# Particle physics

Are air conditioned buildings better at filtering out external pollutants than their naturally ventilated cousins? A recent field study carried out by researchers at the BRE has yielded some surprising results.

BY DR VINA KUKADIA AND JOHN PALMER

As urban environments tend to be relatively highly polluted areas, it is usually assumed that natural ventilation may not be able to provide adequate indoor air quality. Mechanical ventilation and air conditioning systems are seen to clean the incoming air, even though there is evidence that such systems do not always provide clean fresh air to building occupants[1].

To discover whether such perceived differences are borne out in reality, the Building Research Establishment (BRE) undertook an investigation of two urban buildings, one naturally ventilated with openable windows and the other air conditioned, to investigate their relative attenuation of external pollution levels and to compare internal levels with existing air quality guidelines.

The two buildings are located adjacent to each other on an eight-lane major road in a major urban centre (figure 1). The naturally ventilated building is a four storey building with openable vertical sash windows and secondary glazing. Measurements in this building were made in a ground floor office, with windows facing onto the main road on one side and an internal courtyard on the other.

The air conditioned building is ten storeys high with a facade which is mostly sealed, although there is a limited number of unused openable windows. The third floor open-plan office was chosen for monitoring because the lower floors are recessed from the road and shielded by the access stairs to a footbridge.

The mechanical ventilation system draws external air from the tenth floor level via the rooftop plant room. The air is then filtered and heated prior to distribution to the ceiling voids for terminal reheat and cooling. There is no heat recovery. A radiator system also provides heating to the offices.

At the time of the tests, the offices in both buildings were in normal use with variable occupancy and normal office activities. Both offices had a no-smoking policy in place, and there were no gas appliances or any other significant internal sources of the measured pollutants apart from metabolic $CO_2$ from the occupants. Measurements were taken of the following: sulphur dioxide ($SO_2$), carbon monoxide (CO), oxides of nitrogen (NOx), carbon dioxide ($CO_2$), air change rates and traffic density.

Each building was provided with a set of high quality gas analysers, the outputs from which were recorded at five-minute intervals for the whole of the monitoring period (13-20 February 1996).

By using a switchable-pump sampling system, the instruments in the naturally ventilated building were also used for measuring the external levels of pollutants. They were calibrated immediately prior to the monitoring, and the instruments zeroed on alternate days by using a supply of uncontaminated air.

Building air change rates were measured by using the conventional technique of observing the decay of an injected tracer gas (sulphur hexafluoride) seeded into the areas of interest. During unoccupied periods, the decay of $CO_2$ generated by the occupants who had previously been in the building was also used as a measure of the air change rates.

Traffic densities on the main road were recorded by periodic direct observation and by using video recording. Wind speeds and direction were obtained from the local meteorological site.

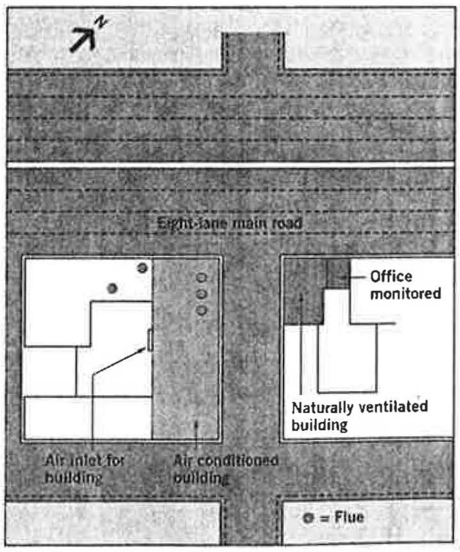


**FIGURE 1: Site plan showing the monitored buildings.**

### Test results

Over the seven day monitoring period, there were times when no significant levels of pollutants were recorded – either outside or inside the buildings (figures 2-5). The buildings appeared not to retain the external pollutants for long periods. The ability of the buildings to attenuate the external pollutants is shown in most cases by the peak internal concentrations being lower than that recorded externally.

Furthermore, it is apparent that neither building reacted to the rapid and sudden fluctuations seen in the external levels. The buildings tended to smooth out the external pollution levels over a time period of about an hour.

For occupants, the period of interest is the occupied day of 08.30 h to 17.30 h during the working week. Table 1 shows the ratio of the internal to external pollution concentration for this period. Generation of metabolic $CO_2$ by building occupants indicated an internal/external ratio greater than one. It is important to note that, for the pollutants, the levels indoors are always less than those outdoors.

### Average air change rates

Average air change rates obtained for the two buildings over the monitoring period were:

- ☐ naturally ventilated building: occupied 1·6 ac/h, unoccupied 0·8 ac/h;
- ☐ mechanically ventilated building: occupied 1·2 ac/h, unoccupied 0·4 ac/h.

