Analysis of Heating Energy Reduction of Wooden-based Korean Hanok Using Passive Houses Planning Package (PHPP)

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This study sought to design a low-energy Hanok house through the PHPP energy simulation program. The goal is to retain the spirit of Hanok, a traditional Korean house style, and spread the adoption of the Hanok style. Using the standard drawings of the wood-frame house and the Hanok, the analysis of the heat loss of each element and the annual heat demand showed that the Hanok had about six times higher energy demand, and the heat loss was mostly associated with the envelope. As a result of applying to the Hanok principles in the same way as the insulation condition of a modern wood-frame house, the analysis showed an opportunity for about an 80% energy reduction. The need for design standards for the development of low-energy Hanok was confirmed.

Keywords: Passive House Planning Package (PHPP); Wood-frame house; Hanok; Heating-energy performance

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INTRODUCTION

Throughout the world, interest concerning energy consumption in buildings, which is estimated at 20% to 40% of the total energy consumption, has increased steadily with the emergence of global warming and extreme weather events (Pérez-Lombard *et al*. 2008; Kang *et al*. 2016; Marin *et al*. 2016). Accordingly, in the case of South Korea, a 26.9% emission reduction by 2020 has been set as a target for the building sector, and the nation's energy-saving policy was enhanced. Also, an energy-related standard that calls for the implementation of the passive-house level from 2017 and the zero-energy house level from 2025 has been introduced (Green Building Construction Support Act 2013). This measure will reduce the main energy uses that cause greenhouse-gas emissions (Kwon 2012; Kang *et al*. 2016).

According to the data released by the Statistics Korea and the Ministry of Agriculture, Food and Rural Affairs (MAFRA), the number of households that returned to farming and rural areas in 2016 was 335,383, representing an increase from the previous year, which was 6,015 households increased. In accordance with this finding, the number of farming/rural-return households has continued to increase steadily. Along with this trend, wood-frame houses are taking center stage in these households because wood-frame houses can be built inexpensively and the corresponding construction periods are relatively short compared to other methods because they can be constructed at any time through the dry construction method, and the one process has no direct effect other processes.

A wood-frame house can save energy because excellent heat-insulation performance can be achieved. Because such houses can last a long time, the wastage of the construction materials can be reduced (Chang 2003). According to data from the Ministry of Land, Infrastructure and Transport, the number of domestic wood-frame houses started to increase from 1,993 houses in 2005 to 13,595 houses in 2015.

In addition, there is a growing attention directed toward the wooden construction-based Korean traditional house, the Hanok, represented in Table 1. This interest arises due to an interest in traditional culture that accompanies rising income levels, environmental, and health benefits of modern materials, and construction methods (Oh *et al*. 2014). Hanok means architecture built with Korean technology and style from prehistoric times. The narrow range means 'residential residence' and includes a wide range of 'traditional Korean architecture'. There is almost no pollution associated with the modern construction of a Hanok dwelling. The Hanok is made of common raw materials, such as timber, stone, and soil, all of which are recyclable and available almost anywhere in South Korea (Kim *et al*. 2015); so such activity is not harmful to the human body and building activities do not damage the ground.

The problems of the traditional Hanok, such as insulation and air tightness are worth highlighting in comparison with modern housing. In particular, among the shortcomings of the traditional Hanok, the ratio of “hot” to “cold” feelings is 18%; to improve this problem, supplemental insulation, air tightness, and the development of construction and design techniques are needed. In terms of heat performance, the traditional Hanok is inferior to the criteria of the current statutes and guidelines (Lee and Park 2011). However, after the enactment of the Ordinance on Supporting Hanok (2002), the interest in the Hanok has been growing along with research regarding a new Hanok, for which the construction cost is affordable, the insulation and air tightness are improved, and eco-friendliness is achieved.

In this study, the aim was to reduce the energy consumption of Hanok and to increase the residence comfort of residents, while continuing the spirit of Hanok, a traditional Korean residential culture. In order to maintain a degree of objectivity, the standard building drawings of wooden houses and the Hanok were used. Ways to reduce the energy performance levels of Hanok to energy levels in modern wooden houses were analyzed and suggested.

