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Academic Article

Study on the Evaluation of Cross Ventilation Possibilities Based on the Simulation Results for Detached Houses

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ABSTRACT

In this study, CFD simulations were carried out for several typical real detached house models with various opening patterns. A method is proposed for the improvement of the indoor thermal environment by cross ventilation at the architectural planning stage by using a calculation results database. The relationship between the ventilation ratio and the opening area ratio is analyzed. The ventilation ratio was increased when a ventilation circuit was formed in the house, and the opening area facing the prevailing wind direction was large. However, the relationship between the ventilation ratio and the opening area facing the south side was not confirmed, because the south side opening area was much larger in all objective typical detached house models. In typical detached houses with large southern side opening areas, the ventilation ratio is larger in the case of winds from the south.

Key Words : Detached house, Cross ventilation, CFD, Ventilation ratio

1. Introduction

In mid-latitude regions such as Germany and Japan, cross ventilation is an effective method for improving the indoor thermal environment, with less energy consumption, during the daytime in autumn and spring, and throughout summer nights. Various studies on the improvement of the indoor thermal environment using natural ventilation have been carried out. In order to evaluate the ventilation performance quantitatively, Akabayashi et al. have proposed a method for evaluating the ventilation performance using three indexes : site index, local index, and building performance index(1). The site index is defined as Cross Ventilation Degree Hours (CVDH), whilst the local index is defined as a cross ventilation ratio corresponding to the building coverage ratio. The building performance index is defined as the volume fraction of CFD calculation results (at wind speeds of more than 0.3 m/s) which have been carried out for simple house models and a real detached house model. In this study, instead of changing the parameters such as the arrangement and area of openings in a simple model of a house with no complex plan, CFD simulations were carried out for several typical real detached house models with various opening patterns. A method is proposed for the improvement of the indoor thermal environment by cross ventilation at the architectural planning stage by using a calculation results database. In addition, through the analysis of the calculation results database, the primary parameters that may be used to improve the cross ventilation performance are considered.

2. Evaluation framework

Cross ventilation improves the indoor thermal environment by the removal of heat and the moderation of the effective temperature. Akabayashi et al. have pointed out that the effect of heat removal by ventilation is considerably larger than the effect of the moderation of effective temperature by airflow(2). Therefore, the ventilation ratio was adopted for the evaluation index, focusing on the effect of heat removal. The calculation method for the ventilation ratio in a detached house is shown in Figure 1, with reference to the method used in the previous study(1). The building performance index is the ventilation ratio calculated under the condition that the building coverage ratio is

0% and inflow wind speed is 3.8 m/s. The local index is a cross ventilation ratio corresponding to the building coverage ratio. The site index is a regional mean wind speed obtained from the calculation results of the WRF (Weather Research and Forecasting model). By using the calculation results from the WRF, it is possible to determine the wind direction and wind speed in the areas where these have not been measured. The actual ventilation ratio is calculated by multiplying these three indexes.

