

Cooling season post-occupancy evaluation of a low energy complex school (City Academy) in the UK

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ABSTRACT

Post Occupancy Evaluation (POE) of buildings has begun to receive more attention from the UK construction industry. In many cases, POE results indicate that even advanced designed buildings are high energy consumers and caused high levels of discomfort amongst occupants. In the UK, there is a move for routine use of POE in the construction industry.

This paper discusses the in-use performance of an Advanced Naturally Ventilated secondary school building in the UK. The building features open plan classrooms, night cooling and automatically controlled solar shading and ventilation openings.

The study includes (a) long term monitoring of the thermal environment in classrooms, (b) short term analysis of environmental conditions and (c) parametric analysis of environmental conditions using advanced thermal modelling.

Monitored data indicate that the summertime overheating criteria was achieved using the night cooling strategy and that the open plan classrooms achieved very good Indoor Air Quality (IAQ). It was also found that the penalty for improved IAQ was worse acoustic performance in the open classrooms.

It was found that the internal environment on the second floor could be improved significantly by controlling sky-light openings using information about wind direction.

The information from the study is being fed back to the design team and findings incorporated in future projects.

1. INTRODUCTION – UK CONTEXT

Post Occupancy Evaluation (POE) of buildings has begun to receive more attention from the construction industry. In many cases, POE results indicate that even supposedly advanced buildings are high energy consumers and caused high levels of discomfort amongst occupants (Bordass 2001). In the UK, there is a move for routine use of POE in the construction industry following the recommendations of the Egan report (1999).

The Department for Education and Skills (DfES) have launched a scheme to modernise secondary school facilities and improve access to Information Communications Technology (ICT) (DfES, 2004), however recently published energy consumption data points to an increasing trend in electricity consumption (DfES, 2004a). Increasing electrical loads, coupled with stringent acoustic (DfES, 2002), overheating and ventilation (DfES, 2002a) requirements means that avoiding mechanical ventilation and cooling in schools is becoming increasingly difficult.

This paper discusses part of a POE of a new school based in the south-east of England with special focus on cooling requirements.

The Building

The new school building replaced an underperforming school in an area of social deprivation in the suburbs of London. The building has 11,000m² floor area, and its design capacity is 1300 students.

The trend for increased heat loads in schools, along with the stringent building performance standards set by the DfES, led the designers to specify night ventilation coupled with exposed thermal mass in the school. Kolokotroni (1999) found that night-cooling could reduce daily peak temperatures by 1-2°C in offices. CIBSE (1998) noted that the effectiveness of the technique was affected by air exchange rate, position and area of heavy building elements (the ceiling was deemed the most effective because of buoyancy effects of airflow), thermal capacity of exposed surfaces and patterns of internal gains.

The night ventilated classrooms were connected directly to a high level atrium space. This effectively meant that the classrooms were 'open plan'. This was to ensure that bullying and poor behaviour can be spotted from almost any point in the building (Figure 1 shows the view over the atrium).

In principle air should be drawn through the classroom openings on the east façade and extracted at high level via atrium openings. This strategy is utilised to enhance natural ventilation (CIBSE, 2001), and will therefore allow cross ventilation of the majority of classrooms.

The night-ventilation regime is fully automated and inputs to the control system come from internal air temperature sensors and an external weather station. Solar protection to these classrooms is provided by external vertical shading, which automatically reacts to track the position of the sun.

At the time of construction the building was designed to comply with DfES (2003), which lays down targets for overheating (less than 80 hours with air temperature greater than 28°C)



Figure 1: Image of Inner Atrium and Connected Classrooms.

and ventilation (must be able to achieve 8 litres per person per second). Since construction, acoustic guidelines have been reshaped for schools with the introduction of the DfES (2003a). These new acoustic guidelines will make an open plan approach to classrooms difficult to repeat in the future and if it were proposed again the designers would need to convince the DfES to make an exception.

This paper looks at the environmental conditions of this open plan arrangement, mainly concentrating on ventilation and thermal comfort, but also presenting and evaluating acoustic measurements.

2. METHODS

The thermal and acoustic environment of a typical first and second floor open classroom on the east side of the building will be assessed in this study. These spaces were assessed using long term logging via the Building Management System, short term monitoring and a parametric modelling study.

2.1 Long Term Monitoring

An Invensys Building Management System is used to monitor and control the night ventilation and use of other plant. A separate self contained control system was installed by Levlux as part of the solar shading package.

