An Influence of the Opening Location of the Trombe Wall System on Indoor Airflow and Thermal Environment

Sangwan Kim[1], Janghoo Seo[2*]

[1]Graduate student, College of Engineering, Chosun University,
Gwangju 501-759, Korea,
[2]Department of Architectural Engineering, Chosun University,
Gwangju 501-759, Korea,

ABSTRACT

In this study, the night time indoor air flow and heat transfer of building with trombe wall system were examined using CFD (Computational Fluid Dynamics). The space of analysis was in the closed state with no ventilation form the outside, and it was set to have natural convection for buoyancy resulted from temperature difference. As a result, this research observed the air in a relatively higher position flowing into the intermediate space where the temperature was getting decreased through the upper opening due to the characteristics of heat transfer, heat loss through the window, and the form of convection that the air of lower temperature flowed in. Also, according to the result of the analysis by applying the vertical distance of the opening differently, as the distance from the opening was closer, flux and heat loss through the glass became reduced, and the air flowing in showed low temperature departure; however, when it was too close, heat transfer resulted from convection was so subtle that it was not very effective. And as the distance from the opening became farther, the air flowing along the trombe wall showed a high mass flow rate for the buoyancy, and the convection became rather higher; however, heat loss through the window within the intermediate space grew more, it was not advantageous in terms of thermal utility on account of temperature reduction in air passing through the opening.

KEYWORDS

Trombe wall system, Openings location, Indoor airflow

INTRODUCTION

In the recent increase of energy depletion and new recycled energy use, there is a trend of increasing number of building structures applying the nature-type solar energy system. (Jaber et al. 2011, Pardo et al. 2010, Wei Sun et al. 2011, Koyunbaba et al. 2011) From the solar thermal systems used in building structures, the nature-type solar energy system that applied nature circulating method for the heat transfer is consisted of direct gain, indirect gain and

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[*] Corresponding author email: seo@chosun.ac.kr

isolated gain. Among them, a type of the representative indirect gain method, the passive system method, is largely classified in the trombe wall method with the upper and lower air circulation vent and the mass wall only with the energy storage mass. The trombe wall method has relatively high system efficiency and easier to apply for the southern walls from the nature-type solar energy system that it is the most widely applied system. (W.K Lee 1992, Y.J Ho et al. 2008)

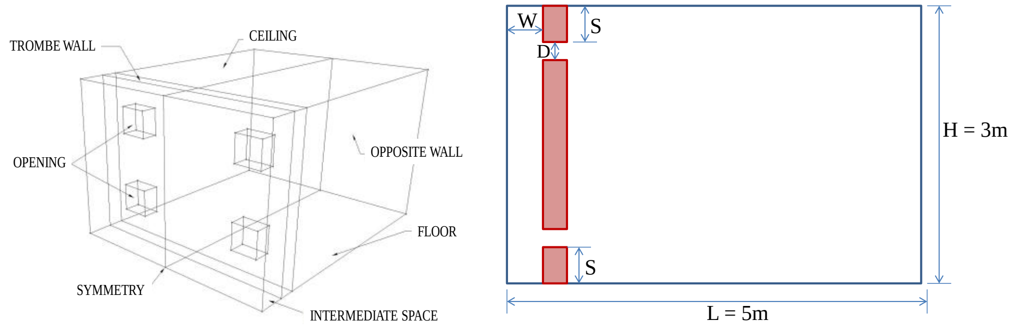
In general, there were many theoretical and empirical advance studies on the trombe wall system (Wei Sun et al. 2011, W.K Lee 1992, Y.J Ho et al. 2008), but there is an insufficient analysis on heat efficiency following the air flow distribution, heat transfer characteristics and vertical gap in the opening by using the computational fluid dynamics (hereinafter, CFD).

Therefore, when the CFD is used to apply the trombe wall system on the building structure in this study, the indoor air flow and thermal transfer of night condition are analyzed and the influence of vertical gap in the opening on the indoor heat and air flow distribution was reviewed.

CFD ANALYSIS METHODS

Analysis model of the CFD is shown on Figure 1 (a). The model for analysis is the 5m×4m×3m space as the air-tight condition without air penetration from outside. The area of opening with the interior is 0.02m^2 and has two each on upper and lower part. The intermediate space between the trombe wall and the glass was set for 0.5m and the material to structure the trombe wall is concrete, and it was set with the model to generate the natural air flow by the buoyancy by the temperature difference. It implemented the steady condition analysis at night (19:00 ~ 20:00) that the trombe wall radiates the heat.

