STACK EFFECT IN LIGHT WELL OF HIGH RISE APARTMENT BUILDING

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ABSTRACT

In the light well (called "Void" in Japan) of high rise apartment buildings, the exhaust from the kitchen and the gas water heater is sometimes discharged to the corridors, which can pollute the air in the Void. Due to the stack effect caused by the exhaust heat, the outdoor air flow in through openings at the bottom of Void to the top of Void.

The purpose of this study is to make clear this natural ventilation characteristics and to predict the airflow rate for removing the pollutant in Void.

Firstly, model experiments are conducted to know the natural ventilation characteristics in the Void with respect to airflow patterns, airflow rates and temperature distributions. As the result, it is made clear that the characteristics are influenced by the vertical position of openings for outdoor air supply.

Secondly, a simplified calculation model dividing the space into multiple zones is used to calculate the airflow rate and the vertical temperature distribution. The calculated airflow rates were nearly agreed with experimental ones except for the some temperature inconsistency.

INTRODUCTION

Lately in Japan, the light well is often designed in a high rise apartment building. This light well is a empty space without ceilings or floors from bottom to top, and the well is called "Void" in Japan.

For this Void is regarded as the outdoor space, there is the possibility that the exhaust gas from each residence is discharged into a Void via a open corridor around Void. The main exhaust gas is discharged from a kitchen or a gas water heater which is set on a corridor in front of each residence. This exhaust gas is hot, and the air inside Void is heated. On the other hand, Void generally has openings in the bottom of it, and there is a large opening in the top of it. Therefore the stack effect is caused due to indoor-outdoor temperature differences, and the air flows from bottom to top.

Today, many studies on ventilation in large spaces have been conducted such as works of IEA Annex 26[1]. But there are few studies on ventilation of the above-mentioned Void. The authors made a model experiments and the zonal ventilation model simulation, and clarified the basic natural ventilation characteristics in Void[2]. Ohira et. al made a model experiment and the CFD simulation in similar conditions[3]. But in both studies, the opening for outdoor air supply was designed only at the bottom of Void(at the ground floor). Actually, it is not a few that the openings are designed at the upper floors divided from the ground floor.

Therefore firstly in this paper, a model experiment is conducted to clarify the effect of the vertical opening position on the air temperature and the airflow rate. Secondly, the air temperature and the airflow rate is calculated by the simplified ventilation model. Experimental data and calculated data are compared to evaluate the accuracy of the prediction using the ventilation model.

EXPERIMENTAL DESIGN

Fig. 1 shows the experimental apparatus as a 1/100 scale model of a 41-storied apartment building in existence. This figure shows the case that the ground floor opening is divided into 8 vertical positions.

In this model, the heat sources were installed in the cavities of the inside wall as models of the open corridors (see Fig. 2). The heat sources were simulated the exhaust heat from a gas water heater, and the heat was generated with following assumptions in the actual building :

(1) the heat generation rate from each gas water heater is 9,280 W,

(2) the total number of gas water heaters is 480,

(3) the simultaneous usage percentage of heaters is 25%.

The heat was assumed to be removed only by convection through the openings, therefore the model was well insulated. In this condition, the Archimedes number of the model, defined as the ratio of the buoyancy force to the inertial force, coincided with that of the actual building and the similarity condition was satisfied[4]. Thus, the scale factor of physical parameter was chosen freely.

In this model, its opening position and the size of opening areas are variable for investigating their effects on the ventilation characteristics. The experimental conditions are shown in Table 1. In the condition, the vertical opening position is defined as "dividing numbers of opening". It means that the openings are located at the upper floors divided from the ground floor with the same total areas in all conditions. Especially, the schematic of opening positions and dividing numbers of opening are shown in Fig. 3.