In the mechanically ventilated building, the air change rate varied little while the system was operating. However, as expected, the air change rate in the naturally ventilated building was more variable and dependent upon the circumstances of operation and weather conditions. Over the period of the tests, wind speeds were recorded as being higher than normal, ranging from 12-24 mph with gusts of about three times the mean wind speed.

The short test period in this study allowed only a limited scope for investigating the performance of the buildings with regard to indoor and outdoor air quality, but a number of useful observations were made with regard to comparisons with guidelines on exposure levels of the contaminants under investigation.

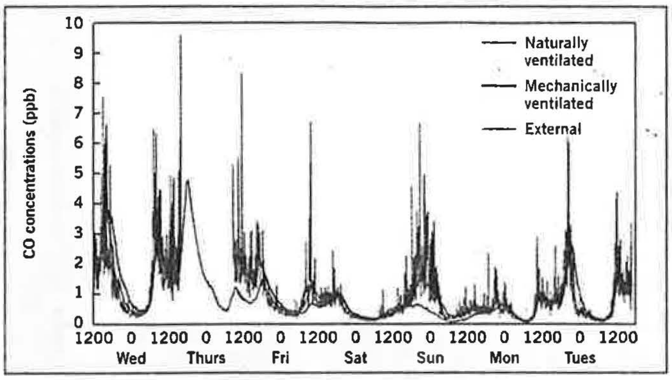


**FIGURE 2: Carbon monoxide concentrations (Birmingham: 13-20 February 1996).**

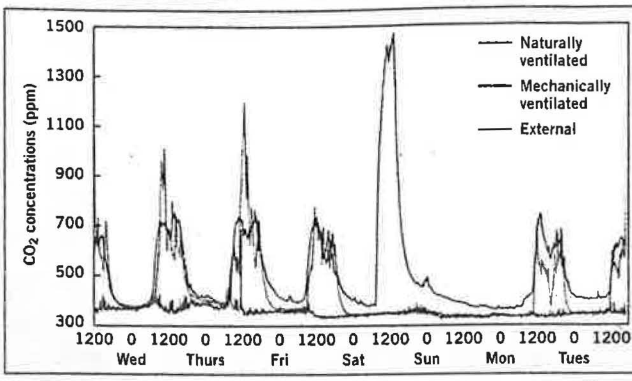


**FIGURE 3: Carbon dioxide concentrations (Birmingham: 13-20 February 1996).**

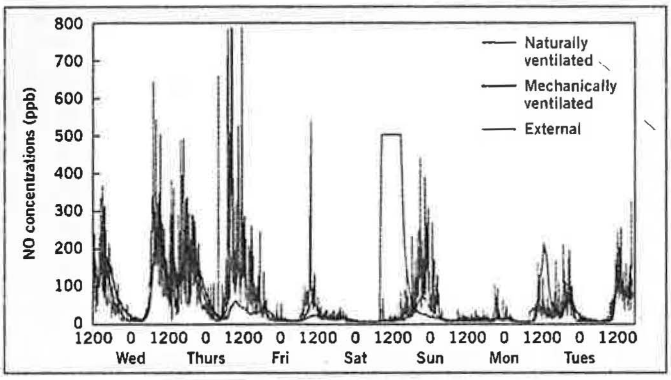


**FIGURE 4: Nitric oxide concentrations (Birmingham: 13-20 February 1996).**

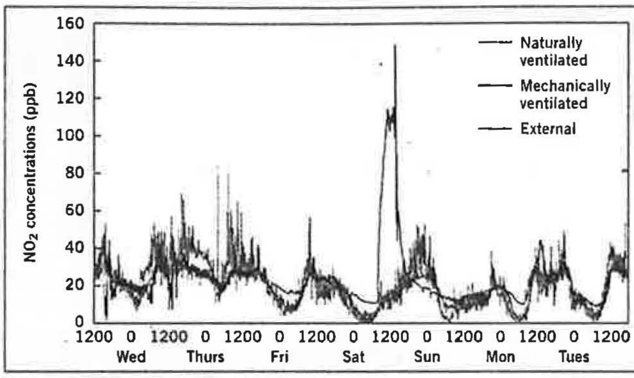


**FIGURE 5: Nitrogen dioxide concentrations (Birmingham: 13-20 February 1996).**

Traffic appeared to be the major source of CO and NOx pollution. Concentrations of these pollutants varied with the traffic density on the main road. $SO_2$ concentrations were not so clearly associated with the traffic.

The most prominent feature of the data is the exceptionally high levels of $CO_2$, $SO_2$, NO and $NO_2$ in the mechanically ventilated building on the Saturday morning from 06.00 h to 12.30 h – coincident with the period between the start-up and shut-down of the building's ventilation system. Levels were well in excess of the external concentrations and not seen inside the naturally ventilated building.

