Post-occupancy monitoring of windcatchers for summer ventilation in the UK

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ABSTRACT

A combined windcatcher and light pipe (SunCatcher) was installed in the building of the School of Construction Management and Engineering in the MSc Seminar Room (2N09). Monitoring of indoor environment in real weather conditions was conducted to evaluate the performance of windcatchers in the room and to conduct occupant survey. External weather conditions and internal indoor environment and air quality indicators were recorded. The tracer gas decay method using SF_6 was used to establish the air change rate for various conditions. The results indicated that, the ventilation rate achieved through the windcatcher depends on wind speed, wind direction and temperature difference between room and outdoor. The indoor air quality parameters improved due to the installation of the windcatcher. The measured air change rate was between 1.5 and 6.8 ac/h. Occupant's questionnaire showed 75% of the occupants were satisfied with the internal conditions and recommended the installation of the system in other buildings in the UK.

INDEX TERMS

Post-occupancy monitoring; Windcatchers; United Kingdom

INTRODUCTION

Designing for comfortable internal conditions in buildings is a necessary goal for occupants' good health, well being and high productivity. The application of passive design principles can help to achieve this goal with less energy consumption and at no extra cost to the building. Such passive design principles include the employment of windcatchers for natural ventilation of buildings. Predictive design tools are commonly used during the early design stage for sizing of the systems. Tools, such as thermal models and CFD, are based on steady state conditions and cannot accurately establish the performance of natural ventilation components in a building, particularly when the external and internal conditions are transient and occupants pattern and activities are changing (Croome *et al.*, 1992). Post-occupancy performance evaluation of indoor environment in buildings where windcatchers are installed will assist in validating the systems and test their applicability in buildings. The subjective assessment of occupants' satisfaction with the indoor air quality and their ability to control the operation of windcatcher, hence, controlling their environment, is an important criterion in validating the application of windcatchers. In the work presented here the performance of windcatchers was investigated in a real building under real UK weather conditions. In addition the occupants' perception of the indoor environment was evaluated using

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questionnaire. The investigation was carried out during the months of April, June, July, August and September of 2002.

BUILDING DESCRIPTION, MONITORING SET-UP AND PROCEDURE

A SunCatcher system, an integrated windcatcher and light pipe, was installed in the MSc Seminar Room (2N09) in the building housing the School of Construction Management and Engineering. The three-storey building was constructed in 1973 and has a split level. It is a rectangular form with two offices running along two corridors, north and south, with atria, services cores and offices in between. The Seminar Room was newly refurbished and located in the second floor of the north side of the building with a floor area of approximately 61 m^2 and a volume of 211 m^3. The room's external and internal walls are light cream paint blockwork with a pitch roof of 2.5°. The room floor is carpeted concrete slab and with a false ceiling giving a floor to ceiling height of approximately 3.5 m. Two windows located in the north wall of the Seminar Room and at adjacent bays each side of the concrete beam in the middle of the room. The windows of area 1.8 × 2.5 m are extend from 1 m above floor level to ceiling level with a size of m. The room IT area include five computers with intermittent occupancy. Figure 1 shows internal views for the seminar room with the windcatcher segments surrounding the internal light pipe diffuser. The (1 × 1 m) square section windcatcher is constructed from glass reinforced plastic with four segments, surrounding the 550 mm diameter light pipe, each with an area of 0.191 m^2 and a total duct area of 0.762 m^2. Each segment was fitted with manual damper for air flow control operated at ceiling level (Figures 1 and 2).

Figure 1 Position of the wind catcher in the MSc Seminar Room.

