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VENTILATION, INDOOR AIR QUALITY AND THERMAL COMFORT

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ABSTRACT

Ventilation is increasingly a subject of concern due to its relation with health and energy loss. Environmental pollution and global warming demands energy conservation and a Airtight structures are being built to reduce the energy losses due to infiltration. Reduced air change rates may lead to accumulation of CO_2 and other toxic pollutants to undesirable levels. In view of such concerns tests are carried out here to study the influence of ventilation on indoor air quality and thermal conditions in a naturally ventilated building. The results show that CO_2 accumulation of depends on the ventilation rate and the level of occupancy. CO_2 dissipation bears a high correlation with 'open window'. The study indicates that night ventilation can provide appropriate means for passive cooling in buildings and its effectiveness is strongly related to relative differences between indoor and outdoor temperatures.

KEYWORDS

Buildings, air quality, pollutants, carbon dioxide, natural ventilation, night cooling, human satisfaction,

INTRODUCTION

Ventilation in buildings is the process of changing air in the internal spaces and is required for many different reasons to meet certain requirements [ASHRAE 1991]. The need for ventilation varies with the use of building; for example in residential buildings the comfort of the occupants is highly related to ventilation where it modifies the indoor thermal environment. When related to indoor air quality ventilation, has two primary objectives, namely:

- supply of fresh air
- removal of contaminants

Ventilation, apart from controlling the indoor air quality has additional tasks such as cooling the building for human comfort, particularly in hot and warm climates. The effectiveness of night ventilation has been established in a number of studies [Awbi 1991, Hancock 1999] and passive cooling techniques are widely used. The air movement increases the dissipation of heat from the building materials significantly. The warmer air is exhausted into the low temperature atmospheric heat sink. Night ventilation can thus reduce the total cooling load of air-conditioned buildings, leading to energy saving and reduction in CO_2 emissions.

The building occupants can modify the indoor thermal conditions by manipulating various controls available to them. In naturally ventilated buildings the usual controls are openable windows and local fans. Studies have showed that control over ventilation rate (e.g. the opening of windows and doors) can provide a useful and effective tool for improving the indoor thermal conditions [Raja & Nicol 1998a]. However, its effectiveness is linked with the differences between outdoor and indoor temperatures and is more effective if the outdoor temperature is lower than the indoor temperature and when the temperature difference is high.

A study was carried out to demonstrate the influence of ventilation on indoor thermal conditions and air quality in a naturally ventilated building. The test was conducted in an office room, located in the Portland Building (which houses the Faculty of Environment) at the University of Portsmouth. Indoor thermal conditions and air quality were monitored. The number of occupants and window opening was varied in a random manner over the day, with 0, 1 and 2 occupants, and the window was closed and opened again for 30mm and 60mm. During the occupancy period, the occupants were asked to fill in questionnaires about the suitability of their environment at half hourly intervals. The indoor thermal condition and air quality was monitored by recording temperature and CO_2 concentration. The outdoor weather data for the test period was obtained from the University's weather station, operated by BMS Group in the Department of Electrical and Electronic Engineering. The analysis of indoor air quality and effect of ventilation on indoor thermal conditions is presented in this paper.

EXPERIMENTAL SETUP

The experiment is conducted in an office in Portland Building at University of Portsmouth. The building is naturally ventilated via stack-effect towers and a central glassed atrium. The room used for the test is a small office located on the second floor in the south wing of the building. It is connected internally to a corridor with a single door. The externally exposed wall is on the north. The size of the room is 3.6m x 3.1m x 2.7m. The room is ventilated through a single north facing top mounted window. The size of the window is 0.91m x 1.3m x0.2m. The ventilation is achieved via towers. These towers use the buoyancy of heated air to draw air through the central corridor of the wing. Air enters and leaves the room through the north-facing window and through infiltration around the door.

The room was monitored continuously for eight days during the summer of 1999. Thermal and environmental parameters measured are listed in Table 1. The table also contains the range and accuracy of the sensors used for monitoring. These parameters were recorded using TESTO 400, '2 Channel Multi-Function Instruments' at intervals of five minutes. The occupancy and opening of the window were varied according to a Pseudo Random Multilevel Sequence (PRMLS). The occupancy was varied from 0 to 1 and 2 persons and the window was either closed, open 30mm or open 60mm. The subjects were asked to change the window position when entering or leaving the room according to a set schedule. The subjects were university academic and research staff.

Table 1: Parameters measured and sensors used to monitor the indoor air quality.

