ENERGY CONSERVATION VS HEALTH. THE AIR QUALITY PICTURE.

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ABSTRACT

With the advent of the concepts of efficient energy use focus has shifted towards buildings becoming more air tight and having lower levels of ventilation. This is due to the fact that as buildings become better insulated and conduction heat loss is reduced the proportion of heating and air conditioning load due to ventilation has increased and may offer the largest scope for reducing energy demand. This may have a detrimental effect on internal air quality (IAQ) and compounds existing environmental issues such as out gassing from materials in new buildings. At the same time environmental standards and expectations have risen as has the technical capability to evaluate their effects through epidemiological studies. Good environmental quality is a fundamental human need, absence of which affects health and productivity. Many occupants express annoyance about modern buildings and terms such as sick building syndrome (SBS) are used to describe the problem. Deterioration of IAQ has been evident from an increase in occupant complaints and an increase in breathing related sicknesses in recent years. With predicted substantial growth of the urban environment the problem will only be exacerbated in the future.

A simple and effective solution to the problem of deficient IAQ is increasing ventilation but increasing the amount of inlet fresh air has direct bearing on energy load. Another important factor is the ventilation scheme (mechanical, natural, mixed-mode). This paper looks at the relationship between good IAQ, ventilation, associated energy overheads and carbon emissions. Also identified are best practices that optimise the performance of a building in relation to this issue.

INTRODUCTION

Over the past few years the term sick building syndrome (SBS) has been increasingly used to describe a general feeling of malaise that an occupant experiences when inside an enclosed space. This term is usually used to refer to poor IAQ and can affect people by reducing comfort levels and is also attributable to poor general health (Samuel 2005). Improving conditions inside buildings can reduce the incidence of SBS and other such complaints. The benefits of such an exercise are not small. It has been stated that the benefits from productivity enhancements alone can potentially generate up to 250% savings over cost in terms of occupant productivity (Fisk and Rosenfeld 1997). The benefits to health are priceless to the individual and will lower health costs at community level.

The problem is two faceted in that buildings have become more air tight in compliance to recent building regulations and that prescribed ventilation practices may not be adequate for the type of activity that takes place in a space. Adequate mechanical ventilation of a space not only depends on a well maintained, correctly sized and properly functioning HVAC system, but also depends on proper use. It is not uncommon to see questionable practices on the part of occupants that compromise ventilation requirements; e.g. placing fresh product chillers directly underneath a warm air inlet in a retail situation or having more workers than designed within an office space. Occupant behaviour is not predictable, nonetheless the building HVAC system should ventilate the building as effectively as possible with respect to design conditions. Natural ventilation is more difficult to predict and control but some principles developed for good IAQ practices in mechanically ventilated buildings may also be applicable to naturally ventilated buildings.

VENTILATION REQUIREMENT AND PROVISION

Figure 1 (adapted from Awbi 2003) shows historic variation of minimum ventilation requirements as given by ASHRAE standards. It shows that ventilation levels have changed from a minimum of 2l/s to a maximum of 15l/s. Factors driving these changes were lifestyle changes, design changes, technology advancement and cost of fuel (Awbi 2003). Other human comfort factors such as comfort temperature have not shown such drastic variation. It can be clearly concluded that little is understood by us about ventilation requirements. One of the reasons for such a range is that poor IAQ is not as easily discerned as poor thermal comfort. Nevertheless the need to provide adequate quality of air still remains.

It has been shown in previous modelling exercises (Samuel 2006) and monitoring studies (Carrer and Maroni 2002; Corsi et al 2002; Sowa 2002) that delivering recommended fresh air rates rarely brings

