Journal of the Korea Academia-Industrial cooperation Society
Vol. 14, No. 2 pp. 955-961, 2013
http://dx.doi.org/10.5762/KAIS.2013.14.2.955

A Study on the Thermal Environment Evaluation of 'Hanok' considering Solid Model of Building Elements

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한옥의 건축요소 솔리드 모델링을 통한 열환경 평가에 관한 연구

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Abstract This study aimed for the scientific approach of Korean traditional house, so called *Hanok*, by analyses of structural elements and thermal environmental performance. *Hanok* is a very unique vernacular architectural style of the Middle East Asia that fits with climate conditions of the Korean Peninsular, designed to withstand high temperature and humidity in summer and cold and dry in winter seasons. In order to evaluate thermal environment of *Hanok*, its sectional structure such as floor, wall, roof structure and *Ondol* which is Korean traditional floor heating system, was built in 3D, as well as heat transfer mechanism of its composing elements was analyzed through 3 dimensional steady state analysis. The results of the thermal environmental performance of *Hanok* will be used as a basic datum of design guidelines for accomplishing ecologic housing fitted with local climate.

요 약 본 연구는 친환경 건축의 대안으로 부각되고 있는 한옥의 열환경 평가를 수행하기 위하여 한옥을 구성하고 있는 건축요소의 전열 메카니즘을 규명하기 한옥건축부재의 규격화와 모델링을 통하여 열환경을 평가하였다. 최근 친환경 건축, 생태건축의 모델로 일반의 한옥 선호도는 높아지고 있으나, 한옥의 우수성이 정성적으로만 평가되고 있다. 이에 한옥의 건축재료 및 형태와 같은 건축요소를 고려, 한옥 건축요소의 Geometry를 작성하여 솔리드 모델을 구축하고, 열환경 평가의 도구로써 CFD를 적용하여 한옥의 실내 열환경을 평가하고자 하였다. 본 연구에서는 복잡한 형태의 Geometry 작성이 가능한 CATIA와 환경 시뮬레이션 Code인 FLUENT 등의 상용 Code를 활용함으로써 연구의 신뢰성을 높이고자 하였다. 본 연구는 일차적으로 서울지방에 건축된 한옥의 기준모델을 설정하여 벽, 천정, 바닥, 창호 등 건축요소의 부위별 형태를 고찰하고, Geometry작성의 입력자료로 사용하기 위하여 각 부위별 치수체계를 구축하였다. 건축요소의 부위별 각각의 형태를 솔리드 모델로 구축하기 위하여 단계별로 벽, 천정, 바닥, 창호 등에 관한 건축요소의 Geometry를 모델링하여 CFD 입력자료로 활용하여 열환경 시뮬레이션을 수행하였다.

Key Words : Building Elements, *Hanok*(Korean Tranditional House), 3-Dimensional Steady State Analysis, Thermal Environment Evaluation

1. Introduction

In a recent trend in the expansion of environmentally friendly atmospheres, a *Hanok* has been recognized as a new perspective.[1] A scientific point of view on living environments has been attempted as a new trend. Although there is no doubt that a *Hanok* is an excellent ecological architecture model that adapts to nature, there

This research was sponsored by the Hanseo University Research Support Program of 2010
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Received December 5, 2012 Revised December 25, 2012 Accepted February 6, 2013

are some issues that are to be technically structure such as floor, wall thermal environmental performance solved before applying it to contemporary architecture. A more urgent issues that are to be solved is the living environment of the *Hanok*. The insulation performance of traditional fittings and the thermal comport by Ondol heating in a *Hanok* are the most urgent issues that are to be scientifically solved. [2]

This study attempts to investigate the thermal environment performance in the interior of a *Hanok* in summer and winter seasons through dividing a living space into a room, which is a heating space, and a living floor, which is a non-heating space. For achieving the objective of this study, this study verifies the thermal buoyant effect in a steady state, thermal transfer, and vertical temperature distribution and stratification for subjective spaces by analyzing 3-dimensional turbulent air flow patters through considering natural ventilation. Although the stratification in modern residential spaces causes thermal discomfort, a properly controlled vertical temperature distribution in interior spaces becomes an essential condition in the fact that human bodies adapt to environments and that will be investigated in future studies.