Indoor air quality parameters were monitored inside the room at two different points (Figure 2). At monitoring point 1, in the centre of the room, internal temperature, humidity and CO_2 concentration were measured using Automatikproducter (AP) and Onset HOBO H08-007-02 indoor air quality logging system. At monitoring point 2 (by the IT equipment area) internal temperature and humidity were measured using a complete Davis Vantage Pro weather station, which measure all external conditions including temperature, humidity, wind speed and direction, atmospheric pressure, rain and solar radiations. The weather station is located at the top of the building (2 m above building roof, 15 m above ground level and 75 m above sea level). Both the Automatikproducter (AP), the Onset HOBO and the weather station were connected to PC to facilitate data recording.

The assessment of air change rate was carried out by using tracer gas decay method. SF_6 was used with CBISS 12 points Intelligent Sampling System (MK2) connected to Brüel and Kjaer (INNOVA) single gas monitor type 3425. The two systems were connected to a PC and CDAS software was used to operate the gas monitor and the data logging. SF_6 gas was injected into the room while all openings including windcatcher were fully closed. Table fans were used for mixing the gas with room air and CDAS software was used to take tracer gas samples from the five sampling points (Figure 2) at pre-set interval of one minute. The sampling points were spread across the room. Three sampling points at 1.2 m above floor level were positioned by the window, in the centre of the room, and at the opposite side of the window. The other two sampling points were position directly under the windcatcher at heights of 1.2 and 1.8 m above floor level. The ventilation rate was then calculated using the following formula (Liddament, 1986): $C_{(t)} = C_{(0)}e^{-Q_t/V}$, where Q/V is the air change per unit time which is given by the logarithmic gradient of the tracer gas concentration curve. $C_{(t)}$ is the tracer gas concentration at time t, after start of the monitoring period (ppm), $C_{(0)}$ is the tracer gas concentration at the start of the period (ppm). The windcatcher was tested with dampers fully open and half open while the windows were closed. Tests were also carried out with windows open half the full size (1.8 × 0.212 m) and full size (1.8 × 0.423m) of the windcatcher duct area of 0.762 m^2 and also for windows open only (windcatcher dampers fully closed).

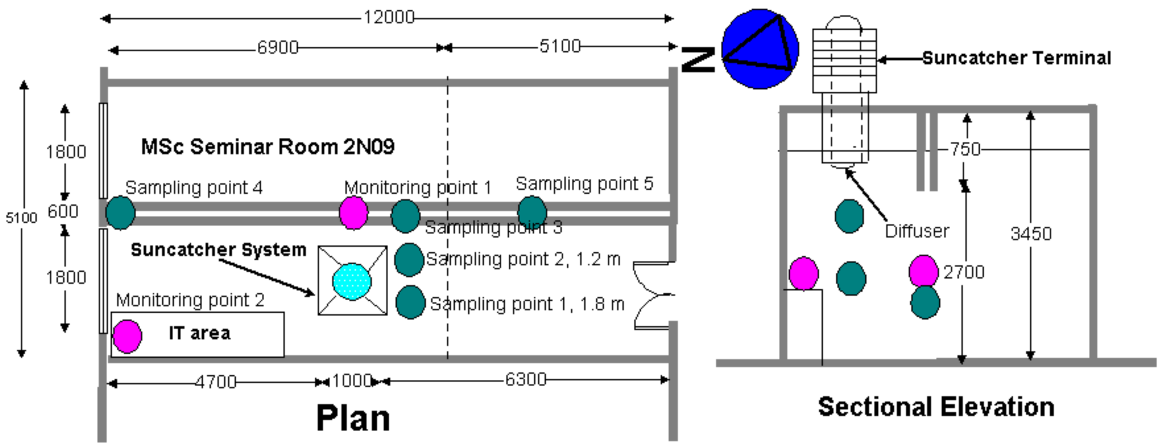

Figure 2 Position of the windcatcher and location of monitoring and sampling points for indoor air quality parameters and tracer gas analysis.