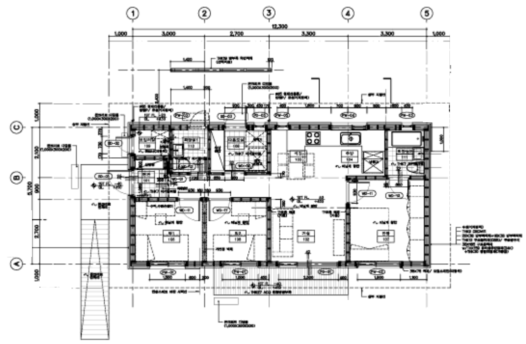
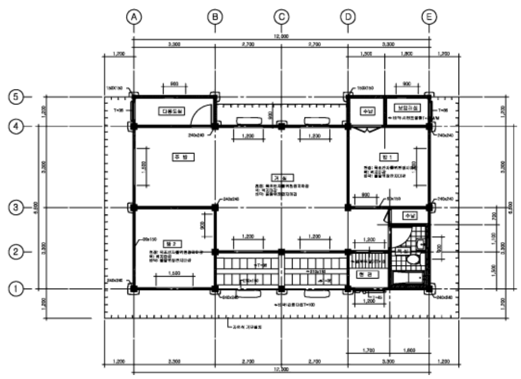
EXPERIMENTAL

Materials

Analysis object houses

For objective comparative analysis, the standard building drawings were used provided by the government of Korea. The standard houses with similar gross areas were selected from a rural-house standard drawing that was provided by the MAFRA and a Hanok-standard drawing that was provided by the Korea Rural Community Corporation. The selected standard wood-frame houses (WFH) were the 14-21-A type (70.40 m^2). The selected standard Hanok is the C-1 type (69.12 m^2). The perspective drawings and the floor plans are represented in Table 1.

Table 1. Perspective Drawing and Floor Plan of Standard Houses

	Perspective Drawing	Floor Plan
WFH		
Hanok		

Envelope Composition of Standard Houses

The envelope thermal transmittances (U-values) of the WFH and the Hanok that were calculated using the PHPP are represented in Table 2. It was assumed that the rubbed red-clay finish on the clay brick and the envelopes, with the exception of the floor slab, on the exterior Hanok wall represented a U-value that was higher than those of the WFH because of the absence of insulation. When the U-value of the envelope was calculated, too-thin layers, such as the vapor-permeable waterproof paper, were excluded, following the instruction of PHPP.

The window U-value of the WFH was 2.4 W/m^{2}K, which is the central region window U-value presented in the rural-house standard drawing. The criteria for regional classification are divided into latitudes and local characteristics, and tend to become warmer forward the south. Those of the Hanok that were the U-values of the windows composed of a wooden frame and window-paper were entered as 4.177 W/m^{2}K (Park and Jo 2013). Also, the solar heat gain coefficients (g-values) of the windows and doors of the wood-frame houses and the Hanok were entered as 0.57 and 0.29, respectively. The applied performances of the windows and doors are represented in Table 3.

Table 4 shows the heat-transfer resistances on the building surfaces that are in the Annex 5 of the Energy-saving Design Criteria. The standard specifies the values of indoor building surfaces (Rsi) of the exterior walls, roofs, and slabs by separating the cases where the surface is directly or indirectly exposed to outdoor air.

Table 2. Configuration and Thermal Transmittance of Floor Slab

	Material	Thermal Conductivity (W/mK)	Thickness (mm)	U-value (W/m²K)
Floor Slab (WFH)	Mortar	1.400	48	0.303
	EPS	0.034	100	
	Concrete Slab	2.000	150	
	Subslab Concrete	2.000	30	
Floor Slab (Hanok)	Mortar	1.400	24	0.432
	EPS	0.034	50	
	Plain Concrete	2.000	200	
	Subslab Concrete	2.000	50	
	Rubble	0.320	150	
Exterior Wall (WFH)	CRC Board	0.240	9	0.216
	Air Space	0.180	38	
	Stud	0.150	38 × 38 @ 450	
	OSB	0.130	12	
	Glass Wool	0.038	159	
	EPS	0.034	30	
	Stud	0.150	38 × 185 @ 400	
	Gypsum Board	0.180	19	
Exterior wall (Hanok)	Red Clay	0.800	5	3.525
	Clay Brick	0.660	80	
	Red Clay	0.800	5	
Roof (WFH)	Asphalt Shingle	0.330	3	0.183
	OSB	0.130	12	
	Glass Wool	0.038	159	
	EPS	0.034	75	
	Stud	0.150	38 × 235 @ 490	
	Plywood	0.150	5	
Roof (Hanok)	Roofing Tile	0.750	20	0.651
	Air Space	0.025	30	
	Stud	0.150	38 × 38 @ 450	
	Soil	0.660	200	
	Wood Frame	0.150	21	

