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.

Dr Vina Kukadia is a senior researcher at the BRE's Environmental Performance Assessment Centre. John Palmer is principal of John Palmer Associates.

Reference

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

This research was supported by the Department of the Environment (DoE) and carried out under the DoE Construction Sponsorship Directorate's Energy-Related Environmental Issues (EnREI) programme.

The research team would like to thank the owners and occupants of the test buildings for their assistance with the project. The assistance of R Woolliscroft (Sheffield Hallam University) when working at the BRE, R Watkins and W Pane of John Palmer Associates and I Ridley of the University of Westminster is also gratefully acknowledged.

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.

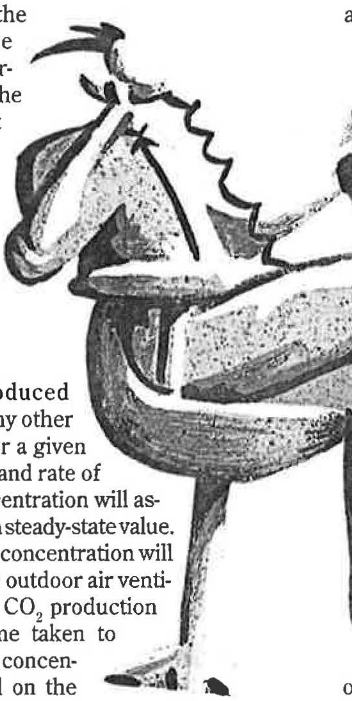
CO_2 is relatively easy and inexpensive to measure, and it is fairly stable in that it is not especially reactive or absorbed by surfaces. So, in principle, CO_2 can be used to evaluate the ventilation rate, determine the proportion of outdoor air that is blended with recirculated air and provide an 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, automatically subtract the outdoor value (ie they give the difference value). On the other hand, most standards that refer to an acceptable indoor CO_2 concentration refer to the absolute or total room concentration.



Steady-state

Metabolically-produced CO_2 behaves like any other pollutant in that, for a given level of occupancy and rate of ventilation, its concentration will asymptotically rise to a steady-state value. At steady-state, the concentration will depend on both the outdoor air ventilation rate and the CO_2 production rate, while the time taken to reach steady-state concentration will depend on the air change rate alone.

The approximate relationship between steady-state concentration (absolute) and ventilation rate is shown in figure 1. If steady-state concentration has been achieved, and the level of activity is known, then provided there is no other source of generation the measured CO_2 concentration provides an indication of the amount of fresh outdoor air being supplied to each building occupant.

Transient concentrations

More often than not, steady-state concentration is not reached. Either the volume of enclosed space is so large that it would take many hours to achieve or the level of occupancy is continually varying.

Under these circumstances a spot measurement of CO_2 can become meaningless. However, various techniques have been developed to estimate ventilation rates from the transient CO_2 concentration. Andrew Persily has investigated this in detail and offers several solutions[2].

This aspect has also been addressed by the US Environmental Protection Agency (EPA), following concerns that too much reliance is placed on transient spot measurements. Work has been carried out on the errors associated with spot measurements, and methods devised to improve upon ventilation estimated from CO_2 measurements. The main areas of error were concerned with the time it takes to reach steady-state conditions, assumptions about the rate of CO_2 generation and fluctuations in outdoor concentration.

Below about 3 ac/h, it takes around three hours to achieve a steady-state condition. However, allowances can be made for the non-attainment of steady-state conditions based on the duration and level of occupancy[3].

For improved accuracy, more precise knowledge is needed about metabolic generation rate, for example the ratio of production for men and women carrying out similar tasks is approximately 1:0·76. Such allowances have been incorporated into a ten-step guide to estimating air change rates from straightforward parameters[3].

Persily has also reviewed some of the background to the interest in CO_2 including its relationship with peoples' perception of indoor air quality, principally in relation to odour. He has cited a number of examples indicating the relationship between CO_2 concentration and body odour. Particularly, there was consistent data linking CO_2 concentration with the percentage of people visiting a space who were dissatisfied with the level of odour (ppd).

This linkage is associated with the actual CO_2 concentration measured rather than the steady-state value. Typically, 20% ppd corresponds to a CO_2 concentration of 650 ppm above the outdoor value, ie approximately 1000 ppm actual CO_2 concentration (figure 2).