RESULTS AND DISCUSSION

The results of three cases in April, July and August are presented in this paper. Figure 3 shows the results for the test case 1 in April with the windcatcher dampers half open and the windows closed. The lowest external temperature recorded was 3 °C and consequently the internal temperature dropped to 12°C. This lower internal temperature indicates that a windcatcher might cause a problem of cold draught and heat losses particularly in cold periods. The internal relative humidity was lower than the external value apart from the last day of test with a minimum and maximum value of 38 and 70% recorded during the test period. In test case 2 in July the windcatcher dampers were fully open and the windows were open and then closed during the monitoring period. Slight variation in internal temperature was observed when the windows open by half duct area and closed. The temperature in the centre of the room was relatively constant throughout the test when the windows were closed reaching a maximum of 23°C. However, the temperature measured by the window (MP1) was higher (31°C) in one instance as the windows were closed. The CO_2 level in this test never exceeded 660 ppm.

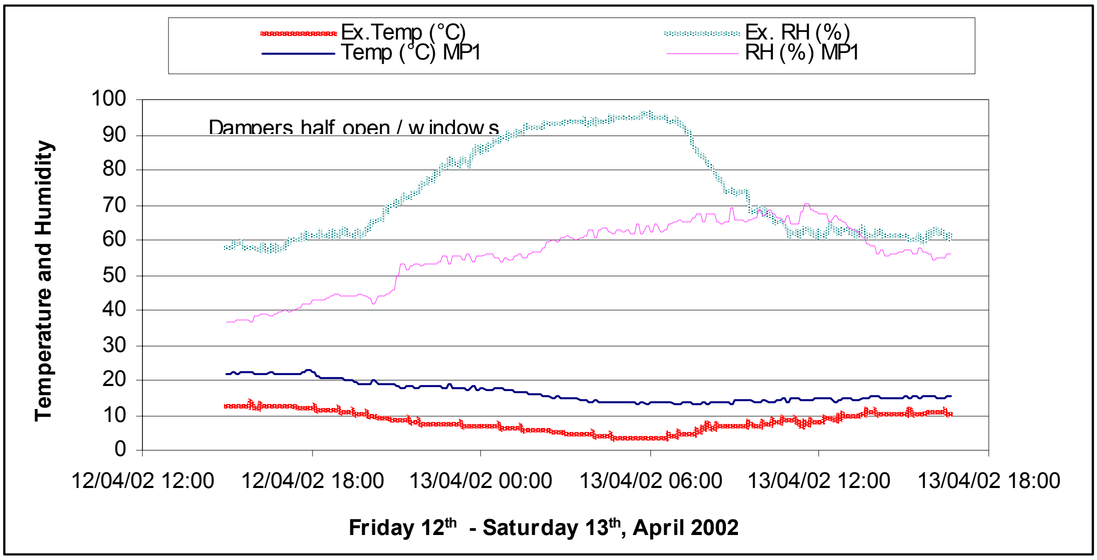

Figure 3 Monitored temperature and humidity for test case 1.

The measured ventilation rates using tracer gas analysis during the test period when the windows were closed were 1.4 ac/h in the afternoon, 2.3 ac/h in the night and increased to 3.5 ac/h in the early hours of the morning of the following day. Table 1 gives the ventilation rate in relation to other recorded averaged internal and external conditions. The indoor air quality parameters were within acceptable limits. Although the average wind speed in the afternoon was higher than in the night, the ventilation rate was lower. This could be due to the high temperature difference acting as the driving force for the ventilation rate and fluctuation in wind speed and direction with time. This temperature difference influence on the ventilation rate can be seen in the morning period. The temperature difference was 8 K, and the recorded wind speed was 1 m/s and still a higher ventilation rate of 3.5 ac/h was measured. As the windows were closed and the test was for only the windcatcher in operation, the results show that the windcatcher supply and extract air from space, ignoring the effect of the thermal mass of the building and air infiltration through the building fabric.

