Energy and Comfort performance of natural ventilation system in office buildings in China

Runming Yao[a], Baizhan Li[b], and Koen Steemers[a]

[a]The Martin Centre for Architectural and Urban Studies Department of Architecture University of Cambridge, UK

[b] Key laboratory of the Three Gorges Reservoir Region's Eco-Environment, Ministry of Education, The Faculty of Urban Construction and Environmental Engineering, Chongqing University, P R China

ABSTRACT

This paper presents an analysis of energy and comfort performance of typical office buildings for summer cooling in five climate zones in China using the natural ventilation assessment tool, which is developed based on the integrated thermal and airflow model. Harbin, Beijing, Shanghai, Kunming and Guangzhou are selected as the five representative cities for Very Cold, Cold, Hot Summer and Cold Winter, Mild and Hot Summer and Warm Winter zones respectively. The cooling energy consumption with air conditioning system is compared to that with natural ventilation system. The simulation results show that for daytime air-conditioning system in conjunction with night ventilation can reduce cooling energy significantly for each zone. Part time air-conditioning operation can reduce cooling energy in Very Cold and Mild zones significantly but not in Hot summer zones such as Guangzhou and Shanghai. In natural ventilation cooling system design, climatic factor must be considered because it is a very important factor, which influences the effectiveness of natural ventilation and cooling energy consumption.

KEYWORDS

Natural ventilation, climate, energy saving, thermal comfort, China

INTRODUCTION

China's buildings sector currently accounts for 23% of China's total energy use and is projected to increase to one-third by 2010[4]. Energy consumption in buildings becomes the major source of greenhouse gas emission in China. Natural ventilation is being increasingly proposed as a mean of low energy design method in "green buildings" community; because it has the potential to significantly reduce energy cost required for mechanical ventilation of buildings. However potential cooling energy saving depends on the climate, internal heat gains and the building design. The climate of China is extremely diverse and variable with a tropical climate in the south and sub-arctic in the north. Therefore, it is very important to evaluate the potential effectiveness of natural ventilation and thermal comfort at the strategic design stage. A natural ventilation assessment tool [5] developed based on the coupled thermal and airflow model at the Martin Centre for Architectural and Urban Studies in University of Cambridge has been used to assess the thermal comfort of natural ventilation system of the typical office buildings in China's Five Climate Zones. The cooling energy consumptions of different cases have been analyzed.

CLIMATE

China is a large country with an area of about 9.6million km^2. About 98% of the land area stretched between a latitude of 20^oN to 50^oN, from subtropical zones in the south to the temperate zones (including warm-temperate and cold temperate) in the north. For building thermal design, five climate zones have been presented by "Thermal design code" [1]. There are different design codes for different zones. Table 1 lists the U-value of building envelopes.

In this paper the five cities, Harbin (HB), Beijing (BJ), Shanghai (SH), Kunming (KM) and Guangzhou (GZ), which represent the five climate zones in China, have been selected for office building energy and comfort studies. The latitudes of the cities are 44.46, 39.56, 31.0, 25.51, and 25.01 respectively from north to south.

Table 1 U-value of envelope in each zone ($W/m^2.K$)

	Very Cold Zone (Harbin)	Cold Zone (Beijing)	Hot summer and cold winter zone(Shanghai)	Mild zone (Kunming)	Hot summer and warm winter zone(Guangzhou)
External wall	0.52	1.16	1.5	1.5	1.5
Glazing	2.5	4	4.7	6.0	6.0

SIMULATION FOR TYPICAL OFFICE BUILDING

Method

The coupled thermal and airflow model is developed for natural ventilation and energy performance analysis. The detailed theoretical model will not be illustrated in this paper. This paper focuses on the analysis of the simulation results. Preliminary energy and discomfort rate are the two indices for energy and comfort performance analysis used in this paper. The discomfort rate is defined as the ratio of the number of hours in which internal air temperature exceeds the fixed comfort temperature over the occupied hours in hot summer days.

Basic Information

The office room can be grouped into two types: one is the high standard fully central air-conditioned cell office and another is the traditional office room equipped with split room air-conditioner. In tradition, the layout of the office building is designed as south-north orientation with a corridor in the middle. A typical office room is selected for this case study, of which the required information for thermal simulation is listed in the table 2 and as following:

- Room dimension is 3.6m in length, 5.4m in depth and 3.0m in height;
- Orientation is south-north orientation;
- Glazing ratio in the south wall is 0.35 and 0.25 in north wall;
- Occupied period is from 8:00 to 18:00;
- Thermal mass is assumed as medium mass;
- Internal shading devices is applied in southern window in summer;
- The office room is located in city.

