

Topic B4 Ventilation

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## **POOR INDOOR AIR QUALITY MEASURED IN UK CLASS ROOMS, INCREASING THE RISK OF REDUCED PUPIL ACADEMIC PERFORMANCE AND HEALTH**

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## 1 SUMMARY

For over 150 years the importance of good classroom ventilation has been acknowledged with respect to providing a healthy environment that is conducive to learning, ensuring that school pupils are able to work optimally. Yet, despite guidance, many UK classrooms fail to meet adequate indoor air quality (IAQ) requirements. We have measured CO<sub>2</sub> and temperature in 28 classrooms disparately located around England for between 3 and 20 months. Excessively high CO<sub>2</sub> concentrations over 4000ppm are not uncommon in classrooms where the principle ventilation is via manually operated windows. IAQ tends to be better during the summer months when occupants are more likely to open vents for thermal comfort, compared to winter months. During November to December 2013, 85% of monitored manually ventilated classrooms fail to deliver average occupied CO<sub>2</sub> concentrations of less than 1500ppm.

## 2 INTRODUCTION

Throughout human history the importance of building ventilation has been evident (Sundell 2004). During the Industrial Revolution urbanisation resulted in people spending more and more of their time indoors, and often in overcrowded workplaces and dwellings. This led to the observation that confined individuals displayed pallid, thin and weak demeanours and before long exhibit forms of scrofulous disease (Arnott 1838). It was understood that the exhaled air was malodourous, harmful and spread contagions through the effect of miasmas. Arnott highlighted school rooms as being particularly prone to the effects of poor ventilation and further elaborated that the effect of breathing hot polluted air caused the minds of children to suffer (Arnott 1838). The effect of poor ventilation in the spread of diseases in hospitals, as highlighted by Florence Nightingale, ensured that focus on the adequate provision of fresh air was incorporated into new buildings and the advent of germ theory further emphasised the importance of good ventilation. In England, subsequent to the publication of the Education Act 1870, a great many school houses were constructed (HMSO 1870). Outlining design guidance for the building of new school houses for the London Board, Robson noted that *“much of the restlessness, inattention and apparent stupidity, often observable among the children, is due more to want of freshness in the air than to dullness in the scholar”*, and provided detailed design solutions to ensure delivery of sufficient fresh air, recommending a constant fresh air movement of 15 to 20 cubic feet of air per minute per child (7.0-9.4l/s/person) (Robson 1874). Whilst in the US 25-30 cubic feet of air per minute per occupant is recommended for school ventilation design (11.8-14.2l/s/person) to maintain CO<sub>2</sub> in the air at 600ppm (Wheelwright 1901; Donovan 1921). This appears to relate to the findings of Surgeon Major De Chaumont who, using a form of predictive mean vote, stipulated that CO<sub>2</sub> concentrations of 600ppm were indicative of good air quality (De Chaumont 1875). Recent evidence corroborates the observations of Victorian ventilators that poor ventilation rates in schools can have an effect on the health, attendance and performance of occupants (Myhrvold et al. 1996; Seppanen et al. 1999; Coley et al. 2007; Bakó-Biró et al. 2012; Shendell et al. 2004). Since

the Victorian age it has been understood that high CO<sub>2</sub> concentrations were indicative of poor air quality, however, recent studies have shown that CO<sub>2</sub> is directly detrimental to pupil performance, a process which may be further exasperated by other impurities in poorly ventilated rooms (Satish et al. 2012).