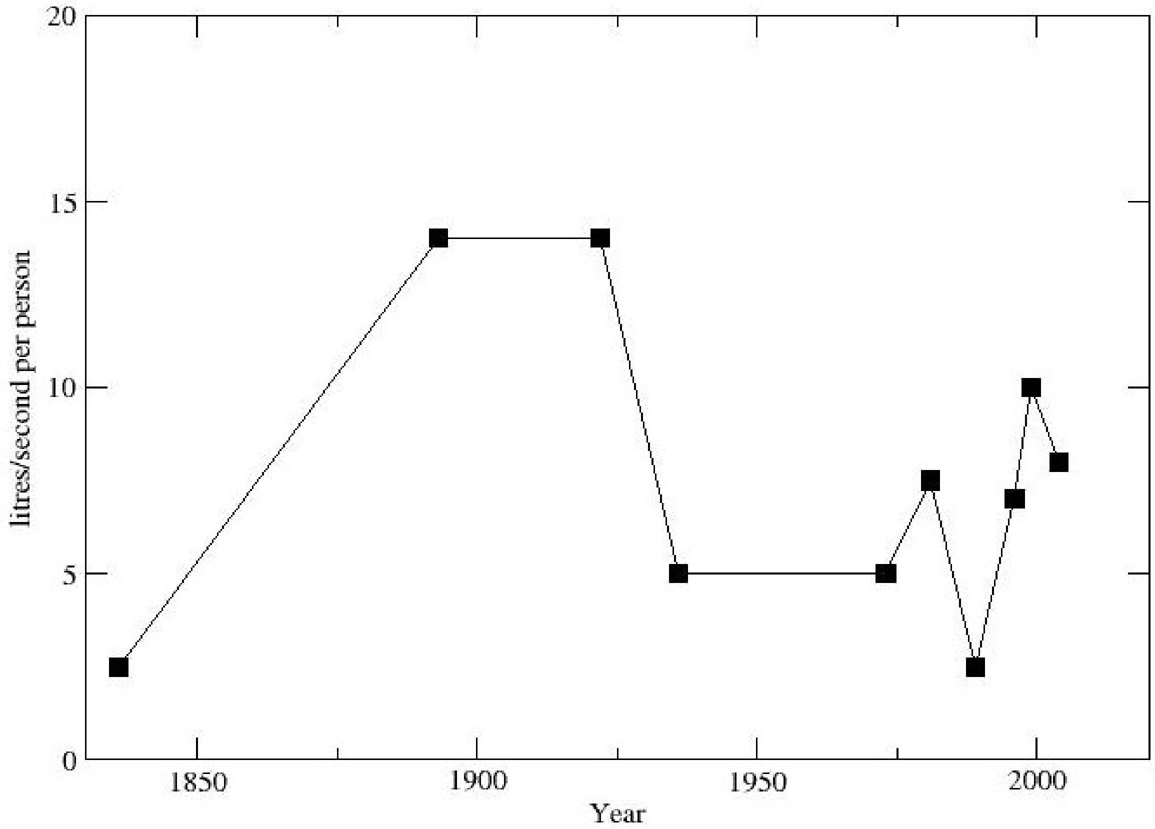


Figure 1 ASHRAE 62 (and equivalent) minimum fresh air requirements

concentrations of contaminants to an acceptable level. It has also been shown that increased levels of ventilation improve performance of occupants (Seppanen et al 2006) with a cut off at around 45l/s per person (i.e. after which increased fresh air does not influence performance). Higher ventilation rates are also shown to reduce the likelihood of SBS (Fisk et al 2009, Jaakkola and Miettinen 1995). Although the number seems to be much higher than currently accepted levels, an increase of 1 to 2 orders of magnitude has been suggested by Fanger (2006) who goes on to suggest ways to increase IAQ while maintaining current levels of ventilation. Corroborating this is monitored and simulated evidence (Godwin and Batterman 2007 and Samuel 2006 respectively) suggesting in excess of 3000ppm of carbon dioxide within the occupied space as compared to recommended levels of ~1000ppm (Sundell 1982). Jenkins et al (2009) have suggested that current ventilation levels may not be sufficient considering foreseeable climate change. Economic implications of bad IAQ run into tens of billions of dollars (Mudari and Fisk 2007) in terms of productivity shortfalls alone.

In recent times ventilation needs have been met by a variety of novel schemes. These can range from supplying fresh air near occupant breathing space – personalised ventilation (Melikov et al 2002), to purging the stale air of contaminants and recirculating a large proportion of it back into the occupied space (ASHRAE 2004).

It can be concluded from the discussion above and the plethora of research done to study IAQ that:

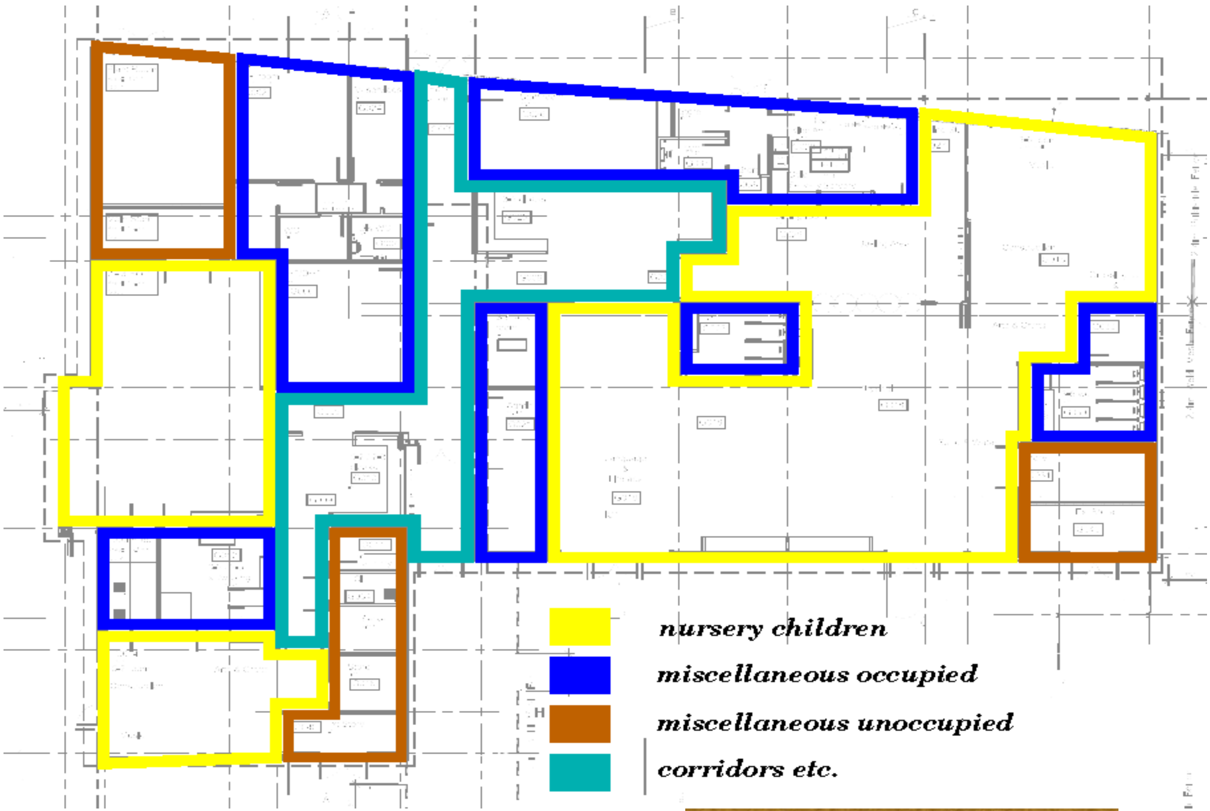
- SBS, associated ailments and other respiratory illnesses e.g. asthma have shown higher incidence in recent years than previously.
- Recommended ventilation rates (with typical strategies like mixing and displacement ventilation) are usually inadequate in order to supply good IAQ.
- For a given ventilation scheme it is the exception and not the rule that most inlet air comes within the breathing space of the occupant.
- IAQ can be improved by increasing ventilation rates and / or effectiveness.
- If the same level of ventilation air can be supplied then natural ventilation systems are superior to mechanical ventilation systems. The exception to this is when outdoor environments are highly polluted e.g. some city centres.
- It is possible to maintain good IAQ with low levels of fresh air using a well filtered HVAC system. These systems where employed should be well maintained because there is a high incidence of

contaminants trapped in filters being reintroduced into the occupied space.

- Building materials can contribute in a detrimental fashion to IAQ due to out gassing of VOC etc. On the other hand some materials can behave as 'reversible sinks' and absorb emitted chemicals.
- The implications of providing good IAQ are significant towards health and productivity of occupants.

UK. Typical construction materials were used and typical nursery use profile was assumed (BRE 2008).

The building is fully mechanically ventilated with ventilation rates at 8l/s per person. Heating set point was taken as 21^0C. Carbon dioxide was assumed to be a suitable surrogate to measure air freshness. This assumption only reflects a subset of IAQ issues surrounding the built environment but nonetheless can be considered a suitable starting point. A constant ambient concentration of 500ppm (by mass) was assumed. It was further assumed that the only source of carbon dioxide was the occupants. Occupants were distributed at 0.25persons/m^2 and assumed to be sedentary. For the purpose of this study only the children's rooms were considered for results outputs. The model was simulated for the winter period so as to emphasise the ventilation energy load.



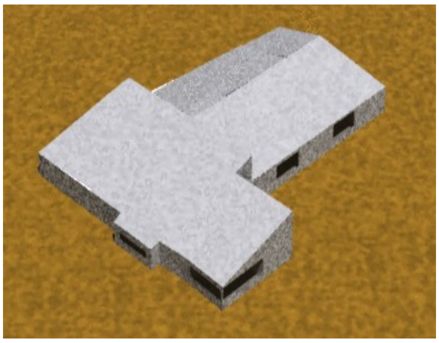


Figure 2 Radiance rendering (right) and plan view (above) of modelled nursery building showing children's rooms, circulation space and various occupied and unoccupied spaces

This paper examines the implications of providing different ventilation rates on energy use and IAQ and recommends means of lowering energy requirements without compromising air quality.