* CRC Board: Cellulose fiber Reinforced Cement Board
* OSB: Oriented Strand Board
* EPS: Expanded Poly Styrene
* Thickness of stud: width × length @ space

Table 3. U-values and g-values of Windows

	WFH	Hanok
U-value (W/m²K)	2.400	4.177
g-value	0.57	0.29

Table 4. Heat-transfer Resistances on Building Surfaces (m^2K/W)

	Indoor (Rsi)	Outdoor (Rse)	
		Direct Facing on Ambient Air	Indirect Facing on Ambient Air
Exterior wall of living room (Including side wall, window, and door)	0.11	0.043	0.11
Floor of living room on bottom floor	0.086	0.043	0.15
Roof on top floor	0.086	0.043	0.086
Floor of multi-unit dwelling	0.086	-	-

Methods

Overview of Passive House Planning Package

In this study, the Passive House Planning Package (PHPP) 8.5, which is a calculation program for passive-house energy performances, was used to evaluate the building-energy performances. The PHPP is a spreadsheet design and compliance program that enables users to check building-energy performances and optimize the energy usage from the design stage onward. The design of the PHPP is based on ISO 13790 (2008), an international standard from the Passive House Institute Germany, which also adheres to the DIN V 18599 (2007) and DIN 4108 (2007) standards, among others (Yu *et al*. 2013; Moran *et al*. 2014). The standard ISO 13790 (2008) is used to define a method for the calculation of the heating and cooling demands of buildings, and it proposes a variety of calculation methods such as the “Monthly” calculation method, the “Simple” hourly calculation method, and the “Dynamic” simulation method. Because the Monthly calculation is used in the PHPP, the collected data can be used to analyze the thermal capacities of structures when the heating and cooling demands are being calculated (Song *et al*. 2010; Cho *et al*. 2011).

Lastly, the PHPP is used to calculate the heating-energy demand if the user inputs the U-values of the components, area, ground condition, window performances, awning type, ventilation efficiency, and internal heat gain after the climate data of the located area has been inputted. The calculated data are then evaluated according to the passive-house design criteria (Yu *et al*. 2013).

Setting condition of PHPP

In this study, the five regions with the highest ratios of the number of farming/rural-return households in 2015 were selected, as follows: Gyeongsangbuk-do, Jeollanam-do, Gyeongsangnam-do, Chungcheongnam-do, and Jeollabuk-do. This selection accorded with the data that were announced by the Statistics Korea and the MAFRA, and the climate data of each of the regions in Table 5, which were provided by the Passive House Institute Korea, an incorporated association, were applied. Also, five regional locations and latitudes on the Korean map are shown in Fig. 1.

