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Summary Pubs, bars and restaurants are places where smoking policy is still left to the discretion of the manager and where smoking is often permitted. However, there is demand to take measures to eliminate or reduce the effects of environmental tobacco smoke (ETS) to non-smoking occupants. This paper reports the results of a field study in which ETS markers and air flow patterns were monitored in a number of occupied spaces. The measurements included CO concentrations as a marker of ETS, CO_2 concentrations as a general indoor air quality (IAQ) indicator and air flow measurements to estimate ventilation and infiltration rates. The findings indicate that shared-space smoking needs action beyond that of simple ventilation, segregation of occupants or simple partitioning to minimise the potentially harmful effects of ETS to both staff and customers.

Effectiveness of simple ventilation strategies and partitioning in mitigating the effects of passive smoking

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1 Introduction

This paper reports some of the findings of a wider study funded by the Chemicals and Biotechnology Division of the Department of Environment, Regions and Transport and carried out by the Buildings Research Establishment Ltd (BRE). The study was concerned with the effectiveness of various simple ventilation strategies to minimise contamination from smoking to non-smoking areas in public buildings.

The project had its basis in the report[1] published in 1988 by the UK Independent Scientific Committee on Smoking and Health, which concluded that there was 'a small increase in the risk of lung cancer from exposure to environmental tobacco smoke (ETS)'. This increase is in the range of 10 to 30% and is calculated to amount to several hundred out of the current total of about 40 000 lung cancer deaths in the UK. Many reports and papers with similar conclusions have also been published in the UK and other countries[2–4]. More recently, the SCOTH[5] report has confirmed that 'exposure to ETS is a cause of lung cancer and, in those with long term exposure, the increased risk is in the order of 20–30%. There is also evidence that passive smoking is a cause of heart disease and cot death, middle ear disease and asthmatic attacks in children. Restrictions on smoking in public places and work places are necessary to protect non smokers'.

As a result, concerns over the exposure of non-smoking building occupants to ETS has imposed smoking restrictions or bans in many public and commercial office buildings. However, smoking is still allowed in some public buildings such as public houses, bars and restaurants. Regulations across Europe are not consistent and in many cases culture and etiquette impose conditions rather than legislation[6]. Catering and hotel industries are increasingly aware of the increased ventilation provision required for smoking areas and the need for physical segregation between smokers and non-smokers[7]. In the UK, the voluntary Code of Practice on Smoking in Public Places[8] states that non-smoking should be the norm in public places because (among other reasons) ventilation alone does not adequately protect against the effects of ETS. The Code of Practice gives practical guidance by dividing premises into two categories. The first category includes places where the public attend out of necessity (or to receive a service) such as for shopping, advice/money transactions, travel, health and education. The policy here should be to ban smoking altogether, especially where people are not expected to stay long. The second category is places where the public attend out of choice for food or entertainment, education (e.g. museums) and sport or recreation. In places such as these, implementation of an effective smoking policy is at the discretion of the manager of the facility, but in all cases the Government expects efforts to be made to cater for the interests of the non-smoker. Food/entertainment premises are considered to be the most likely places to permit smoking.

In such cases, setting up rooms or areas for smoking and the relationship of these with non-smoking areas will affect the amount of contamination transfer from one space to the other. Where separate rooms for smoking are available, a ventilation strategy can be more easily provided to minimise contamination in the non-smoking rooms. However, if only one area of a larger enclosure is a smoking area (the most likely case in a restaurant or public house), the ventilation strategy is the crucial factor in getting it right. In addition, partitioning of the space, coupled with an optimum ventilation strategy, may help to alleviate the effect.

This paper first reports the conclusions of a computational study published elsewhere[9] on the effectiveness of various ventilation strategies and single space partitioning. It then discusses the suitability of using carbon monoxide (CO) as an indicator of ETS in the context of the present study. Finally, it reports results of a field study of CO, metabolic carbon dioxide (CO_2) and air flow measurements in one bar, one pub and one restaurant where smoking and non-smoking areas were assigned with or without partitioning.

2 Previous work: computational study

A comparative assessment was initially carried out using computational fluid dynamics (CFD) modelling of alternative ventilation strategies and space partitioning[9]. The main results from the simulations are summarised below.