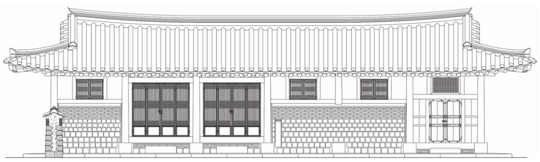
2. Descriptions of Hanok

2.1 General Description

Generally a *Hanok* consists of three different sections, such as a roof, living space, and stylobate, which is contacted with the ground. The roof of a *Hanok* becomes the most important factor that directly determines living conditions, such as natural lighting and control of thermal environments, besides the peculiar architectural form in a *Hanok*.

[Fig. 1] and [Fig. 2] show the south and north elevations of the subjects of analysis, respectively. From the left side of the south elevation, it represents an arrange of kitchen space, room, living floor, and room in which the subjects of analysis are the room, which is a heating space, and the living floor, which is a non-heating space, presented by the section A and B, respectively, as shown in [Fig. 1].

[Figure 1] Elevation of south side



[Figure 2] Elevation of north side

2.2 Environmental Descriptions

The wall structure of the subject *Hanok* consists of some major parts, such as columns, beams, and plates, and doors, windows, clay walls, and so on. The wooden door at the front of the living floor is called as a patio door and is lifted up to the eaves at the summer season in order to increase the ventilation in an indoor space. Also, it intercepts cold air in the winter season. The door installed at the south side of an Ondol room consists of a patio door and a sliding door at the outside and inside, respectively, and that mainly plays a role in protecting privacy and for the ventilation and lighting. The wall was built as a mud-plastered wall (c= 0.7692 kcal/mh℃, ρ =1280kg/m^2, and C=317 kcal/m^2℃) with plastering a mixture of mud and plant fibers with to the inside and outside of the wall after building a core wall in which the millet stalk was filled. Also, the section that contacts the outdoor air was finished using mortar (c=0.6250 kcal/m h℃, ρ=1320kg/m^2, C=330 kcal/m^2℃), and the mid section of the wall was piled up using Korean bricks(c=0.5263 kcal/mh℃, ρ=1660kg/m^2, C=332 kcal/m^2℃). Then, the lower part was piled up using granites (c=1.8692 kcal/m h℃, ρ=2810kg/m^2, C=562 kcal/m^2℃) to protect mud walls, which are weak in rain. A part of the south wall, the north wall, and the entire east wall were built by yellow soil, and the lower sections of the north and east walls were finished by laying granites and blocks (Fig. 3, 4, and 5). The scale and physical properties of the subjective space can be presented as follows Fig. 1, 2, 3, 4.

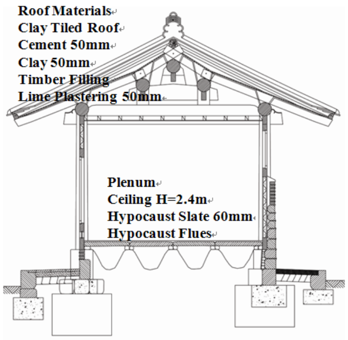
The living space can be divided into a room, which is a heating space, and a living floor, which is a non-heating space. For the room that is a space of analysis, a type of sliding door for mainly lighting purpose at the south front and a small fixed window at the north were installed. Each door and window were built by wood and finished by *Hanji* which is Korean handmade paper. The properties of the thickness, water absorption, and air-permeability of the *Hanji* used in architectural materials represent 0.04-0.05㎜, 49.7-65.0g/㎡, and 2.7-2.9sec, respectively. Also, it shows a very important weight in composing comfortable interior environments because it is able to control natural ventilation and humidity according to the pore of such natural fiber.

The living floor, shown as [Fig. 4], that is a non-heating space has no heating system compared to that of the room and consists of a single space from the bottom of the roof to the wooden floor at the floor. The lower section of the living floor has a crawl space for ventilation. The doors installed at the front in South and rear in North are opened to the left and right sides, and each door can be rolled up to an upper direction and provide convective cooling for the cross ventilation by opening the living floor space in a summer season. Regarding the living floor that is a non-heating space, as shown in the section and plan presented in [Fig. 3] and [Fig. 5] respectively, the same sized project doors, which are similar to the style of an accordion, were installed at the south and north sections and that makes possible to present the living floor as an open space to the outside at the summer season by lifting such project doors.