The air temperature was measured by C-C thermocouples. Data was taken from 17

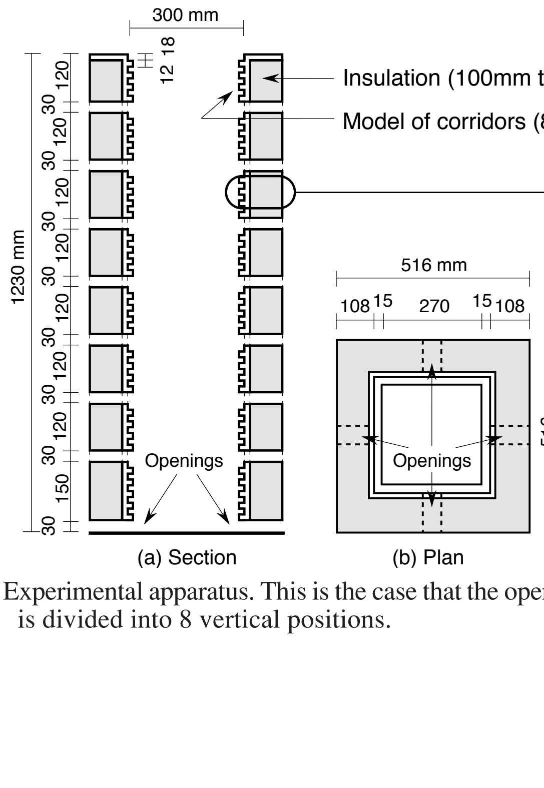

Fig. 1: Experimental apparatus. This is the case that the opening is divided into 8 vertical positions.

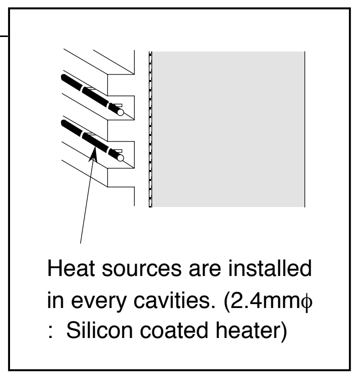

Fig. 2: Installation of heat source.

Table 1: Experimental conditions.

Case No.	Opening Position		Dividing Numbers of Opening	Opening Area [cm^2]		Heat Supply [W]	Heating Position
	Horizontal	Vertical		Total	Each		
!	All sides	in Fig3	1	144	36	125.2	All corridors (from bottom to top)
"			2		18		
#			4		9		
$			8		4.5		

separate vertical points and 49 separate horizontal points, as a result, the total number of measuring points in one experiment is 833. To investigate the airflow rates, the wind velocity through each opening was measured by an omnidirectional temperature-compensated anemometer, then the velocity was multiplied by the opening area.

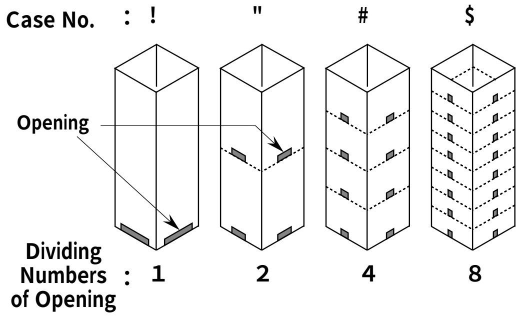

Fig. 3: Schematic of opening positions and dividing numbers of opening.

EXPERIMENTAL RESULTS

Fig. 4 shows the airflow patterns in vertical sections located in the center of horizontal planes, observed by smoke visualization. In all conditions, the outdoor air flows from bottom to top by the stack effect. It is not seen the outflow from Void to the outdoors at any openings divided upper floors. In the condition of large dividing numbers(Case# and $), the outdoor air from openings is well mixed near the openings and flows to the top. From the point of view of the air velocity, higher velocity is observed near the walls that the heat sources are installed and lower part of Void.

