Proceedings of 2nd Conference: *People and Buildings* held at Graduate Centre, London Metropolitan University, London, UK, 18th September 2012
Network for Comfort and Energy Use in Buildings: http://www.nceub.org.uk

Minimising excessive winter energy consumption in Victorian classrooms while maintaining acceptable indoor air quality

Sven Hallin[1]

1 M.Res Energy Demand Reduction, Dept. of Civil and Building Engineering, Loughborough University, s.hallin-11@student.lboro.ac.uk

Abstract

This paper presents an assessment of how to minimise excessive winter energy consumption in a case study Victorian classroom while maintaining acceptable indoor air quality. Classroom winter temperature and carbon dioxide measurements were evaluated. The resultant information was then used to develop a dynamic thermal simulation computer model. Eight different interventions were modelled reflecting improved energy supply and a variety of ventilation strategies. The results showed that these interventions, which included automatic window opening, low level air vents, double glazed windows and construction of a plenum and rooflight, met the regulatory ventilation requirements of Building Bulletin 101 while also lowering energy use. The most cost effective intervention reduced energy costs by 37%. Key research findings were that adequate control and design of energy supply systems is critical to minimising excessive energy consumption, and adequate internal air quality is achievable through a variety of low cost natural ventilation strategies.

Keywords: Energy Design, Energy Control, Indoor Air Quality, Victorian Classroom

1. Introduction

Indoor air quality in schools has long been an area of concern by both government and private individuals. This is because poor air quality can have impacts on health, productivity and comfort (Fisk, 2002). A study by Dasgupta et al (2012) shows newly built schools are failing to meet basic performance criteria in relation to efficient energy consumption and good environmental air quality. The cause is largely due to lack of adequate design. It asserts that the engineering science of designing learning environments is remarkably undeveloped. While the research does not suggest any new design principles, it indicates behavioural aspects are responsible for significant energy use in schools. Technological design solutions will only be successful when occupants of a building are committed and informed on how to use energy-efficient systems in an appropriate way (UNEP, 2007).

A number of studies including Mumovic, et al. (2009) and Santamouris, et al. (2008) show that around 36% of all daily average values of carbon dioxide in monitored classrooms exceed the government's recommended guidelines of 1500 ppm, as set out in Building Bulletin 101 (DCLG, 2006). Daisey et al (2003) report that inadequate ventilation can possibly lead to negative health effects while Fisk (2002) determined that excess carbon dioxide can lead to an increase in occupants experiencing Sick Building Syndrome .

Coley's research on ventilation rates and cognitive performance in UK schools (Coley and Greeves, 2004) concludes that the performance of children is significantly slower (by an average of 5%) when the level of CO_2 in classrooms is over 1500 ppm.

The relationship between thermal comfort and indoor air quality was examined as part of a study of a naturally ventilated classroom by Griffiths & Eftekhari (2008). In this research the room had adequate ventilation available to meet building regulations but it could not always be used without affecting thermal comfort. Pupils and staff were found to control the ventilation to satisfy thermal comfort rather than ensure adequate internal air quality.

Given these findings**,** as schools have four times higher occupancy levels per unit area than office buildings, (Seppanen et al,1999), they represent an important area of research into optimum levels of indoor air quality (IAQ), temperature and energy use.

2. Research Methodology

This research used IES modelling software (IES, 2011) to create a "base case" of the Victorian classroom under study, reproducing a reasonable approximation of existing energy consumption, temperatures and CO_2 levels. As energy use in buildings depends on the interaction between the occupants, the building fabric, the way energy is delivered and the local climate (Lomas, 2010), metrics for occupancy patterns, building fabric, energy delivery and the local climate were incorporated in the IES models.