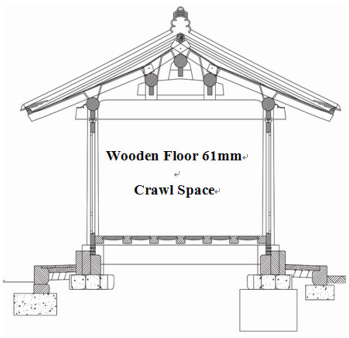
Also, the *Ondol* that is a floor radiant heating system was installed at the floor. An *Ondol* system consists of a type of flat floor heating stone called '*Gudol*'. The *Gudol* is processed as a thickness of about 50mm and a size of 400mm×600mm. It forms a heating floor and accumulates the heat supplied by a furnace. The upper part of *Gudol* that is distanced from the location of a furnace is fabricated a bit thinner than other part in order to complement a thermal balance on the *Ondol* and to facilitate heat transfers to the surface of indoors. The *Ondol* is able to accumulate heat to the floor *Godul* for a long time and that is considered as a low temperature radiant heating system that has a heating source, which is installed at outdoors. Advantages in the *Ondol* are able to maintain the heat of the *Gudol* for a long time after removing a heating source from the furnace and represent a small deviation in vertical temperature distribution and excellent thermal feeling.

The environmental property in a *Hanok* represents a low insulation performance in fittings compared with that of modern residences and that shows a high thermal transmittance coefficient. In addition, it shows a high air change rate due to the air leakage rate in fittings and that leads to produce cold drafts in interior fittings. The values for representing the insulation performance, K-value, for each component in a *Hanok* are determined by 0.51-2.46, 2.64-3.27, 0.57-0.8, and 7.4-8.4 W/m^2℃ for the floor, wall, roof, and fitting, respectively. It can be seen that the wall and fitting represent the highest thermal losses.[3-6]

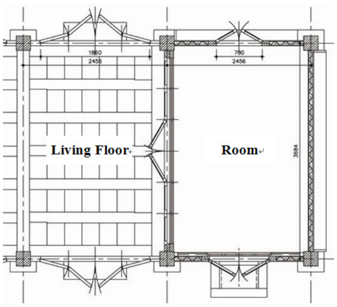
The *Ondol* used in a *Hanok* is a under floor radiant heating system that generates stratification in interior spaces in a winter season and that represents a difference in air temperature according to the interior sectional height, such as floor surface, interior space, and plenum. However, the general thermal comfort is determined by PMV 0.4 and that shows comfort relatively due to the fact that the amount of heat sensed by a human body is provided by the floor.[7-8]



[Figure 3] A Section of Room, Heating Space



[Figure 4] B Section of Floor, Non-heating



[Figure 5] Plan of Room and Living Floor

The material performance of the *Hanji* is determined by air flow, moisture transfer, and equilibrium moisture ratio. The air flow is an amount of air flow that passes through the unit area of a specimen for one hour as there is a pressure difference between indoors and outdoors. Then, the wind speed is measured at such a pressure difference and that is to be converted. As a pressure difference of 50Pa between indoors and outdoors, the air flow performance can be presented by 140.7㎥/㎡h. In the indoor air control performance of the *Hanji*, the filtering efficiency that filters dusts from the inflow of outdoor air is about 47.5% (the average dust capturing rate of a dried preprocessing filter used in an air controlling unit is about 60%-80%). Although it shows a bit lower efficiency than that of a low performance filter, it shows a filtering performance that filters a 47.5% of dusts with a diameter of more than 5㎛ in the air.

The biotite used in *Godol*s is a type of silicate mineral in mica and is largely distributed in metamorphic rocks, pegmatite granites, and other extrusive igneous rocks. It shows some appearance colors like black, brownish black, and greenish black and the perfect split at the bottom side. Also, it represents the Mohs hardness ranged by about 2.5-3.0, and the thermal conductivity is about 1.87 ㎉/mh℃. It is largely distributed in the Korean Peninsular, and the large part of pegmatite exists as a plat shape and that can be used as various architectural materials including the *Gndol*. In addition, metamorphic rocks called blue stones, which are a type of blue tuff, or chlorite schists are used as *Gudol* stones. Also, olivine is used to the place, which is directly contact with fire.

