

SIMULATION STUDY OF NATURAL VENTILATION IN BEIJING: THE INFLUENCE OF ROOM STRUCTURE ON ENERGY SAVING

Kelin Li and Xiaofeng Li

Department of Building Science, Tsinghua University, Beijing, China

ABSTRACT

As Beijing becomes a modern yet more populated city, people now are faced with an increasing number of choices when they want to purchase commercial building. Beside from apartment price, location and other factors, building room structure has always been a major determinant for apartment buyers. Traditionally, when it comes to the room structure people will mainly focus on space-sufficiency as well as convenience. This paper tries to explore the importance of the building room structure in terms of energy saving and energy saving ratio. The differences of various types of building structures are mainly about space allocation of different rooms and directions each window or door is facing. Such difference will lead to the variation of the level of natural ventilation. Besides, natural ventilation is the most common way to provide fresh air to indoor environment.

To study the difference of natural ventilation for different room structures, this paper focuses on three most common room structures with the same building outer design. The changes will only be made on the location of different rooms in a household and the orientation of each room's door, window etc. By using CFD simulation software, the first simulation will be about the external wind field of the building and to get the tuyere air pressure. Then DeST-VENT+, a software developed by Tsinghua University specified for building environment design simulation, is used to calculate the cooling and heating load for the building. After that a thorough comparison between different room structures and building load is made. Finally, we can find that the influences room structure has on building energy-saving ratio cannot be ignored and ventilation demand and ventilating ability are two main factors when we analyse energy-saving ratio.

Key words: room structure, natural ventilation, energy-saving ratio, building simulation

INTRODUCTION

Natural ventilation is the exchange of fluid between the interior of some space and its exterior environment when the flow is produced by naturally occurring pressure differences (P. F. Linden, 1990). It is the major means by which most residential buildings are ventilated. Besides, natural ventilation is proved to be a good way to reduce the cooling load of building, enhance indoor thermal comfort and improve indoor air quality, as long as it is used efficiently. Especially during the age when global

warming and energy poverty become major problems, natural ventilation should be better utilized to help solve such issues.

When it comes to efficient natural ventilation, many factors which influence the performance of natural ventilation have been studied. AlAnzi, A., D. Seo, et al. (2009) established a correlation equation to assess the impact of shape on the energy efficiency of office buildings in Kuwait. Huang et al. (2012) studied the impact of the residential building shape on natural ventilation. They found natural ventilation performance in the plate residential building is better than that in the tower building, while cooling load saving ratios of the two models with natural ventilation are similar. Li et al (2012) found that annual cooling load saving ratio increases with ROF (the area ratio of operable window to floor) until ROF reaches its critical point. This paper pays close attention to the building room structure's impact on the performance of natural ventilation.

In order to study the impact of building room structure, this paper picks up three typical different building room structures as simulation sample, which all with similar outer design—slab-type residential building and the structures are based on the national 90~120 m² residential building room structure survey. And we uses CLSR (Cooling Load Saving Ratio) as an evaluation index to study this topic. To get the cooling load with and without natural ventilation, DeST-Vent+ is a useful software developed by Tsinghua University, and CFD simulation software Phoenix is a good auxiliary tools. The specific method and models are presented below.

METHOD

In this paper, DeST-Vent+ and Phoenix are most important simulation software. DeST(Yan et al.,2008) is a reliable simulation software which has been widely used in the simulation of building's energy consumption in practice. DeST-Vent+ (Zhang, 2011) is a developed simulation software calculating building's energy consumption with natural ventilation based on DeST. Vent+ uses multi-zonal model to calculate natural ventilation's airflow rate. The main input parameters of DeST-Vent+ and the coupling relationship between DeST and Vent+ are presented in figure 1.

As for accuracy and credibility of DeST-Vent+, Zhang(2011) has proved that DeST-Vent+ building's consumption simulation on airflow rate and air temperature is credible and accurate compared with results of experiment data. So DeST-Vent+ is a

reliable software for the building consumption simulation with natural ventilation.