In addition, as shown on Figure 2 (b), there are many variables to optimize the trombe wall system as in height (H), length (L), opening width (D), intermediate space interval (W), and step height (S). However, in this study, the value of W and D was secured with the change in S value only to confirm the optimal S value. The requirement for detailed set for the CFD analysis for this research model is shown on the Table 1.



(a) *(b)*

Figure 1. *Model used for CFD analysis*

In order to set the trombe wall system for ideal condition to discharge the stored heat during the day into the inside at night, W.K Lee (1992) set the temperature of ambient and interior walls discharged from the interior window wall of the trombe wall to outside as consistent without the classification of space. However, this is attributable as not realistically appropriate to the subject building structure not having the heating system in operation.

Table 1. *Condition of numerical analysis*

Classification	*Model*
Surface temperature of trombe wall	32.2℃
Ambient temperature	-10℃
Boundary space temperature	Window side : -10℃ Others : 10℃
Turbulence flow model	Low-Reynolds-number-type k-ε model
Analysis of air-flow field and temperature field	Consider the symmetry of 3D to interpret only 1/2 area of the space.
Trombe wall (Solid)	Density 2,240 kg/m^3 Specific Heat capacity 2,040 J/kg·K Thermal conductivity 1.4 W/m·K
Convective Heat loss coefficient	Window side wall of heat storage wall 5.56 W/m^2·K Inner side wall of heat storage wall 3.05 W/m^2·K
Change of S value	Up to the upper and lower S = 0~100cm, change in 10cm interval

Therefore, in this study, the standard temperature for the night radiation of the trombe wall was set for 32.2℃, as the figure surveyed in the advance study (Y.J Ho et al, 2008), and in order to calibrate the heat radiation volume flowing toward the window and indoor side, the TRNSYS analysis value presented in the advanced study is converted into the heat transfer showing the level of heat loss coefficient on the basis of the analysis value in a way of inputting on the boundary condition of the trombe wall (K.S Park et al. 2012).

RESULTS AND DISCUSSION

In fact, the winter residential space is heated to set the wall temperature not the ambient temperature of -10℃ that, in this study, the wall temperature was set for 10℃ to have the result shown in Figure 2 and Figure 3.

Under the characteristics of heat transfer, the warm indoor air on the upper part is flown in through the opening part for the intermediate space to descend with the air temperature and the heat loss occurs toward the window that is adjacent to the external air was confirmed for the air flow phenomenon to flowing inside through the lower opening.

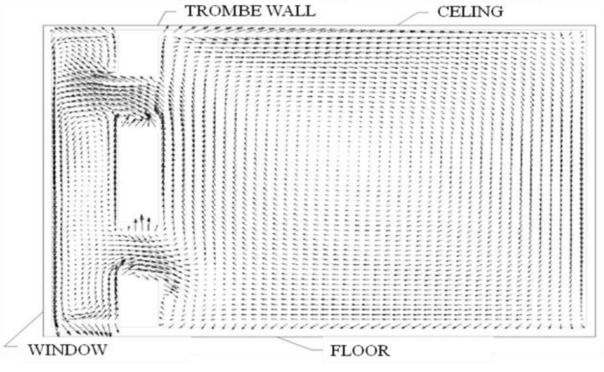


Figure 2. *Indoor airflow distribution*

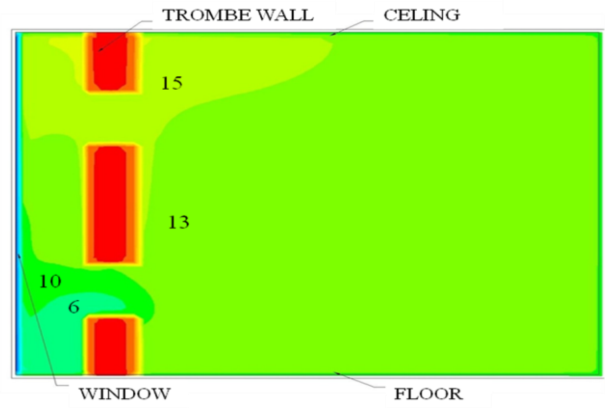


Figure 3. *Indoor temperature distribution (℃)*

Figure 4. is the distribution of indoor average temperature of 1.2m height from the floor, the residential area of human following the step change. The optimal S value had the highest value for 30cm with 13.47℃.