2.1 Temperature and CO_2 Measurement

Classroom temperature and CO_2 data were recorded using the following:

1. A Hobo Pendant Temperature Data Logger (UA-001-08) was placed under the classroom whiteboard in the Victorian classroom, recording temperatures every 5 minutes.
2. Two Telaire 7001 Carbon Dioxide and Temperature Monitors were placed at opposite sides of the classroom. These recorded CO_2 and temperature levels every 5 minutes. The data was downloaded at regular intervals onto Hoboware software and exported in CSV format onto an Excel spreadsheet.
3. A Hobo Pendant Temperature Data Logger (UA-001-08) was placed outside the school building, behind a wall near the school entrance and the data recorded.

3. The IES "Base Case" Model

3.1 Classroom Temperature Levels

The Victorian classroom temperatures were measured from the 13th January throughout the following months until the end of May. The intended set point temperature of 19°C was clearly not being satisfied. To verify this, a winter average occupied temperature of 22.3 °C was calculated from the 20th February to 30th March (see chart 1).

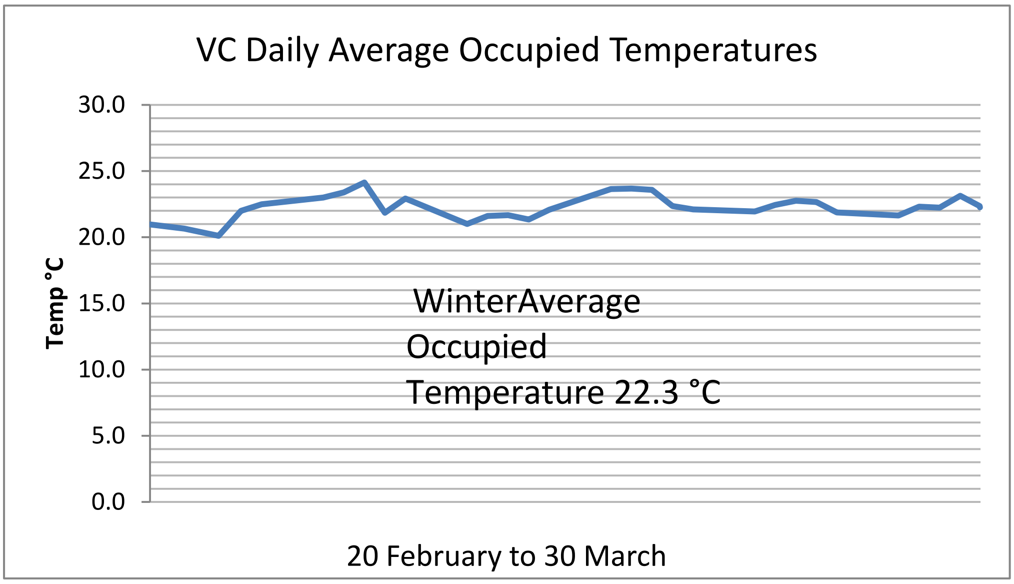

Chart 1 Victorian Classroom Winter Average Temperature

As classrooms in the school were on average too warm which affected the thermal comfort of the occupants, the heating pumps were sometimes turned off at night affecting the automatic heating controls. In addition, the complexity of the "intelligent" heating system was not fully understood by staff at the school, and lack of visible thermostats reduced occupant control.

3.2 Classroom CO2 Levels

The Victorian classroom CO2 levels were also measured from the 13th January until the end of May. A minimum average CO_2 level was calculated to show that it exceeded the recommended average of 1500 ppm (see chart 2).