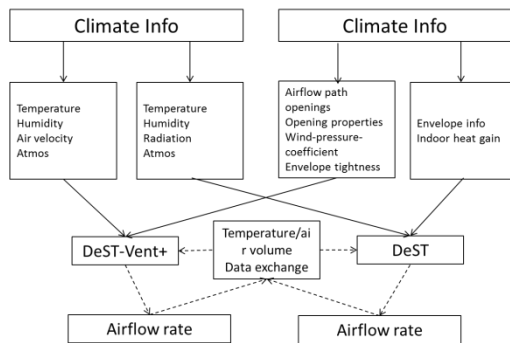


Figure 1 Input data of coupling calculation

In order to get building's wind pressure coefficient (figure 1), we also use CFD simulation software Phoenix. As most buildings in China are constructed near other buildings as a cluster, a 3×3 array buildings model is adopted in the CFD simulation. Wind pressure coefficients of 16 wind directions are calculated through CFD simulation.

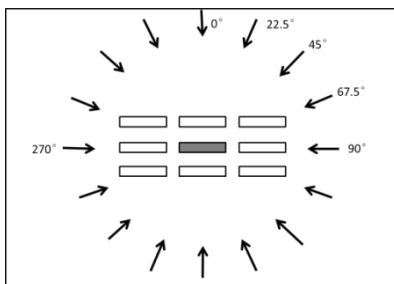


Figure 2 16 wind directions of CFD simulation

Boundary conditions and convergence criterion in CFD simulation are according to AIJ. The Durbin turbulence model is one of the best 2-equation models (Mochida et al., 2008; Durbin 1996), therefore, in present paper Durbin turbulence model is adopted to predict the outdoor wind environment.

MODEL

In this paper, we pick up three typical different building room structures with similar outer design—slab-type residential building in Beijing, China. All these three are 6-story low-rise residential buildings and each story is 3 meters high. According to former simulation study(Feng et al, 2003), low-rise building and high-rise building present the same conclusion when studying how different factors influence natural ventilation in Beijing. So this paper will only focuses on low-rise building in Beijing.

In this paper, we pick up three typical different building room structures with similar outer design—slab-type residential building in China, and these three all have same area 92 m², same room type and number of rooms, such as one living room, one kitchen, three bedrooms and two toilets.

The first model's specific room structure is presented in figure 3. Different numbers in figure 4 stand for different room types.

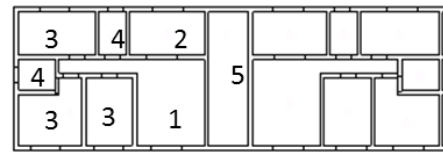


Figure 3 First building room structure (1: Living room; 2: Kitchen; 3: Bedroom; 4: Toilet; 5: Stairs)

The second model's specific building room structure is presented in figure 4.

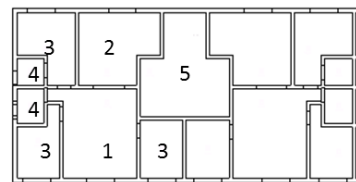


Figure 4 Second building room structure (1: Living room; 2: Kitchen; 3: Bedroom; 4: Toilet; 5: Stairs)

The third model's specific building room structure is presented as figure 5.

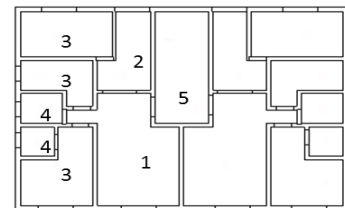


Figure 5 Third building room structure (1: Living room; 2: Kitchen; 3: Bedroom; 4: Toilet; 5: Stairs)

The three models are all presented in figure 6.

In these three models, there are eight households per storey. The two black frames stand for two households using one stairs.(Figure 6)

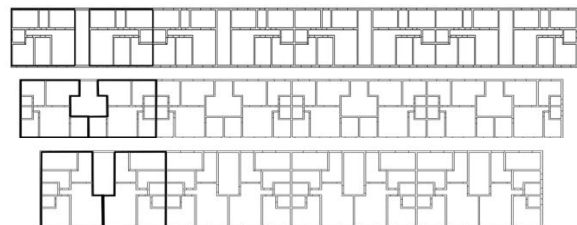


Figure 6 3 models in DeST (top to bottom: 1,2,3)

Building envelope parameters

Building envelope parameters of these models are determined by Design Standard for Energy Efficiency of Residential Buildings in Beijing. The detailed parameters of the building envelope are given in Table 1. Schedules for the usage of the rooms and equipment in each room in three models are the same according to the most people's habits.