This is attributable to increase the temperature of the upper opening from the insulation effect of air layer in the intermediate space to have high heat flux between the lower openings distributed with relatively low air to reduce the heat loss through the window to have smaller temperature deviation of air flowing into the interior. This trend has the flux increase more than necessary if the step value gets smaller, and if the step value is larger than certain limit, it is adjacent to the opening sides to have not great effect with the minimal heat transfer by the air transfer.

Figure 5. shows the average flux flowing toward the intermediate space for the upper opening for each step height. As the step value gets smaller, the air flowing along the trombe wall has the buoyancy to have active air flow with high flux to confirm the lowering of flux from the buoyancy as the step value gets larger.

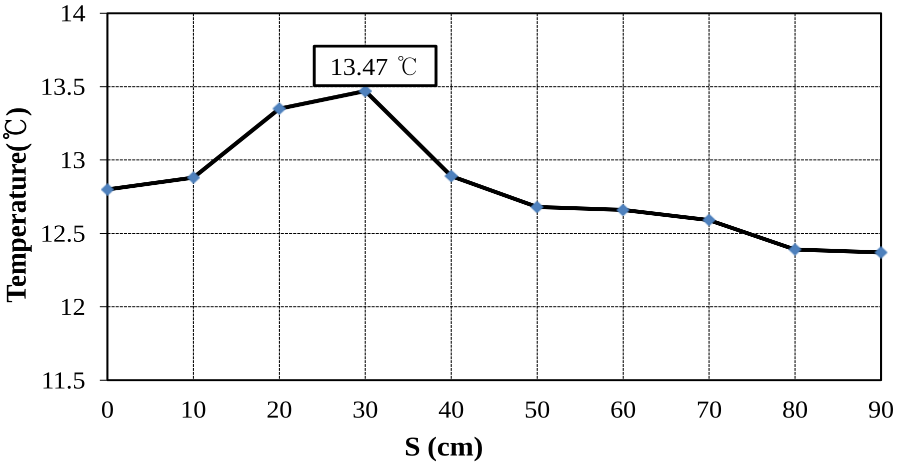


Figure 4. *Average internal temperature distribution of 1.2m height following the S value change*

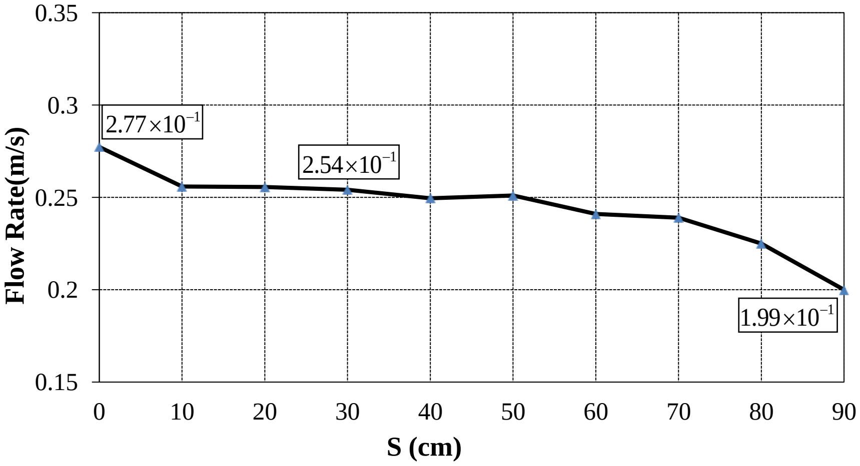


Figure 5. *Velocity of air that penetrates the opening following the S value change*

CONCLUSION AND IMPLICATIONS

In this study, the CFD analysis was used to review at night for the indoor airflow and heat distribution from the use of trombe wall in the residential space.

(1) With the warm indoor air to flow out for low temperature intermediate space and the air is circulated from the influence of natural air flow by the temperature difference, the heat loss is made toward the window side to have the cold air flowing into the inside.

(2) As a result of applying the step value with the change, the indoor average temperature distribution was confirmed as the best effect when the step value is 30cm. However, if the value is enlarged, the heat transfer by the airflow was minimal to have inefficient effect.

(3) As the step value gets smaller, the air flowing along the trombe wall side has greater buoyancy to heighten the volume flux to have active airflow, but due to the temperature decline of air flowing in with larger heat loss through the glass, it was confirmed as disadvantageous on use.

Therefore, the application of the trombe wall system at winter night increases the heat loss through the opening that there is a need for consideration thereof.

Corresponding experiments and the gird refinement test will be also performed as a future work.

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