Table 5. Climate Data of Standard Houses by Regional Group

Classification		Month			
		Dec.	Jan.	Feb.	Mar.
Yeongcheon	Outdoor Temperature (°C)	2.7	1.0	3.5	8.3
	Dew-point Temperature (°C)	- 6.2	- 8.3	- 7.2	- 2.7
	Sky Temperature (°C)	- 15.0	- 17.6	- 15.0	- 9.0
	Underground Temperature (°C)	14.3	11.4	9.7	9.8
	Total Global Radiation (kWh/m^2·month)	305	311	329	372
	Latitude (°)	36.0			
	Altitude (m)	94			
Muan	Outdoor Temperature (°C)	3.9	1.6	3.0	7.1
	Dew Point Temperature (°C)	- 1.4	- 3.5	- 2.8	0.6
	Sky Temperature (°C)	- 9.9	- 11.8	- 11.1	- 6.1
	Underground Temperature (°C)	14.8	11.8	9.9	9.6
	Total Global Radiation (kWh/m^2·month)	264	274	312	399
	Latitude (°)	35.0			
	Altitude (m)	32			
Geochang	Outdoor Temperature (°C)	1.4	- 0.4	1.9	6.9
	Dew-point Temperature (°C)	- 6.1	- 8.1	- 7.2	- 3.2
	Sky Temperature (°C)	- 15.6	- 17.8	- 15.6	- 9.8
	Underground Temperature (°C)	13.3	10.3	8.6	8.6
	Total Global Radiation (kWh/m^2·month)	301	306	327	389
	Latitude (°)	35.7			
	Altitude (m)	201			
Asan	Outdoor Temperature (°C)	- 0.2	- 2.2	0.1	5.4
	Dew-point Temperature (°C)	- 4.8	- 6.8	- 5.5	- 1.4
	Sky Temperature (°C)	- 14.1	- 16.3	- 14.5	- 8.4
	Underground Temperature (°C)	12.6	9.3	7.4	7.4
	Total Global Radiation (kWh/m^2·month)	234	254	297	367
	Latitude (°)	36.8			
	Altitude (m)	33			
Gimje	Outdoor Temperature (°C)	2.3	0.2	1.9	6.3
	Dew-point Temperature (°C)	- 3.1	- 5.1	- 4.0	- 0.3
	Sky Temperature (°C)	- 11.6	- 13.6	- 12.4	- 7.1
	Underground Temperature (°C)	14.1	10.9	9.0	8.8
	Total Global Radiation (kWh/m^2·month)	239	249	303	381
	Latitude (°)	35.8			
	Altitude (m)	25			

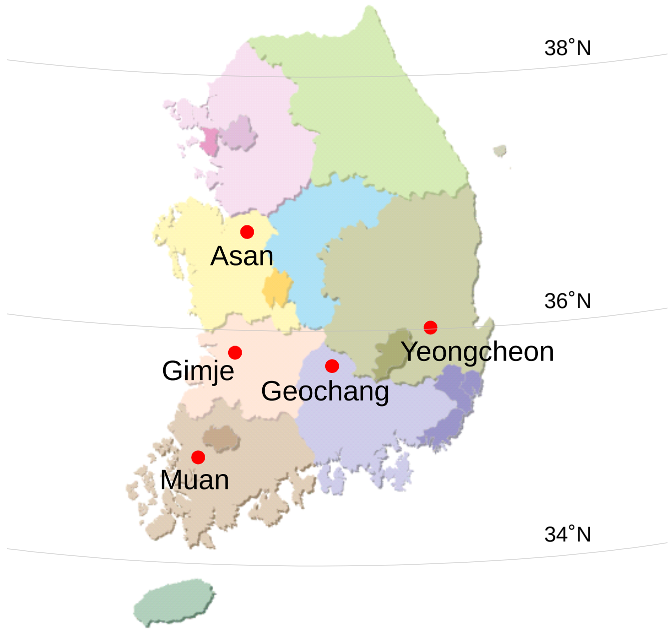


Fig. 1. Location and Latitude of five selected regions

The details of the common input parameters for buildings are represented in Table 6, and most of this data are based on the default value and manual of the PHPP. The heating-degree days and heating-degree hours were calculated based on the following content that the room temperature standard for heating is 20 °C, and it is calculated that the heating starts from the outside temperature 12 °C, and the standard occupation-ratio value that was required for a residential building for the passive-house certification was 35 m^2 per person (Yu *et al*. 2013).

