EVALUATING A CONTROL STRATEGY FOR A HYBRID AIR-CONDITIONING AND WINDCATCHERS VENTILATION SYSTEM

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ABSTRACT

A control strategy for an integrated air-conditioning and windcatchers natural ventilation was investigated. 39 units of a rotating cowl windcatchers were installed in three street malls at the Bluewater Shopping Centre, Kent, UK. The windcatchers form part of an integrated air-conditioning system controlled automatically via air handling units. The Building Energy Management Systems (BEMS) provided a fully integrated control system sending malfunctioning alarms of faulty equipment and collecting data for external and internal conditions in the shopping malls. The data of external wind conditions, temperature, humidity and internal environment parameters (temperature, humidity and CO_2) were stored directly into computers.

The monitoring of the summer and winter month operations showed that the indoor air quality parameters were kept within the design target range. The fan came into operation whenever the CO_2 level was increasing above the threshold of 1000 ppm. The operation of the fan increased the ventilation rate and hence reduced the CO_2 concentration to the recommended level. The windcatchers' rotating cowls mechanism was effective in adjusting the windcatcher opening to face the head wind. While the windcatchers were operational, however, no data was recorded regarding their operation, opening time and position. Though the implemented control strategy was working effectively in monitoring the operation of mechanical ventilation systems, i.e. AHU, did not integrate the windcatchers with the mechanical ventilation system. Controlling the operation of the windcatchers via the AHU will lead to isolation of the windcatchers in the event of malfunctioning of the AHU. Windcatchers will contribute to the ventilation of space, particularly in the summer months. However, due to short-falls in the control strategy implemented in this project, it was found difficult to quantify and verify the contribution of the windcatchers to the internal conditions and, hence, energy savings.

1. 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 in buildings. Predictive design tools are commonly used during the early design stage for sizing of systems. These prediction tools, such as thermal models and CFD, are based on steady state conditions and cannot accurately establish the performance of natural ventilation components in building, particularly when the external and internal conditions are transient and occupants pattern and activities are changing (Croome, Gan *et al.* 1992).

It is critically important to gauge building occupants' feed back through post occupancy

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evaluation studies. Such studies are, rarely taken in the building industry in the UK for cost reason. Government's initiative such as the Building Regulations future performance certification of buildings, air pressurisation and thermo-graphic testing promote such studies to develop energy performance indicators for new and existing buildings (Bordass, Cohen *et al.* 1997, Bordass, Leaman *et al.* 2002).

The windcatcher system is a passive ventilation system which not only extracts air using passive stack principles but also utilises the concept of a wind tower to supply air to the spaces as well. Traditionally, windcatchers were employed in buildings in the Middle East for many centuries and they are known by different names in different parts of the region (Battle Mccarthy 1999). They were constructed, traditionally, from wood-reinforced masonry with openings at height above the building roof ranging from 2 m to 20 m. With taller towers capturing winds at higher speeds and with less dust (Bahadori 1994, Karakatsanis, Bahadori *et al.* 1986). Their application in the hot arid region of the Middle East is to provide for natural ventilation/passive cooling and hence thermal comfort. Windcatchers are traditionally used in places of high urban densities where surrounding buildings obstruct free stream air flow (Sharag-Eldin 1994). Traditional windctachers can be beautiful objects, feasible architectural feature additions to buildings and are inherently durable (Fathy 1986, Gage and Graham 2000).

In modern design of windcatchers, the two ventilation principles of wind tower and passive stack are combined in one design around a stack that is divided into two halves or four quadrants with the division running the full length of the stack (Harris and Webb 1996, Yaghoubi, Sabzevari *et al.* 1991). As the wind direction changes so do the functions of each of the halves or the quadrants in the windcatcher. This renders the windcatcher as being operational whichever way the wind is blowing. As there are no free parts to the windcatchers, their maintenance is very small. It has the benefit of taking supply air at roof level, which is often cleaner than air supplied at ground level, particularly where the building is adjacent to a road in urban areas (Elmualim and Awbi 2002a, b).

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 for natural ventilation. The subjective assessment of occupants' satisfaction with indoor air quality and their ability to control the operation of windcatcher, hence controlling their environment, is an important criteria in validating the application of windcatchers.