Table 1 Averaged measured indoor air quality, thermal and ventilation parameters, case 2 (windows closed)

Date and time	ventilation rate ac/h (average)	Temp diff	Wind speed m/s	Direction	Ex.Temp (°C)	Ex. RH (%)	Temp MP1 (°C)	RH MP1 (%)	CO_2, ppm	Solar Rad. (W/m^2)
Afternoon; 23/07/20021; 5:52–18:40	1.4	5.3	2.8	W	18.7	81.1	24.0	59.0	488.4	143.1
Night; 23/07/2002; 20:30–23:29	2.3	7.1	2.0	W	17.1	81.8	24.2	55.1	469.2	2.3
Morning; 24/07/2002; 00:08–03:08	3.5	8.0	1.0	NNE	16.2	82.1	24.2	53.0	411.6	0.0

The combined effect of windcatcher, and open windows fully open was investigated in case 3 test in August. The size of open windows area was half the size of the duct area of the windcatcher. Figure 4 shows the results for the test in case 3. While internal humidity and CO_2 levels were maintained at an acceptable level, the internal temperature is higher due to the high external temperature. The combined effect of window/windcatcher operation reduces the internal temperature by the window. The CO_2 concentrations inside the room did not exceed 500 ppm (Figure 4), which is below the ASHREA recommendations of CO_2 concentration not to exceed a level of 1500–2000 ppm in properly ventilated buildings or never exceeding 1000 ppm (ASHRAE, 1999)

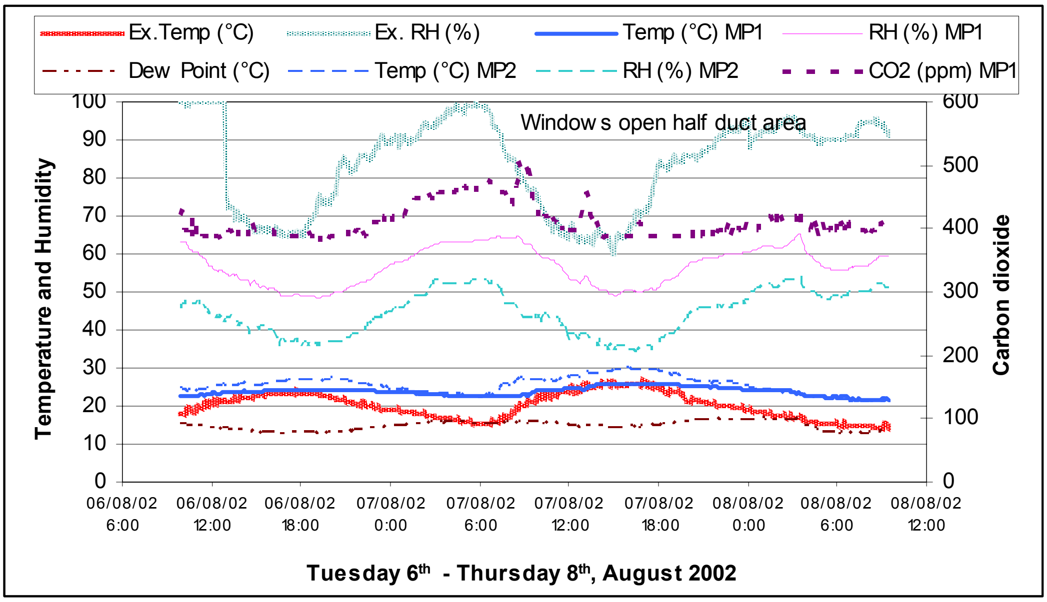

Figure 4 Measured indoor and air quality parameters in case 3.

OCCUPANTS SURVEY

The study of subjective assessment of the indoor environment was conducted using a questionnaire. The questionnaire is structured around four main areas; personal details, thermal environment, visual environment and overall environment in the Seminar Room. For the data entry, data manipulation and statistical analysis, the SPSS software for Windows was used. SPSS is a package developed originally for social scientists using large mainframe computers. Since then it has been refined and redeveloped for different types of computer architecture including Windows. The results showed the majority of the occupants were feeling neutral (41.7%), third of the occupants were feeling warm, and 16.7% of the occupants were feeling slightly warm.