The purposes of good ventilation in school rooms was, as today, for the removal of odours and contaminants deleterious to health and for the production of an environment clement for the industrious application of inquiring minds. However, ventilation was recognised as costly, through the heat energy required to temper incoming fresh air and for any mechanical energy required for the distribution of air throughout the building (Robson 1874; Donovan 1921). Since the improvement of personal hygiene and the advent of antibiotics, the importance of ventilation for health has been overtaken by the need to save energy, whether due to the oil crisis of the 1970s or the implication of energy usage on Climate Change. Typically 1000ppm is used to represent adequate ventilation (8-10 l/s/person) (CIBSE 2005). Current school ventilation design guidance reflects the need to balance the requirement of fresh air with the need to manage energy use with recommendations for natural ventilation strategies outlined in BB101 as a flow rate of 8 l/s/person with a daily average occupied concentration of 1500ppm deemed to represent appropriate ventilation on the basis that natural ventilation air flow rates can vary, and a minimum of 3 l/s/person must be delivered, the maximum allowable CO<sub>2</sub> concentration being 5000ppm (Department for Education 2006)

### 3 METHODOLOGIES

28 classrooms in 6 schools around England were monitored for CO<sub>2</sub> and temperature using NVlogiQ dataloggers. Classrooms were chosen to be representative of the variety of construction and ventilation regimes of UK schools, Table 1. Thirteen of the classrooms are of Victorian (V) design, typically high thermal mass with high ceilings and good natural day-lighting, although two have been refurbished with the addition of a mechanical ventilation system (North West B) and a further two have been refurbished with the addition of a ceiling grid to reduce the room volume (North West A). Five of the classrooms are of 1970-1980 modular style (M), low thermal mass, low ceilings and room volumes. Ten of the classrooms are new build (NB), well insulated with good levels of airtightness. All monitored classrooms have openable windows and for the majority, 20, these are the only mode of ventilating the room (W). Mechanical ventilation (MV) is the main source of room ventilation of two of the monitored classrooms and 6 of the monitored classrooms have assisted natural ventilation (AN) being automated windows with low energy fans to facilitate cross ventilation in the classroom. With the exception of West Midlands B, the schools monitored are primary schools with pupils aged between 4 and 11 and class sizes of between 25-30 pupils. The classes monitored in West Midlands B school are occupied by secondary aged pupils (11-18) with occupancy levels of 16 pupils.

| Location        | Classrooms | Build type    |                      |                | Ventilation strategy |                             |                       |
|-----------------|------------|---------------|----------------------|----------------|----------------------|-----------------------------|-----------------------|
|                 |            | Victorian (V) | 1970-80s modular (M) | New build (NB) | Manual windows (W)   | Mechanical ventilation (MV) | Assisted Natural (AN) |
| East Midlands   | 5          | 2             | 3                    |                | 5                    |                             |                       |
| Midlands        | 6          | 4             | 2                    |                | 6                    |                             |                       |
| North West A    | 5          | 2             |                      | 3              | 5                    |                             |                       |
| North West B    | 3          | 2             |                      | 1              | 1                    | 2                           |                       |
| West Midlands A | 3          | 3             |                      |                | 3                    |                             |                       |
| West Midlands B | 6          |               |                      | 6              |                      |                             | 6                     |

Table 1. List of classrooms in the monitored six schools describing the build type and ventilation strategy.

Carbon dioxide measurements is used as a representation of ventilation rates, as in the absence of a combustion source, the rate of CO<sub>2</sub> production in a space depends upon the number of occupants (Persily 1997). Internal temperature, CO<sub>2</sub> and RH measurements were recorded hourly and every 15 minutes if the absolute rate of change in CO<sub>2</sub> is greater than 5ppm/min or the absolute rate of change in temperature or humidity is greater than 2.5°C or 5% respectively over any 15 minute period, using the SE controls NVlogiQ data logger. Here the temperature measurements are accurate to ±0.5°C, CO<sub>2</sub> measurements are accurate to ±30ppm and ±5% and the RH readings are ±4.5%.