Table2 Basic information of traditional office building

Fresh air requirement (m^3/h.person)	Gain of occupant			Gain of lighting (W/m^2)	Gain of equipment (W/m^2)
	Density (person/m^2)	Heat emit of people (W/person)	Moisture content emit from people(Kg/h)		
30	0.1	64	0.084	10	10

Natural Ventilation

The dynamic simulations for the typical office rooms in the five cities have been performed for summer season. The "all day and night" ventilation strategy has been applied. According to the Chinese Thermal Design code, the internal design air temperature is selected as 26^{o}C and not exceeding 28 ^{o}C. The simulation results are shown in Fig.1. From the figure we can see that generally, in June and September, natural ventilation can improve office internal thermal comfort condition in the most cities, but the internal air temperature in Guangzhou exceeds 28^{o}C. In the hottest months July and August, natural ventilation can improve office internal thermal comfort in Harbin and Kunming, where the monthly average internal air temperature is below 26 ^{o}C; but it cannot fully improve that in Beijing, Shanghai, and Guangzhou. In particular, the thermal conditions in the afternoon in these cities cannot achieve comfort level. Table 3 lists the discomfort rate of the offices with all day and night ventilation systems in the five cities. Tc is the comfort temperature. In order to reduce discomfort risk, obviously mechanical cooling system is desired.

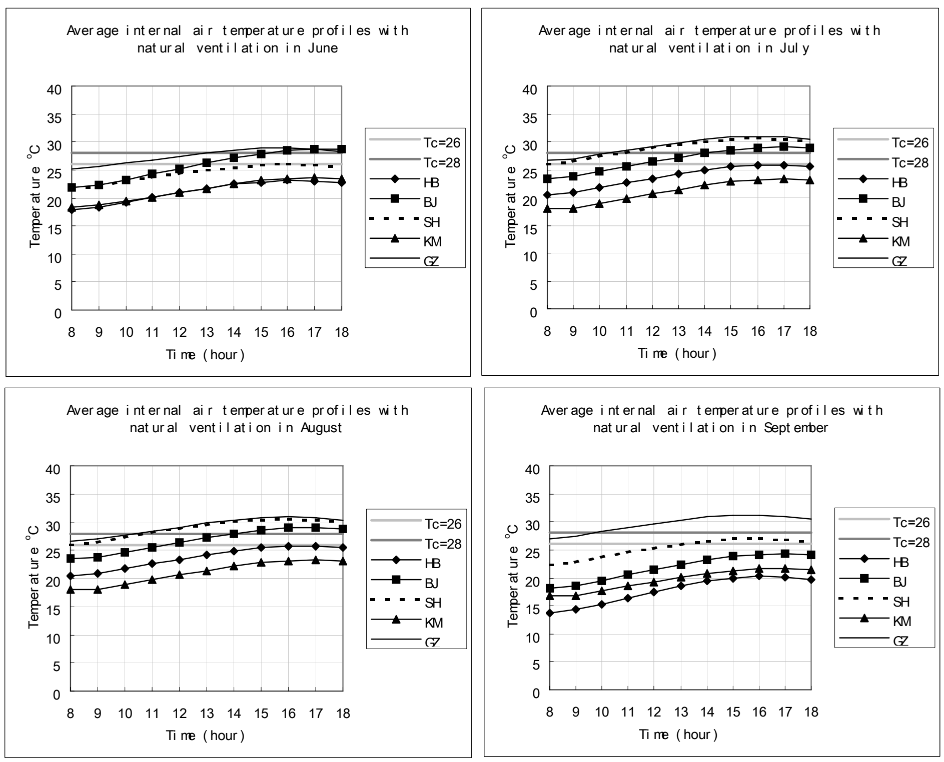

Fig.1 Monthly average temperature profiles in the five cities.

Table 3 Discomfort rate of the office with night natural ventilation in summer season

Discomfort rate %	Harbin	Beijing	Shanghai	Kunming	Guangzhou
Tc=28	5	21	34	2	48
Tc=26	11	35	49	6	58

