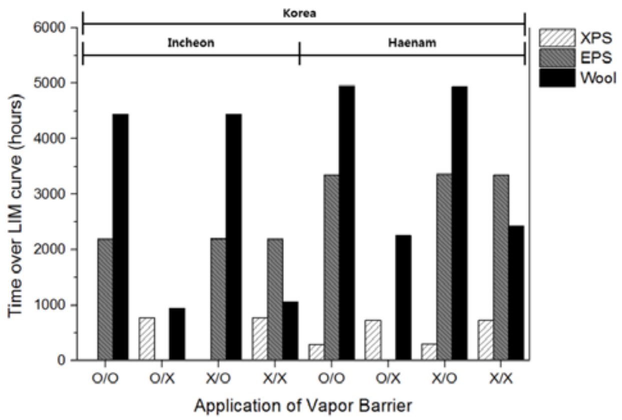


Figure 6. Hours of likely to grow mold (Korea standard).

3.2 Analysis of results using WUFI

3.2.1 Water content (WC) of the insulation

In WUFI, water content can be known in certain material that was selected by users in the set period. Figure 6 shows the maximum value for comparing WC in each case on the Korea standard basis. When the moisture content of insulation, the XPS, EPS, Mineral Wool accounts for each 1.793, 1.8, 2.399 kg/m^3. Therefore, the water content increases in order of O/O = X/O = X/X < O/X. When calculated the average of the Water content by region, the Water content of Incheon and Haenam is higher than the one in Incheon.

4 CONCLUSION

This study used CLT made of domestic wood. The thermal moisture behavior of the wall system was analyzed to see how it could be easily obtained. To find the optimal CLT wall system, cases were divided by applying various conditions that affect the heat and moisture behavior, and the safest conditions applied in the simulation for heat and moisture problems were found out. The Lar_Lar_p was applied to WUFI to determine the stability of thermal moisture through the water content; the long-term moisture stability, which can be known by the Total Water content; and the potential for mold growth, which can be known by the LIM graph. As the results, to ensure that the CLT wall is hygrothermally stable, insulation should be EPS or XPS, breathable waterproofing paper should be installed inside, and the thickness of insulation should be designed according to the Passive house standard. The CLT wall system is more heavily influenced by heat and moisture in the climate of Haenam, compared with the climate of Incheon.

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