Table 1
Parameters of building envelopes

Item	K-Value(W/(m ² • K))
External Wall	0.622
Window	2.8
Roof	0.6
Floor	0.6

Internal connections between rooms

In three models, doors between air-conditioned rooms are assumed to be opened. Specifically, toilet door and kitchen door are assumed to be closed, while bedroom door is assumed to be opened, which follows the habits and customs. (Figure 7)

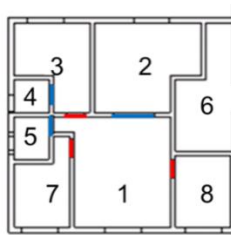


Figure 7 internal connections between rooms (red door: opened blue door: closed)

Through the analysis of ventilation rate and source of ventilation, we can find that this purpose-provided opening are applied inside the buildings. Take room 3 for example, this room have an air exchange with room 1 and outdoor, but without room 4.

Weather data

In this paper, we pick Beijing as the only simulation location, and the weather data we used in the simulation comes from the Beijing weather bureau, which provides outdoor temperature and humidity data per hour for the whole year (8760 hours) in Beijing(Figure 8). The hottest month is July and the highest temperature is 34.7°C. The coldest month is January and the lowest temperature is -14.2°C.

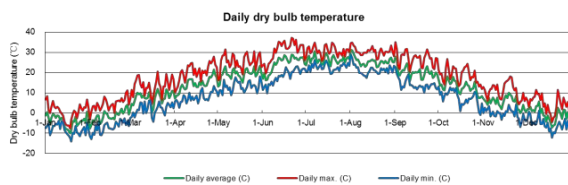


Figure 8 hourly weather data in Beijing

Natural ventilation controlling strategy

Natural ventilation strategy plays an important part in the natural ventilation. The core of the strategy is the intervals of temperature and humidity, which determine the ventilation opening. The intervals are also the comfortable temperature and humidity intervals of rooms. When outdoor air's temperature and humidity are in these intervals, incoming outdoor air is an efficient way to keep the indoor air's parameters in the intervals and meanwhile the ventilation openings are open. The comfortable temperature and humidity intervals of rooms are listed in Table 2.

Table 2
The comfortable temperature and humidity intervals of rooms

Item	Temperature (°C)		Humidity (%)	
	Low	Up	Low	Up
parameters	≥18	≤28	≥20%	≤80%

In addition to natural ventilation, each room has minimum fresh air per person to ensure the health of people. (Table 3)

Table 3
Room's setting minimum fresh air per person

Item	bedroom	Living room	toilet	kitchen
MFAPP(m ³ /H)	20	70	20	25

Models in CFD

These three models in DeST-Vent+ are showed as below. In order to get building's wind pressure coefficient, the three 3×3 array buildings models of CFD simulation and their specific parameters are showed in figure 8.

Moreover, in these CFD simulations, more intensive mesh and much stricter convergence criterion have no distinct influence on result.

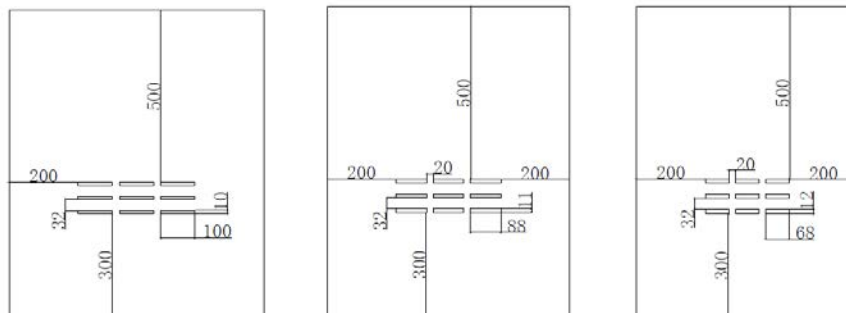


Figure 8 Three model's CFD simulation

RESULT

CLSR

CLSR (Cooling Load Saving Ratio) is an important evaluation index to study this topic.

$$CLSR = 1 - \frac{Q_{Vent}}{Q_{No Vent}}$$

In this equation, CLSR is cooling load saving ratio, Q_{Vent} is the cooling load with natural ventilation, and $Q_{No Vent}$ is the cooling load without natural ventilation.

The influence of S (shape coefficient of building)

As for three models in this paper, although they have similar outer design—slab-type residential building, their S is different.

In order to eliminate influence of S, we introduce a new model named model 3*. Model 3* is half of model 3. They have same room structure and the only different between model 3 and model 3* is that there are 8 households per storey in model 3, but 4 in model 3*. These four models' S is shown in Table 4.