2. DESCRIPTION OF BUILDING AND VENTILATION STRATEGY

Bluewater Shopping Malls in Kent are newly constructed, out off town, shopping malls. The buildings incorporate windcatchers to ventilate the malls. The windcatchers cowl is inspired by the old form of a Kent oats houses as seen in Figure 1. These forms of oats houses were widely used in the area and became an architectural feature in modern buildings around Kent (Barnwell and Adams 1994, Pearson 1994). The building is an innovative application for windcatchers in the UK and provides the opportunity for validating the application of windcatchers in a temperate climate, such as the UK. The building is managed via an Integrated Building Management System. The windcatchers are automatically controlled in conjunction with mechanical ventilation system.

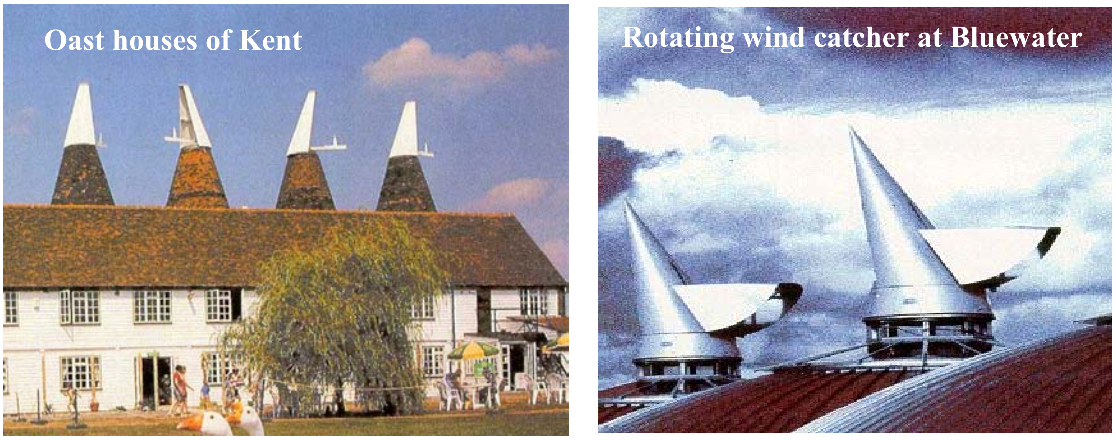
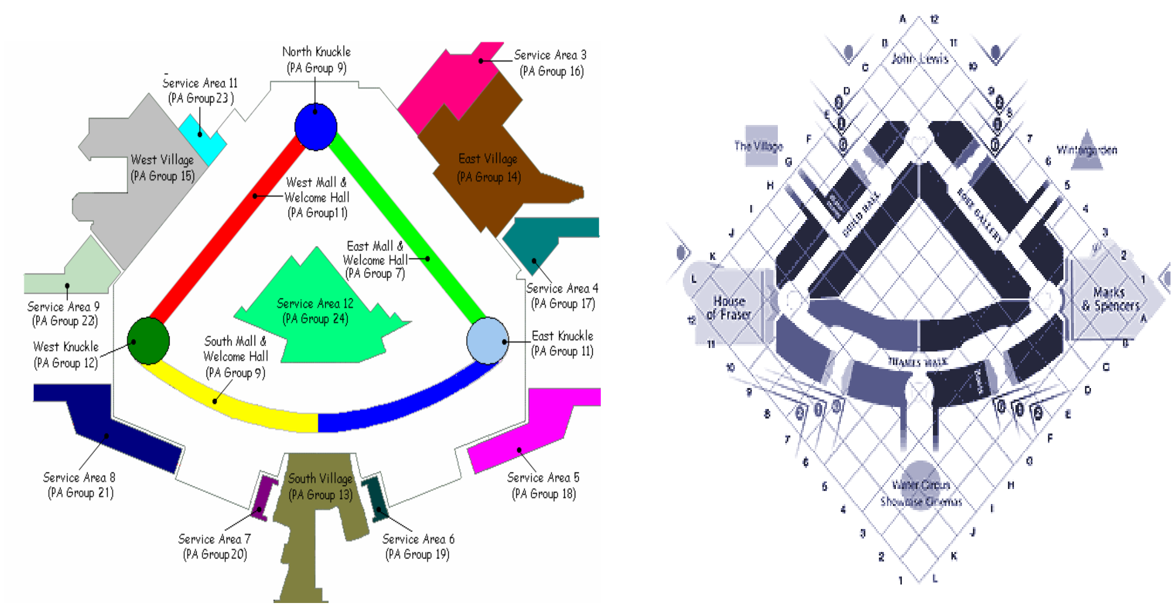


Figure 1: Traditional and modern rotating windcatcher at Bluewater shopping malls, Kent

2.1 The Building Description

The Bluewater building consists of three rectilinear form shopping malls with other reception halls and ancinary services (Figure 2). The three malls are forming a triangular shape with south, west and east facing malls and service courtyard in between. Shops were distributed around the three mall streets over two floors. The malls were ventilated using a mixed mode of natural ventilation applying windcatchers and air-conditioning system using the air handling units located on the roof of the buildings. There are 39 rotating windcatcher units distributed along the malls (13 units in each mall street). The performance investigation is carried out by taking the centre of each mall as a monitoring point. Indoor air quality parameters such as temperature, humidity and CO_2 level were controlled by the AHU units.



