Problems with classroom air quality

Classrooms that are clean, warm and dry are not good enough

Problem schools?

Scandinavian countries pride themselves on providing good working conditions for all. In buildings where adults work, they have largely succeeded, but in places where children work - in the classrooms where children spend ten years of their lives tackling new and unfamiliar tasks every day - it turns out that they could do much better. When the problems in schools were visible - when classrooms were dimly lit, dirty, crowded, poorly furnished and poorly equipped - something was done by our predecessors. Nineteenth-century classrooms had all these problems, and today classrooms do not have them. Nineteenth-century classrooms, even twentieth-century classrooms, were often much too cold or much too hot. Today, in the twenty-first century, better design has largely ensured that they are not. Yet it has just been shown that children would be able to perform schoolwork 30% faster, with no more effort, if their working conditions were improved. This is now our problem to solve.

There is still a problem

The remaining problem is that although neither children nor teachers find them unacceptable or even uncomfortable, subjectively comfortable air temperatures and unseen air pollutants in classrooms are making it much harder for children to work during the greater part of the year. New research reveals that it would be enough to simply provide children with what is already agreed to be the minimum amount of fresh air for adults at work.

Field experiments in schools revealed this problem

In 2003, ASHRAE, the American Society of Heating, Refrigeration and Air Conditioning Engineers, funded a research contract (1257-RP) whose purpose was to determine whether the performance of schoolwork by children would improve if the air quality and temperature control in school classrooms were improved, and if so, by how much. ASHRAE is a non-profit organisation that supports a modest amount of mainly technical research, funding it by asking members for voluntary contributions. The International Centre for Indoor Environment and Energy at DTU (ICIEE), in competition with many other research institutions worldwide, submitted a proposal that was accepted in December 2004. The present author was one of the two Principal Investigators.

ICIEE researchers modified several pairs of school classrooms in a school in a Copenhagen suburb so that in each of a succession of experiments, two classes of 10-12-year-old children could be simultaneously exposed to two different conditions. These conditions were maintained for a week at a time and during the following weekend they were switched between the paired classrooms so that each of the two classes would then experience the set of conditions that the other class had experienced during the previous week. This procedure is called a crossover experiment, and it has three main advantages: 1) Comparisons between conditions can be made for each child, removing the effect of individual differences in ability or attitude to school work; 2) The order in which conditions are experienced is balanced, so that changes over time that are due to learning or boredom affect each condition equally; and 3) Any uncontrolled external disturbance that affects the performance of school work, such as bad weather, an accident or a fire drill, has the same effect on the results obtained under both conditions. The researchers never met the children. Instead, they worked in the basement or outside school hours to increase the capacity of the ventilation system and to rebalance it so that each classroom could receive either the normal amount of outdoor air or about 4 times as much. Cooling was installed in two classrooms, so that the benefits of reducing summertime temperatures could be examined. The classrooms were unobtrusively instrumented to continuously record the physical conditions during these 'field intervention experiments.'

There are obviously hundreds of factors that affect children's performance of schoolwork, but in field intervention experiments, any systematic difference in performance between conditions must be due to the effect of those conditions, as no other factors change at exactly the same time as they are changed. The performance of schoolwork was measured by having the class teachers themselves insert 8 standard exercises into the timetable of appropriate lessons, e.g. reading exercises in a Danish class, or addition and subtraction exercises in a mathematics class. The children worked on these exercises, usually for about 10 minutes, and their worksheets were made available to the ICIEE researchers. Neither the teachers nor the children knew which conditions had been imposed in a given week, so they had no expectation of being able to work any better in the weeks in which conditions were improved. The reference condition was always what would have been experienced in that classroom had no changes been made.

By 2006 the startling results of these experiments had been hastily communicated to ASHRAE Members [1], and in 2007 they were published as two scientific articles in a peer-reviewed journal [2, 3]. The field intervention experiments showed very clearly that children's performance of schoolwork would be greatly improved if classrooms received as much outdoor air per person per second as the minimum outdoor air supply rate for offices, and if classrooms did not become as warm in summertime as they currently do. There was excellent agreement between the results of all the experiments in each series, which were performed at different times of year, in different classrooms and with different groups of children. The average CO_2 concentrations were always within the range 750 to 1300 ppm. This is at the low end of what is usually found in classrooms. CO_2 is continuously emitted by occupants and so is diluted when fresh air enters through doors, open windows or cracks in the facade, and when outdoor air is supplied by a ventilation system. Average temperatures in the thermal experiments in warm weather in the summer remained in the apparently innocuous range of 20° to 25°C.