Parameter	**Sensors/Devices**	**Range**	**Accuracy**
Air Temperature	Testo Comfort level Probe	0 - 50°C	±0.3°C
Air Movement	Testo Robust Hot Ball Velocity probe	0 – 5 m/s	±0.2 m/s
CO_2	Testo Ambient CO_2 Probe	0 – 10,000 ppm	±50 ppm
Mean Radiant Temperature	Tinytalk II	-50 to +300°C	±0.7°C

In addition the occupants of the room were asked to complete a questionnaire giving their feelings about the temperature in the room at half hourly intervals. They were also asked questions about their clothing and mean activity level as well as their sensation of the air quality. The analysis of subjective data is presented elsewhere [Raja et al, 2000].

VENTILATION AND AIR QUALITY

Effect of Window Open

Ventilation is increasingly a subject of concern. It bears a strong relation with health and influences energy loss. Also environmental pollution and global warming demands energy conservation and reduction in energy losses due to infiltration. Airtight structures are being strongly encouraged. Such building may lead to accumulation of CO_2 and other toxic pollutants to reach undesirable levels and become health hazards. In fact, ventilation in buildings should conform to the 'Build tight – ventilate right' philosophy. This will help to avoid uncontrolled air leakage by paying careful attention to the building 'envelope' - whilst providing controllable and adequate background ventilation in winter and 'rapid' ventilation to avoid overheating in summer and to reduce the concentration of toxic pollutants.

During the present study the CO_2 level was measured by varying occupancy from no one present to one and two persons present over a minimum period of 24 hours. The ventilation rates were varied by changing 'window open' from a closed position to level-1 (30mm opening) and level-2 (60mm opening). Using hourly values, the CO_2 concentration is plotted against input variable'window open' for none, one and two persons in the room, as shown in Figure 1.

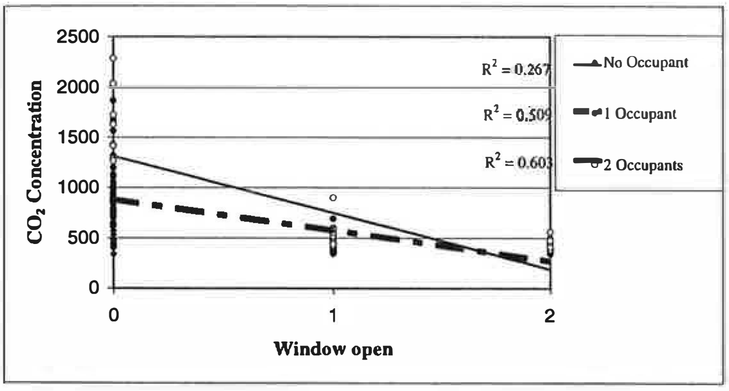

Figure 1: Dissipation of CO_2 by ventilation through 'window open'.

Effect of Occupancy

The occupants breathing raises the concentration of CO_2 and humidity in the indoor air above the level outdoors. For healthy indoor environment this needs to be replaced by fresh air at a rate equivalent to its production. This is usually achieved by ventilating the space and through air infiltration.

The effect of occupancy on indoor air quality is demonstrated in Figure 2. The figure is constructed with the data for one and two occupants for an occupancy period of two hours. Prior to occupancy the window was kept open for at least one hour while there was no body in the room. Then with occupancy, the window was closed for the first one hour and opened for the next one hour. The CO_2 concentration was recorded at 5 minutes interval. Five tests were carried out with one person and two tests with two persons in room. The values averaged over a quarter of an hour were plotted in Figure 2.