3. GOVERNING EQUATIONS

The Room and living floor space of *Hanok* airflow simulation based on the k-ε model was first conducted and has been generally applied in predicting various types of turbulent flow with sufficient. The governing equations for the averaged steady flow can be written in the general elliptic form for an incompressible fluid as;

$$\frac{\partial}{\partial x_t}(\rho\phi)+\frac{\partial}{\partial x_j}(\rho U_j\phi)=\frac{\partial}{\partial x_j}\left(\Gamma_\phi\frac{\partial\phi}{\partial x_j}\right)+S_\phi \qquad (1)$$

The parameters ϕ, Γ_ϕ and S_ϕ are defined for each equation in [Table 1]. For the empirical constants of the k-ε model were applied the standard value proposed and for the Prandtl number a value of 0, 9 was used. The finite difference form of the 3D governing equations is obtained using a finite volume method. The pressure field which does not have and explicit differential equation to be discretized was iteratively treated.

[Table 1] Defined Parameters

ϕ	Γ_ϕ	S_ϕ
1	0	0(continuity)
U	$\mu+\mu_t$	$-\frac{\partial P}{\partial x}(+\rho g_x)$
V	$\mu+\mu_t$	$-\frac{\partial P}{\partial y}$
W	$\mu+\mu_t$	$-\frac{\partial P}{\partial z}$
E	0	$\nabla\cdot(\sigma\cdot\vec{v})$
k	$\mu+\frac{\mu_t}{\sigma_k}$	$\rho(p-\varepsilon)$
ε	$\mu+\frac{\mu_t}{\sigma_\varepsilon}$	$\rho(C_1\frac{p\varepsilon}{k}-C_2\frac{\varepsilon^2}{k})$

4. BOUNDARY CONDITIONS

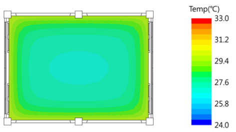
The Korean traditional House of standard type, *Hanok* is located in Seoul. The simulation model simplifies the *Hanok* geometry and includes room and living floor. The computation model for *Hanok* was developed to solve transient, mixed boundary condition circumstances to implement in most commercial CFD codes. It is based on the finite volume method, non-staggered grid arrangement, and a bounded highly order treatment for the convective terms. The solution algorithm for analysis *Hanok* is used solve the steady state. The weather data of the THY(Test Reference Year) of Seoul, South Korea, is used in the simulations to estimate the impact of *Ondol* heating and passive cooling on the thermal comfort of room and living floor, The specification of building components found in experimental *Hanok*, are given in [Table 2].

[Table 2] Specification of Hanok

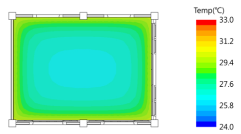
Building Components		Dimensions(m) Height/Depth/Width	K(W/m^2℃)
Room	Wall 1, 2	H2.47ÎD3.68	2.95
	Wall 3, 4	H2.47ÎD2.45	2.95
	Ceiling	H2.47ÎD3.68ÎW2.45	6.82
	Floor	D3.68ÎW2.45	0.51
	Window 1	H0.76ÎW0.77	7.90
	Window 2	H1.36ÎW0.80	7.90
	Door	H2.47ÎD3.68	2.51
Living Floor		D3.68ÎW2.45	

5. RESULTS AND DISCUSSION

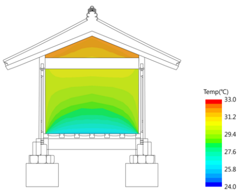
Figures 6 thru 13 presents computed results of mean air temperature of the room and the living floor of *Hanok* during summer and winter season.