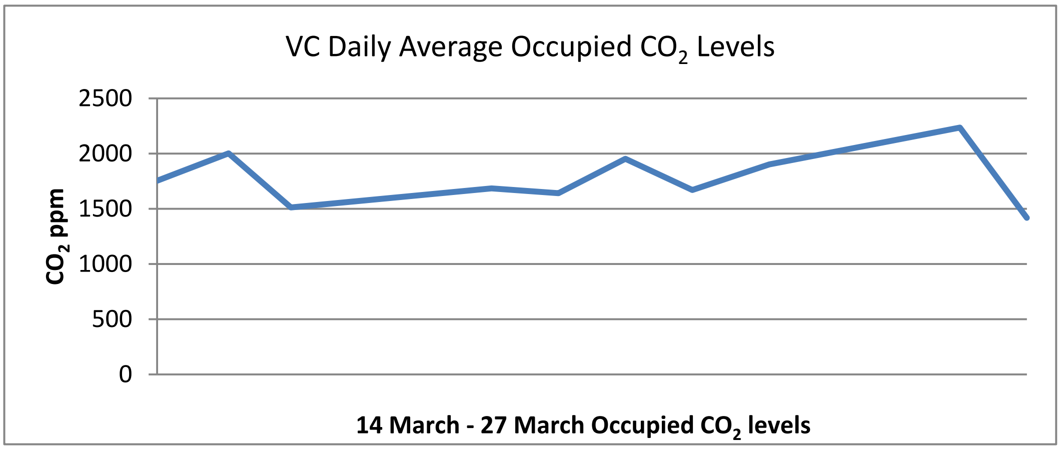

Chart 2 Average Occupied Carbon Dioxide Levels

4. Modelling Results and Interventions

All the interventions in table 6 assume the heating system is corrected to reliably supply space heating to the classroom at 19 °C during occupied hours, and the window/ventilation opening profile is changed to work automatically according to a set profile. This profile varies with each intervention to reflect various ventilation

Table 1 Summary of Interventions

	Space Heating (Gas) kWh/m^2/Year	Electricity kWh/m^2/Year	Total Energy kWh/m^2/Year	Air Quality (CO_2)	Comment
Display Energy Certificate (DEC)	248	58	306	N/A	
Base Case IES Apache Simulation	279	36	315	>1500 ppm	Insufficient internal air quality (IAQ)
IES Intervention 1 automatic single glazed existing windows	195	36	231	1441 ppm	Meets BB101 requirements Energy saving is 27%
IES Intervention 2 automatic top double glazed windows	165	36	201	1437 ppm	Slightly better IAQ than 1 Energy saving is 36%
IES Intervention 3 automatic bottom double glazed windows	164	36	200	1445 ppm	Slightly worse IAQ than 1 & 2 Energy saving is 36%
IES Intervention 4 automatic top double glazed windows with low level air vents	183	36	219	1307 ppm	Better IAQ than 1,2,3, 5, & 7 Energy saving is 30%
IES Intervention 5 automatic mixed double glazed windows	162	36	198	1446 ppm	Similar IAQ to 1 & 2 Energy saving is 37%
IES Intervention 6 automatic double glazed parallel opening windows	212	36	248	1024 ppm	Excellent air quality Energy saving is 21%
IES Intervention 7 automatic top double glazed windows and a plenum	263	36	299	1328 ppm	Good air quality Energy saving is 5%
IES Intervention 8 automatic top double glazed windows with a rooflight	253	36	289	943 ppm	The best air quality. Energy saving is 8%

strategies. A large number of combinations of automatic window opening were modelled, with the optimum combinations included in the results. In general the interventions assume that approximately a third of available existing windows will open slowly to their maximum opening angle window between the occupied times of 09.00 and 15.15. The opening threshold is 19°C for this one third (which include interventions with vents, plenums or rooflights) and 21°C for the remaining window openings. Window opening starts when CO_2 levels reach 850 ppm and continues until windows are fully open when CO_2 levels reach 950 ppm. When CO_2 levels drop below 950 ppm windows will start to close, and will fully close when CO_2 levels reach 850 ppm.

5. Discussion

This research confirms an important finding from previous work ((UNEP, 2007 and Dasgupta et al, 2012), notably that heating system design has a critical role to play in optimising energy use. Designs that limit the occupants' ability to understand how the heating system is performing are inviting an insufficient response by those occupants when the system malfunctions. This research shows how expensive this can be in energy use terms, where the case study school is using 50% more energy than the optimum level.

Control systems are also critical. Systems which are designed to be automatic and do not require human intervention in day to day use, need to be easily understood by whoever is in charge of the heating system. There needs to be awareness of when there is a system malfunction and how it can be corrected. A simple way to improve the heating would be to deactivate the "intelligent" controls and make room thermostats visible and adjustable by the occupants.