Table 6. Common Input values in the PHPP

	Category	Input Value
Basic outline	Building Type	Residential Building
	Building Use Pattern	Dwelling
	The Number of Households	1
	The Number of Occupants	4
	Heat Capacity (Wh/m^2·K)	60
	Indoor Temperature in Winter (°C)	20
	Indoor Temperature in Summer (°C)	26
Ground	Floor Slab Type	Unheated Basement
	Thermal Conductivity of Soil (W/m·K)	10.0
	Heat Capacity of Soil (MJ/m^2·K)	10.0
	The Number of Air Changes of Unheated Basement (h^{-1})	0.20
	Ground-water Depth (m)	3.0
	Ground-water Flow Rate (m/d)	0.05
Ventilation	Result Value of Tightness-test;n50 (h^{-1})	0.22

Calculation method of heating-energy demand

The heating-energy demand of a building is calculated by the subtraction of the heat gains from the heat losses. The heat losses of a building are calculated by the addition of the heat losses that are through the structure (Q_T) to the heat losses that are through the ventilation (Q_V), as based on the ISO 13790 standard (2008). Each of the heat losses, Q_T and Q_V, were calculated according to Eqs. 1 and 2,

$$Q_T = U_W \times A \times f_t \times G_T \tag{1}$$

$$Q_V = V \times n \times C_P \times G_T \tag{2}$$

where Q_T is the heat loss through structure (kWh/a), Q_V is the heat loss through ventilation (kWh/a), U_W is the U-value (W/m^{2}K), A is the envelope area (m^2), f_t is the temperature-modification factor, V is the building volume (m^3), n is the ventilation amount (1/h), C_P is the specific heat under constant air pressure (Wh/m^{3}K), and G_T is the heating-degree hours (kKh/a).

The building-heat gains were also calculated according to the addition of the heat gains that are through the windows (Q_s) to the heat gains that are through the internal heat gain (Q_i). Each of the heat gains, Q_s and Q_i, were calculated following Eqs. 3 and 4,

$$Q_s = r \times g\text{-}value \times Ag \times G \tag{3}$$

$$Q_i = 0.024h/day \times HDD \times qi \times ATFA \tag{4}$$

where r is the reduction factor of insolation (shading factor), the *g-value* is the acquisition factor of insolation, Ag is the glass area (m^2), G is the insolation by each bearing (kWh/m^{2}a), HDD is the heating-degree days (day/year), qi is the internal heat-gain rate (W/m^2), and $ATFA$ is the heating and cooling area (m^2).

RESULTS AND DISCUSSION

Annual Heat Loss and Heat gain Analysis by Component

In order to confirm the thermal performance of the WFH and the Hanok, the ratio of the heat loss and the heat gain to the heat-affected elements were calculated, and the results are shown in Fig. 2. The annual heating energy demand of Hanok was calculated as 419.4 kKh/m^{2}a, which is about six times higher than WFH. As the heat insulation performance of the building structure (envelope) of the Hanok is weaker than that of the WFH, the heat loss of the structure accounted for 98.86%. In the case of WFG, the heat loss of the structure accounted for a high ratio of 94.95%, which establishes that the heat loss through the envelope, rather than the ventilation system, has the greatest influence on the heat loss of the residential building.

Both WFH and Hanok have the same window area of 13 m^2, but the value of heat loss due to window is higher in Hanok. This is because the U-value of the traditional Hanok window is higher. On the other hand, in solar gain, WFH is 2.5 times higher than Hanok, because the g-value of Hanok window is low, which is disadvantageous to solar heat acquisition. This means that the U-value and the g-value of the window play an important role as the principle of lowering the heating energy requirement by acquiring and maintaining heat through the window.

