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Experimental Assessment of Mechanical Night Ventilation on Inner Wall Surfaces

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Abstract
The cooling potential of night ventilation largely depends on the heat exchange at the internal room surfaces. During night time, increased heat transfer on a vertical wall is expected due to cool supply air that flows along the internal wall surface from the top of the wall. This paper presents an experimental study of the cooling of wall surfaces in a test room by mechanical night-time ventilation. Significant improvement of indoor thermal environment is presented resulting from the enhanced internal convection heat transfer.

Keywords - night cooling; mechanical ventilation; enhanced heat transfer

1. Introduction

A large number of studies have demonstrated that night ventilation contributes to energy savings and improving both the indoor thermal comfort and the indoor air quality. Thermal mass of buildings such as ceilings, walls, floors and furniture can be utilized to store heat gains during daytime, while ventilation is used to take away the heat accumulated in the thermal mass when the ambient temperature is lower than the indoor air temperature at night. Recent studies indicated the effectiveness of night ventilation in residential buildings [1], office buildings [2] and commercial buildings [3].

As shown by many numerical and experimental studies of night ventilation the main parameters related to the cooling potential of night ventilation can be classified into three groups including the climatic conditions, the building parameters and the ventilation parameters [4]. Using a building energy simulation program (HELIOS) to evaluate the influence of different parameters, Artmann et al. [5] reported that during night-time ventilation the climatic conditions and air flow rate have the largest effect, while thermal mass and internal heat gains also have a significant effect on the cooling performance and the achievable level of thermal comfort. However, regarding to a particular existing building, enhancing the mechanical ventilation strongly benefit to the cooling capacity of night ventilation.

In rooms with ventilation systems, the position of supply air devices largely affects convective heat transfer on building constructions. Many research has been done studying the convection over different room surfaces. Awbi and Hatton [6] studied the convective heat transfer of short longitudinal jet over different heated room surfaces. Jeong and Mumma [7-9] estimated the enhancement of cooling capacity of cooled ceiling panels by mixed convection. In the research work by Samo Venco et al. [10], convection caused by longitudinal air jet over thermally activated cooled wall were experimentally investigated. Results show a significant decrease of energy consumption with enhanced convection.

Considering that exterior walls usually contribute a lot to the potential of thermal storage, this paper proposes a new system named wall-attached night ventilation, which is the mechanical ventilation over inner surface of vertical exterior walls during night-time. The goal of the new system is to make full use of the natural cooling source, and is achieved by enhancement of the convective heat transfer.

2. Set up of the test room

The experimental study was performed in a full-sized test chamber with the external dimensions of 3.6 m × 3 m × 3 m (length × width × height), resulting in a volume of 30.5 m^3. The test room had three windows (W × H= 1.45 m ×1.46 m) in the eastern wall, northern wall and western wall, respectively, while the door (W × H= 0.8 m ×2 m) was installed in the southern wall. The detailed materials used in the chamber are summarized in Table 1.

Table 1. Characteristic of the building components

Envelope component	Material	Thickness d [m]	Density ρ [kg/m^3]	Conductivity λ [W/(m ·K)]	Capacity C_p [J/(kg ·K)]
Roof	Cement	0.015	1800	0.93	1050
	Cystosepiment	0.2	20	0.031	1470
	Iron sheet, cast	0.002	7272	52	420
Exterior	Cement	0.015	1800	0.93	1050

Wall	Thermal mortar	0.025	400	0.085	1050
	Concrete blocks–hollow, with ceramsite	0.2	1100	0.334	1050
	Cement	0.015	1800	0.93	1050
Floor	Cement	0.015	1800	0.93	1050
	Asphalt	0.004	1700	0.5	1000
	Cement	0.015	1800	0.93	1050
	Concrete cast - reinforced	0.2	2300	1.9	840
	Cement	0.015	1800	0.93	1050
Window	U-value 1.7, G-value 0.45, LT-value 0.57				

The test room was located in Chongqing, southwest of China, which presents a typical monsoon-influenced humid subtropical climate. Chongqing is among the hottest and most humid cities in China. Table 2 shows the average temperatures and relative humidity. However, in the hot summer, the highest air temperature could reach 42 ℃ - 44 ℃, and the largest relative humidity could be 96 % - 98 %.