The outlined interventions in table 6 all offer improvements to a differing degree in energy use and internal air quality in the Victorian classroom under study. The most suitable ventilation strategy depends on whether energy cost or air quality is given the higher priority. Ultimately there is some trade-off between energy cost and indoor air quality in all the outlined interventions. However, the potential energy savings achieved through proper heating system control can more than offset the cost of improved natural ventilation strategies.

This research is qualified by a number of limitations. The gathered data was limited to roughly a three month winter period. While this was considered satisfactory, a longer period of data gathering would have meant a greater degree of accuracy.

The data analysed is from one school classroom, and can not necessarily be assumed to be typical. Also, while it seems apparent from the measured data that the heating system was not performing in an optimal manner, it remains unknown at what level problems may have occurred. The level of valve control, the exact set point temperature settings, and the level of human intervention is not certain.

Given the substantial savings identified through correcting heating controls and the clear possibility of improving indoor air quality through automatic window opening, further research is justified to determine the extent to which schools around the UK could benefit from these interventions. An initial survey of Display Energy Certificates at UK schools would provide a good sample of those which are using excessive energy for their building type. Within this group, internal air quality could then be assessed.

6. Conclusion

This work has described how a Victorian classroom was characterised and modelled using IES computer simulation for eight different interventions which included automatic window opening, low level air vents, double glazed windows and construction of a plenum and rooflight. Each intervention met the regulatory ventilation requirements of Building Bulletin 101 while also lowering energy use. The research confirmed the critical role of design and control in energy system performance. Adequate internal air quality combined with substantial energy savings of 37% was a possible outcome using automatic opening mixed double glazed windows and a simple but reliable heating system..

7. References

Coley, D. & Greeves,R. (2004) *The Effect of Low Ventilation Rates on the Cognitive Function of a Primary School Class*. Exeter: Centre for Energy and the Environment, University of Exeter.

Daisey, J., Angell, W. & Apte, M. (2003) Indoor air quality, ventilation and health symptoms in schools: An analysis of existing information. *Indoor Air*, 13(1)

Dasgupta, A., Prodromou, A. & Mumovic, D., (2012) Operational versus designed performance of low carbon schools in England: Bridging a credibility gap, *HVAC&R Research*, 18(1-2), pp.37-50

Department for Communities and Local Government: The Building Regulations (2006) Approved Documents F, Ventilation. [Available Online] http://www.odpm.gov.uk/index.asp?id=1164179 Accessed 12/4/2012

Fisk, W. (2002) How IEQ affects health, productivity. *ASHRAE journal*, 44(5). pp.

56-60.

Griffiths, M. & Eftekhari, M. (2008) Control of CO2 in a naturally ventilated classroom. *Energy and Buildings*, 40(4), pp.556-560

Integrated Environmental Solutions, (2011). *VE Pro* software, [Online] Available from http://www.iesve.com/

Lomas, K. J.,2010, Carbon reduction in existing buildings: a transdisciplinary approach. *Building Research & Information*, 38 (1) p.1 – 11

Mumovic, D., Davies, M., Ridley, I., Altamirano-Medina, H., Oreszczyn, T. (2009). A methodology for post-occupancy evaluation of ventilation rates in schools. *Building Services Engineering Research & Technology*, 30(2), pp.143-152

Santamouris, M. ; Synnefa, A. ; Asssimakopoulos, M. ; Livada, I. ; Pavlou, K. ; Papaglastra, M. ; Gaitani, N. ; Kolokotsa, D. & Assimakopoulos, V. (2008). Experimental investigation of the air flow and indoor carbon dioxide concentration in classrooms with intermittent natural ventilation. *Energy & Buildings*, 40(10), pp.1833-1843

Seppanen, O., Fisk, W. & Mendell, M. (1999) Association of ventilation rates and CO2 concentrations with health and other responses in commercial and institutional buildings. *Indoor Air*, 9 pp. 226-252

UNEP,(2007). *Buildings and Climate Change: Status, Challenges and Opportunities*. United Nations Environment Programme