Cooling strategies

The mechanical measures are necessary in order to improve office thermal comfort in summer in most zones in China because natural ventilation cannot work properly by its own. The hourly auxiliary cooling load has been simulated for different cases in order to calculate the cooling energy consumption. The setting up of the internal comfort temperature is a key factor, which influences the cooling energy consumption and thermal comfort. The effects of indoor air movement on human thermal comfort in hot climate have been extensively studied. Air movement may provide desirable cooling in warm and humid conditions. Air velocities increase the body's convective and direct evaporative heat loss rate. Li states that people, who feel warm, find air movement pleasant in China [3]. Ceiling or table fans for cooling are the most common measures used by Chinese people in summer. People choose higher operating speeds when the indoor air temperature is higher. Usually, in the occupied parts of rooms, the air velocity is below 0.1 m/s, and then the air temperature is a sufficient index of the warmth of the environment. However, when a ceiling or table fan is used as a cooling measure for body comfort, the comfort temperature should be corrected to take account of the effect of air movement. The correction for air movement indicates that the effect of increasing the air movement to 1 m/s is equivalent to lowering the globe temperature (if the air temperature and the mean radiant temperature are equal) by 3^{o}C. Air velocities higher than this are unlikely to be acceptable in offices, because of the risk of disturbing papers. When ceiling fans are provided for summer 'cooling', it may not be necessary to measure the air movement; it would usually be sufficient to assume that their provision gave a benefit potentially equivalent to a 3 degree drop in temperature [2].

In order to assess the energy performance of natural ventilation and mechanical cooling systems, three cases for traditional office room equipped with split air-conditioner have been selected for energy consumption analysis. We suppose the discomfort rate of each case is under 2%.

(1) Air-conditioner operates during the working period (0800 to 1800)
This is proposed as a base case for comparisons. In this case the occupants can freely select the desired internal air temperature. According to the Chinese design standard, the desired internal air temperature can be set as 26^{o}C. Considering the adaptive comfort and the survey in China, 28^{o}C is the acceptable temperature. The energy consumptions of these two setting temperatures have been simulated for each city in summer season.
(2) Daytime air-conditioning in conjunction with night time natural ventilation
In order to assess the impact of night ventilation on energy performance, the simulation for this case has been performed.
(3) Part time air-conditioning in the afternoon and fan operation in the morning
The table fan and the ceiling fan are the most common cooling measures in offices in China. The equivalent comfort temperature is 3^{o}C lower than internal air temperature due to the air movement with fan.

Computer simulations for the above cases for each city have been performed.

RESULTS ANALYSIS

(1) Night ventilation can save cooling energy

Fig.2 shows the percentage of cooling energy saving of the case "daytime air-conditioning with night ventilation" comparing to the case "daytime air-conditioning without night ventilation. Tc=28 means the comfort temperature is set as 28^{o}C and Tc=26 is set as 26^{o}C. From the figure we can see that the saving percentage is slightly higher when comfort temperature is set higher. In the Very Cold and Mild zones, there is a significant energy saving due to the implementation of night ventilation. For example, in Harbin, the average energy saving can achieve about 80% and in Kuming about 90%. This is because in these two zones, the differences of day and night air temperature are high. There is about 60% of energy saving in Beijing and 50% in Shanghai. Even in the Hot Summer and Warm Winter zone –Guangzhou, there is about 40% of energy saving by implying nigh ventilation. To explain this situation, the temperature and load profiles of July 21st in Beijing of the cases "Daytime air-conditioning without night ventilation" and "Daytime air-conditioning with night ventilation" are illustrated in Fig.3, in which Ta is outdoor air temperature; T1 is the internal air temperature without night ventilation; T2 is the internal surface temperature without night ventilation; T1nv is the internal air temperature with night ventilation; T2nv is the internal surface temperature with night ventilation; Load cooling is the cooling load without night ventilation and Loadnv is the cooling load with night ventilation. From the figure we can see that the internal surface and air temperature of this case with night ventilation is lower than those without night ventilation. The cooler outdoor air offset the heat stored in the building structure and this reduces cooling load for the next day morning. The air-conditioning operating hour can delay two hours.