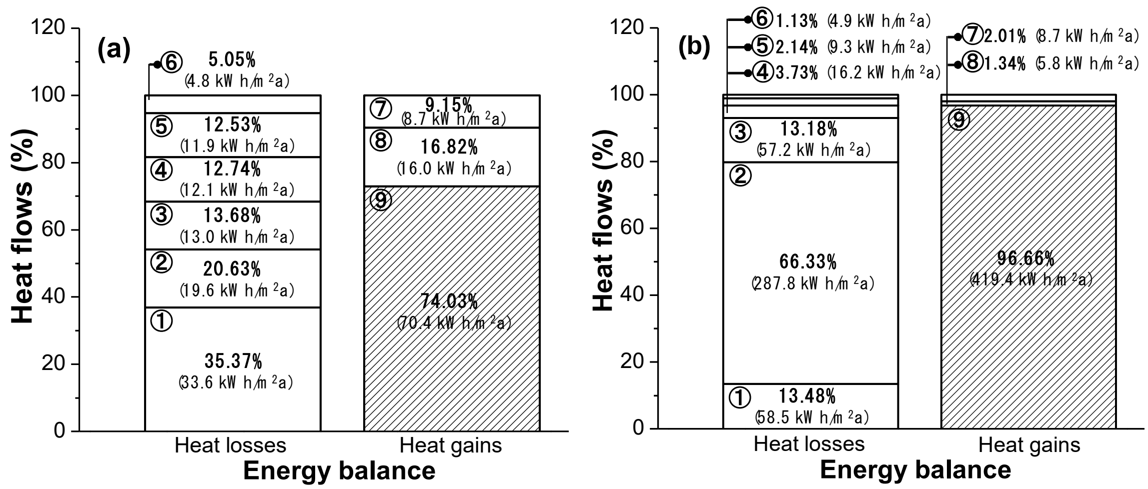


Fig. 2. Annual heat losses and heat gains of (a) WFH, (b) Hanok by component (①windows; ②Exterior wall; ③Roof; ④Floor slab; ⑤Exterior door; ⑥Ventilation; ⑦Internal heat gain; ⑧Solar gain; ⑨Heating demand)

Monthly Heat Loss Analysis

Figure 3 shows monthly heat loss of WFH and Hanok. For Hanok, the heat loss of 100.1 kWh/m^2 in January is calculated, which is about 4.5 times higher than that of 21.5 kWh/m^2 WFH. On the other hand, the minimum heat loss of -23.8 kWh/m^2 is calculated in August, which is the cooling period, and it is expected that the cooling energy demand will also increase because the heat gain is higher than that of -4.3 kWh/m^2 WFH. In this case, since the difference in heat loss between WFH and Hanok heating period is remarkably large, research for minimizing the use of heating energy is continuously required.

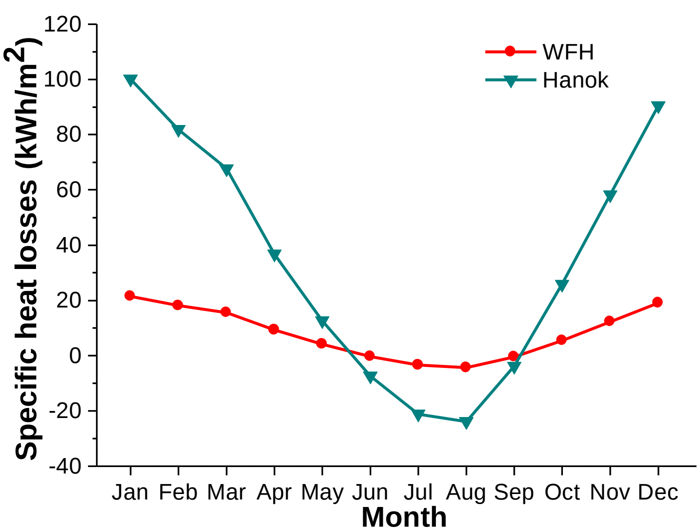


Fig. 3. Monthly Heat Loss Analysis

Energy Demand Reduction Analysis of Hanok

Change the building envelope layer

In order to simulate the energy reduction of Hanok, the layer composition of building envelope of Hanok on PHPP was changed. There are two cases. Case 1 is assumed to be the same as the exterior wall, slab thickness of WFH, and insulation is added. At this time, the assumed type of insulation and the stud style were the same as those of WFH, as shown in Table 2. In case 2, regardless of the thickness of the exterior wall, the building envelope layer was changed by the same type and thickness of insulation material and stud style of WFH. Also, cases 1 and 2 were changed to the same window as WFH. The simulation results of the case 1 and 2 are shown in Fig. 4, and the required annual heating energy demand is compared with the reference Hanok. Table 7 shows the building envelope U-value in case 1, 2 and current criteria which is regulations in Annex 1 of the Energy-saving Design Criteria.

