

Lifting the lid

Are our schools adequately ventilated? New research carried out by Cranfield University suggests not.

BUILDING SERVICES REPORTS

The need for adequate ventilation in buildings is an engineering tablet of stone. Quite apart from the obvious health implications, most evidence suggests a strong link between internal comfort conditions and human productivity.

Indoor air quality is determined by a number of factors, such as the presence of odour, water vapour, formaldehyde, volatile organic compounds, ozone, NOx and SOx, and particulates. However, by far and away the most important variable is carbon dioxide (CO₂).

Table 1 shows the recommended carbon dioxide concentrations for indoor air. BSRIA research has concluded that 800 ppm is the control level for acceptable indoor air quality (at least for short-term exposure), while the generally held view is that a CO₂ concentration of 600 ppm or less will give good indoor quality. These values are also followed in CIBSE *Guide A*.

To discover whether these limits have any relevance to naturally ventilated school buildings, Cranfield University carried out a series of air quality measurements in an infant school and a junior school. The two monitored classrooms in the infant school followed the layout in figure 1. The occupant density in both classrooms averaged 60 pupils and two teachers. The spaces had four windows and two doors. Tests were carried out on a relatively windless October day. On the days that the measurements were taken, three of the windows were half open.

Two CO₂ sensors – one in either classroom –

delivered the CO₂ concentrations shown in figure 2. As can be seen, carbon dioxide concentrations reached as high as 1700 ppm in one classroom and 1400 ppm in the other.

If one accepts that a limit of good air quality is around 1000 ppm of CO₂, then it is fair to say that the air quality in these classrooms was not very good, despite the three open windows.

As figure 2 shows, the concentrations go up and down as pupils enter and leave the spaces. Indeed the occupancy pattern follows the CO₂ concentration pattern very closely.

Similar tests were carried out in a junior school. Again two classes of 60 pupils and two members of staff were monitored. During this study all the windows in the classroom were closed. In this study, CO₂ concentrations rose to over 3000 ppm.

So does this research reveal a problem, and if it does, what are the design implications?

The modelling work

Once these studies had been carried out, the research team used the monitored data to develop a CO₂ prediction tool based on air change rates, occupancy density and the metabolic rates of the occupants.

The latter proved an extremely difficult issue to resolve. Reliable data on the metabolic rate of children was very difficult to find, along with the consequent rate of metabolic CO₂ production. To compound the difficulty, little is known about actual air change rates in schools.

Initially, the researchers used data provided by Professor Ole Fanger for average basal metabolic rates based on age and gender. Fanger's data showed that, despite their smaller body size, children have a metabolic rate 2.7 times that of adults'. A higher metabolic rate means more energy consumption, and more CO₂.

However, relating the Fanger metabolic data to CO₂ production was far more difficult. Despite searching published and web-based sources of information, the research team failed to discover any meaningful index which they could use in the model.

The solution was to create metabolic rates based on the Dubois equation, which relates body surface area to weight and height. Data was tracked down on average weight and height data for children up to 10 years old, and that formed the basis of metabolic CO₂ output related to age and activity.

The research found that the metabolic CO₂ production rate based on light work for 5-6 year olds is between 5.88 to 8.60 mg/s/p, while for 7-8 year olds, the rate is 7.10 to 10.50 mg/s/p.

For adults, light work generates 11.34 mg/s/p to 16.64 mg/s/p, although in this context teachers are likely to be more sedentary than the pupils. If so, it is reasonable to suppose that the actual metabolic CO₂ rate might be as low as 8 mg/s/p – very close to that of the children.

Table 1 shows how the assessment of metabolic CO₂ production rate related to the two schools under study. Without knowledge of the true air change rates in the classrooms, the researchers used decay rates of the concentration of CO₂ at the end of the school day as a way of determining the likely air change rate.

In the infant school, the air change rate was calculated to be around 2.9 ac/h, which equates to around 4.3 l/s/p. In the junior school (with closed windows), the rates varied according to time of day, but the figures varied between 1.9 l/s/p and 6.7 l/s/p – the latter figure relating to the lunch hour when doors are likely to be open.

TABLE 1: RECOMMENDED CARBON DIOXIDE CONCENTRATIONS IN INDOOR AIR

CO ₂ concentration (ppm)	Recommended quality rating
300-400	Typical background (atmospheric) concentrations
600	Good indoor quality
800	BSRIA control level for acceptable indoor air quality (short-term exposure)
1000	WHO (1984) concentration of limited or no concern (short-term exposure)
5000	8 h occupational exposure limit
6600 and above	WHO (1984) concentration of concern (short-term exposure)

main feature

School design

After school, when doors are shut, the air change rate drops to 1.0 ac/h.

The research team then related the air change rates to the metabolic CO_2 production rates to see if metabolic CO_2 production could be calculated from the decay rates. This exercise generated figures of between 9 mg/s/p and 13 mg/s/p which, being close to the theoretical estimates, made the research team fairly confident about the data. In the end, the researchers settled on a basal metabolic production rate for schoolchildren of 11 mg/s/p.

When the modelled CO_2 concentrations were overlain on the monitored results for the infant school, the data showed a close correlation (to a value of 0.87). More important, when the modelled carbon dioxide concentrations for ventilation ranges of 3 l/s/p and 8 l/s/p were overlain on the monitored data for the infant school, it became clear that acceptable values for indoor air quality could only be achieved at 8 l/s/p, which correlates with the rate quoted in engineering guidance (figure 3). However, at 3 l/s/p (the legal standard for background ventilation²), CO_2 concentrations peaked at nearly 2000 ppm, and did not decay below 1000 ppm, even when the classrooms were unoccupied.