Figs 1 and 2 show that changes in the outdoor air supply rate and the air temperature within these ranges systematically affected how much schoolwork was completed in a given time. Doubling the outdoor air supply rate would have improved performance by between 8% and 14%, while each reduction of 1°C during warm weather would have improved performance by between 2% and 4% (the lower figure is an average for all the tasks, while the higher figure is for those tasks that could be shown individually to have been affected). This means that increasing the outdoor air supply rate from 2.5 to 10 Litres per second per person (L/s/p) would improve performance by 16-28%. Note that 2.5 L/s/p was the normal unmodified outdoor air supply rate in the classrooms studied, and 10.0 L/s/p is the minimum ventilation rate recommended for adults in office buildings. Reducing the air temperature from 25° to 20°C would have improved performance by 10-20%. At 27°C, which is often regarded as an acceptable temperature in classrooms, we would expect performance to be 14-28% worse than it would be at 20°C. Poor air quality occurs during the heating season when windows are kept closed and it is cold outside. Windows are opened more often in warm summer weather, improving the ventilation, so the negative effects of warmth and poor air quality seldom occur at the same time. Nevertheless, these numbers show that each factor separately constitutes a very serious handicap for children who are trying to learn something by performing schoolwork.

<u>New surveys have revealed the extent of the problem</u>

In September 2009, two HVAC engineering students and their supervisors at DTU in Denmark collaborated with science promotion associations in three Scandinavian countries to mobilise thousands of pupils in hundreds of schools to measure the air temperatures and CO_2 levels in their own classrooms, sending them instructions and equipment by post. Measurements were made in 743 classrooms in Denmark, 244 in Sweden and 676 in Norway. The researchers also installed instrumentation in classrooms in a random sample of 100 schools in Denmark and obtained continuous records of air temperature, humidity and CO2 level during two weeks in November 2009, when outdoor temperatures were in the range 0-15°C. Their analysis of these two sets of data is described in a MSc thesis dated March 2010 [4]. It is a very informative report. It shows that while air temperatures in the heating season are satisfactory, thousands of children are being exposed to some very poor air quality right across Scandinavia, and especially in Denmark. Fig. 3 reproduces Table 3 of the thesis, which summarises the results of the mass experiment. The CO2 level in naturally ventilated classrooms was above the recommended maximum limit of 1000 ppm in 69% of Danish classrooms, 47% of Swedish classrooms and 48% of Norwegian classrooms. It was above 2000 ppm in 30%, 7% and 7% of the classrooms, respectively. Even in classrooms with balanced mechanical supply and exhaust ventilation, the CO2 level was above 1000 ppm in 37% of Danish classrooms, 12% of Swedish classrooms and 10% of Norwegian classrooms, indicating that when ventilation systems are designed to achieve minimum ventilation, many will fail to provide it. Better margins are required to ensure good ventilation. Natural ventilation is not at present providing good ventilation, and because Denmark has the largest proportion of naturally ventilated classrooms, the CO2 level in 56% of all classrooms in Denmark exceeded 1000 ppm, compared to in only 16% in Sweden and 21% in Norway. The measurements in the mass experiment were made at the end of a lesson, but seem to be quite representative - in the 100 randomly selected classrooms in Denmark in which CO2 levels were monitored continuously for 2 weeks, the recommended maximum level of 1000 ppm was exceeded for 50% of school hours (including breaks when the classroom was unoccupied and the CO2 level became lower) in 65% of the classrooms.