2.2 Windcatchers Specification

Figure 2: Plans of the shopping malls at Bluewater, Kent

The windcatcher systems consist of the conical cowl that shrouds the mechanics of the vent with a sail (rudder) that tracks wind direction ensuring air is taken into the mall and not extracted out. The cowl incorporates the access grille for the intake vent on one face and a pressure relief vent on the opposite face. Circular pneumatic actuator driven translucent dampers were situated at the base of the cowl with an inclination of 3° to allow water run off. The dampers are constructed from aluminium with transparent blades to allow natural light in the malls streets. The dampers were housed into a galvanized circular webbed ring which holds the cassettes for the rotating wheels. At the circumference of the cowl, there are six cassettes holding the bearing wheels to allow the rotation of the cowl situated at dampers level. Each one of the six cassette holds two wheels: One wheel for working rotation whilst the other is a stabilising wheel. The bearing ring that the wheels run on is fixed directly to the main secondary steel work of the building's roof structure. The windcatcher cowl is fitted with pneumatic brake located to the underside of the steel chassis. A partially glazed octagonal lantern steel is fitted to the primary steel work and supports the passive vent cowl assembly. Figure 3 shows an internal view of the windcatcher and external view of the windcatchers installed in the south mall street. The Figure shows that all of the windcatchers intakes were facing the same direction. This supports the proper working of the rotation mechanism of all cowls in relation to the prevailing wind.

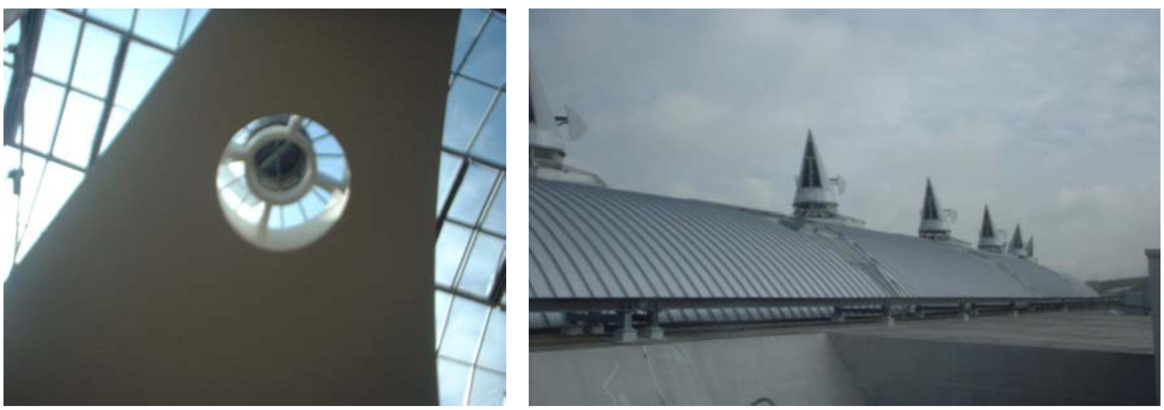


Figure 3: Internal and external views of south mall windcatcher cowls

2.3 Windcatchers' Control Strategy

Windcatchers operation inside the malls is activated by selecting the pre-set mood management control conditions over the Integrated Building Management System (See Table 1). Once selected at the IBMS, the control strategies necessary to operate the passive ventilation are activated via the stand alone outstation on the air handling unit. The weather station provides information about external wind speed and direction, occurrence of rain, snow or wet fog, external temperature and relative humidity to the IBMS via the AHU outstation. This information and data is then used by the IBMS to limit the conditions in which passive ventilation operates as follows:

- If it is raining, snowing or there is wet fog, the windcatchers will close and mechanical ventilation will be activated.

- If the average external dry bulb temperatures are outside of the range 14 -25 °C, passive vent will not be activated.
- If the average external wind speed is less than 1 m/s or greater than 7 m/s, the windcatchers will not operate and mechanical ventilation will be activated.