Hourly, averaged data is available from the BMS for the following:

- Internal temperature (thimble type sensor TT518/SAT 3, stated accuracy $\pm 0.2^\circ\text{C}$);
- Automatic window position (as a percentage of the full range);
- External temperature;
- Wind speed and direction.

Unfortunately some of the key ambient conditions data was lost due to a data collection error. Therefore weather data from the nearest Meteorological station was obtained.

2.2 Short Term Monitoring

The first floor open classroom was studied in detail for a full school day on the 1st of July 2004, it was intended to study the conditions of a typical closed classroom (single sided ventilation) at the same time as a comparator of conditions, however the data was lost due to interfer-

ence from the room occupants.

The following measurements and observations were made:

- CO₂ measurements (TSI 8551, ±3%)
- Air temperature (TSI 8551, ±0.6°C)
- Relative humidity (TSI 8551, ±3%)
- Observations of manual window positions
- Observations of occupancy

Spot measurements of CO₂, temperature and humidity were also taken in the atrium space.

Coley (2001) discussed the use of CO₂ as a tracer gas to determine the ventilation rate in classrooms. This was done by estimating the CO₂ production from the occupants and determining the decay over logical intervals using equation 1. In this case the classroom air would not necessarily be replaced by external air, as air from the atrium space will enter the room as well.

$$C_t = C_{ex} + \frac{G}{Q} + \left(C_{in} - C_{ex} - \frac{G}{Q} \right) e^{-\frac{Q}{V}t} \quad (1)$$

However the CO₂ levels will give an indication of the dilution of bio-effluents, which have been related to perception of Indoor Air Quality (IAQ) (Wargocki, 2002) and Sick Building Syndrome (SBS), (Seppanen, 1999). This analysis will be presented.

Acoustic tests were carried out to determine the noise from the occupied atrium, these were carried out using a Bruel and Kjaer sound level meter. Sound levels were measured in open and closed classrooms, both when occupied and unoccupied. Measurements were also taken in the atrium areas. It was ensured that the measurements of unoccupied were carried during what could be considered 'normal' lesson time, i.e. not during assemblies or break times.

2.3 Modelling Study

A parametric assessment of the benefits of using 'open' classrooms, natural ventilation, night-cooling and exposed thermal mass was carried out using a thermal dynamic zonal model (developed using IES Virtual Environment 5.0). The model is based on first principle modelling of heat transfer occurring within and around the building.

Only the classrooms adjacent to the east atrium space and the surrounding open and

closed classrooms on the East façade of the building were modelled to reduce processing time. The central finger (containing science laboratories) acts as a barrier to air flowing through to the technology Atrium on the west side of the building.

Realistic occupancy patterns were assigned to each of the rooms (based on observations and timetabled information). BMS data was obtained from the classrooms in the central finger, it was found that as these rooms were mechanically ventilated science rooms, air temperature was controlled to between 21-23.5°C for the majority of the occupied year, and therefore the temperature was set for these rooms in the simulation during occupied hours.

Automatic window openings were simulated using the actual control schedule, as was the shading. Construction parameters were based on those specified in design reports and drawings.

Initially parametric analysis was carried out for key parameters to determine the effect of small changes in the model, and the effect of uncertainty. This was carried out manually for a single day, results were compared to a base scheme.

The model was then compared to the short-term data to account for ventilation and temperature within the single room. Small changes in the parameters with the most uncertainty attached were altered, and the sum of the squares for the data set were compared. The model was deemed to be calibrated when each data-point was within the measurement accuracy of the data logger.

The model was then subjected to parametric analysis to determine the relative comfort in each room by investigating:

- Heavyweight Vs lightweight ceiling.
- Night-time cooling Vs no night-time cooling.
- Open Vs Closed arrangement.

3. RESULTS

The results are presented in this section for the long-term measurements, short-term measurements and modelling study.

3.1 Long Term Measurements

Initially the temperatures were compared to the DfES targets for overheating (DfES, 2003), the

Table 1: Overheating analysis from BMS data, occupied hours over 28 and 25°C.

	Hours Greater than 28°C	Hours Greater than 25°C
Ground	23	296
1	19	226
2	31	330

criteria is to have fewer than 80 hours with an internal air temperature greater than 28°C.

Table 1 shows the results for the ground, first and second floor.

It can be seen that the first floor room has fewer hours at high temperatures than the

ground or second floor. Figure 3 shows the air temperatures for a hot period during June, note that the first floor seems more effective at inducing cool air at night-time.

Analysis of the automatic window openings demonstrate that the night time cooling regime is only in operation between 1am and 6am.