Fig. 5 shows the isotherms of measured air temperature in all conditions. The values of temperature are not described as ones of the actual building scale but of the model scale. The stack effect generally makes such a temperature distribution as the highest temperature at the top. But it is seen that the temperature near the top opening is lower

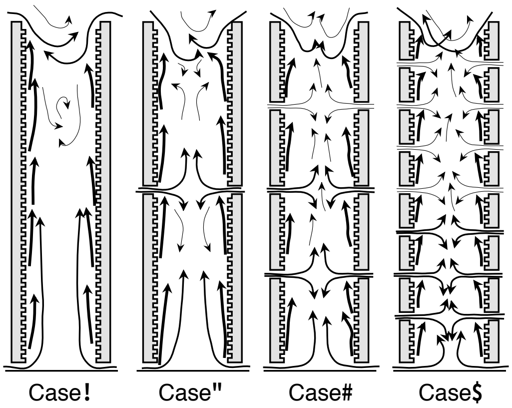

Fig. 4: Airflow patterns. Heavy lines mean the main flow with high velocity. Fine ones mean low velocity.

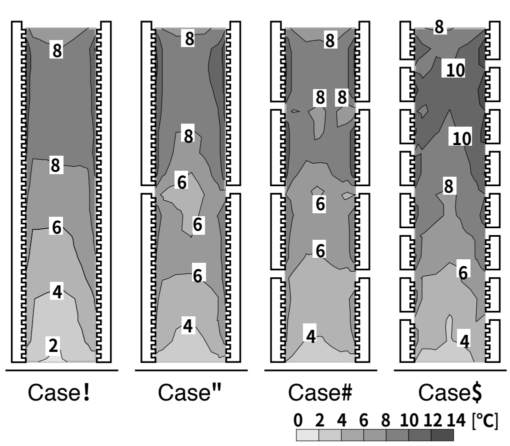

Fig. 5: Isotherms of measured air temperature. This sections are located in the center of horizontal planes. The values are described by differences between inside and ambient air temperature.

than the other spaces. It is due to the air down flow from the top opening that is observed by the visualization. There is the lower part of the temperature near the center of Void. It is assumed that the air from the openings flows vertically in the center of space. In all conditions, the shape of the distribution seems to be in a layer, that is, the vertical temperature differences are larger than the horizontal ones. Therefore in the following paragraphs, the temperature distribution is described as a vertical distribution of the mean value over the data of 49 measuring points in each horizontal plane.

The vertical temperature distributions in all conditions are shown in Fig. 6. The increase of the dividing numbers of opening(from Case ! to $) causes the increase of the temperature at almost all heights. It is definitely observed the shape of the distribution that higher temperature is caused at high positions. But the evident effect of the dividing numbers of opening on the shape of the distribution is not observed.

The measured airflow rates through each opening in all conditions are shown in Fig. 7. The values at side openings are obtained from measurements, and ones at the top opening are the total of ones at the side openings. The airflow rates through the top opening are almost same in all conditions, because the total opening areas are the same. At the side openings, the increase of the dividing numbers of opening causes the decrease of the airflow rate per opening. On the other hand, it is recognized that the higher openings are located, the lower the airflow rates are. It can be said that the higher openings are at a disadvantage for the ventilation in Void.

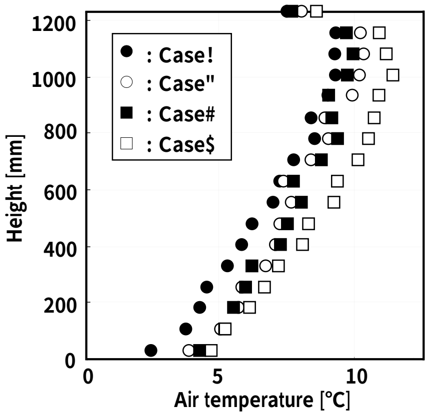

Fig. 6: Vertical temperature distributions. The values are the average of 49 points in each horizontal plane.