The obvious source for these gases in such high concentrations was either cross-contamination from the ventilation exhaust or high level discharges from boiler plant being drawn into the ventilation inlet. There are a number of boiler flues close to the building which may have been responsible for this, if not those on the building itself. A similar event on the Monday morning suggests that this was not an isolated incident.

Measured daily mean concentrations for the working week compared against some of the most appropriate guidelines for air quality demonstrated that there was little health risk in either of the buildings.

However, if the results from the weekend (figures 2-5) are compared, then the NO concentration exceeded (for a limited period) Her Majesty's Inspectorate of Pollution's guidelines, while the $NO_2$ concentration exceeded almost all the guidelines.

Results suggest that, for this particular building, there may be a cause for concern if these concentrations occurred when the building was occupied.

### Attenuation of pollutants

The results show that both buildings significantly attenuated the concentration of external pollutants. The ratios of the internal/external peak values in the occupied periods (table 1) indicate that the levels of the external pollutants monitored inside the buildings were generally less than 50% of the peak external concentrations. This was consistent over the period of monitoring and shows that this damping of the fluctuations of external pollutant levels would be valuable in reducing short-term exposure levels.

There was less attenuation of the mean concentration, but both buildings show better air quality indoors than outdoors in terms of the externally generated pollutants. The attenuation of the CO in the mechanically ventilated building was greater than in the naturally ventilated building. However, for the other pollutants the difference was somewhat less marked.

Based on these findings, a number of initial conclusions can be drawn about the attenuating capability of the buildings and the comparison of the internal measured pollutant concentrations with existing air quality guidelines. In both the naturally and mechanically ventilated buildings the indoor air quality followed the trend of that of the external air to which they were exposed. However, the concentrations of the external pollutants were attenuated by the building and the transient peak concentrations measured externally were approximately halved in value.

The possibility of drawing combustion products into buildings at high level has been shown to exist in the mechanically ventilated building. The building was chosen only for its location with respect to traffic density. However, the findings highlight the real danger of cross-contamination between ventilation exhausts and inlets at roof level and contamination from other sources.

The indoor air quality in both buildings over the main occupied period did not exceed any of the main health standards. However, most of the $NO_2$ guideline values were exceeded over the weekend when combustion products were possibly drawn into the air conditioned building.

In terms of indoor air quality it is not clear which guidelines should be followed when designing buildings. If the more stringent

**TABLE 1: CONCENTRATIONS OF MEASURED GASES FOR THE OCCUPIED PERIODS FOR MONDAY TO FRIDAY**

| Measured gas | | | External Naturally ventilated | | | | Internal Mechanically ventilated | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Peak | Mean | Peak | Mean | Internal/external ratio Peak | Internal/external ratio Mean | Peak | Mean | Internal/external ratio Peak | Internal/external ratio Mean |
| CO (ppm) | 9·6 | 1·8 | 4·1 | 1·7 | 0·4 | 1·0 | 3·0 | 0·9 | 0·3 | 0·5 |
| $CO_2$ (ppm) | 478 | 366 | 1197 | 650 | 1·5 | 1·8 | 800 | 646 | 1·0 | 1·8 |
| NO (ppb) | 798 | 114 | 241 | 97 | 0·3 | 0·9 | 256 | 78 | 0·3 | 0·7 |
| $NO_2$ (ppb) | 70 | 31 | 33 | 28 | 0·5 | 0·9 | 45 | 25 | 0·6 | 0·8 |
| $SO_2$ (ppb) | 40 | 11 | 10·6 | 4·4 | 0·3 | 0·4 | 13·4 | 3·9 | 0·3 | 0·4 |

## GUIDELINES AND STANDARDS

A number of guidelines or standards exist which deal with human exposure to contaminants which are potentially injurious to health. In the UK these are contained within the *Control of Substances Hazardous to Health (COSHH) Regulations 1988*[2] and the Health and Safety Executive's (HSE) *Occupational exposure limits EH40/95*[3].

Standards which deal more explicitly with air quality for the general populace are those of the World Health Organisation[4], which deal with indoor and outdoor air quality, and those of the UK's DoE Expert Panel on Air Quality Standards, which has begun to publish reports on the health effects of certain pollutants, recommending air quality standards for these.

Other more stringent guidelines are those which are included in Her Majesty's Inspectorate of Pollution Technical Guidance Note[5]. The European Community also sets guideline or limit values for some pollutants[6].

Turner and Binnie[7] studied the CO levels in a number of naturally and mechanically ventilated buildings, finding that externally produced CO was more prevalent in the mechanically ventilated buildings. This was thought to be due to the ingress of contaminated air from underground car parks in the ahus.