3.2 Short Term Measurements

The classroom occupancy profile and CO₂ concentration is shown in Figure 2. Equation 1 was used to assess the effective ventilation rate of the open plan room based on the steady state concentration for each lesson. The range of ven-

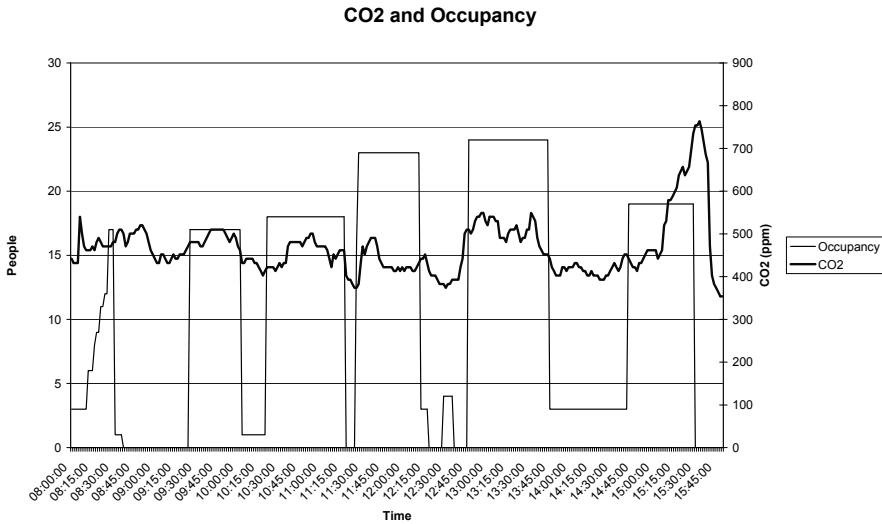


Figure 2: CO₂ and occupancy pattern for July 1st 2004 in first floor classroom.

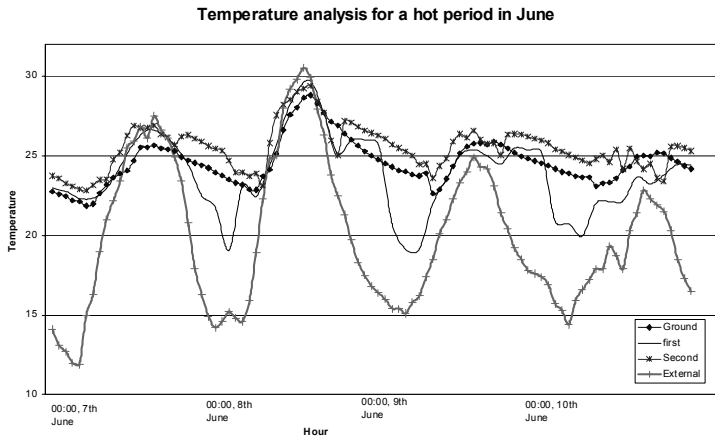


Figure 3: Patterns of air temperature for a hot period in June 2004.

Table 2: L equivalent values for various spaces.

Area	Leq dBA
Atrium (occupied)	64.09
Open Class (Unoccupied)	56.155
Closed Class (unoccupied)	42.235

tilation rates were from 15-22 litres/second/person.

The Leq values for each of the areas are shown in Table 2. The Leq is the equivalent level of sustained noise during a sample, this takes into account intermittent and continuous noise.

These results have the most impact on speech intelligibility and the signal to noise ratio, however cannot be compared directly to standards in DfES (2003a) because the building was designed pre-2003 and measurements were taken when adjacent classrooms were occupied.

3.3 Modelling Study

The modelling study consisted of carrying out sensitivity analysis, calibrating the model and carrying out parametric analysis of the calibrated model.

Parametric Analysis

Parametric analysis was first of all carried out to determine the success of different design features within the building, eight different scenarios were initially compared.

Only the first and second floor results were considered as the ground floor classroom is a closed classroom and therefore not connected to the atrium.

All models were first subjected to the actual summer experienced by the school, all schemes were assessed by the occupied number of hours greater than 25 (Fig. 4) and 28°C (Fig. 5) for each of the schemes.

The open classes on the first floor have improved performance when considering temperatures greater than 25°C, however a closed scheme with high mass and night cooling has comparable performance when considering temperatures above 28°C.

This is because the open scheme is more suited to removing heat using increased air movement, both from ambient air and from atrium air, however when external temperatures exceed 25°C the driving force for heat transfer is reduced and a high mass solution, coupled with

nigh ventilation are the most important factors.