Table 2. Average values of climatic conditions in Chongqing

Month	June	July	August	September
Average Highest Temperature ℃ (℉)	29.4 (84.9)	32.8 (91)	33.6 (92.5)	27.7 (81.9)
Average Lowest Temperature ℃ (℉)	22.0 (71.6)	24.6 (76.3)	24.7 (76.5)	20.8 (69.4)
Average relative Humidity (%)	80	76	73	80

A mechanical system (Fig. 1) was designed to supply outdoor air into the test room. Air was taken from the ambient environment through a square opening of 0.4 × 0.4 m^2 located directly below the ceiling, and flowed through an air duct (W × H × L = 0.25 m × 0.25 m × 3 m). It then flowed over the vertical western wall from a long and narrow opening of 0.02 m width and 2.8 m length at the bottom of the duct. The northern window kept opening during the night time as the air outlet opening. An axial flow fan was utilized as the driving force of ventilation devices. The supply air with air flow rate ranging from 150 m^3/h to 2100 m^3/h, was driven by the supply fan regulated by a frequency converter.

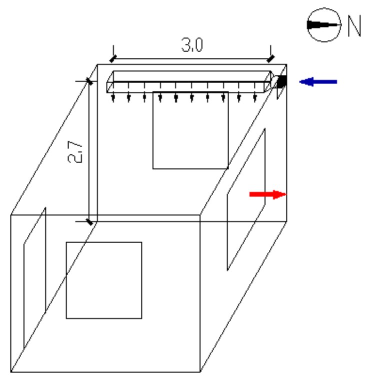

Fig. 1 The mechanical system

3. Measurement instrumentation and location sensors

For temperature measurement, type T thermocouples were used and connected to a Keysight 34980A multifunction switch/measure unit with 40 channels. Temperature sensors were installed on the internal surfaces of four exterior walls as shown in Fig. 2, in accordance with the code JGJ/T 177-2009. Additional two temperature sensors were located in the center of the test chamber at the heights 0.8m and 1.5m above the floor to monitor the air temperature of indoor environment. Air velocity and average temperature of supply air were calculated based on five sensors positioned at different locations of supply air duct.

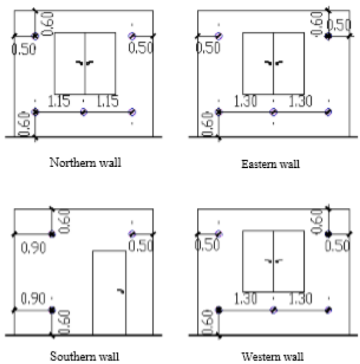

Fig. 2 The location of thermalcouples for measuring surface temperatures

4. Procedure for experiments

In July 2015, the experiments were initiated when the chamber had stable thermal conditions and a homogeneous temperature. Totally eleven cases were conducted (Table 3) with different ventilation schedules, supply air flow rates and climate conditions. In case 1, temperatures were measured with the door and windows closed during the whole 48 hours. All the rest ten cases were tested for 24 hours.

Table 3 List of experimental cases

Case	Ventilation schedule	Supply air flow rate (m^3/h)	Highest ambient temperature (℃)	Lowest ambient temperature (℃)
1	Heat-storage	0	38	26
			38	27
2	21:00 – next day 8:00	605	33	24
3	21:00– next day 8:00	806	34	23
4	21:00– next day 8:00	1210	36	27
5	21:00– next day 8:00	1411	37	27
6	22:00– next day 8:00	605	33	24
7	22:00– next day 8:00	907	36	26
8	22:00– next day 8:00	1008	34	25
9	22:00– next day 8:00	1210	33	24
10	22:00– next day 8:00	1411	34	25
11	22:00– next day 8:00	1613	35	26

5. Results and discussion

Fig. 3-5 present the experimental results of night ventilation on the western wall. It is shown that in early summer, better indoor thermal environment can be achieved by utilizing mechanical night-time ventilation.