The windcatchers were regulated as follows:

- If the average wind speed is less than 1 m/s for two consecutive 20 minutes sampling periods , the passive ventilation is to be closed down and mechanical ventilation system enabled.
- If the average wind speed is between 1 and 3 m/s, all 39 wind catchers will be opened when the passive ventilation is activated.
- If the average wind speed is greater than 3 m/s and lower than 7 m/s, only 19 of the windcatchers are to be opened when the passive mode is activated, i.e. every other windcatcher along the mall roof.
- If the internal conditions arising which is outside of the desired set point range, an alarm is activated at the IBMS Console to warn management staff to take the appropriate action, e.g. turning off the passive ventilation if necessary.

There are two operations control for the windcatchers system; it works as supply in summer with outside temperature range of 16-29 °C and extract in winter and other mild weather conditions for external temperature in the range of -4 – 16 °C. The design ventilation rate is in the range of 1.5 – 2.5 ac/h.

2.4 Ventilation Strategy

The AHU were supplied with control functions, power supply and software engineering allowing the outgoing Data/Signals to the IBMS. This allowed the logging of data for all indoor air quality parameters and the weather station. The air handling plant functions as a constant air volume, variable air temperature system controlling both internal temperature and air quality. At the start of occupancy, providing the required internal temperature and air quality has been achieved, each air handling unit shall run at a preset minimum volume depending on which mode of operation (heating or cooling) is required. The space temperature sensors modulates in sequence the gas fired heater, mixing dampers and cooling coil to maintain an internal temperature of 18°C ± 2°C during a heating cycle and 23°C ± 2°C during a cooling cycle.

At full heating demand the supply fan is operated at full air volume, with the gas fired heater operating at 100% duty. The outstation programme determines the application of heating or cooling setting according to the combination of calendar date, outdoor air temperature, indoor air temperature and time of day. With increasing internal temperature the outdoor air dampers, fan volume and cooling coil can be sequenced to satisfy the demand. The fresh air dampers can be re-set to minimum when the indoor temperature value is below the outdoor temperature.

A space mounted humidity sensor was provided to limit internal humidity to 70% by overriding the control sequence effecting the cooling coil and mixing dampers. This in addition to frost protection sensor and a pressure differential sensor fitted across the supply fan to detect the fan operation. A variable time delay was incorporated to give sufficient time for the pressure to be obtained. In the event of an airflow failure an alarm is registered on the IBMS. The writing of mood settings is a menu driven operation in which the available variable parameters can be assigned by simple choices, e.g. on/off, low/high, select engineering set point value, etc. Should more complicated mood management sequences be required these shall be written at the AHU outstation. In the event of loss of communication between the IBMS and AHU outstation, the AHU shall continue to operate in the last mood selected unless management staff override the selection at the AHU outstation. The windcatchers operation was mainly controlled by the AHU and can't work separately. However, no signals from the AHU to IBMS were logged regarding the operation of the windcatchers.

Table 1: Mood settings of the ventilation system

Mood Setting	Description
Passive:	Mechanical plant off: Passive ventilation achieved via opening of roof smoke ventilators not via AHU and/or air flow to adjacent mall areas.
Calm:	Mechanical vent on minimum outdoor air for occupation levels according to CO_2 system. Fans at minimum speed necessary to maintain internal conditions.
Normal:	Mechanical vent normal operating mode under full auto control.
Fresh:	Mechanical vent on full outdoor air but otherwise under full auto control.
Breezy:	Mechanical vent in normal operating mode under full temperature auto control. Motorised nozzles enabled and sweeping full 60° arc every 10 minutes (variable time setting)

3. RESULTS AND DISCUSSIONS

The Integrated Building Management System provide the interface for operating all building equipment and their operations. The system is mainly used to check on the operation of the equipment. Alarms were sent to the IBMS console about any failure and malfunctioning of the equipment such as the air handling units and windcatchers. The IBMS log external weather conditions parameters, AHU status and operation data and internal air quality parameters at an interval of 15 minutes.

The IBMS system has been operational for more than three years. The recorded data is saved into MS Access software. The database is then interrogated via a program in MS Excel developed using MS Visual Basic programming tool. The Excel program provide the data required for any week in the year. The saved database for the year 2001 was interrogated and analysed to investigate the operation of the ventilation system and establish the performance of windcatchers at one central point in each malls street (south, west and east malls). Particularly, their contribution to the indoor air environment and energy savings achieved if any.