EXAMPLE NURSERY BUILDING

Model details (base case)

Figure 2 shows a one storey building. The building is used as a nursery for children up to the age of five. The building is predominantly open plan in terms of space reserved for children of different ages and is around 700 square meters. The location is Glasgow,

Simulation methodology

Simulations were based on the air flow network (multi-zone) model which was integrated with a thermal simulation model on a time step basis.

Temperature effects were thus taken into consideration dynamically. This was considered important because not including thermal effects can lead to erroneous results (many references are available e.g. Srebric 2008, Samuel and Strachan 2006). The network approach provides results at a macroscopic scale and does not resolve down to the micro-climatic detail one might expect when using CFD. This was considered superfluous because the purpose of this study is to look at ventilation rates and how it affects energy requirements in general and for the whole building. It is not to look at e.g. localised effects of specialised ventilation schemes for one room. Furthermore for the network approach contaminant concentration is obtained as a single number and it is assumed that incoming air is fully mixed with zone air before concentrations are calculated. This equates to perfect dilution of generated contaminants and is only rarely achieved in practice (Awbi 2003). The results from such an approach will give the lowest possible contaminant levels and even these were found to be considerably more than recommended. Acceptable levels were only obtained for a small subset of the simulated cases.

Results

Simulations were run in order to quantify how changing ventilation rates affects carbon dioxide concentration. The base case simulation was run with a ventilation rate of 8l/s per person. Results are presented for 2nd October which is fairly typical of the winter period. Worst case results were seen for extreme winter days and better results were seen for summer days. It was seen that with this level of ventilation the maximum carbon dioxide concentration was around 1500ppm which is in excess of the recommended value of 1000ppm (Sundell 1982). Such a result is not unusual and has been reported in monitoring studies (Carrer and Maroni 2002; Corsi et al 2002; Sowa 2002) and simulations (Samuel and Strachan 2006). Simulated carbon dioxide concentrations for one of the rooms

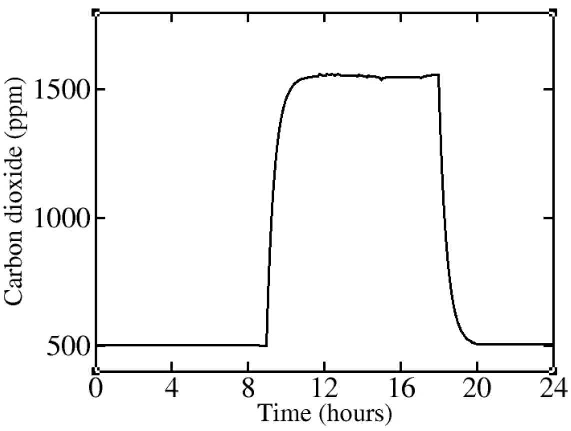


Figure 3 Carbon dioxide concentration in 2-3 year old children's room during typical winter day

is shown in figure 3. Such a distribution is typical of the other rooms in the building as well.

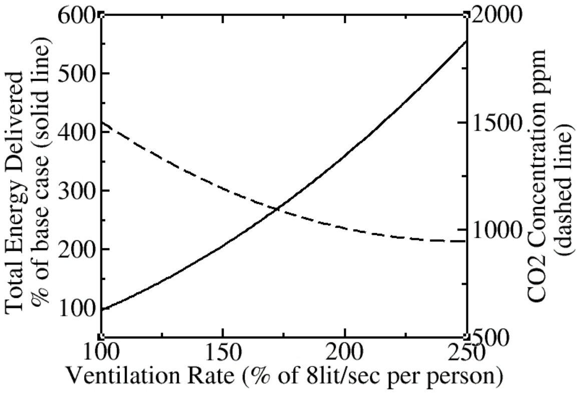


Figure 4 Energy use and CO2 concentration by ventilation rate

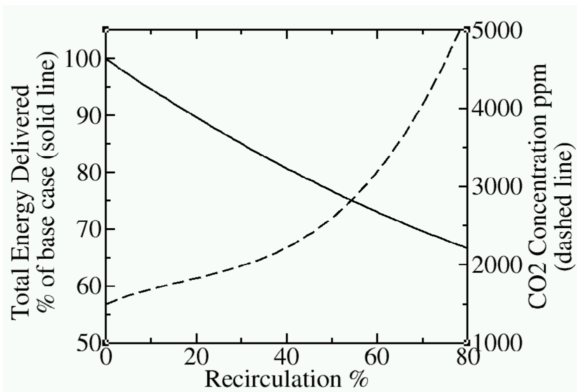


Figure 5 Energy use and CO2 concentration by recirculation

Ventilation rates for the rooms were then increased up to a maximum of 250% and the effect of this on carbon dioxide concentration and heating energy was studied. It was found that increasing ventilation rate to 250% increased heating energy to 550% while lowering concentrations by just 40%. This situation is shown in figure 4. Recommended maximum allowable concentration of 1000ppm was achieved by using a ventilation rate twice the recommended value of 8l/s.