The large discrepancy between first floor and second floor conditions suggested that the two main means of heat rejection, ventilation and night-cooling were impeded. It was deduced that significant amounts of airflow within the building was entering the atrium and first floor classes and leaving via the second floor openings. The extent of this was largely related to wind direction (Figure 6).

Further modelling showed that having a roof-light actuator control schedule based on wind direction led to significantly improved internal environment on the second floor and gave modest improvements on the first floor (denoted as WD in Figure 4 and Figure 5).

The heavyweight, open, night cooled scheme with wind direction control was assessed against the London design summer year data, one of the most onerous weather files for the UK. It was found that both the first and second floor classrooms would comply with DfES guidelines (40 and 63 hours greater than 28°C), whilst a closed, light classroom with no night ventilation would require mechanical cooling to be acceptable as simulation indicates that over 200 hours will have temperatures greater than 28°C.

4. DISCUSSION

Current acoustic, overheating and ventilation requirements mean that controlling the cooling season class temperatures is difficult. Factors such as rising trends in ICT and climate change means that mechanical ventilation and cooling are becoming more prominent.

The overheating target has been met at this school building without the use of mechanical cooling. This is partly due to a well engineered atrium space, night cooling and ventilation strategy, however must also be attributed in part to the moderate summer conditions of 2004 in this part of London. Further analysis has shown that the open classroom design will meet the DfES overheating criteria even when using the most onerous weather data file, whilst a lightweight scheme would require mechanical cooling, adding to capital and whole life costs.

Analysis of the second floor classroom data (both real and modelled) showed that the open arrangement had higher temperatures than the first floor scheme. Modelling showed that there

was a net flow of air into the second floor classroom from the atrium and out of the windows for the actual control scheme.

When the roof-light openings were controlled using wind direction it was found that the second floor environment could be improved significantly.

The CO₂ levels measured on the first floor and simulated for the second floor are reduced when compared to the closed schemes. This is a good indication of the dilution of bio-effluents, which have been linked to health by Seppanen (1999).

Acoustic measurements were not favourable for the open areas, it is likely that the open rooms would have a lower Speech Transmission Index (STI) than permitted by the DfES, this is because of background noise levels greater than 56 dBA_{Leq}, which would reduce the signal strength from a teachers voice. Discussions with teachers suggested that noise was not a large issue, however it will be more significant for children with hearing difficulties.

The results from the entire study of the school has been fed back to designers to allow them to understand current issues and trends in

Comparison of Schemes - Temp greater than 25 degrees

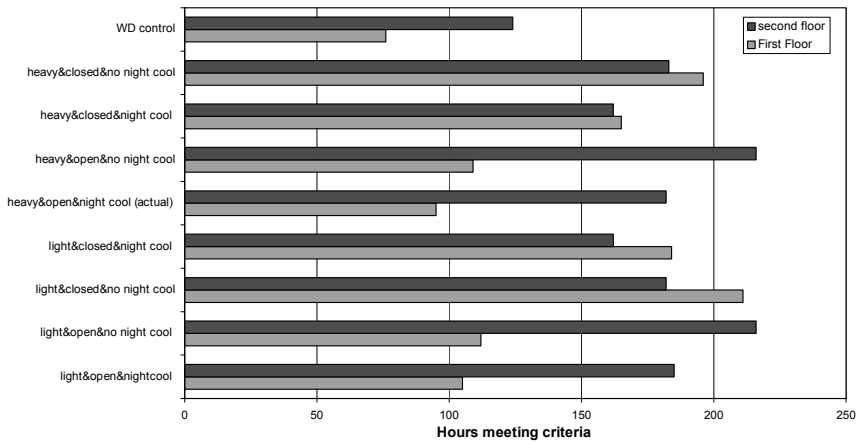


Figure 4: Comparison of occupied hours with temperature greater than 25°C for all schemes.

Hours Greater than 28 degrees

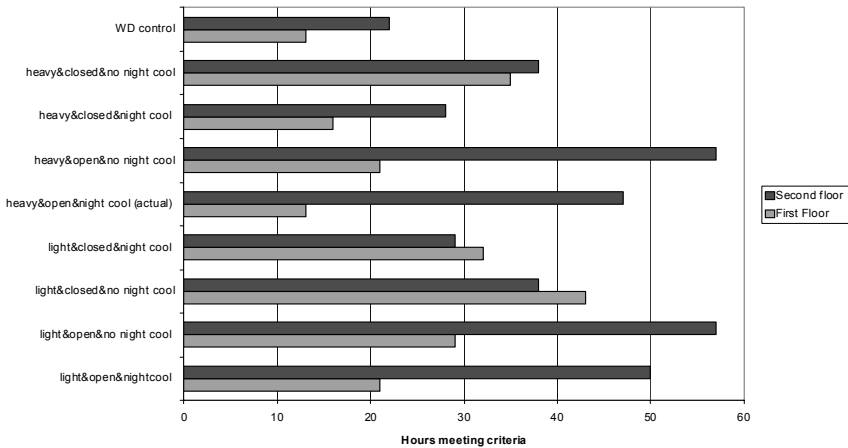


Figure 5: Comparison of occupied hours with temperature greater than 28°C for all schemes.