Fig. 3 illustrates the surfaces temperatures when the whole room was closed for 48 hours, without using air conditioning or ventilation facilities. Periodic variations of both outer surface temperatures and inner surface temperatures are observed as the outdoor air temperatures changed cyclically. During the daytime, the outer surface temperatures can reach more than 55 ℃ and are much higher than the outdoor air temperatures. On the other hand, the inner surface temperatures are higher than the outdoor air temperatures during the night-time. Without air conditioning or any ventilation facilities, it is very likely to achieve extremely high temperatures in summer in Chongqing. The heat gains cannot be easily dissipated during the daytime due to the insulation effect of insulation materials. Hence the heat warms the room and accumulates in the thermal mass, resulting in increased energy consumption for air conditioning. Considering that insulation has been employed in a large number of buildings, this paper proposes mechanical ventilation over inner surfaces of vertical walls in buildings with external insulation, with the aim of removing away the heat stored in the thermal mass and improving the indoor thermal comfort.

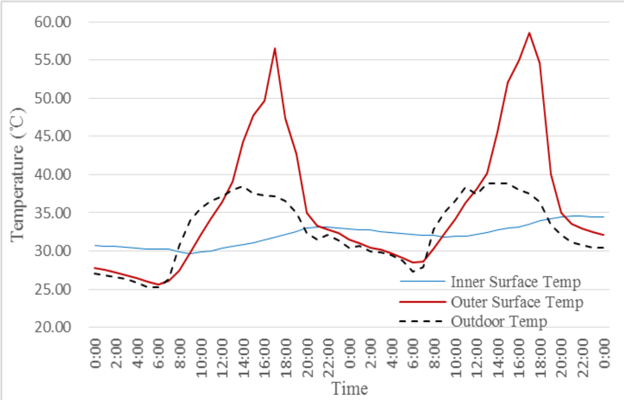

Fig. 3 Surface temperatures and outdoor temperatures measured during case 1 without night ventilation

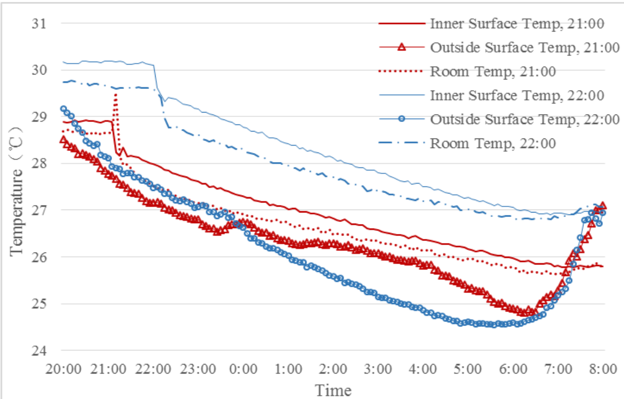

Fig. 4 Surface temperatures and room air temperatures measured during case 2 and case 6 with different start-up time of night ventilation

As shown in Fig. 4, case 2 and case 6 have the same supply air flow rate (v=605 m^3/h) and similar ambient conditions, while the start-up time of night ventilation is different. In case 2, when the supply air was supplied into the test room, at 21: 00, the outdoor temperature, the inner surface temperature, the outside surface temperature and room air temperature were 27.72 ℃, 28.90 ℃, 27.78 ℃ and 28.65 ℃, respectively. An hour later, at 22: 00, the outdoor temperature was 27.57 ℃, and the inner surface temperature, the outside surface temperature and room air temperature were declined to 27.99 ℃, 27.16 ℃, 27.53 ℃, respectively. Thus, the differences between previous temperatures and later ones were 0.91 ℃, 0.62 ℃ and 1.12 ℃, respectively, while the outdoor air temperature declined only 0.15 ℃. In case 6, the initial temperatures at 22: 00 were 27.85 ℃, 30.10 ℃, 27.48 ℃ and 29.60 ℃, respectively. The later temperatures at 23: 00 were 27.81 ℃, 29.16 ℃, 27.07 ℃ and 28.62 ℃, respectively; the corresponding temperature differences in this case were 0.04 ℃, 0.94 ℃, 0.41 ℃ and 0.98 ℃, respectively.

For evaluating the impact of mechanical night ventilation, the cooling efficiency of night ventilation is described as:

$$\varepsilon = \frac{\Delta T_{inner-surface}}{\Delta T_{outdoor}}$$

Accordingly, the cooling efficiency are 5.95 and 24.11 during the first hour of case 2 and case 6, respectively. This means that during the first hour of night ventilation in both cases, the temperature of inner surface declined sharply while the outdoor temperature changed a little bit, and the performance of ventilation in case 6 is much better than that in case 2.