3.1 Monitoring During Summer Operation

For investigating the summer operation the database was interrogated for different weeks in the summer period. The results for one week in July and another week in August are presented here. Figure 4 and 5give the results for one week in July in the south and west streets malls, respectively. The indoor air quality monitors were kept within the design target providing acceptable indoor air environments for the shoppers. The CO_2 never exceeded 1000 ppm, which is an acceptable level according to ASHREA recommendations (ASHRAE 1999).

To investigate the co-ordinated operation of the windcatchers with the AHU, fan pressures were plotted across the external wind speed, external temperature and humidity. The results show that the fan pressure was at its highest, approximately 130 Pa, while the recorded external wind speed at its peak with a recorded maximum measurement of 4.4 m/s. It was well established by observation that all the windcatchers units were facing the prevailing wind direction. The fan pressure in the centre of the three streets malls was plotted against the external weather conditions as can be seen in Figure 6. Again, the results show that in all the malls the fans were at their highest operations at the same time the external wind speed was in the range of 1-3 m/s for the full windcatchers' operation, hence not reducing fan pressure by operation of the windcatchers. This was due to the lack of co-ordination between windcatchers and the AU which is not considered in the IBMS system.

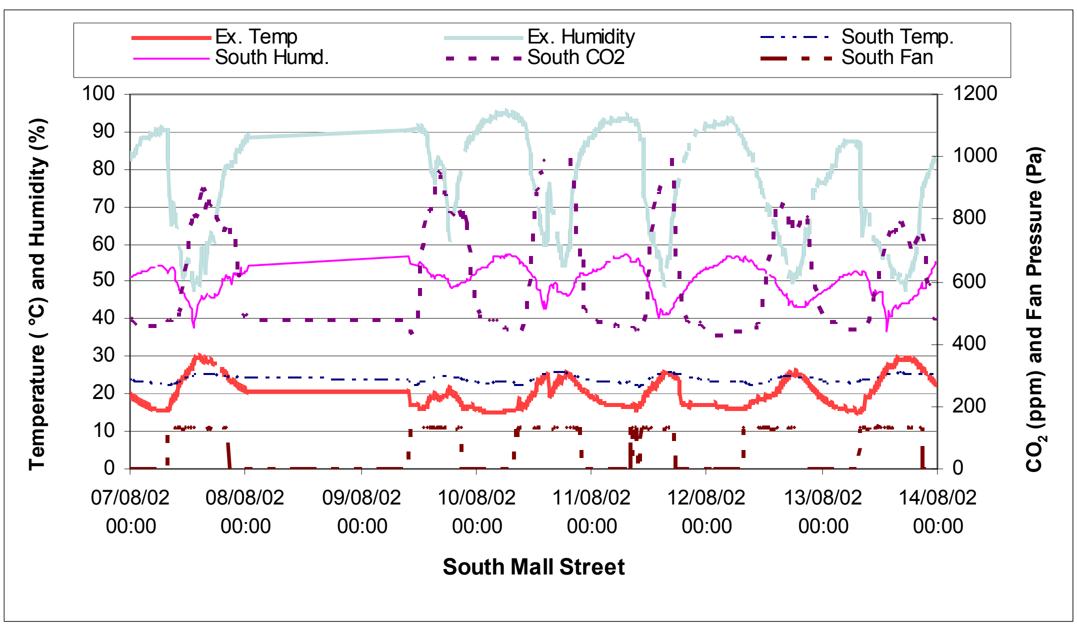


Figure 4: Measured indoor air quality parameters and fan pressure in the centre of the south mall street