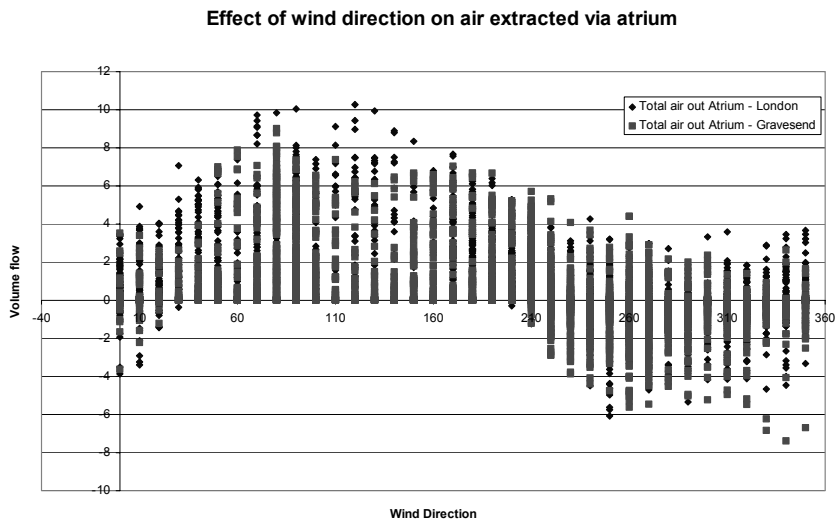


Figure 6: Flowrate (m^3/s) out of the rooflights vs. wind direction (degrees east of north).

schools and assess their design assumptions. It is intended that the results of this POE can aid the design of subsequent schools.

5. CONCLUSIONS

It was found that the studied classrooms provided a good thermal environment and decent dilution of bioeffluents. Parametric modelling showed that the scheme had less instances of overheating than alternative strategies, however the second floor environment was improved significantly by considering wind direction in the control strategy.

REFERENCES

Bordass, B., Cohen, R., Standeven, & Leaman, A, 2001, Assessing building performance in use 3: energy performance of the Probe buildings. *Building Research & Information*, Vol 29 No 2

CIBSE, 1998, Thermal Storage: environmental benefits, Research Report RR6, The Chartered Institute of Building Services Engineers.

CIBSE, 1999, Ventilation and Air Conditioning, CIBSE guide B2, The Chartered Institute of Building Services Engineers

Coley, D & Beisteiner, A, Carbon Dioxide Levels and Ventilation Rates in Schools, *International journal of ventilation* (1) 1, pp 45-52

Construction Task Force, 1998, Rethinking Construction. DETR, London ('The Egan Report')

DfES, 2003, Building Bulletin 87 – guidelines for envi-

ronmental design in schools. Department for Education and Skills, The Stationary Office

DfES, 2003a, Building Bulletin 93 – Acoustic Design of Schools. Department for Education and Skills, The Stationary Office

DfES, 2004, Energy and Water Benchmarks for Maintained Schools in England: 2002-03, Department for Education and Skills (<http://www.dfes.gov.uk/rsgateway/DB/SBU/b000477/index.shtml>)

DfES, 2004a, Schools Capital – Investment for All, Department for Education and Skills. DfES publications.

Kolokotroni, M, 1998, Night ventilation for cooling office buildings, *Building Research and Information*, Construction Research Ltd.

Leaman, A & Bordass, B., 2001, Assessing building performance in use 4: the Probe occupant surveys and their implications. *Building Research & Information*, Vol 29 No 2

Seppanen O, Fisk W & Mendell J. 1999, Association of ventilation rates and CO₂ concentrations with health and other responses in commercial and institutional buildings. *Indoor Air*, Vol. 9, Issues 4 pp226.

Wargocki P, Bako-Biro Z, Clausen G & Fanger O, 2002, Air Quality in a simulated office environment as a result of reducing pollution sources and increasing ventilation. *Energy and Buildings*, Vol. 34, n. 8, pp775-783.