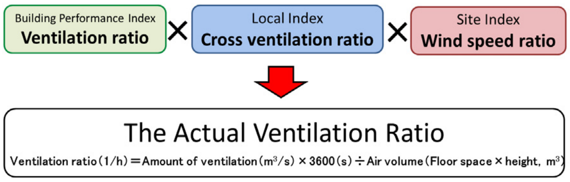


Fig. 1 Calculation method for the ventilation ratio in a detached house

3. Calculation of the airflow distribution

3.1 Outline of the calculations

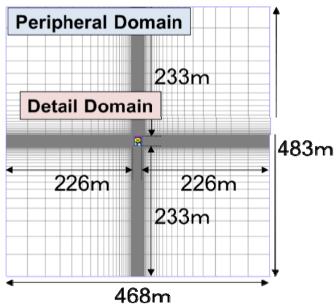
The CFD simulations were carried out for 12 detached houses, each with two stories under the conditions that the building coverage ratio in the surrounding area was 0 %, the inflow wind speed was 3.8 m/s and the directions were N, E, S, W, NE, NW, SE, SW. Table 1 shows the characteristics of the objective detached houses under study. Figure 2 shows the calculation domain. Figure 3 shows an example of the objective model used in the study (plan number 1). Figure 4 shows the plan and perspective drawings of plan number 1. Table 2 shows the conditions for the CFD calculation. The CFD simulation uses the standard k-ε model in the turbulence model. The calculation domain is divided into the peripheral domain and the detail domain. Grid sizes are 100 mm × 100 mm × 100 mm in the calculation domain. The minimum grid size is 60 mm, in order to reproduce the shape of the opening. The grid sizes in the peripheral domain increase gradually in the horizontal and vertical directions. The opening ratio is assumed to be 70 %, with respect to the screen door. The calculation has been performed for 96 patterns (12 plans × 8 wind directions), and the mean wind speed is calculated for each respective opening.

3.2 Calculation results

Figure 5 shows an example of the wind vector distribution and the wind speed contour of the CFD simulation results (plan number 3). The plan of the objective house model is shown in the center, and the calculation results corresponding to each inflow wind direction are shown around the plan. If the wind flows out of the room through an opening, the wind speed is by a negative value. The ventilation is particularly effective on the

Table 1 Characteristics of objective detached houses under study

Plan number	Total floor area (m^2)	The entrance orientation	The roof shape	The stairs in the living room	The stairs position
1	117.0	S	hip roof	non-existent	NE
2	117.0		gable roof	non-existent	NW
3	118.8		gable roof	existent	E
6	125.5		hip roof	existent	N
13	117.0	EW	hip roof	non-existent	N
14	118.0		gable roof	existent	N
15	118.5		gable roof	non-existent	N
17	122.0		hip roof	existent	Center
22	116.0	N	gable roof	non-existent	W
23	116.0		hip roof	non-existent	N
24	116.5		hip roof	existent	Center
26	122.5		gable roof	existent	E



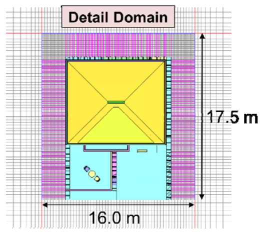


Fig. 2(a) Calculation domain Fig. 2(b) Detail domain

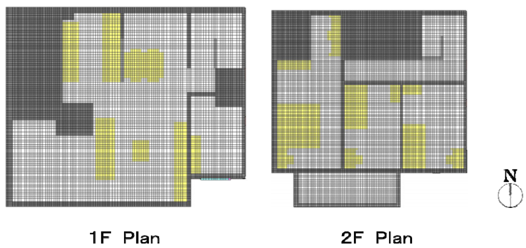


Fig. 3(a) Objective model (Left to right: 1st floor, 2nd floor), plan number 1

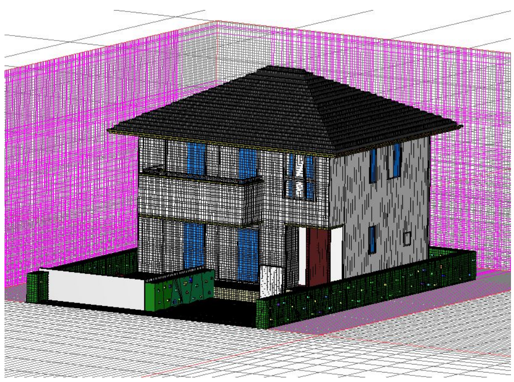


Fig. 3(b) Objective model (perspective), plan number 1

floor where a clear ventilation circuit is formed.There are a couple of large openings in different directions; the wind flows in and out through the openings.