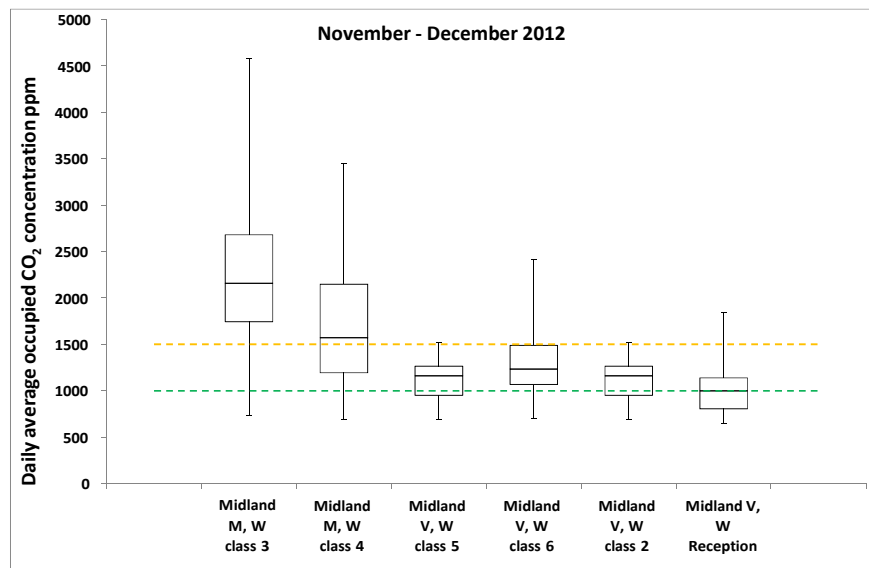
BB101 guidelines recommend that measurements are taken at seated head height, and in most classrooms this was possible. Two of the classrooms in the East Midland school were located higher than head height due to restrictions on the availability of appropriate wall spaces due to power supply constraints and wall displays, it is noted that similar problems were encountered in previous studies (Coley & Beisteiner 2002; Jones & Kirby 2012). However, in all cases effort was taken to place the equipment away from heat sources and in regions of free air flow in order to obtain reliable and accurate readings.

Average occupied CO<sub>2</sub> concentrations are calculated as the sum of the product of CO<sub>2</sub> concentration and time between each data point, between the occupant start time  $T_{start}$  and the occupant end time  $T_{end}$ . This value is then divided by the total occupation time

$$\frac{\sum_{T_{start}}^{T_{end}} C_i \times (T_i - T_{i-1})}{(T_{end} - T_{start})} \quad (1)$$

Data was collected from a school located in the Midlands for over 18 months and 2 out of the 6 measured classrooms consistently demonstrated inadequate IAQ, ie average occupied CO<sub>2</sub> concentrations regularly exceed 1500ppm and CO<sub>2</sub> levels exceed 5000ppm. Figure 1 represents the population of daily average occupied CO<sub>2</sub> concentrations during the heating season for each Midland classroom over the months of November and December 2012 using a box and whisker diagram. The box

represents the mid 50 percentile of the population with the line representing the median value. Each whisker represents the first and last quartile with the extremities representing the minimum and maximum value in the population set. It is clear from the diagram that the IAQ is inadequate for more than 50% of the time in Class 4 and more than 75% of the time in class 5 where the maximum recorded average occupied CO<sub>2</sub> concentration was 4575ppm. Both of these classes are of the 1970-80s modular construction with low ceilings and therefore low room volumes. The Victorian classrooms class 5 and 6 generally provide IAQ to levels that meet the guidelines of BB101 having average occupied CO<sub>2</sub> levels less than 1500ppm for more than 75% of the monitored period. These spaces still maintain the original high ceilings, typical of Victorian school room, and this increased volume reservoir may be a contributing factor to the improved IAQ in comparison to the modular classrooms. Class 2 and reception demonstrate adequate IAQ during this period, both the classrooms host the youngest children who regularly partake in outdoor activities, thus serving to ensure regular purging of the internal environment.



• Figure 1 Box and Whisker diagram illustrating the population of daily average occupied CO<sub>2</sub> concentrations in six classrooms of a school located in the Midlands during the heating season, November and December 2012. Green and orange dotted lines indicate 1000ppm and 1500ppm respectively.