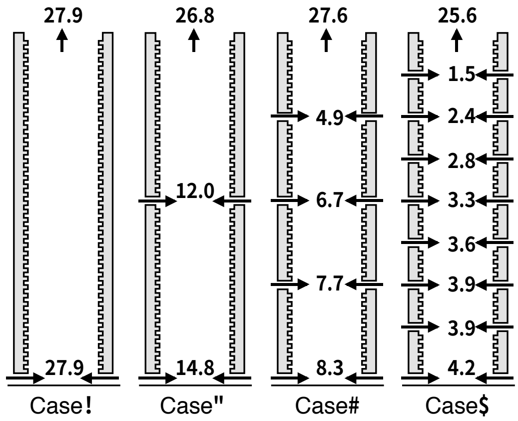

Fig. 7: Measured airflow rate [m^3/h] through each opening.

CALCULATION BY VENTILATION MODEL

The basic ventilation model is used to predict the air temperature and the airflow rate of Void. It is useful to calculate the temperature and the airflow rate of the large space that the space is divided into the multiple stratified zones. There is an excellent work for the air-conditioned large space[5]. But there are few studies for natural ventilated space. On the other hand, in future of this study, the calculation in the condition of natural ventilation must be made in consideration of such fluctuating outside conditions as outdoor wind velocities and outdoor air temperatures. Therefore, the ventilation model should be very simplified one.

The space is divided into 9 stratified zones. It is assumed that the outdoor air flows only from the side openings to the top opening, and there is no down flow between each zone (see Fig. 8 for Case#). In each zone, the perfect mixing and the uniform temperature are assumed, and the equations based on the mass balance and the heat balance are described. At each opening, the airflow rate is expressed by a simplified equation based on Bernoulli's equation. The equation is expressed by the pressure differences caused by the indoor-outdoor temperature differences[6]. They are solved as simultaneous equations of many unknowns. The values of the discharge coefficient is 0.64 for the side opening and 1.0 for the top opening.

COMPARISON WITH EXPERIMENTAL DATA

Fig. 9 shows the comparison between measured data and calculated one by the ventilation model. The air temperature is left in figure, and the airflow rate is right. The plots of ● and black bars are the measured data, the lines and white bars mean the calculated one. The calculated air temperature shows the shape of the distribution that the temperature lowers at zones where the openings are located, and higher temperature is caused at high positions. The decrease of temperature at these opening zones in calculation is larger than one in the measurement. This can be explained that the assumption of the perfect mixing in the zone in calculation causes the larger decrease than that actually occurs.

In small dividing numbers of opening(Case! and "), the calculated temperature is in agreement with measured one in the rough values, but the gradient of the distribution differs. On the other hand, in large dividing numbers of opening(Case# and $), the

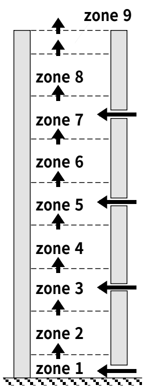

Fig. 8: Ventilation model.