- Increased ventilation decreases the overall concentration levels but not linearly.
- Increasing the number of smokers produces a linear increase in the concentration of tobacco smoke everywhere in the space.
- Higher extract rates in the smoking area (for the same ventilation rate) reduce the migration of tobacco smoke to the non-smoking area. Simulations indicate that an increase of the extraction rate of 50% in the smoking area can result in a 25% reduction of pollutant concentration in the non-smoking area. However, the reduction is smaller in the smoking area.
- Concentration of ETS increases with height when the space is ventilated through displacement systems, while a more even concentration results from mechanical extract systems.
- A full height partition with open access between smoking and non-smoking areas and combined with a displacement ventilation system or a natural ventilation strategy can reduce the contaminant in both smoking and non-smoking areas. In the case of displacement ventilation with full partitions, it was observed that concentrations in both areas were reduced by about 10% relative to the same strategy without partitions. Such a strategy results in almost negligible concentrations in the non-smoking area, equating to a reduction over 95% relative to the smoking area. In the case of natural ventilation with full partitions, it was observed that concentrations in the non-smoking area were reduced by about 10% relative to the same strategy with no partitions. No reduction was observed in the smoking area; on the contrary, levels there were increased marginally. The difference in concentration between smoking and non-smoking areas with full partitions was about 80%.
- A low-level (say 1.7 to 2.0 m high) partition with open access between smoking and non-smoking areas reduces the concentration in the non-smoking by about 10% compared to an arrangement without partitions. However, there is no such decrease in the smoking area. The difference in concentrations between smoking and non-smoking areas with full partitions was about 75%.

Therefore it was concluded that ventilation coupled with open partitioning may reduce somewhat the effects of passive smoking but that it is not sufficient to eliminate the effects unless specific attention is paid to the ventilation system.

3 Carbon monoxide as an indicator of ETS

In order to confirm and enhance the conclusions of the computational study, field measurements were carried out in suitable occupied spaces. For this, the easily detected CO, a major by-product from tobacco smoking, was used as an indicator of ETS. Although CO is not the best ETS marker because of possible cross contamination from other sources, for the purpose of the present study—which examines the effect of ventilation—it was considered adequate provided that secondary sources (such as background and cooking) were identified and eliminated.

This assumption was tested by taking measurements in two public houses. In the first, CO was measured for six consecutive days in the smoking area at a discreet place at about 2.2 m height on a shelf behind the bar. Figure 1 shows a typical daily trace. Background levels were measured between 0.5 and 2.5 ppm. Each day there are two peaks corresponding to the two opening times, with the evening peak being higher. Levels regularly exceeded 10 ppm and on two occasions reached 16 ppm. Lunchtime values were typically 8 ppm. CO levels are seen to fall dramatically each evening, after closing time, when the doors are kept open to usher out the customers.

Similar CO measurements were taken over a busy weekend in another typical traditional pub where smoking is permitted. Measurements were taken from eight sampling points including one in the seating area, one above the bar, one in the centre of drinking areas and another three in the seating area at three heights; 1, 2 and 3 m above the floor. Figure 2 shows the monitored values of three points (seating areas, above the bar and drinking area) and indicates an occupancy-related pattern with increased levels at lunchtime, an early evening peak and a build-up towards late evening/closing time (0130 h). No significant variations were observed at the vertical plane.

In general, the data gathered during the measurements indicated that CO appeared to be a very useful indicator of ETS with the levels recorded matching the observed intensity of smoking (i.e. correlation between the CO levels measured and the counted number of smokers). Therefore, CO was subsequently measured during the main field study.