Table 4
S of three models

Item	Model 1	Model 2	Model 3	Model 3*
S	0.220	0.205	0.196	0.225

We calculate these four models' annual and monthly cooling load per unit area with and without natural ventilation through simulation mentioned above. Then CLSR of four models is easy to get (Figure 11).

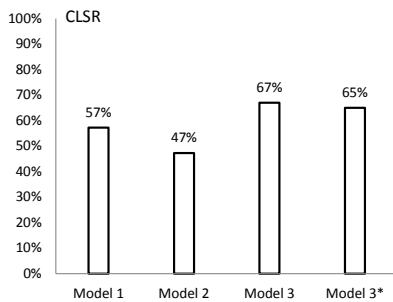


Figure 9 CLSR of building's annual cooling load

As shown in the graph above, model 3's and model 3*'s CLSR is very similar, which can prove that when we talk about different room structure's CLSR, the influence of S (from 0.196 to 0.225) can be ignored. Therefore, in this paper, we can safely compare three models' room structure and CLSR without considering influence of S.

CLSR

In Figure 11, the relative order of cooling load CLSR between three models is: model 3 > model 1 > model 2.

In order to ensure this order credibility and find the changing pattern of CLSR at a monthly frequency,

we simulate the monthly CLSR of the three models (Figure 12):

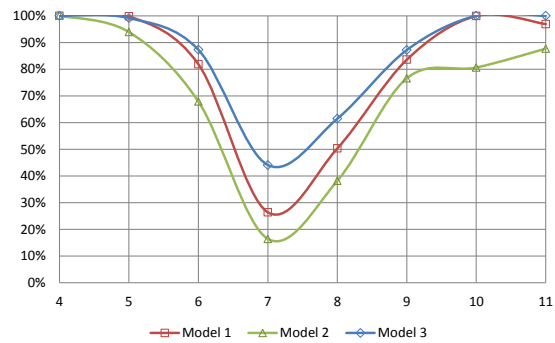


Figure 10 CLSR of building's monthly cooling load in Apr. - Nov.

In Figure 11, whole CLSR order is also: model 3 > model 1 > model 2. In July and August, the temperature of outdoor air is usually higher than 28°C and it is not appropriate for natural ventilation, so that CLSR in these two months is lower than other months. In the meantime, the difference between these CLSRs in these two months is much bigger than CLSRs in other months. For example, in April, May, October and November, CLSRs of model 1 and model 3 are nearly 100% because the temperature of outdoor air is always lower than 28°C and through natural ventilation, building's cooling load is nearly null.

Three bedrooms and one living room are the main rooms demanding air condition in a household. By comparing bedroom's and living room's CLSRs of three models on the third floor, we can see how the differences of rooms' structure affect their annual cooling load (Figure 11).

Actually, when we look at the each model's entire rooms' annual cooling load, we can find that the rooms' cooling load in the middle floors (second, third, fourth, fifth) is very similar. Moreover, when it comes to CLSR of rooms' annual cooling load, the influence of different floor is very small. Therefore, we just choose the bedrooms and living room on the third floor in every model.

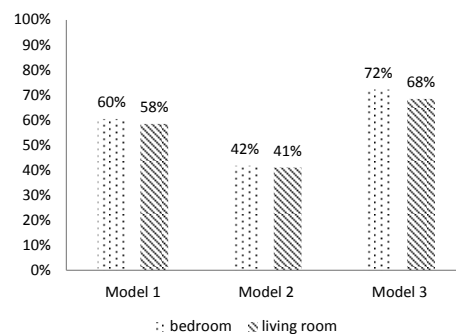


Figure 11 CLSR of rooms' annual cooling load (bedroom's CLSR represents the average of three bedrooms)

CLSRs of model 3's both bedroom and living room are the highest and CLSRs of model 2's are the lowest. Figure 11 shows the same relative order with Figure 9 (CLSR of building's annual cooling load).

Natural ventilation hours and natural ventilation rate

Through simulation, we can get each building's ventilation hours, which stands for each building's ventilation demand. The following figure is three models natural ventilation hours.