In the junior school, where the windows were closed, a very similar situation arose, with slightly higher maximum values of CO_2 at 3 l/s/p.

So what are the implications? In the infants school, the average air change rate is about 2.6 ac/h in the school where the windows were open. That translated to a ventilation rate to about 4.5 l/s/p of outside air. For the junior school, where there was 1 ac/h (quite airtight), the ventilation rate per pupil was about 2 l/s/p.

To achieve an acceptable ventilation rate in the infant school would require about 5 ac/h, and in the junior school about 4.4-5 ac/h. The big question here is: can this be achieved by natural ventilation alone?

It can be argued that the drive for energy efficiency, coupled to tight control of capital expenditure by local authorities – is compromising the ability of schools to be adequately ventilated. Indeed, the only way either of two schools could be adequately ventilated would be to open all the windows on a windy day, and this is clearly an unacceptable mode of operation.

This article is based on a presentation given by Dr W J Batty at the CIBSE seminar, 'Ventilation and Indoor Air Quality' in Schools. Dr W J Batty is with the Applied Energy Group at Cranfield University.

References

- ¹Indoor air quality and its impact on man: guidelines for ventilation requirements in buildings, Report No 11, Commission of the European Communities, 1992.
- ²The Education (School Premises) Regulations 1999.

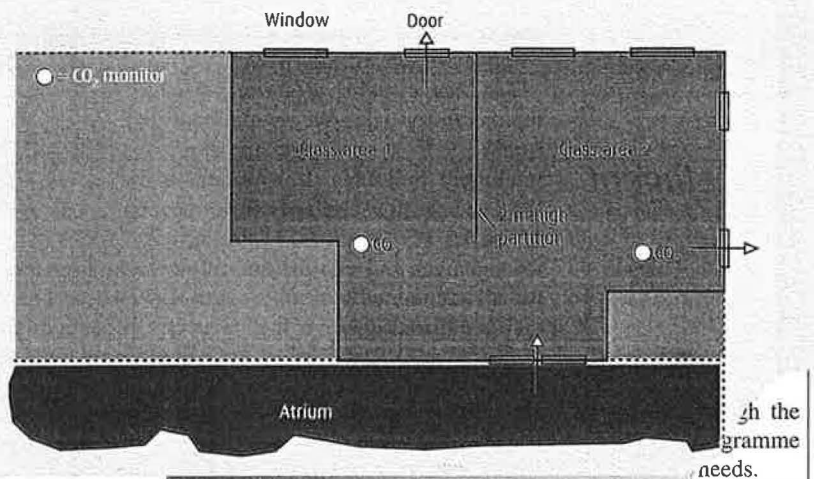


FIGURE 1: Plan of the monitored classrooms in the infant school

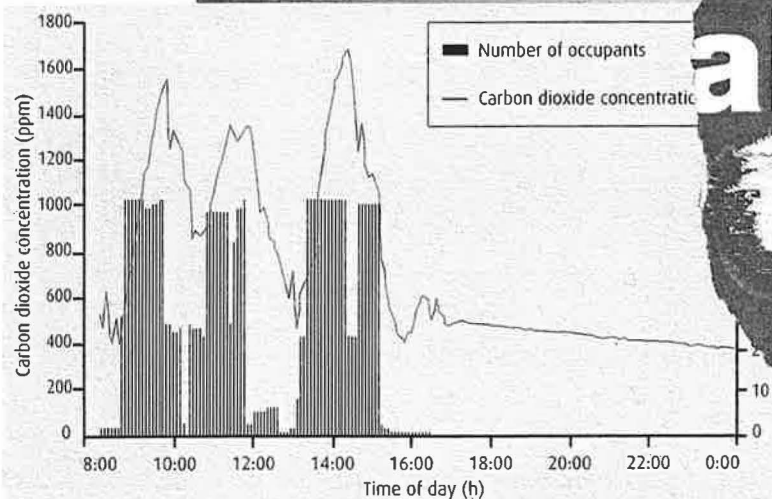


FIGURE 2: Averaged carbon dioxide concentration against occupancy patterns for a monitored day in the infant school.

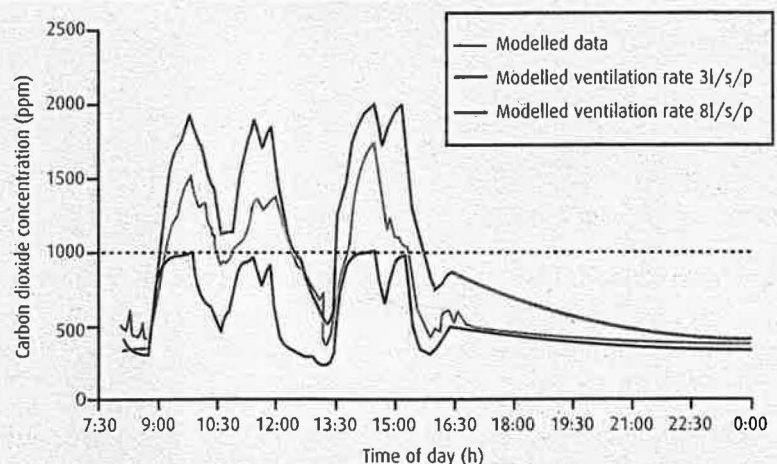


FIGURE 3: Modelled carbon dioxide concentrations for ventilation ranges of 3 l/s/person and 8 l/s/p during the occupied period for the infant school against the modelled data.