Measuring CO_2

Various techniques are available for measuring CO_2 and they have been well documented[4]. Probably the most common method for demand control systems is non-dispersive infrared detection, which makes use of the property of a gas to absorb energy from an infrared light source. The resultant heat generated is detected as a volumetric change.

This absorption property is also applied to photo-acoustic detection in which absorption from a pulsed infra-red source, tuned to the specific characteristics of CO_2, is translated to a sound wave. The sound intensity is then related to gas concentration. Both systems have a resolution of, typically, ±50 ppm and suffer from drift caused by dust on optics and a gradual deterioration in lamp performance.

Other methods include potentiometric, in which CO_2 is diffused into an electrolyte resulting in a change in applied voltage, and amperometric, which is based on the electrochemical diffusion of CO_2 across a membrane into an electrolyte. Again, sensitivity is typically ±50-100 ppm and drift can be significant. Sensor life can also be limited.

Experience, therefore, indicates significant instrument drift. One monitored study has shown that, after a few months, a system having a set-point of 1000 ppm did not react until the actual concentration had reached 1800 ppm. Several contributors to the study emphasised the need for regular instrument calibration. The conclusion, then, must be that any demand control sensor must contain provision for simple (possibly automatic) calibration. In short, an unattended system will fail, probably within only a few months.

CO_2 is largely non-toxic, with evidence suggesting that concentrations as high as 10 000 ppm or more have no significant health effects. For normal occupancy conditions, however, measured CO_2 concentrations significantly above 1000 ppm provide an indication of inadequate ventilation for comfort and may mean that the ventilation rate is inadequate to dilute other, more harmful pollutants that may be present.

In this case, monitoring CO_2 concentrations can make a valuable contribution to indoor air quality assessment.

Unfortunately, a measurement of concentration (especially a 'spot' measurement) at or below 1000 ppm does not necessarily provide an indication of the adequacy of ventilation – there may be other pollutants present, perhaps insufficient time has elapsed to provide a steady-state reading or the building may be at reduced occupancy.

If CO_2 is continuously monitored then it is possible to evaluate the adequacy of air change by considering the rates of growth and decay in concentration as the building occupancy level varies.

Martin Liddament is head of the Air Infiltration and Ventilation Centre at the University of Warwick Science Park, Coventry.

References

[1]British Standards Institution, *BS 5925:1990.*

[2]Persily A K, "A study of ventilation and carbon dioxide in an office building", *ASHRAE Transactions*, Vol 100, Part 2, 1994.

[3]Mudarri D, "*Interpretation of CO_2 measurements in buildings*", US Environmental Protection Association Draft Report, April 26, 1996.

[4]Liddament M W, "*A guide to energy efficient ventilation*", AIVC, 1996.

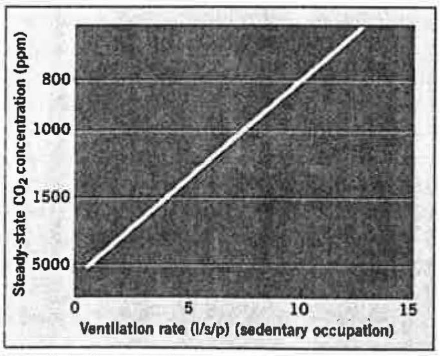


FIGURE 1: The approximate relationship between steady-state concentrations of CO_2 and building ventilation rates.

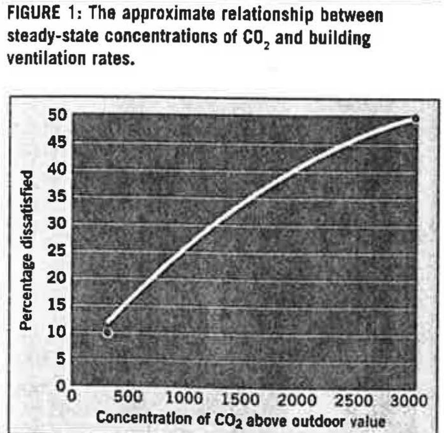


FIGURE 2: Metabolic CO_2 as an indicator of acceptable indoor air quality levels.