Figure 2 shows the CO<sub>2</sub> concentration and internal temperature during week commencing 19th November 2012 of class 3 from the Midland school, the worst performing class with respect to IAQ. The recommended guideline limit for average occupied CO<sub>2</sub> concentration is exceeded on four of the five days during this week, whilst the BB101 stipulated maximum concentration of 5000ppm is exceeded on 21<sup>st</sup> November, with the maximum recorded concentration being 7350ppm. Discussions with the teachers suggest that on this day a joint class venture was being carried out such that the room housed the occupants of two classes, increasing the room occupant level resulting in greater CO<sub>2</sub> exhalations. During this particular week the CO<sub>2</sub> concentration exceeded 2000ppm for more than 20 minutes on each day, the maximum allowable under the most recent UK school design guidance, PSPB Facilities Output Specification (Education Funding Agency 2013). This week is not untypical of the range of CO<sub>2</sub> concentrations seen in classrooms during the heating season, where the provision of fresh air is from manual openable windows alone.

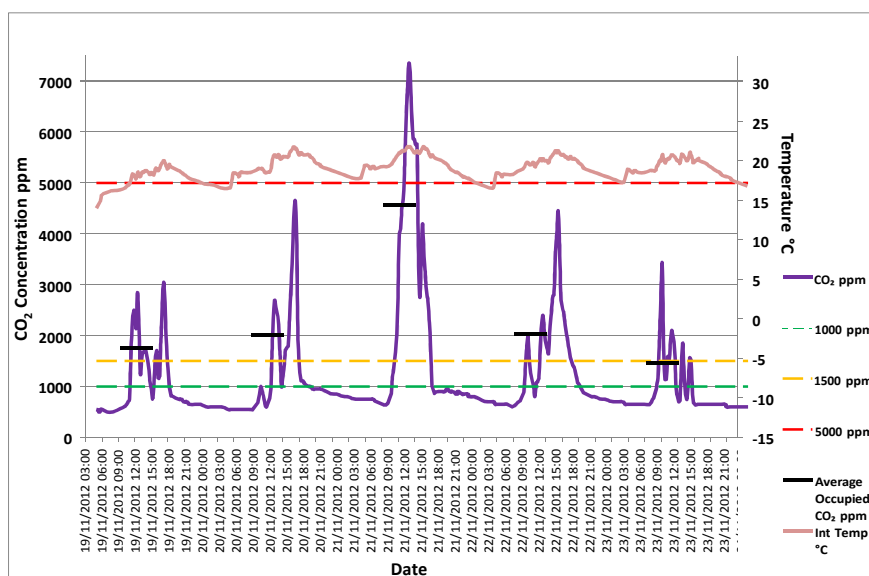


Figure 2 Typical internal CO<sub>2</sub> concentration (purple line) and temperature (pink line) over a week in class 3, Midland modular 1970s construction with manual operated window openings, during a week in November 2012. Black bars indicate the average occupied CO<sub>2</sub> concentration during the day. Green, orange and red dotted lines indicate 1000ppm, 1500ppm and 5000ppm respectively.

The air quality in the previously studied classrooms in the Midlands school is much improved during June and July compared to November and December, Figure 3, which suggests that the manually operated windows are opened more frequently during this period to ensure delivery of adequate fresh air to maintain good IAQ. It has been shown in numerous studies that occupants more readily open windows or vents for fresh air to regulate thermal comfort rather than for IAQ, and the results shown in Figure 3 corroborate these findings (Robinson & Haldi 2011; Robinson & Haldi 2012;

Haldi & Robinson 2009; Bruce-Konuah et al. 2012). During June and July average CO<sub>2</sub> concentrations were below 1500ppm for almost all days recorded, being exceeded on a couple of occasions in classes 6 and 2. Regrettably no data was collected in the Reception class due to the data logger having power disconnected.

