STUDY ON THE INFLUENCE ON NATURAL VENTILATION CAUSED BY DIFFERENT BUILDING DENSITIES

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ABSTRACT

The article studies the effects of different building densities in a certain layout of building clusters on slab-type buildings' natural ventilation. It is through investigation on real buildings and published academic articles that we conclude a 3×3 layout to emulate the most common layout of slab-type building clusters. Simulations are done with CFD and thermal load, and results are compared with those of isolated building and non-natural ventilation building. With parameters such as annual cooling load saving rate and air exchange rate of natural ventilation, a conclusion about the influence on slab-type buildings' natural ventilation caused by different building densities are obtained.

INTRODUCTION

Natural ventilation is able to not only meet the requirements of thermal comfort and healthy indoor environment, but also potentially contribute a large amount of energy saving. Well organized natural ventilation can save energy as well as improve the indoor thermal environment and air quality effectively. Therefore, as a passive way of building energy conservation, natural ventilation is gradually receiving more attention

Earlier researchers in this field have conducted many researches of natural ventilation with various building models in different outside conditions. And most of these researches mainly focused on one single isolated building. Sang-Ho Suh (1997) studied the surface wind pressure coefficient distribution of an irregularly shaped building through CFD numerical simulations. John Burnett (2005) studied the surface wind pressure coefficient distribution and natural ventilation of a Hong Kong high-rise residential building.

However, isolated buildings are not so common in reality. While building clusters are much more, researches on building clusters are rare. Feng (2007) summarized a few common layouts of residential building and used CFD numerical simulation to study the surface wind pressure coefficient in those layouts. Feng also proposed a simplified method called *The Three Basic Examples Method* to calculate the surface wind pressure in regular residential building clusters, which greatly reduced the amount of numerical simulation calculations.

Nonetheless, most of the studies of natural ventilation in building clusters mainly focused on the surface wind pressure, not the natural ventilation effect. Therefore, by using Star-CCM+, DeST-vent+ etc., this article studies the simulations of different building densities of building cluster, is intended to deal with the influence on slab-type buildings' natural ventilation caused by different building densities.

CASE STUDY

Building model

Slab-type building is the most common form of residential buildings, especially prevalent in the urban residential area. One obvious feature is that the length is much larger than the width. It is through investigation on real buildings and published academic articles that we conclude the most common layout of slab-type building clusters, which is neatly aligned. Mostly, in order to receive more sunlight, the long edges of the buildings are towards north or south. The distances between two buildings are mainly decided by the requirements of fire prevention and sunshine. To simplify the case, the research simulates the 3×3 layout of nine same slab-type buildings, and studies the centre building of the cluster.

The research simulates a slab-type building with only wind pressure ventilation in a 3×3 building cluster through CFD technology. The CFD simulations obtains the surface wind pressure coefficient distribution of 16 different wind directions (each 22.5°), establishes the wind pressure coefficient database. Then, the database is put in DeST-vent+ to conduct the thermal load simulation and calculate the cooling load and the ventilation rate. The results are compared with those of isolated building and non-natural ventilation building. So that the effects on the centre building's natural ventilation caused by different building densities in a 3×3 building clusters are measured.

The simulation example picks a typical slab-type apartment building and a typical building layout in China. The apartment building has 18 floors, with a length of 77.6 meter, width 13 meter, story height 3 meter and total height 54 meter. There are 8 residential units on each floor. Each residential units has 3 windows and 3 natural ventilated room, 2 to the south, 1 to the north.

Figure 1 shows the floor plan of the west half of the slab-type building. The walls are coloured black, while the windows are coloured red.

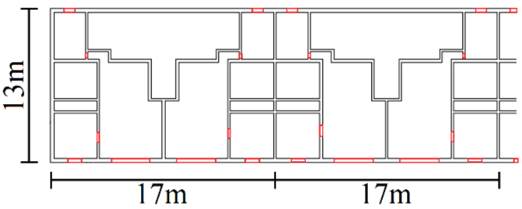

Figure 1 Floor plan of the case (west half)

The layout of the building cluster is set as 3×3 to emulate the real situation. The long edge of the buildings are towards north or south. The simulation picks five cases with different building distances and building densities. The building density is defined as Figure 2.