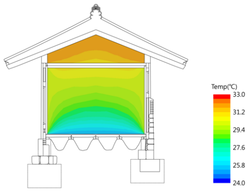
[Figure 6] Summer Living Floor Plan



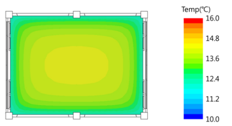
[Figure 10] Summer Room Plan



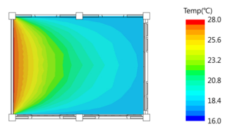
[Figure 7] Summer Living Floor Section



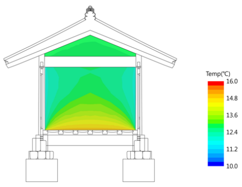
[Figure 11] Summer Room Section



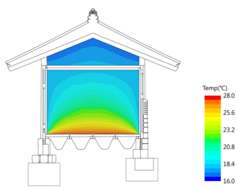
[Figure 8] Winter Living Floor Plan



[Figure 12] Winter Room Plan



[Figure 9] Winter Living Floor Section



[Figure 13] Summer Room Section

5.1 Cooling season

Maintaining a constant level in temperature that is lower than the outside at the hypocaust of the room floor and the crawl space of the bottom of the living floor increases the thermal comfort by the radiant cooling from the room floor and living floor that directly contact with a human body. As the outside temperature is determined by 30℃, the average temperature at the surface and bottom of the living floor represent 25.3℃ and 24.3℃, respectively.

5.2 Heating season

While the heat produced by a fireplace is transferred to the inside through the hypocaust as a form of radiant heat energy, the floor will be heated and that represents a stratification, which shows low air temperature at a sitting height from the floor.

As a heat supply with the interval of 8 hours, the floor surface temperature shows the average of 27.6℃, and the average temperature at the height of 0.3-0.6m from the floor represents 19.1℃.

The vertical temperature distribution in the winter season is determined as an outdoor air temperature distribution of －13.47～2.48℃ (average outdoor air temperature, -5.85℃), an indoor temperature distribution of 4.34～24.27℃ (average indoor air temperature, 16.26℃), and a glove temperature distribution of 7.85～24.38℃ (average glove temperature, 16.74℃) based on the breathing height of 70㎝ in a floor sitting life, head height of 110㎝ in a floor sitting posture, and breathing height of 160㎝ in a floor standing life. As the comfortable indoor temperature and relative humidity are determined by 22℃ and 20～60%, relatively, the heating system satisfied an indoor thermal comfort zone for five hours and thirty minutes after starting the heating of the room, and the relative humidity was the distribution of 22.17～62.04%. In addition, it showed a decrease in the relative humidity to 22.17% at 11:00 after a lapse of one hour and thirty minutes, and the relative humidity showed the distribution of below % at 17:00. The vertical temperature distribution in a heating space represented a range of －0.05～2.18℃ (average, 0.55℃) at the height of 0.1mrma and 1.6mrma on the floor as a homogeneous level. As a deviation in the vertical temperature in an indoor space occurs, it causes some local discomforts. Thus, the vertical temperature distribution in a Korean-style house satisfies the standard of comfort environments based on the reference of ISO 7730 (1994) in which a vertical temperature difference should not exceed 3℃ for the height of 0.1～1.1m from the floor and the height of 0.1～1.7m for the ASHRAE standard 55-1992.[8]

In the results of the analysis of the thermal environment of the inside in a *Hanok*, the thermal comfort represents an excellent level of PMV as 0.5～0.7 even though there is certain stratification due to the direct contact of the lower part of the body to the heated hypocaust.[8] The standard of ISO 7730 recommended for acceptable environment is -0.5<PMV<0.5, PPD<10% [8].)

NOMENCLATURE :

C_p specific heat of air [J/kgK]

G_i gravitational acceleration in $x_i$direction[m/s^2]

U_i mean velocity component in x_i direction [m/s]

x_j Cartesian coordinate [m]

T local air temperature [℃]

I turbulence intensity [%]

PMV Predicted Mean Vote

PPD Predicted Percentage of Dissatisfied [%]

DR draught risk [%]

Γ diffusivity [m^2/s]

ϕ variable

α thermal diffusivity [m^2/s]

β coefficient of thermal expansion [1/k]

ε dissipation rate of turbulent kinetic energy [J/kgs]

k turbulent kinetic energy [J/kg]

p pressure [kg/m^2]

q volumetric heat generation rate [W/m^3]

μ viscosity [kgf s/ m^2]

μ_t eddy viscosity [kgf s/ m^2]

v mean air velocity [m/s]

v′air velocity fluctuation [m/s]

ρ air density [kg/m^3]

σ Prandtl number

$C_\mu, C_1, C_2, \sigma_k, \sigma_\varepsilon$ empirical constant of the k-ε model

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