Energy conservation is a related problem

When informed of these measurements, the Danish Minister of Education Bertil Haarder remarked in a newspaper interview that the solution was to open the windows more often. There are three problems with this traditional solution. The first is that opening windows in cold weather ensures that it will be very cold near the floor. The second is that thermostatic radiator valves will open and ensure that a large amount of heat leaves the room by the window without being of use in the classroom. This is not the way to conserve energy. The third problem is that before opening a window, teachers and children must notice that the air quality is poor. In the controlled experiments performed by DTU [1-3], window opening was recorded over many weeks while the classroom conditions were changed [5]. Windows were opened more often when air temperatures were allowed to rise, but not when CO2 levels were allowed to increase (by unobtrusively reducing the outdoor air supply rate). Teachers and children clearly did not feel the need to open windows even when the air quality was so poor that it was greatly reducing the performance of schoolwork. This is because although people entering a stuffy room notice the odour at once, the occupants of a room do not notice as the air quality slowly deteriorates.

Good engineering can resolve these problems

Engineering solutions that conserve energy while providing good air quality in classrooms are urgently required. There are three main types of solution: 1) CO2 sensors linked to signal lights that indicate to teachers when windows should be opened, and when they should be closed to conserve energy. On most days, these signals will occur hourly and constitute a distraction; 2) Computerised systems that open and close windows automatically when anybody is present, taking account of indoor and outdoor temperatures and CO2 levels, wind speed and direction, rain, solar gain and external noise. These systems will have to continuously weigh some very different sources of distraction and discomfort against each other to achieve an acceptable compromise; and 3) Mechanical ventilation that provides outside air to each classroom at an appropriate rate, conserving energy by transferring heat between the supply and exhaust airstreams. An additional unit in such systems might continuously process classroom air to remove pollutants, to reduce the amount of outdoor air required. For this to work effectively, we need more research to discover which pollutants are affecting schoolwork. At present we do not even know whether the active pollutants are emitted by people or by materials.

References

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Author
David P. Wyon, Visiting Professor, ICIEE, Department of Civil Engineering, DTU

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Figure 1 The effect of outdoor air supply rate on performance of schoolwork
(Open circles for the tasks that were significantly affected) from [1]

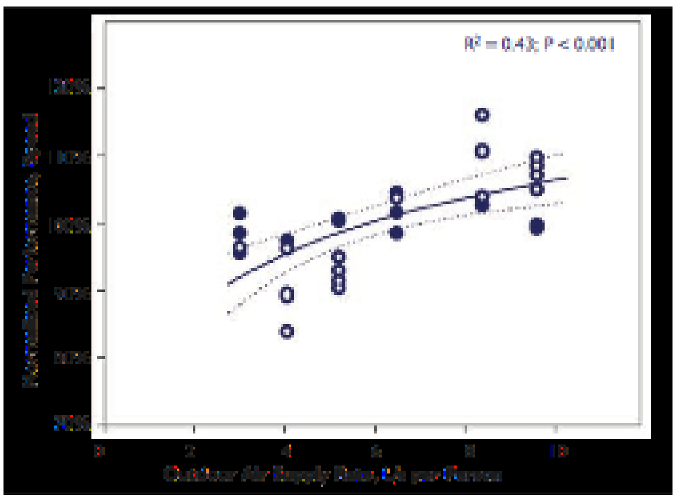

Figure 2 The effect of classroom air temperature on performance of schoolwork
(Open circles for the tasks that were significantly affected) from [1]

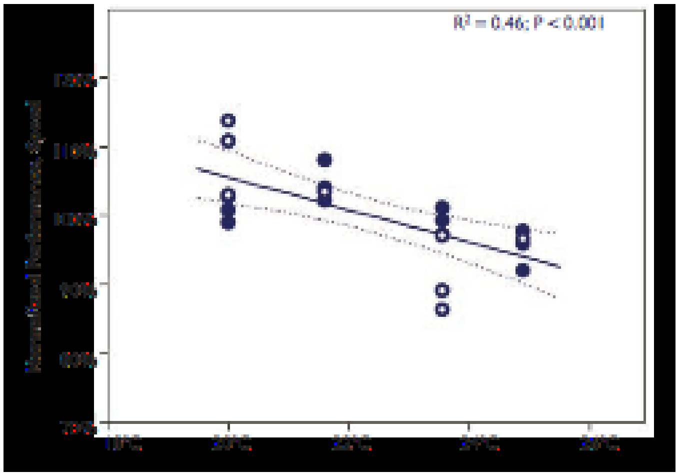

Figure 3 Results of the mass experiment - Table 3 from [4]