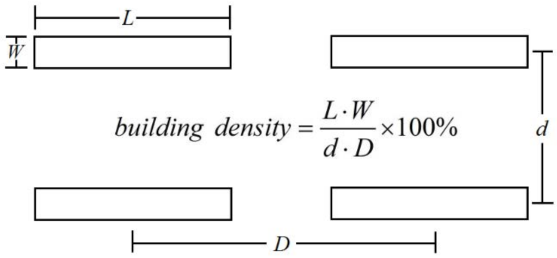

Figure 2 definition of building density

Specific case settings are shown in Table 1.

Table 1

Case settings

No.	Column spacing/m	Line spacing/m	Building density/%
1	10	45	5
2	13	61	7.5
3	20	90	10
4	26	117	15
5	34	162	20

Considering the sunshine and fire prevent requirements as well as the economic efficiency in the real estate, the building density range from 5% to 20% can cover most of the common situations.

CFD Simulations

This study uses Star-CCM+ to conduct CFD simulation. Star-CCM+ is a production of CD-adapco, and is widely used in CFD numerial simulation field.

- Computational domain and model arrangement

This study needs to calculate the surface wind pressure of five directions, 0°, 22.5°, 45°, 67.5° and 90° (north wind as 0°, clockwise arrangement). Wind pressure of the other directions can be obtained by symmetry. Therefore the building cluster is arranged in the middle of the computational domain.

The computational domain has a size of 2500×2300×300m, which is shown in Figure 3. The upper boundary is about 5 times of the building height above the rooftop. The other boundaries are about 10 times of the building length away from the building cluster. Maximum windward obstruction rate is no more than 2.3%.

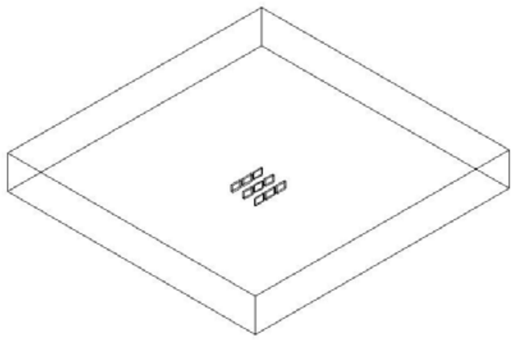

Figure 3 model computational domain

- Meshing

AIJ (2008) proposed that the minimum mesh size in wind field simulation of human settlement should be about one-tenth of the architectural scale, roughly 0.5m ~ 5.0m. In this case, the minimum mesh size is 2m, while the maximum is 16m. The cells surround the buildings are thicker, and gradually grows bigger. The surface growth rate is set as 1.015.

- Boundary conditions

Inlet boundary condition is set as velocity inlet in Star-CCM+. Wind speed magnitude is set to the gradient wind with velocity function as Equation 1.

$$v_h = 1.6 \times \left(\frac{h}{10} \right)^{0.22} \quad (1)$$

The function represents that the wind speed is v_h (m/s) where the height from the ground is h (m).

Outlet boundary condition is set as pressure outlet with boundary pressure as 0 Pa. Upper boundary applies symmetry plane condition. And condition wall is applied to building surface and the ground.

- Accuracy verification

Through simulation comparison, further expansion in computational domain or increase in meshing density has very limited improvement in accuracy, and will significantly increase the number of cells, thereby affecting the calculation speed.

Thermal Load Simulations

Thermal load simulations are conducted by DeST-vent+. As an independently developed thermal simulation software, DeST has a high accuracy which has been validated by many other thermal simulation software. Based on DeST, DeST-vent+ has added a ventilation module using multi-network method, which increases the accuracy of thermal load simulation with ventilation.

Based on the results of wind pressure obtained from CFD simulation, wind pressure coefficients of each window of all 16 wind directions are calculated and input into DeST-vent+ to conduct thermal load simulation. The DeST-vent+ model adopts 8 different glazing floor area ratios to emulate different sizes of window area. The 8 different glazing floor area ratios are 0.25%, 0.5%, 0.75%, 1%, 2.5%, 5%, 7.5%, 10% respectively.