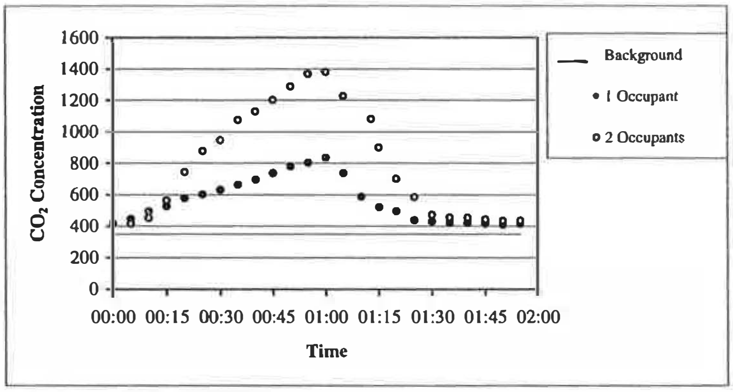

Figure 2: Effect of occupancy, accumulation and dissipation of CO_2

VENTILATION AND NIGHT COOLING

Night Ventilation Effect

Night ventilation significantly decreases the indoor air and structural temperatures. The decrease depends on the external temperature and ventilation rate. This reduces the need for additional cooling to some extent during daytime. It was originally not aimed to study the effect of night cooling on indoor thermal conditions. Therefore, the present experiment was not designed to measure certain parameters, like temperature of the structure, required for such studies. However, from the measured data, a profound effect of night cooling is noticed. Eight graphs of indoor and outdoor temperatures, one for each day, against time of the day are plotted in Figure 3.

DISCUSSION AND CONCLUSION

Figure 1 demonstrates that the dilution of indoor CO_2 concentration is strongly correlated with 'window open' i.e. the ventilation rate. The correlation coefficients are 0.51 for 1 occupant and 0.60 for 2 persons in the room. Carbon dioxide builds up during the first hour when the widow is closed, as shown in Figure 2. At the end of one hour the CO_2 concentration increases to about 1400 ppm when two persons are present in the room. It is almost double to that when there is one. By allowing fresh air through the window the indoor CO_2 concentration drops sharply during the first half an hour of 'open window' and reaches a lowest value close to the background CO_2 level. The background CO_2 was assumed to be constant at 350 ppm over the test period. The accumulation of the indoor CO_2 or pollution depends on the occupancy and ventilation rate.

The graphs in Figure 3, demonstrate the influence of outdoor temperature on indoor thermal conditions. For example, looking at the plot for 19th August 1999, the window was opened at 22:00 hours when the indoor temperature was 25°C, about 10°C higher than the corresponding outdoor temperature. The temperature drops sharply lowering the indoor temperature by 5°C during the first half an hour. The difference between indoor and outdoor temperature is narrowed to about 3°C during the night. The time 05:30 marks the start of the day, when both indoor and outdoor temperatures start rising.

Hancock studied the effect of passive night cooling of natural ventilated school buildings in Pakistan and reported a difference of 1°C between indoor and outdoor temperatures [Hancock 1999]. During the test, cross ventilation was allowed and the buildings were uninhabited at night. In the present study however, the door was kept closed restricting the ventilation through the window and occupancy was varied from none to 1 and 2 persons. This may be a possible reason that the difference between indoor and outdoor temperatures is slightly higher than that reported by Hancock. The high rate of night ventilation provides a useful level of cooling in most conventional buildings. To provide a degree of local control over the ventilation, night cooling ventilators are available which are closed automatically once a target temperature is reached. This prevents over-cooling or in extreme weather conditions, prevents rain ingress.

The results of an earlier study of thermal comfort of occupants in an office building [Raja et. al. 1998a] as shown in the Table 2, suggests that on average, the occupants close to a window are more comfortable than those further away. At 7-point scale, given in Table 3, occupants away from the window are reported warmer at 5.5 on the scale, about one level higher than those close to window (4.5 on the scale).

Table 2: Use of control by the occupants in building.

Subject code	Seating Position	Outdoor T (C)	Thermal Sensation	Door (%)	Window (%)
1.01	Away	21.0	4.75	00.0	46.0
1.02	Away	21.5	4.88	00.0	31.0
1.03	Near	20.7	4.46	00.0	79.8
1.04	Near	19.8	4.40	00.0	83.1
1.05	Near	19.9	4.19	100	74.1
1.06	Near	19.8	5.09	100	89.2
1.07	Away	20.2	6.74	99.3	96.3
1.09	Near	21.5	4.29	33.3	100
1.10	Away	19.9	4.94	12.5	56.3
1.12	Near	20.3	4.88	2.4	94.7
1.13	Near	19.9	3.73	96.8	69.9

Based on day time records (10:00am to 06:00pm) of the present study, Table 3 shows that with window closed the thermal sensation of occupants shifts toward warmer side of the scale (25% slightly warm and 5 % warm) as compared to 5% voting slightly warm when window was opened. In naturally ventilated buildings the comfort of occupants is related to the use of ventilation means. As indicated in Table 4, the occupants' discomfort decreases with the increase in the use of windows, i.e. frequency of opening windows, [Raja et. al. 1998b]. In building 2, the discomfort was reduced to only 11% with the highest use of window (81%). Low frequency of window use was compensated by the use of fan in building 14. The proportion of people recording discomfort is strongly correlated with the number of people using fans or windows and particularly when both are used together; it gives a correlation coefficient of 0.80 [Nicol & Raja 1998c]. This implies that the local controls are used in response to uncomfortable conditions.