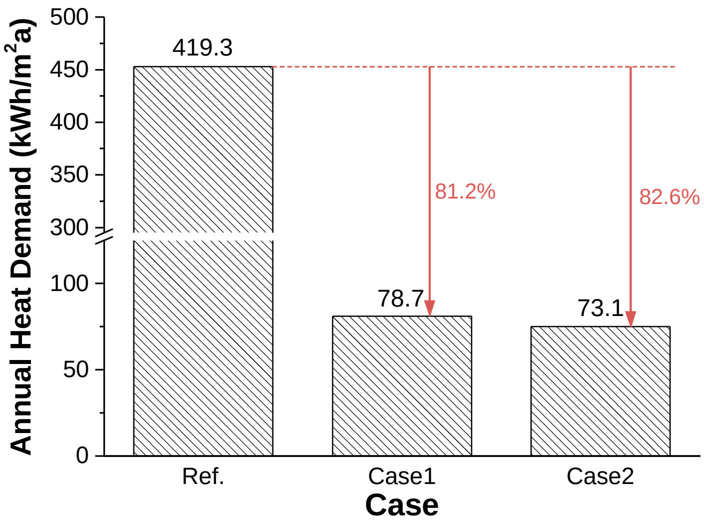


Fig. 4. Heating Energy Reduction of Hanok by Case

Table 7. U-value of Building Envelope by Case

	WFH	Ref. Hanok	Case1	Case2	Regulation
Roof (W/m^{2}K)	0.183	0.651	0.148	0.148	0.150
Exterior wall (W/m^{2}K)	0.216	3.525	0.315	0.249	0.260
Slab (W/m^{2}K)	0.303	0.432	0.264	0.264	0.180

As shown in the Fig. 4, annual heat demand reduction of 81.2% in case 1 and 82.6% in case 2 was achieved when insulation was added in the same manner as wooden standard houses. This demonstrates that the heat loss through the envelope has the greatest effect on the heating energy of the building. In case 1 and 2 show that the envelope U-values are below the standard, except for the roof and case 2 exterior wall. In particular, it is considered that only the case 2 in which the exterior wall thickness is not limited satisfies the criterion, so that the development and application of the high performance insulation material should be made so that the high insulation performance can be achieved even at a thin thickness.

Change the opening position

At the south side of the buildings in South Korea, a relatively large insolation was found in winter because South Korea is located in the northern hemisphere. Therefore, to save the heating energy of buildings, positioning houses to face south has been an effective measure to increase the south-side window area during building design. According to the climate data that has been entered in the PHPP, in the case of Asan, the global horizontal irradiance of the north, east, south, and west sides were 142, 270, 481 and 276 kWh/m^{2}a, respectively. Namely, the value of the global horizontal irradiance at the south side was the highest value.

The proportions of the south-window area to the total window area of the WFH was 85.93% while that of the Hanok, which was a considerably smaller value, was 32.97 %. Based on these data, a change of the northern and southern windows of the AFH and the Hanok in Asan was performed, and the rates of the increase of the annual heat demand were calculated; the results are shown in Fig. 5.

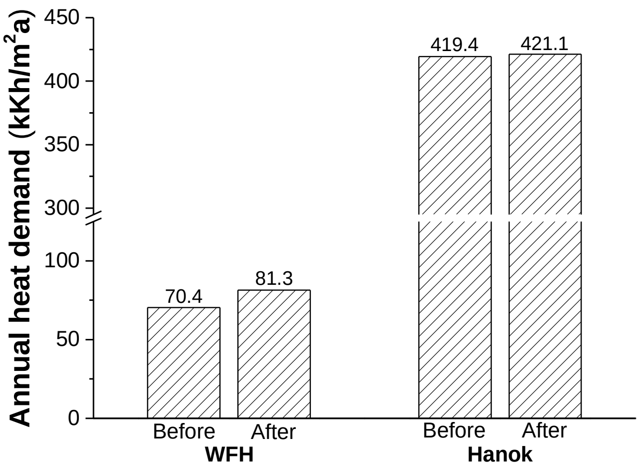


Fig. 5. Annual Heat Demand When Changing Opening Position

The rates of the increase of the annual heat demand of the AFH was 15.48% and that of the Hanok, which was a much lower value, was 0.41%. These results verified the influence of window-position selection on the saving of the heating energy of buildings. Especially, it is important to increase the window area of the Hanok, for which the g-value of the window is relatively small and the solar gain is low.