A study by Phillips et al[8] of four naturally ventilated buildings concluded that the air change rate was the determining factor for air quality – the greater the supply of external air the greater the presence of external pollutants indoors.

However, Ekberg[9] showed that it is unlikely that the relationship is related to the air change rate alone, since there is the potential for sinks and sources within the building.

Ekberg also showed that the effect of the rapidly changing concentrations of external pollutants is important in obtaining a more complete understanding of the relationship between indoor and outdoor air quality, and that short-term peaks in the concentration of external pollutants are significantly affected by the general response of the building.

This is also highlighted in Treple's[10] studies of ventilation strategies in cases of external pollution events.

Although evidence from recent buildings employing natural ventilation as a design strategy shows that acceptable ventilation rates can be achieved without resorting to mechanical ventilation[11], the level of externally generated pollution experienced in these buildings has not been considered directly with reference to indoor air quality and air quality standards.

**References**


[2]*COSHH Regulations 1994 Approved Codes of Practice* (ISBN 0-7176-0819-0).
[3]HSE, *Occupational exposure limits EH40/95*.
[4]WHO, "*Air quality guidelines for Europe*", WHO Regional Publications, European Series No 23, Copenhagen.
[5]Her Majesty's Inspectorate of Pollution, "Guidelines on discharge stack heights for polluting emissions", *Technical Guidance Note D1 (Dispersion)*, 1993.
[6]*EC Directive No 80/779/EE, Official Journal of the European Communities*, No L229, Vol 23.
[7]Turner S and Binnie P, "An indoor air quality survey of 26 Swiss office buildings", *Environmental Technology*, Vol 11, pp303-314, 1990.
[8]Phillips J *et al*, "The relationship between indoor and outdoor air quality in four naturally ventilated offices in the UK", *Atmospheric Environment*, Vol 27A, No 11, pp1743-1753, 1993.
[9]Ekberg L E, "The relationships between indoor and outdoor contaminants in mechanically ventilated buildings", *Indoor Air*, Vol 6, pp41-47, 1996.
[10]Treple I, "Ventilation strategies in the case of polluted outdoor situations", 9th AIVC Conference, Gwent, Belgium, 1988.
[11]ETSU, S 1160/11 *Gateway Two: Energy performance assessment*.


guidelines are applied, designers need to think carefully when designing for non-domestic buildings and their ventilation systems in urban areas to avoid exceeding the guideline values.

The study shows that there is no clear distinction between the two ventilation strategies in providing adequate indoor air quality with respect to externally generated air pollutants, other than when combustion products were entrained into the air conditioned building. It has highlighted a real need to address issues related to external air pollution and its sources, and the ways in which they affect the internal environment of buildings in urban areas whatever ventilation strategy is used.

Work in this area is continuing at the BRE with a view to providing strategies and solutions for effectively ventilating buildings located in urban areas where external air pollution is a problem.


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**Reference**


[1]Morris R H, "Indoor air pollution", *Heating, Piping and Air Conditioning*, 2/85.



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# Totally metabolic?

In principle, the results of carbon dioxide monitoring can be used to evaluate building ventilation rates and provide an indication of perceived indoor air quality. Here we review current knowledge about the use of metabolically-produced $CO_2$ in indoor air quality evaluation and control.


BY MARTIN LIDDAMENT


The concentration of metabolically-produced carbon dioxide ($CO_2$) in a space has become a popular indicator of indoor air quality – it is the basis by which many ventilation systems are controlled, and is used as a measure of compliance with various building codes and standards. However, there is an underlying concern that such measurements could give erroneous information, and that there may be a general misconception about the significance of metabolic $CO_2$.

Rates of $CO_2$ production are fairly well defined, and are dependent on the level of metabolic activity[1]. For any specific activity, production rate increases with body rate, reflecting the greater level of physical effort which must be applied. Physically fit people are able to do a greater level of work for each unit of $CO_2$ produced.

$CO_2$ is relatively easy and inexpensive to measure, and it is fairly stable in that it is not especially reactive or absorbed by surfaces. So, in principle, $CO_2$ can be used to evaluate the ventilation rate, determine the proportion of outdoor air that is blended with recirculated air and provide an indication of perceived indoor air quality.

### Indoor concentrations of $CO_2$

Indoor concentrations of $CO_2$ depend on outdoor levels of the gas and the production rate of $CO_2$ within the space. In the office space itself, this extra contribution is primarily assumed to result from metabolism, but in the home open gas cookers could make a further significant contribution.

To determine the contribution to $CO_2$ generated in a space, the difference between the indoor concentration and the outdoor concentration should be measured. However, for approximate purposes, an outdoor value of between 350-400 ppm is usually assumed.

For precise analysis some authors, when referring to indoor $CO_2$ concentrations, auto-