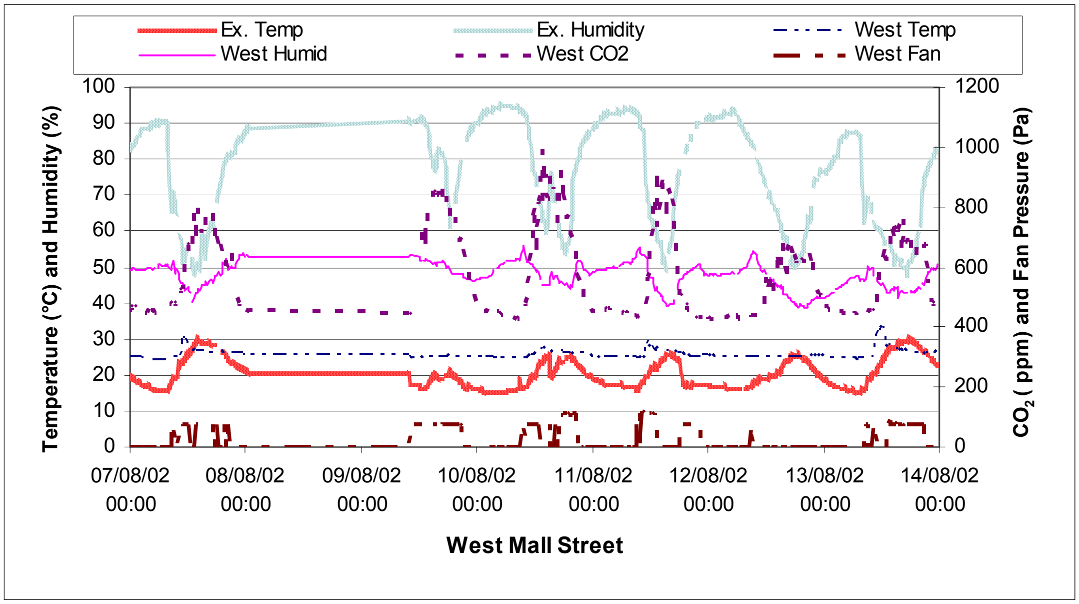


Figure 5: Measured indoor air quality indicators and fan pressure in the centre of the west mall street

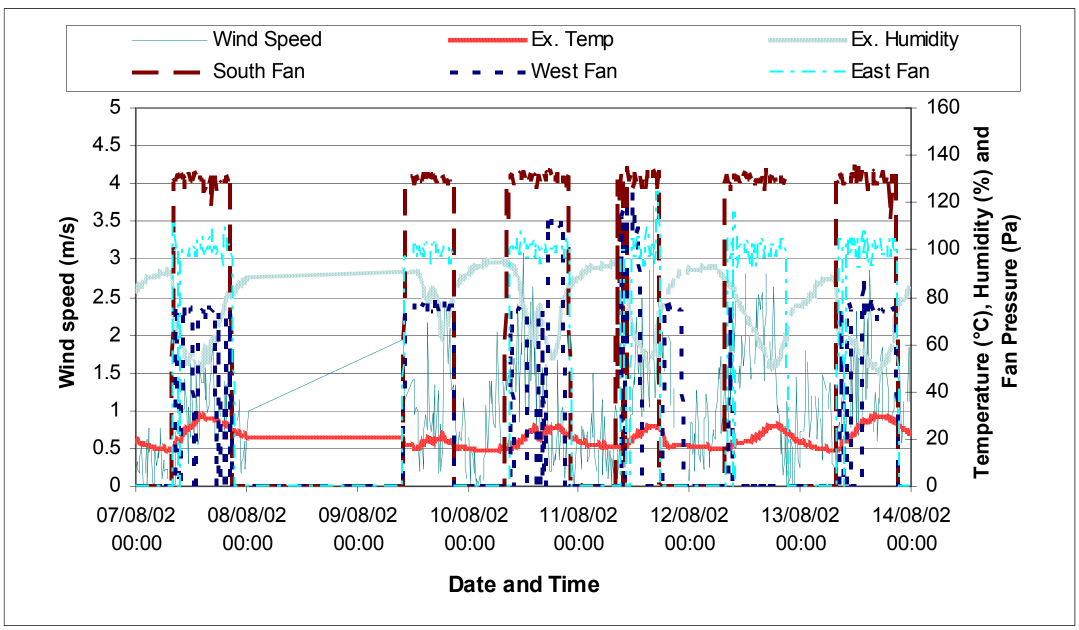


Figure 6: Plotted external wind speed against fan pressure and external temperature and humidity

3.2 Monitoring During Winter and Mild Weather Operation

For winter and mild weather months investigation, the results for one week in January and September are presented. Figure 7 gives the measured indoor air quality parameters and fan pressure recorded in the centre of the south street mall in January while Figure 8 gives the results for the west mall street in the month of September. During this month no data was available for the external wind speed. The results reflected the operation of the mechanical system in controlling the required internal air conditions for shopper's satisfaction. The operation of the windcatchers was limited to minimize heat losses and, hence, creating warmer comfortable internal environments.