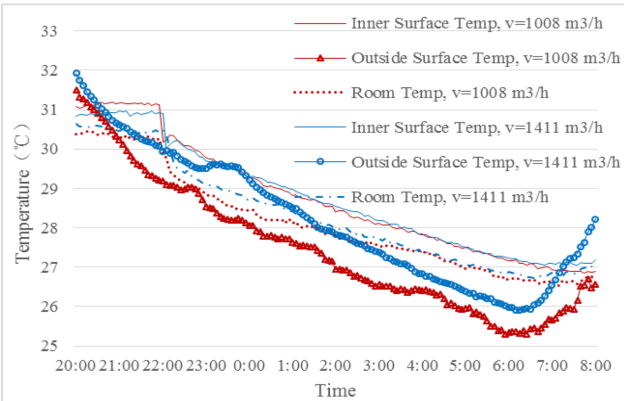

Fig. 5 Surface temperatures and room air temperatures measured during case 8 and case 10 with different supply air flow rates

In Fig. 5, case 8 and case 10 have the same start-up time (22: 00) of night ventilation and similar ambient conditions, but the supply air flow rates were different. In case 8, the outdoor temperature, the inner surface temperature, the outside surface temperature and the room air temperature at 22: 00 were 29.38 ℃, 30.37 ℃, 29.19 ℃ and 29.84 ℃, respectively. An hour later, at 23: 00, temperatures were declined to 28.94 ℃, 29.80 ℃, 28.54 ℃ and 28.83 ℃, respectively. Thus, the differences of the temperatures at 22: 00 and 23: 00 were 0.44 ℃, 0.38 ℃, 0.65 ℃ and 1.01 ℃, respectively. In case 10, the initial temperatures at 22: 00 were 30.14 ℃, 30.90 ℃, 29.94 ℃ and 30.50 ℃, respectively. The later temperatures at 23: 00 were 29.70 ℃, 29.71 ℃, 29.51 ℃ and 29.09 ℃, respectively; the corresponding temperature differences were 0.44 ℃, 1.19 ℃, 0.37 ℃ and 1.41 ℃, respectively. Thus, the cooling efficiencies of case 8 and case 10 are 1.31 and 2.76, which shows that higher air flow rate is more easily to achieve effective cooling.

Fig. 6 illustrates the result of the temperature efficencies from the measurements. After one hour's night ventilation, the best performance is achieved in case 6 (night ventilation began at 22:00 and the supply air flow rate is 605 m^3/h). In contrast, the cooling efficiency of case 3 is only 0.92. The main reason for the noneffective night ventilation in case 3 is that the temperature of supply air was even higher than that of the interior surface of the western wall at 21:00. For the remaining cases, the cooling efficiencies exceeds 1 after one hour's ventilation, which reveals that the air flow pattern can result in effective dissipation of the heat stored in the exterior wall during a short period. It should be noted that the efficiencies turn out to be a little random due to variable weather conditions of each case. Therefore, the performance of ventilation depends on both the temperature conditions of the start-up time and the air flow rate.

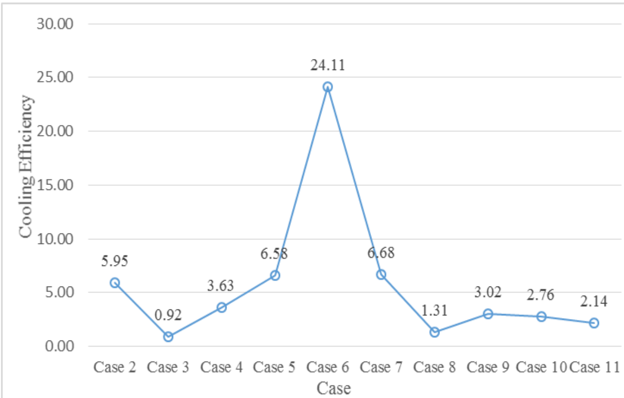

Fig. 6 Cooling efficiency after one hour's night ventilation

6. Conclusions

In the present study, experiments of mechanical night ventilation on inner surfaces of vertical walls have been carried out, considering variable ventilation schedules, supply air flow rates and climatic conditions. It turns out that the performance of ventilation depends on both the temperature conditions of the start-up time and the air flow pattern. For improvement and better understanding of mechanical ventilation on vertical walls during night-time, further experimental and theoretical work are required to identify the influence of various ventilation parameters.

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