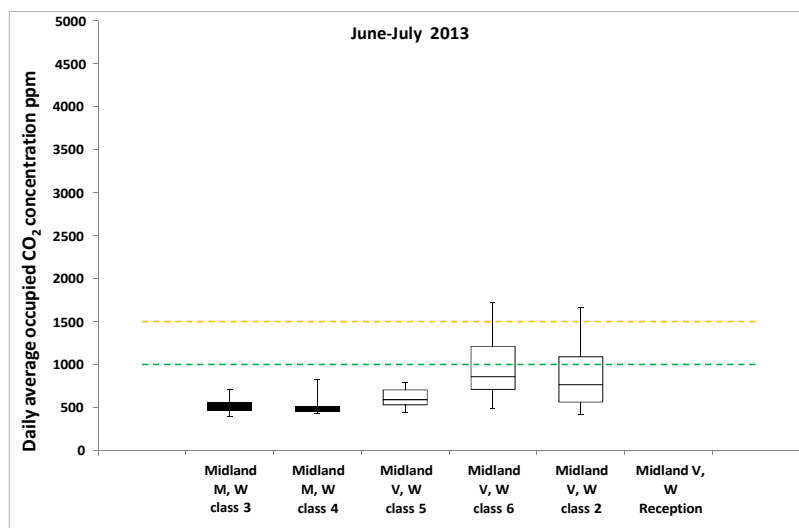


Figure 3 Box and Whisker diagram illustrating the population of daily average occupied CO<sub>2</sub> concentrations in six classrooms of a school located in the Midlands during June and July 2013. Green and orange dotted lines indicate 1000ppm and 1500ppm respectively.

Data was collected from all 28 monitored classrooms during November and December 2013 and the population of daily occupied average CO<sub>2</sub> concentrations for each class is represented in the box and whisker diagram in Figure 4. It is evident that during this period only 3 of the 20 classrooms with manual window ventilation demonstrate adequate IAQ as defined by BB101, i.e. average occupied CO<sub>2</sub> concentration less than 1500ppm and all these three classes are occupied by the youngest primary aged pupils who regularly undertake outdoor activities and are rooms with direct external door access to the outside play area. 35% of the monitored classes with windows fail to deliver adequate IAQ for over 75% of the monitored days and 60% of the monitored classes fail to deliver adequate IAQ for over 50% of the monitored days.

These results suggest that classes with manual operated windows regularly and significantly fail to deliver adequate IAQ. Maximum daily concentrations exceeding 3000ppm was a common occurrence of many window ventilated classrooms. Definitive conclusions between the performance of Victorian and more modern class designs with respect to air quality are difficult to draw due to the various uses of the rooms and subsequent refurbishments that the Victorian classes have undergone. However, in general the performance of Victorian classes with manual windows is better than those of 1970-80s modular and new build construction, probably because these rooms have greater infiltration and have larger volumes due to high ceilings, providing increased reservoirs for CO<sub>2</sub>. Of the two classes with mechanical ventilation, only one delivered adequate IAQ which suggests that the performance of the ventilation system in the poor performing class requires investigation. West Midlands School (B) implements an assisted natural ventilation strategy with automated windows that open when CO<sub>2</sub> levels increase to implement a cross ventilation strategy that is assisted by low energy fans. All monitored classes in this school demonstrate adequate IAQ, however it must be noted that these are subject classes that are not constantly occupied during the school day. Nevertheless, further analysis of recorded CO<sub>2</sub> concentrations in these classes revealed that CO<sub>2</sub> concentrations never exceeded 5000ppm nor 2000ppm for more than 30 minutes on any day.