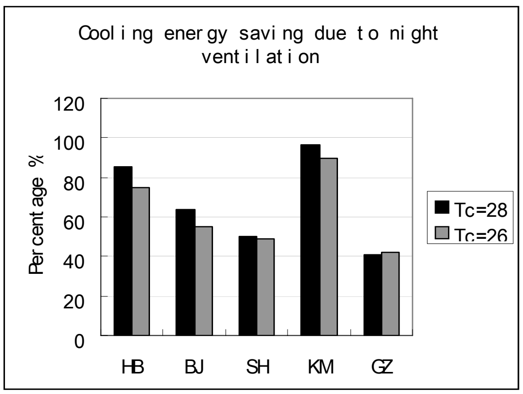

Fig.2 Percentage of energy saving

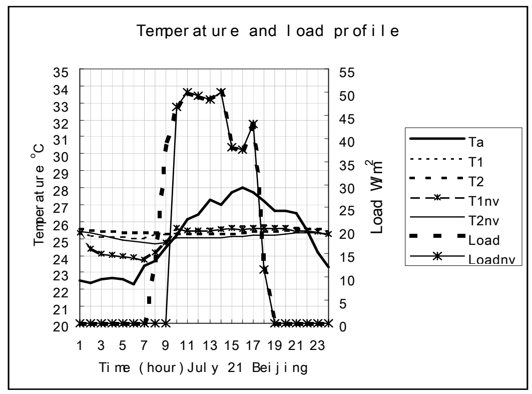

Fig.3 Temperature and load profiles

(2)Part time air-conditioning operation in the afternoon

From the natural ventilation simulation analysis we can see that office internal thermal condition in the morning can be improved by natural ventilation in the most cities except hottest month. This will give the opportunity for the integration of natural ventilation and mechanical cooling measures. It is noted that fan is the commonly used measures for thermal comfort improvement, which can equivalently offset air temperature by 3 ^oC. Fig. 4 shows the energy saving of part time air-conditioning operation. From the figure we can see that the case of "fan cooling in the morning and air-conditioning in the afternoon" can save about 85% energy comparing "all day air-conditioning without night ventilation" in Kunming, about 60% in Harbin, about 25% in Beijing and 15% in Shanghai. However there is less than 10% saving for comfort setting temperature of 28^{o}C and almost no saving for that of 26^{o}C in Guangzhou. This is because the daytime outdoor air temperature in the morning in Guangzhou is higher than that in the other four cities. When outdoor air temperature is high there will be no benefit for energy saving using natural ventilation. In contrast, all day air-conditioning operating can immediately remove the internal gains, while the afternoon part time air-conditioning operating system cannot remove the internal gains due to the high outdoor air temperature and the heat will be stored in the building structure and furniture and this will cause the higher cooling load in the afternoon. To explain this situation, the temperature and load profiles of July 17th in Guangzhou of the cases "Full time daytime air-conditioning" and "Part time air-conditioning" are illustrated in Fig.5, in which Ta is the outdoor air temperature; T1 is the internal air temperature with full time air-conditioning; T1p is the internal air temperature with part time air-conditioning; T1p-eq is the equivalent air temperature internal air temperature considering air movement due to fan operation with par time air-conditioning; Load is the cooling load of full time air-conditioning and Load-p is the cooling load of part time air-conditioning. From the figure we can see that there is no significant saving for the part time air-conditioning operation comparing with full time air-conditioning, because there is a high peak cooling load when air-conditioning starts to operate in the afternoon. From the above analysis we can see that when outdoor air temperature is high, natural ventilation cannot save cooling energy.

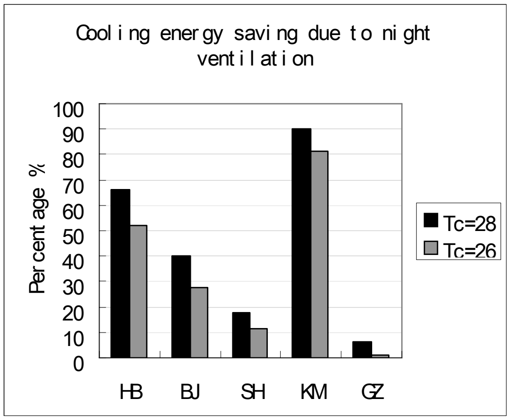

Fig.4 Percentage of energy saving

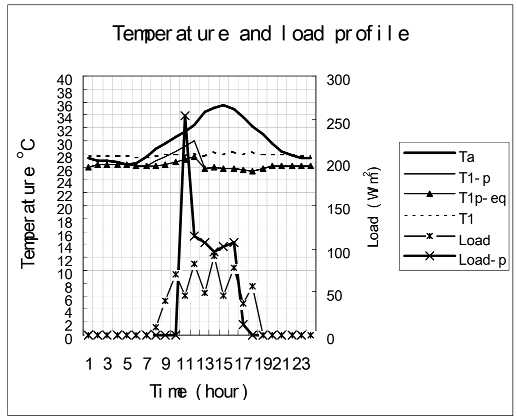

Fig. 5 Temperature and load profile in Guangzhou

CONCLUSION

The computer simulations for the typical office building in Chinese five cities, which represent the five climate zones in China, have been performed with different cases. Natural ventilation is a sufficient measure for improving summer thermal comfort however local climate plays an important role in energy saving. Night ventilation can reduce cooling energy. Air-conditioning in conjunction with natural ventilation system can achieve significant energy saving in Very Cold Zone and Mild zone and less saving in Hot summer zones.

ACKNOWLEDGEMENT

The authors wish to acknowledge the funding from CMI (Cambridge-MIT Institute) for the project Sustainable Building Design. The authors thank the financial support form UK FCO GOF Program. The authors thank Samantha Lawton for the administrative support provided.

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