Fig. 4(a) Plan drawing (Left to right: 1st floor, 2nd floor), plan number 1

Fig. 4(b) Perspective drawing , plan number 1

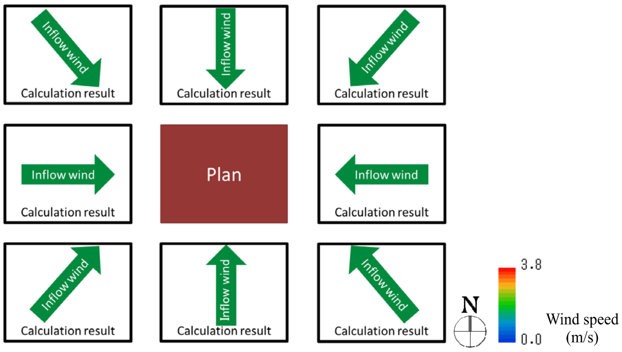
Table 2 CFD calculation conditions

Simulation software		STREAM ver.8 and ver.9
Turbulence model		Standard k- ε model
Boundary condition	Inlet	Power low (reference height 17.2m, wind speed 3.8m/s)
	Outlet	Natural inflow and outflow
	Lateral	free-slip
	Upper	free-slip
	ground surface	Generalized log low
	Wall	Generalized log low
	Opening	Pressure drop model : aperture ratio 70%
Flat terrain categories		Ⅲ (power low index a=0.20)
Convergence criterion		10^{-4}
Wind direction		N, E, S, W, NE, NW, SE, SW

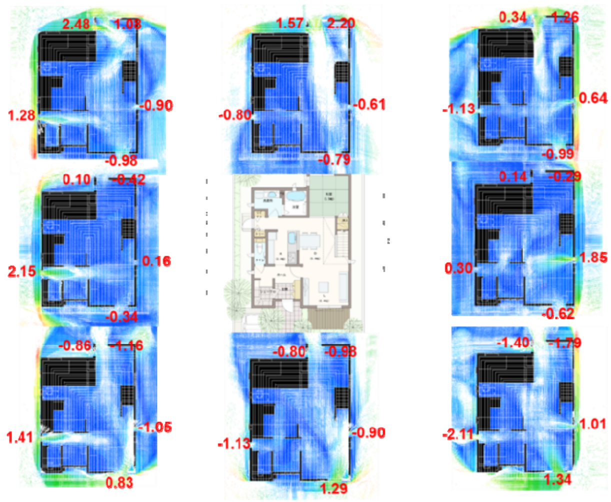
4. Effects of the building shape and the opening area on the ventilation ratio

4.1 Outline

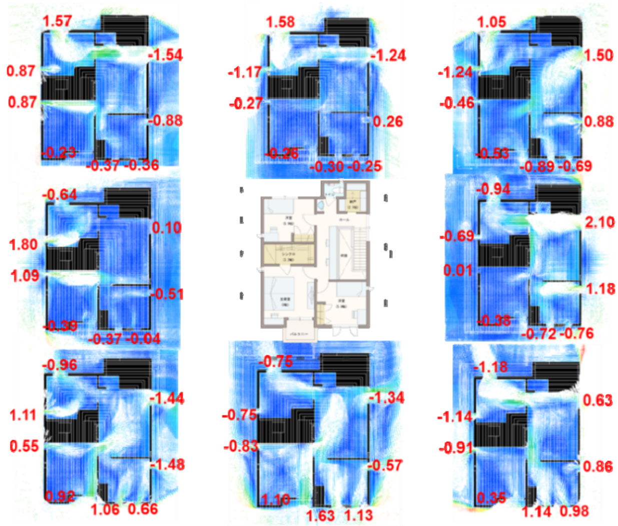
The ventilation ratio of each plan was calculated from the inflow and outflow wind speeds through the openings, and the relationship between the ventilation ratio and the building shape was analyzed. The influence of the positions of the entrance and stairs were analyzed, as was the effect of the opening area on the ventilation ratio for each wind direction.



(a) Example of calculation results expression



(b) FL + 1.5 m (1 F)



(c) FL + 1.5 m (2 F)

Fig. 5 Calculation results of wind speed (plan number 3)

Plan of the objective house model is shown in the center, and the calculation results corresponding to each inflow wind direction are shown around the plan. If the wind flows out of the room through the opening, the wind speed is denoted by a negative value.

4.2 Relationship between the ventilation ratio and the opening area

Figure 6 shows the opening area in each plan for each wind direction. The opening area on the south side was very large in all plans, except for plans 3 and 22. The opening areas on the east, west and north sides were small in all plans.