Through the simulation, the hourly cooling load and hourly natural ventilation volume of the whole building are calculated. Sum up the hourly cooling load, the total annual cooling load is obtained. The average ventilation volume of natural ventilation hours divided by the volume of total natural ventilation volume of the whole building, 33263m³, we can get the average air exchange rate of natural ventilation. The results are compared with those of isolated building and non-natural ventilation building obtained by former researchers.

RESULTS

After CFD simulations and thermal load simulations, results are calculated.

Table 2 shows the summaries of the annual cooling load per unit area (ACL, MW/㎡) and average air exchange rate of natural ventilation (AER, times) of different building densities and glazing floor area ratios (GFAR, %).

Table 2

ACL and AER

of different building densities and GFAR

building density = 5%								
GFAR	0.25	0.5	0.75	1	2.5	5	7.5	10
ACL	29.7	28.0	26.6	25.4	21.3	19.2	18.5	18.2
AER	0.32	0.63	0.94	1.24	2.73	4.05	4.61	4.88

building density = 7.5%								
GFAR	0.25	0.5	0.75	1	2.5	5	7.5	10
ACL	29.5	27.8	26.3	25.0	20.9	18.7	18.0	17.7
AER	0.34	0.67	1.00	1.32	2.90	4.33	4.96	5.26

building density = 10%								
GFAR	0.25	0.5	0.75	1	2.5	5	7.5	10
ACL	29.1	27.0	25.3	24.0	19.8	17.7	17.0	16.7
AER	0.39	0.78	1.16	1.53	3.37	5.08	5.86	6.23

building density = 15%								
GFAR	0.25	0.5	0.75	1	2.5	5	7.5	10
ACL	28.8	26.6	24.8	23.5	19.3	17.2	16.5	16.2
AER	0.43	0.86	1.27	1.68	3.69	5.58	6.42	6.82

building density = 20%								
GFAR	0.25	0.5	0.75	1	2.5	5	7.5	10
ACL	28.4	26.0	24.1	22.7	18.6	16.5	15.9	15.6
AER	0.49	0.97	1.44	1.90	4.16	6.31	7.29	7.75

isolated building								
GFAR	0.25	0.5	0.75	1	2.5	5	7.5	10
ACL	27.2	24.2	22.1	20.7	16.7	14.9	14.3	14.1
AER	0.72	1.42	2.11	2.78	6.01	9.04	10.39	11.04

Former researchers have done similar simulations on isolated building and non-natural ventilation building of the same apartment. This article is authorized to use these results. Based on former researchers' simulation study, the annual cooling load per unit area of the non-natural ventilation model is 31.333MW/㎡. Then the natural ventilation annual cooling-load saving rate (ACSR) can be calculated, as shown in Equation 2.

$$ACSR = \frac{ACL_{NV}}{ACL_n} \times 100\% \qquad (2)$$

Plot the natural ventilation annual cooling-load saving rate and average air exchange rate of natural ventilation according to glazing floor area ratio as Figure 4 and Figure 5.