The distribution of overall thermal comfort in conjunction with age is shown in Figure 5. It shows that the majority of occupants in the age range 20 – 40 were feeling neutral to slightly warm. With regard to the recommendations of the installation of the systems, windcatchers and light pipes, 75% of the surveyed occupants recommended the application of the systems for natural ventilation in buildings. The same percentage found the air movement inside the room to be acceptable. Interestingly, although 25% of the occupants found the air to be stagnant still they have recommended the installation of windcatchers. This could be due to the environmental awareness of the occupants and their desire to apply low energy architecture systems in buildings. Furthermore, through informal interviews many occupants of the Seminar Room expressed their satisfaction with the performance of the windcatcher and they changed their sitting area to be under and around the windcatcher.

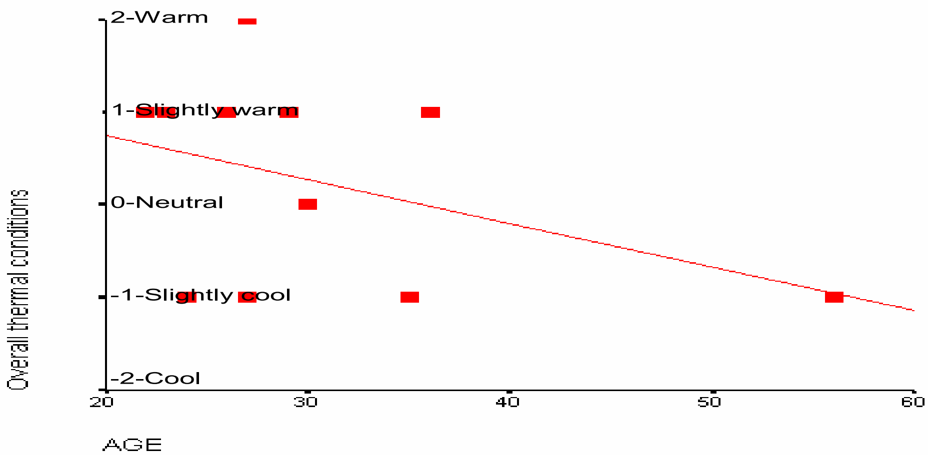

Figure 5 Distribution of overall thermal comfort with age of occupants.

CONCLUSIONS

Monitoring of indoor environment in real weather conditions was conducted to evaluate the application of windcatchers for natural ventilation in buildings together with occupant survey. The monitoring and occupants survey were conducted in the MSc Seminar Room in the building of the School of Construction Management and Engineering, the University of Reading. External weather conditions and internal indoor and air quality parameters were recorded. The tracer gas decay method using SF_6 was used to measure air change rate for various conditions. The results indicated that, the ventilation rate achieved through windcatchers depends on wind speed, wind direction and temperature difference, which is found to be with agreement with other published work using wind tunnel testing and CFD investigation. The indoor parameters were found to be within acceptable level due to the installation of windcatchers. Though the air change rate was in the range of 1.5–6.8 ac/h recorded in some cases.

These results were complemented with occupant's survey analysis where 75% of the occupants recommended the installation of windcatchers systems. However, to achieve acceptable ventilation rate in the summer the optimum windcatchers number and sizing should be determine with external weather conditions and occupancy pattern in mind. The application of windcatchers in buildings will contribute to natural ventilation, particularly during the hot summer month. Their operation, however, during winter should be limited to avoid problems of cold draught and heat losses. Having said that, the integration of windcatchers renewable energy sources, such as dichroic light pipe, heat convector and low volt photovoltaic fan, will make them more attractive. Their performance can be enhanced during summer and heat losses and cold draughts problems in winter could be eliminated.

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