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

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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 CO₂ 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 CO₂ 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 CO₂ Measurement

Classroom temperature and CO₂ 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 CO₂ 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).
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 CO2 level was calculated to show that it exceeded the recommended average of 1500 ppm (see chart 2).

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>
<thead>
<tr>
<th>Intervention</th>
<th>Space Heating (Gas) kWh/m²/Year</th>
<th>Electricity kWh/m²/Year</th>
<th>Total Energy kWh/m²/Year</th>
<th>Air Quality (CO₂)</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Display Energy Certificate (DEC)</td>
<td>248</td>
<td>58</td>
<td>306</td>
<td>N/A</td>
<td></td>
</tr>
<tr>
<td>Base Case IES Apache Simulation</td>
<td>279</td>
<td>36</td>
<td>315</td>
<td>&gt;1500 ppm</td>
<td>Insufficient internal air quality (IAQ)</td>
</tr>
<tr>
<td>IES Intervention 1 automatic single glazed existing windows</td>
<td>195</td>
<td>36</td>
<td>231</td>
<td>1441 ppm</td>
<td>Meets BB101 requirements Energy saving is 27%</td>
</tr>
<tr>
<td>IES Intervention 2 automatic top double glazed windows</td>
<td>165</td>
<td>36</td>
<td>201</td>
<td>1437 ppm</td>
<td>Slightly better IAQ than 1 Energy saving is 36%</td>
</tr>
<tr>
<td>IES Intervention 3 automatic bottom double glazed windows</td>
<td>164</td>
<td>36</td>
<td>200</td>
<td>1445 ppm</td>
<td>Slightly worse IAQ than 1 &amp; 2 Energy saving is 36%</td>
</tr>
<tr>
<td>IES Intervention 4 automatic top double glazed windows with low level air vents</td>
<td>183</td>
<td>36</td>
<td>219</td>
<td>1307 ppm</td>
<td>Better IAQ than 1, 2, 3, 5, &amp; 7 Energy saving is 30%</td>
</tr>
<tr>
<td>IES Intervention 5 automatic mixed double glazed windows</td>
<td>162</td>
<td>36</td>
<td>198</td>
<td>1446 ppm</td>
<td>Similar IAQ to 1 &amp; 2 Energy saving is 37%</td>
</tr>
<tr>
<td>IES Intervention 6 automatic double glazed parallel opening windows</td>
<td>212</td>
<td>36</td>
<td>248</td>
<td>1024 ppm</td>
<td>Excellent air quality Energy saving is 21%</td>
</tr>
<tr>
<td>IES Intervention 7 automatic top double glazed windows and a plenum</td>
<td>263</td>
<td>36</td>
<td>299</td>
<td>1328 ppm</td>
<td>Good air quality Energy saving is 5%</td>
</tr>
<tr>
<td>IES Intervention 8 automatic top double glazed windows with a rooflight</td>
<td>253</td>
<td>36</td>
<td>289</td>
<td>943 ppm</td>
<td>The best air quality. Energy saving is 8%</td>
</tr>
</tbody>
</table>

Table 1 Summary of Interventions
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 CO₂ levels reach 850 ppm and continues until windows are fully open when CO₂ levels reach 950 ppm. When CO₂ levels drop below 950 ppm windows will start to close, and will fully close when CO₂ 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