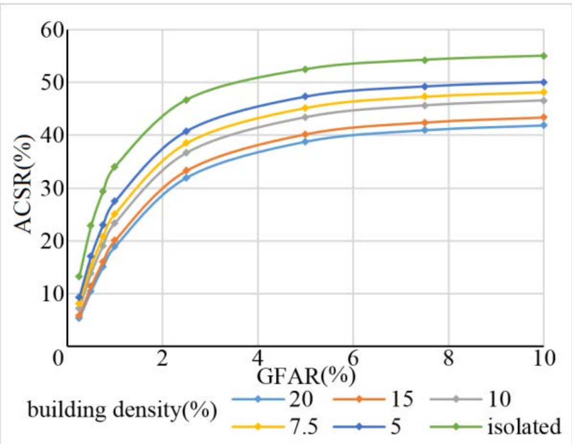

Figure 4 annual cooling load saving rates

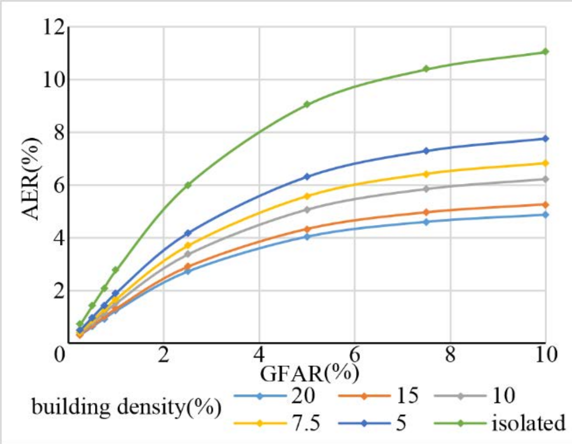

Figure 5 average air exchange rates

From the results, it can be seen that there is an obvious similarity among the results of different cases.

DISCUSSIONS

The simulation results show that when the building density increases, the annual cooling load saving rate and average air exchange rate of natural ventilation decrease. And the trend lines of results from isolated building and building in a cluster are similar. Therefore, when the simulation results of an isolated building are given, there is a possibility to get the natural ventilation condition of a same building within a cluster according to the empirical values.

Table 3 and Table 4 on the next page show the ratios of annual cooling load saving rate and air exchange rate of centre buildings within clusters to those of isolated building. And the building density of isolated building is regarded as 0. Different rows refer to different building densities (%), while different columns refer to different glazing floor area ratios (%).

With regard to annual cooling load saving ratio, it can be estimated by doing interpolation according to Table 3, when the glazing floor area ratio and building density of certain case are given.

As for air exchange rate, it is observed that with different glazing floor area ratios and same building density, the ratios of air exchange rate of building in a cluster to that of an isolated building are almost equal. And the relative deviations are less than 2% when the ratio is represented by the average value. Therefore, it is practicable to use the average values to estimate the air exchange rate with a certain building density.

Table 3

Ratios of ACSR of centre buildings within clusters to ACSR of isolated building

	0.25	0.5	0.75	1	2.5	5	7.5	10
20	0.402	0.460	0.513	0.556	0.685	0.740	0.755	0.762
15	0.438	0.497	0.548	0.589	0.713	0.766	0.782	0.788
10	0.547	0.604	0.651	0.686	0.785	0.827	0.841	0.847
7.5	0.613	0.665	0.708	0.738	0.824	0.861	0.872	0.875
5	0.704	0.749	0.784	0.807	0.873	0.901	0.907	0.910
0	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000

Table 4

Ratios of AER of centre buildings within clusters to AER of isolated building

	0.25	0.5	0.75	1	2.5	5	7.5	10	AVG
20	0.442	0.445	0.448	0.447	0.454	0.448	0.444	0.442	0.446
15	0.469	0.472	0.474	0.474	0.483	0.479	0.478	0.477	0.476
10	0.546	0.549	0.552	0.551	0.562	0.562	0.564	0.564	0.556
7.5	0.598	0.601	0.604	0.604	0.615	0.617	0.618	0.618	0.609
5	0.680	0.682	0.686	0.684	0.693	0.697	0.701	0.702	0.691
0	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000

CONCLUSIONS

Based on the studied cases, the results can be summarized as follows.

1. Building density effects natural ventilation. The annual cooling load saving rate and average air exchange rate of natural ventilation decrease when the building density increases
2. There is a similarity among the results of same building with different building densities and different glazing floor area ratios. The natural ventilation of a building within a cluster can be obtained according to empirical values.
3. With different glazing floor area ratios and same building density, the ratios of air exchange rate of building in a cluster to those of an isolated building are almost equal.

NOMENCLATURE

h = height from the ground (m)

v_h = wind speed at the height h (m/s)

ACL = annual cooling load per unit area (MW/m^2)

AER = average air exchange rate

$GFAR$ = glazing floor area ratio

$ACSR$ = annual cooling load saving rate

ACL_{NV} = annual cooling load per unit area with natural ventilation (MW/㎡)

ACL_n = annual cooling load per unit area with no natural ventilation (MW/㎡)

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