In the next set of simulations the effects of recirculating were studied. Recirculation was varied from 25% to 75%. It was seen that energy requirements were lowered but IAQ worsened. This situation is shown in figure 5. It was found that with 75% recirculation heating energy requirement was reduced by around a third.

The third set of simulations looked at ventilation heat recovery. This mechanism can in theory give lower energy loads as compared to recirculation because good heat recovery units can have typical efficiencies around 90% whereas it is uncommon to have such recirculation levels. It was found that with 75% heat recovery efficiency the heating energy requirement was reduced by a third. There was not much appreciable benefit in heating energy requirement when heat recovery was increased to 90%. Base case ventilation levels were maintained so there was no change in concentration levels. The variation of heating load with different heat recovery efficiencies is displayed in figure 6.

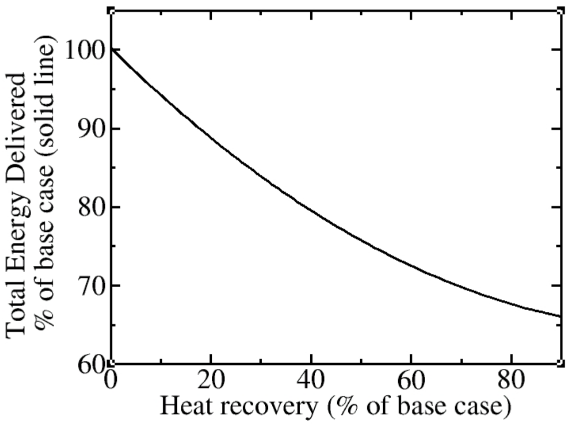


Figure 6 Energy use by heat recovery (same CO2 concentration as base case)

With 90% heat recovery and twice the recommended ventilation levels it was possible to bring CO_2 concentration to around 1000ppm. This translated into 130% base case energy use. Major outputs from some of the simulation runs are reported in table 1. The general trend is as expected.

CONCLUSIONS AND RECOMMENDATIONS

Implications of simulated and monitored findings suggest that with ventilation systems built to current requirements it is unusual that recommended IAQ requirements are met. There is need to improve upon ventilation recommendations being prescriptive, because these are not adequate enough to ensure that required fresh air is actually breathed in by the occupants. There needs to be more fresh (low contaminant concentration) air supplied to occupants to ensure optimal productivity and health. The two ways in which this can be done is by ensuring fresh air is introduced predominantly in the breathing zone or by increasing ventilation rates. The energy required to condition additional ventilation air is not proportional to improvement in IAQ but is in excess of it. Heat recovery alone although beneficial may be insufficient to overcome IAQ problems. The same can be concluded about extensive filtration where “fresh” air can be regenerated from stale air. A better method is by employing effective ventilation techniques such as provision of fresh air near the breathing space. Such techniques should be studied further because these methods can provide much better overall IAQ with lesser fresh air and energy requirements (Fanger 2006).

To portray an accurate picture the simulation tools employed should be sufficiently capable in terms of integration between thermal and air flow domains. Simplistic assumptions such as temperature scheduling should not be made as these can give misleading and sometimes totally inaccurate results (Srebric et al 2008, Samuel 2005). One simulation approach is multi-zone / network air flow methods coupled with CFD. The nodal method can look at the building and surroundings whereas CFD can be used to study micro-climatic variations of contaminants.

#	Model detail			CO_2 (ppm)	Heat load (kWh)
	fresh air %**	recirculation %	heat recovery %		
1*	100	0	0	>1500	21.2
2	150	0	0	1200	41.2
3	200	0	0	1000	77.7
4	250	0	0	950	115.6
5	100	25	0	1900	18.4
6	100	50	0	2600	16.3
7	100	75	0	4600	14.5
8	100	0	25	>1500	18.1
9	100	0	50	>1500	15.9
10	100	0	75	>1500	14.6
11	100	0	90	>1500	14.0
12	200	0	90	>1000	27.7

Table 1 Summary of major simulation runs
(base case model, **fresh air is expressed as a percentage of base case rate of 8l/s per person. Recirculation and heat recovery are expressed as percentage of fresh air rate)*

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