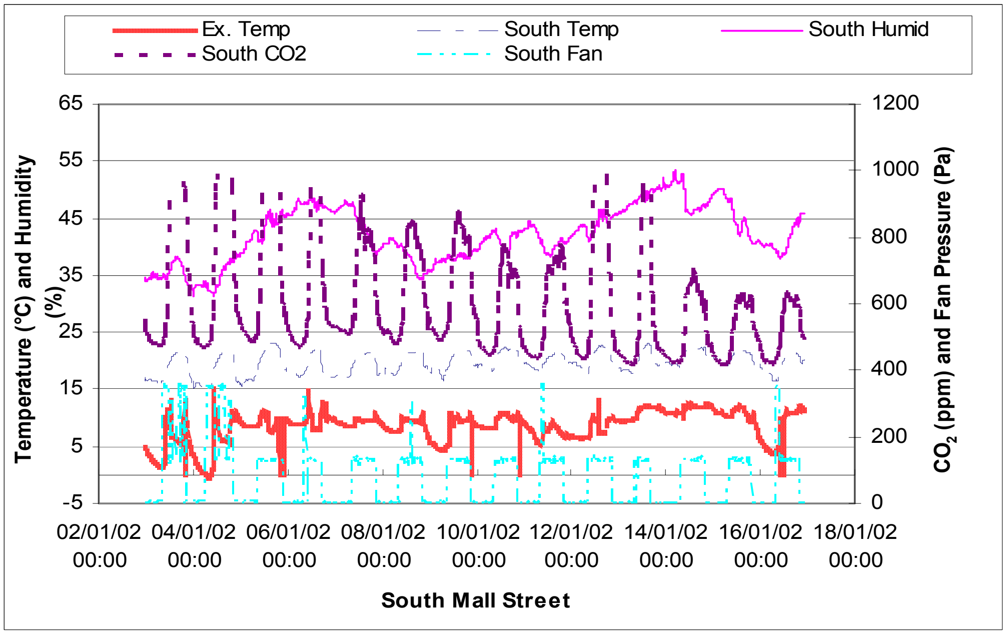


Figure 7: Measured indoor air quality parameters and fan pressure in south mall street (January 2002)

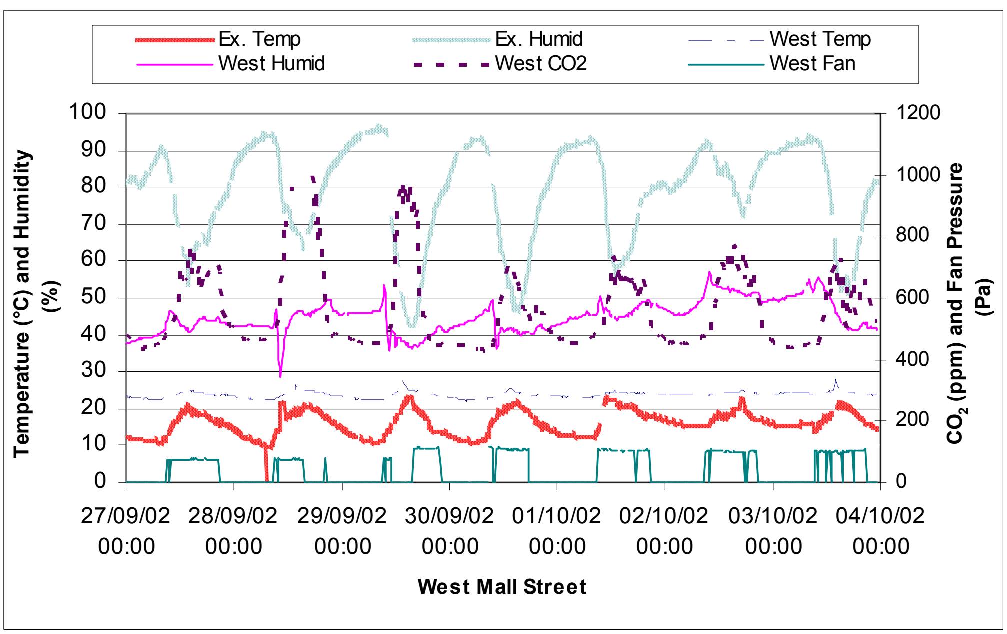


Figure 8: Measured indoor air quality parameters and fan pressure in the west mall street (September – October 2002)

4. CONCLUSIONS

Bluewater Shopping Malls provided an innovative application of windcatchers integrated with the mechanical ventilation system. 39 windcatcher units were installed in this building. The integrated system is controlled via the Integrated Building Management System (IBMS) which recorded all external and internal parameters into a computer database. The summer month operation showed that the indoor air quality parameters were kept within the design target range. It showed that the fans came into operation whenever the CO_2 level was reaching a set-point of 1000 ppm. The operation of the fan increased the ventilation rate and hence reduced the CO_2 concentration to the recommended value. Similarly, for winter and mild months operation the results showed that acceptable values of indoor air quality parameters was achieved. When the windcatchers were operational, however, no data was recorded regarding their operation, opening time and position.