Figure 7 shows the relationship between the effective opening area per unit floor area and the averaged ventilation ratio. The effective opening area was calculated using the flow rate coefficient α=0.65. The averaged ventilation ratio was calculated for all wind directions (N, E, S, W, NE, NW, SE, SW) for each plan. The averaged ventilation ratio increased with the increase of the effective opening area per unit floor area, but there was not a high correlation between them. The value of R^2 was small because the averaged ventilation ratio in plan 3 was very large against the effective opening area per unit floor area.

Figure 8 shows the relationship between the opening area ratio facing the prevailing wind direction and the ventilation ratio. The correlation of the ventilation ratio is high with the east, west and north opening area ratios (which are small and in the range 0 % to 7.5 %) and low with the south opening area ratio (which is large, more than 14 %). In typical detached houses with large southern side opening areas, the ventilation ratio is larger in the case of winds from the south. The results also confirmed that the influence on the ventilation ratio of the opening area facing the prevailing wind direction is greater than that of the position of the stairs and the entrance orientation.

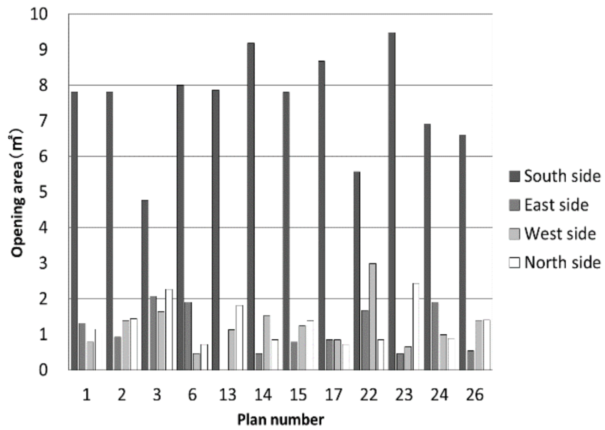


Fig. 6 Opening area in each plan for every wind direction

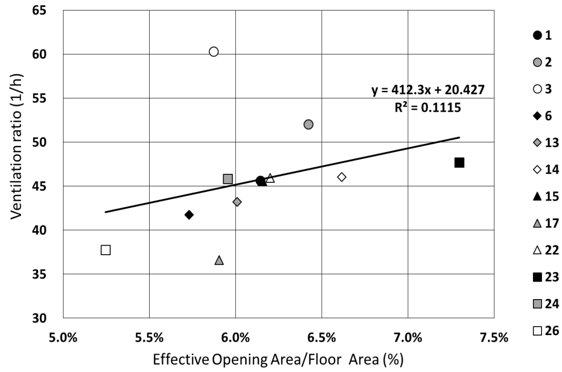


Fig. 7 Relationship between effective opening area per unit floor area and averaged ventilation ratio

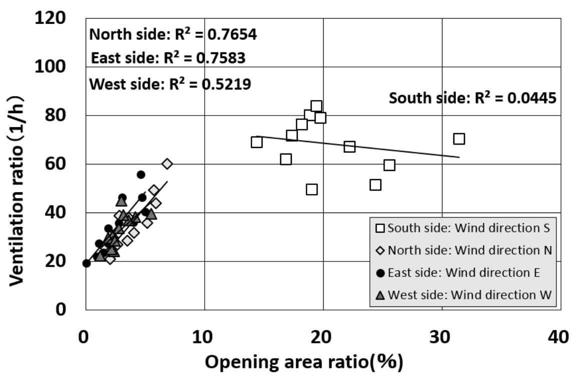


Fig. 8 Relationship between opening area ratio facing to main wind direction and ventilation ratio

5. Conclusion

The relationship between the ventilation ratio and the effective opening area was analyzed for 12 typical real detached house models with various opening patterns. The ventilation ratio was increased when a ventilation circuit was formed in the house, and the opening area facing the prevailing wind direction was large. However, the relationship between the ventilation ratio and the opening area facing the south side was not confirmed, because the south side opening area was much larger in all objective typical detached house models. In the typical detached houses with large southern side opening areas, the ventilation ratio was larger in the case of the winds from the south. It was also confirmed that the influence on the ventilation ratio by the opening area facing the prevailing wind direction was greater than that of the position of the stairs and the entrance orientation.

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