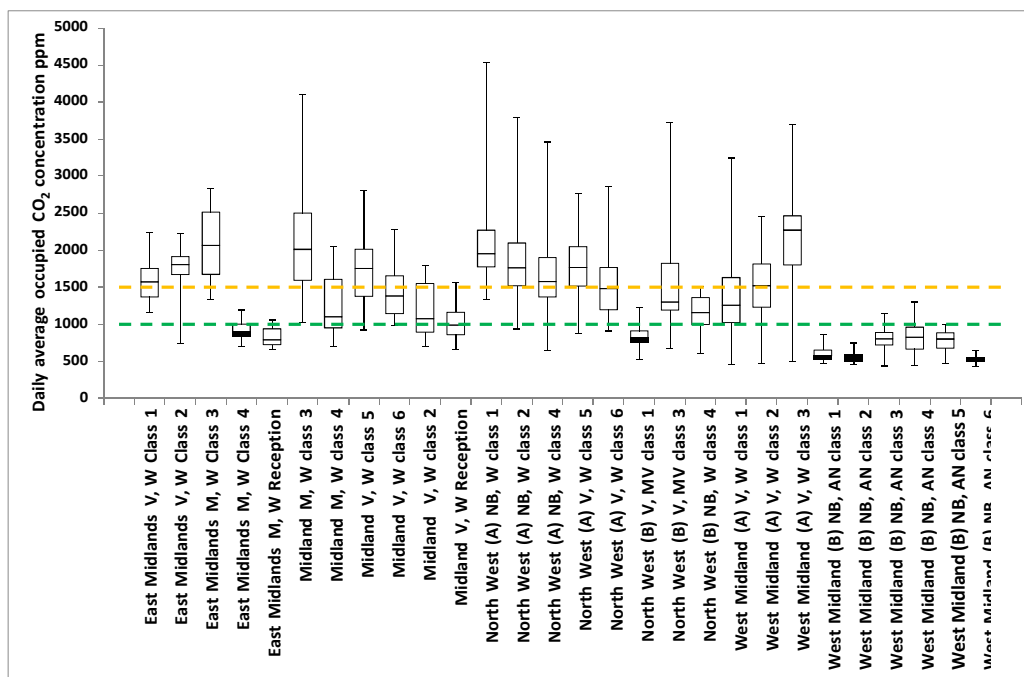


Figure 4 Box and Whisker diagram illustrating the population of daily average occupied CO<sub>2</sub> concentrations in all monitored classrooms during the heating season, November and December 2013. Green and orange dotted lines indicate 1000ppm and 1500ppm respectively. Construction and ventilation types as described above are V=Victorian, M=Modular 1970-80s, NB = New Build, W = manual windows, MV = mechanical ventilation, AN = assisted natural ventilation.

## 4 CONCLUSIONS

The results of this study clearly demonstrate that the air quality in classrooms, where the main source of ventilation fresh air is via manually opened windows, is poor. This corroborates findings of previous studies (Theodosiou & Ordoumpozanis 2008; Mumovic et al. 2009; Clements-Croome et al. 2008; Jones & Kirby 2012)

It is also clear that adequate class ventilation can be achieved with manual windows, mechanical ventilation and assisted automated natural ventilation and therefore it should be possible to improve poor performing classes by reviewing current ventilation strategies and implementing enhanced or alternative appropriate ventilation strategies and control to deliver the required adequate IAQ.

For many years window ventilation has been seen as the easiest and best method of flushing a room with pure air, and rated as superior to mechanical ventilation (Donovan 1921), however it has always been recognised that air for respiration must be perfectly fresh, comfortably warm and imperceptible in movement to never be productive of draughts (Robson 1874) something which continues to be reflected in current UK school design guidance (Education Funding Agency 2013). Traditionally, perimeter heating has been used to pre-warm air entering through windows, but the perception of draughts and of wasted energy through opened windows regularly prevents occupants opening windows for ventilation purposes. Education of teachers and pupils is required to raise the understanding of the adverse effects of poor IAQ so that ventilation can be improved. School facilities managers need to review, monitor and check the effectiveness of implemented class ventilation strategies and control in delivering adequate IAQ that is beneficial to the health and performance of the pupils.