Table 3: Percentage of votes for a comfort level.

Thermal Sensation	Window Open	Window Closed
1 - Cold	0	0
2 - Cool	12	5
3 - Slightly Cool	28	15
4 - Neutral	56	50
5 -Slightly Warm	5	25
6 - Warm	0	5
7 - Hot	0	0

Table 4:Frequency of the use of available controls and discomfort .

Building	Discomfort (%)	Doors	Windows	Fans
1	30	0.59	0.75	0.22
2	11	-	0.81	0.17
4	35	-	0.70	0.67
6	10	0.67	0.40	0.18
7	51	0.60	0.66	0.61
8	33	0.75	0.71	0.40
9	21	0.76	0.79	0.17
11	16	0.60	0.71	0.08
13	23	0.75	0.54	0.23
14	19	0.76	0.11	0.80

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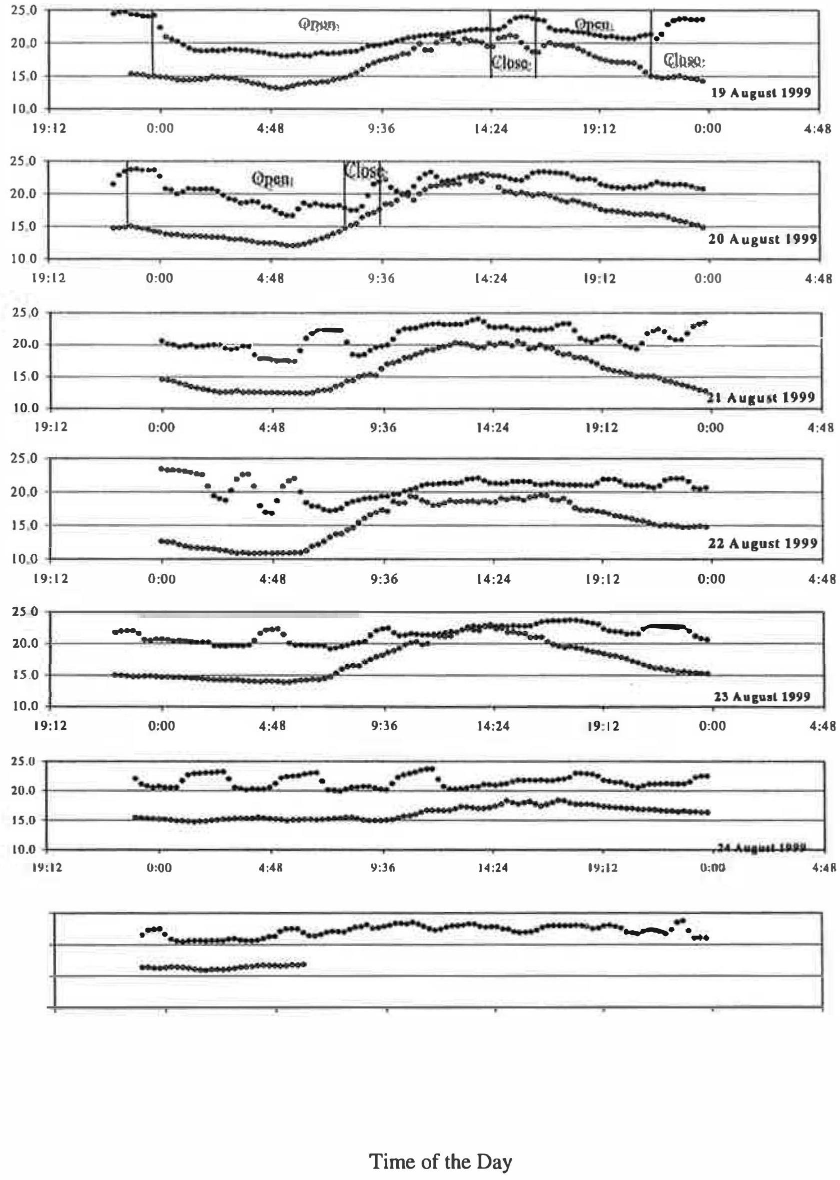

Figure 3: Effect of night cooling on indoor thermal conditions (outdoor temperature 'o', and indoor temperature '•')