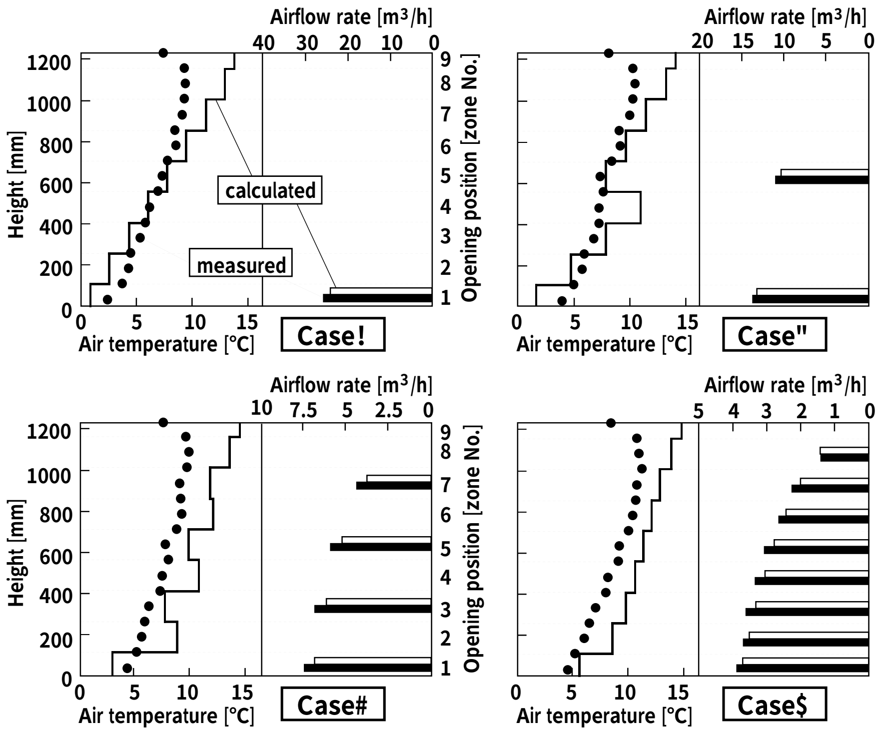

Fig. 9: Comparison between measured data and calculated one; Vertical temperature distribution [℃] (left in Fig.) and Airflow rate [m³/h] (right in Fig.).

calculation is in agreement in the gradient, but the values differ.

In the airflow rate at each opening, the calculated values are in good agreement with the measured ones both in the distribution and the value. The calculation has enough accuracy for predicting the airflow rate, because it is considered that the error of under about10% is very small.

In the temperature distribution, there are some differences. But in the airflow rate, the differences are less than those in the temperature, because it is calculated by total effect of the temperature differences of the whole space.

CONCLUSIONS

The air temperature distribution in Void of the high rise apartment building becomes in a layer in general. The enlargement of the dividing numbers of opening causes the increase of the temperature at almost all heights and the decrease of the airflow rate through each opening, but the total airflow rate through the top opening is constant. It is also recognized that the higher openings are located, the lower the airflow rates per opening are. It can be said that the higher openings are at a disadvantage for the ventilation in Void.

The ventilation model that have been used in this paper is very simple. Although it should be improved for the wide using, it is useful to predict the airflow rate in all conditions. But the inconsistency of the temperature is one of the present pending questions, that is, there is a problem in the assumption of the perfect mixing in zones where the openings are located.

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REFERENCES

[1] IEA ANNEX 26(1996). Outcome of IEA ANNEX 26 "Energy efficient-ventilation of large enclosures". 5th International Conference on Air Distribution in Rooms (ROOMVENT'96) Workshop, Yokohama 1996.

[2] Kotani, H., Narasaki, M., Sato, R., Yamanaka, T.(1996). Natural ventilation caused by stack effect in large courtyard of high-rise building. 5th International Conference on Air Distribution in Rooms (ROOMVENT'96), Yokohama 1996, Vol.2, 299-306.

[3] Ohira, N., Omori, T.(1996). Ventilation behavior in a void space furnished with gas water-heaters. 5th International Conference on Air Distribution in Rooms (ROOMVENT'96), Yokohama 1996, Vol.3, 255-262.

[4] Kato, S., Murakami, S., Kong, C.N., Nakagawa, H.(1988). Model experiment on indoor climate and space air distribution in large-scale room. International Symposium on Scale Modeling, Tokyo 1988, Japan Society of Mechanical Engineers, 245-255.

[5] Togari, S., Arai Y., Miura K.(1993). A Simplified model for predicting vertical temperature distribution in a large space. *ASHRAE Transactions,* Vol.99, Part.1, 84-99.

[6] ASHRAE(1993). Infiltration and Ventilation. In: *1993 ASHRAE HANDBOOK-FUNDAMENTALS*, chapter 23, 23.1-23.23.