## 5 ACKNOWLEDGEMENT

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## 6 REFERENCES

- Arnott, N.**, 1838. *On Warming and Ventilation*, Forgotten Books.
- Bakó-Biró, Z.** et al., 2012. Ventilation rates in schools and pupils' performance. *Building and Environment*, 48, pp.215–223.
- Bruce-Konuah, A., Hathway, A.A. & Fotios, S.**, 2012. Window use in single person offices: do occupants control personal ventilation to provide adequate IAQ? In *Healthy Buildings 2012. Brisbane, Queensland, Australia, 8 July 2012 - 12 July 2012*.
- De Chaumont, F.S.B.F.**, 1875. On the Theory of Ventilation: An Attempt to Establish a Positive Basis for the Calculation of the Amount of Fresh Air Required for an Inhabited Air-Space. *Proceedings of the Royal Society of London*, 23, pp.187–201.
- CIBSE**, 2005. *CIBSE Guide B - heating, Ventilating, air conditioning and refrigeration*, CIBSE.
- Clements-Croome, D.J.** et al., 2008. Ventilation rates in schools. *Building and Environment*, 43(3), pp.362–367
- Coley, D.A. & Beisteiner, A.**, 2002. Carbon Dioxide Levels and Ventilation Rates in Schools. *International Journal of Ventilation*, 1, pp.45–52.
- Coley, D.A., Greeves, R. & Saxby, B.K.**, 2007. The Effect of Low Ventilation Rates on the Cognitive Function of a Primary School Class. *International Journal of Ventilation*, 6(2), pp.107–112.
- Department for Education**, 2006. *Building Bulletin 101 Ventilation of School Buildings*,
- Donovan, J.J.**, 1921. *School Architecture Principles and Practices*.
- Education Funding Agency**, 2013. Priority School Building Programme Facilities Output Specification: General Design Brief. , (June).
- Haldi, F. & Robinson, D.**, 2009. Interactions with window openings by office occupants. *Building and Environment*, 44(12), pp.2378–2395. HMSO, 1870. Elementary Education Act 1870 (c.75).
- Jones, B.M. & Kirby, R.**, 2012. Indoor Air Quality in U.K. School Classrooms Ventilated by Natural Ventilation Windcatchers. *International Journal of Ventilation*, 10(4), pp.323–337.
- Mumovic, D.** et al., 2009. Winter indoor air quality, thermal comfort and acoustic performance of newly built secondary schools in England. *Building and Environment*, 44(7), pp.1466–1477.
- Myhrvold, A.N., Olsen, E. & Lauridsen, O.**, 1996. Indoor Environment in Schools - Pupils Health and Performance in Regard to CO<sub>2</sub> Concentrations. In *Indoor Air '96: The 7th International Conference on Indoor Air Quality and Climate*. Nagoya, Japan.
- Persily, A.K.**, 1997. Evaluating Building IAQ and Ventilation with Indoor Carbon Dioxide. *ASHRAE Transactions*, 103, pp.193–204.
- Robinson, D. & Haldi, F.**, 2011. Modelling Occupants' Presence and Behaviour – Part I. *Journal of Building Performance Simulation*, 4(4), pp.301–302.
- Robinson, D. & Haldi, F.**, 2012. Modelling Occupants' Presence and Behaviour – Part II. *Journal of Building Performance Simulation*, 5(1), pp.1–3.
- Robson, E.R.**, 1874. *School Architecture being practical remarks on the planning, designing, building and furnishing of school-houses*.
- Satish, U.** et al., 2012. Is CO<sub>2</sub> an indoor pollutant? Direct effects of low-to-moderate CO<sub>2</sub> concentrations on human decision-making performance. *Environmental Health Perspectives*, 120(12), pp.1671–1677.

**Seppanen, O., Fisk, W. & Mendell, M.**, 1999. Association of Ventilation Rates and CO2 Concentrations with Health and Other Responses. *Indoor air*, 9, pp.226–252.

**Shendell, D.G.** et al., 2004. Associations between classroom CO2 concentrations and student attendance in Washington and Idaho. *Indoor air*, 14(5), pp.333–41.

**Sundell, J.**, 2004. On the history of indoor air quality and health. *Indoor air*, 14 Suppl 7(Suppl7), pp.51–8.

**Theodosiou, T.G. & Ordoumpozanis, K.T.**, 2008. Energy, comfort and indoor air quality in nursery and elementary school buildings in the cold climatic zone of Greece. *Energy and Buildings*, 40(12), pp.2207–2214.

**Wheelwright, E.M.**, 1901. *School Architecture A General Treatise for the Use of Architects and Others*, Forgotten Book.