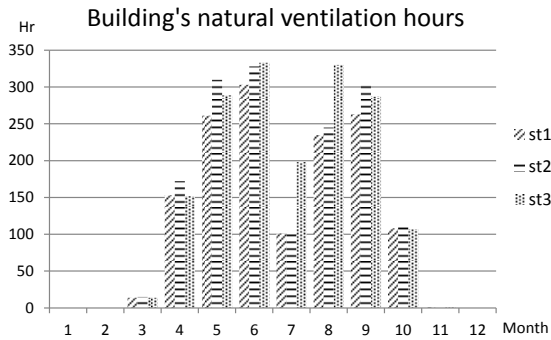


Figure 12 Building's natural ventilation hours

In Figure 12, we can find that different model's natural ventilation hours are similar except that model 3's natural ventilation hours in July and August are higher than other models'. The results imply that three models' natural indoor humidity and temperatures per hour are similar because the differences between indoor and outdoor temperature and humidity determine whether to ventilate or not.

When we look at the building's monthly natural ventilation rate, we can find something quite difference.(Figure 13)

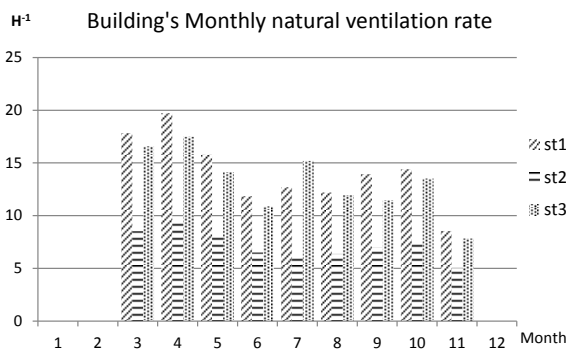


Figure 13 Building's monthly natural ventilation rate

The model 2's natural ventilation rate is much lower than the other two's. And the model 1' is a little higher than model 3'. Natural ventilation rate can stand for ventilating ability.

Considering all data and figures above, we can find that: 1. model 2's natural ventilation hours are the highest and ventilation is most needed in model 2, while its ventilating ability is the worst. So taken all factors together, model 2's CLSR is the worst. 2. Model 1's ventilation hours are lowest and ventilation is least needed in this model, while its ventilating ability is the best. So taken all these

factors into account, model 1'CLSR is higher than model 2's. 3. Model 3's natural ventilation hours and ventilating ability both rank in the middle. However, considering its ventilation demand and ventilating ability in summer, model 3's CLSR is the highest.

When we look at these models' room structure specially, we can find that all the inner doors and windows of model 1 and model 3 are opened facing north-south, thus each door or window in the south can have a straight faced door or window that help to provide effective cross ventilation. In comparison, the bedroom doors of model 2 are opened facing east and west, therefore cross ventilation is not as effective and thus making the overall ventilating ability of model 2 inferior to that of model 1 and 3 (Figure 14)

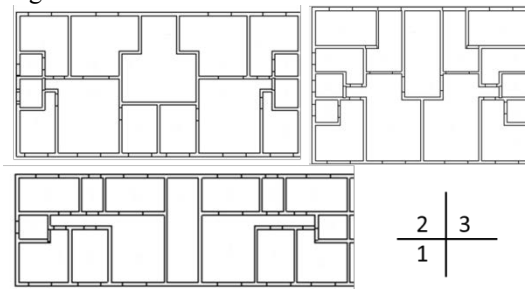


Figure 14 three models' room structure

CONCLUSION

In this paper, we simulate three models of different room structures. Through the data and graph showed above, it is safe to reach the following four conclusions.

1. The influences room structure has on building energy-saving ratio cannot be ignored, at least when it comes to slab-type residential buildings in Beijing. In those three models, the highest CLSR of building's annual cooling load can reach to 67%, while the lowest one is only 47%, and the difference between them is as much as 20%.
2. The effects that room structure has on cooling loads are associated with seasons. During transitional seasons, CLSRs of three models are similar, especially during April and November when CLSRs reached 100%, thus the difference can be neglected. In contrast, in summer months like July and August, energy saving potential brought by structure difference is still large.
3. Specifically, building's CLSR is influenced by two main factors: ventilation demand and ventilating ability. As for building with high ventilation demand, enhancing its ventilating ability can improve its CLSR efficiently. Therefore, when we compare different room structures' CLSR, we should judge them from these two aspects, so that we can analyse more deeply about that.
4. As shown in the three models we have discussed in the paper, we can find that models, whose inner doors and windows are opened facing North-South and located on the same line, are more suitable for

cross ventilation and exhibit higher overall ventilating ability. For slab-type buildings, there are few differences among different models regarding ventilating demand. Thus choosing a model of higher ventilating ability would make a larger energy-saving ratio brought by natural ventilation.

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