Evaluation of Heating-energy Demand by Regional Group

Table 5 shows the factors of the climate data of 5 regions. The highest outdoor-temperature value by regional group was in Asan, from December to March, and the smallest values were in Muan, during December and January, and Yeongcheon, during February and March. Generally, the highest total-insolation value by regional group was in Yeongcheon, and the smallest value was in Asan. However, these values vary slightly by month. The monthly heating-degree hours and heating-energy demands of the WFH in terms of the heating period by regional group (the calculations of which were based on the entered climate data) are represented in Figs. 6a and 6b, respectively.

The heating-degree hours were influenced by the outdoor temperature, and thus the tendency of the regional heating-degree hours was the same as that of the outdoor temperature. However, the tendency of the demand of the monthly regional heating-energy on the heating period was different from the tendency of the heating-degree hours. When the calculation variables were considered (they were calculated according to the subtraction of the heat losses of buildings from the heat gains of buildings), it was reasoned that both the heating-degree hours (kKh/a) and the insolation (kWh/m^{2}a) were responsible for the heat losses and the heat gains, respectively, during the calculation process.

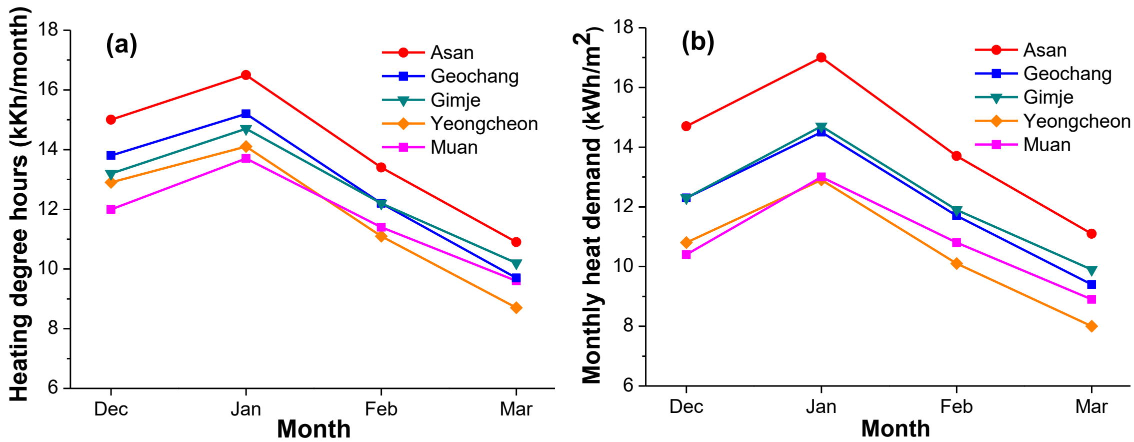


Fig. 6. (a) Monthly heating-degree hours and (b) monthly heat demand by regional group

CONCLUSIONS

1. This study was aimed at reducing the energy demand of the Hanok style of traditional Korean houses. Hanok is a unique residential style in Korea. There appears to be potential for the spread of a new version of Hanok that achieves good energy efficiency while retaining the traditional style elements.
2. For the purpose of objective comparison, the standard building drawings of Wood-frame houses and Hanok were used provided by the government of South Korea. Also, the heat loss by building components and annual heat demand were analyzed using Passive House Planning Package (PHPP).
3. Analysis of annual heat loss and heat gain by component showed that the annual heating demand of Hanok is about 6 times higher than that of Wood-frame house. The reason for this is the envelope that accounts for most of the heat loss. Considering that the envelope occupies 98.86% of the heat loss factor of Hanok, it's clear that the heat loss through the envelope has the greatest influence on the heat loss of the building.
4. In order to propose a solution for the design of low-energy Hanok, the conditions on PHPP were modified by adding insulation in the same condition as the wood-frame house. As a result, energy saving performance of about 80% was confirmed by the addition of insulation, but considering the thickness of the Exterior wall, it is necessary to establish a standard for low-energy Hanok design.
5. As a result of confirming the energy reduction according to the orientation of a building relative to the sun, the analysis showed the importance of the ratio of the south side window area. Especially, since the g-value and solar gain of Hanok are small, the position of opening in Hanok is important and it is essential to develop a high-fuctional Hanok window.

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