Though the control strategy implemented was working effectively in monitoring the operation of mechanical ventilation systems, i.e. AHU, it did not cover the integration of the natural ventilation system, i.e. windcatchers, with the mechanical ventilation. Controlling the operation of the windcatchers via the AHU led to isolation of these systems in the event of malfunctioning of the AHU, hence the windcatchers will remain shut. It is evident from this investigation and other published work in the area that windcatchers will contribute to the ventilation of space, particularly in the summer months. However, due to the shortcoming of the control strategy implemented in this project, it was found difficult to quantify and verify the contribution of the windcatchers to the internal conditions and, hence, energy savings.

It is therefore recommended that a new control strategy be develop and tested and that the AHUs and windcatchers be controlled in a way that they complement each other. Windcatchers operation should be controlled according to the external weather conditions, wind speed and temperature. The control strategy should be so that whenever the windcatchers are in full operation and the internal air quality parameters are within the target level, the fans should be shut off. The fans should only be operated if the external weather conditions limit the full operation of the windcatchers. The fan should be operated to complement the windcatchers in a way that they only enhance the indoor air quality if it drops below the recommended levels.

5. ACKNOWLEDGEMENT

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6. REFERENCES

ASHRAE (1999) *ASHRAE STANDARD: Ventilation for Acceptable Indoor Air Quality.* ASHRAE 62-1999, Atlanta, Georgia, USA: The American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc.

Bahadori, M N (1994) Viability of Wind Towers in Achieving Summer Comfort in the Hot Arid Regions of the Middle-East. . *Renewable Energy*, **5**(5-8), 879-892.

Barnwell, P S and Adams, A T (1994) *The House Within: Interpreting Medieval Houses of Kent*. London: Royal Commission on the Historical Monuments of England, London: HMSO.

Battle McCarthy (1999) *Wind Towers: Detail in Building*. West Sussex, UK: Academy Edition, John Wiley & Sons.

Bordass, B, Cohen, R and Standeven, M (1997) PROBE 9: Benchmarks for Better Buildings. *Building Services Journal*, 37-41.

Bordass, B, Leaman, A and Cohen, R (2002) Forum Walking the Tightrope: the Probe team's response to BRI commentaries. *Building Research and Information*, **30**(1), 62-72.

Croome, D J, Gan, G and Awbi, H B (1992) Evaluation of Thermal Comfort and Indoor Air Quality in Offices. *Building Research and Information*, **20**(4), 211-225.

Elmualim, A A and Awbi, H B (2002a) Wind Tunnel and CFD Investigation of the Performance of Windcatcher Ventilation Systems. *International Journal of Ventilation*, **1**(1), 53-64.

Elmualim, A A and Awbi, H B (2002b) Full Scale Model Windcatcher Performance Evaluation Using A Wind Tunnel. *In:* Sayigh, A A M (Ed.), *World Renewable Energy Congress VII (WREC 2002)*, 29 June - 5 July, Cologne, Germany. Elsevier Science Ltd.

Fathy, H (1986) *Natural Energy and Vernacular Architecture: Principles and Examples with Reference to Hot Arid Climates*. Chicago, USA: The University of Chicago Press.

Gage, S A and Graham, J M R (2000) Static Split Duct Roof Ventilation. *Building Research and Information*, **28**(4), 234-244.

Harris, D J and Webb, R S (1996) Wind Towers - Old Technology to Solve a New Problem. *In*, *the 17th AIVC Conference. Optimum Ventilation and Air Flow Control in Buildings*, 17-20 September, Gothernburg, Sweden.613-621.

Karakatsanis, C, Bahadori, M N and Vickery, B J (1986) Evaluation of pressure coefficients and estimation of air flow rates in buildings employing wind towers. *Solar Energy*, **37**(5), 363-374.

Pearson, S (1994) *The Medieval Houses of Ken: An Historical Analysis*. London: Royal Commission on the Historical Monuments of England, London: HMSO.

Sharag-Eldin, A (1994) Wind direction sensitivity analysis of wind towers. *In*, *the 19th National Passive Solar Conference (Passive 94)*, 25-30 June, 273-277.

Yaghoubi, M A, Sabzevari, A and Golnesham, A A (1991) Wind Towers: Measurement and Performance. *Solar Energy*, **47**(2), 97-106.