4 Field monitoring

Field monitoring including continuous sampling of CO and metabolic carbon dioxide (CO_2) and air flow measurements was carried out in the following three spaces:

- University bar with a mechanical ventilation system and segregated (but not partitioned) smoking and non-smoking areas

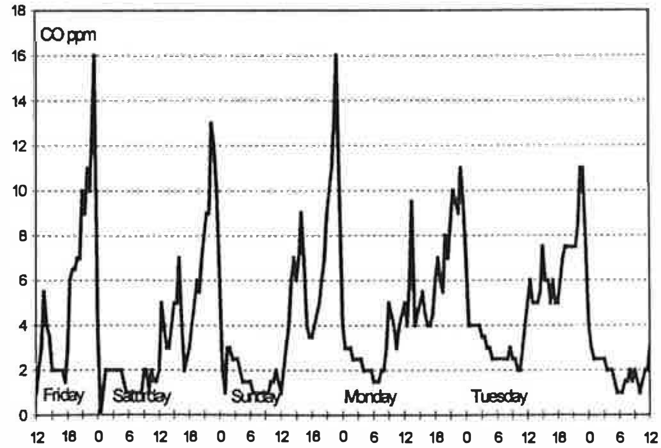

Figure 1 Carbon monoxide levels behind the bar in a pub over five days. Each day includes two peaks corresponding to the two opening times, with the evening peak being higher

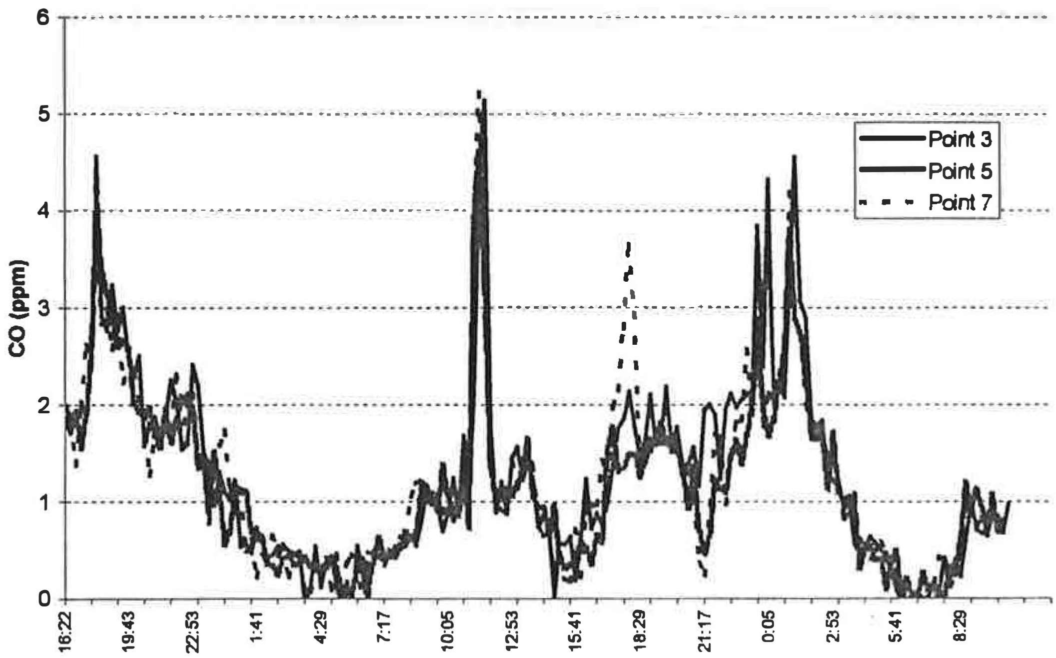

Figure 2 Carbon monoxide levels at three locations in a pub over a weekend. Point 3 is located in the seating smoking areas, point 5 above the bar and point 7 in the drinking area. Smoking is permitted throughout the pub. Lunchtime and evening peaks are observed

— 'Modern' public house serving food and including a children's area with a ducted warm air heating and ventilating system with additional extraction in the non-smoking children's area (but not partitioning)
— Restaurant with mechanical ventilation and separated smoking and non smoking areas through a partition.

4.1 University bar

Description of the bar

The bar is situated on the ground floor of a university building and is L-shaped with dimensions 23 m × 12 m. Approximately one third of the space is designated non-smoking area and is at a raised level 0.7 m above the main part of the bar. Apart from a handrail along the edge of this dais, there is no physical separation of the two areas. Double doors lead off both areas to circulation spaces. The bar was mechanically ventilated without recirculation; air was supplied through six ceiling-mounted grilles, with one in the non-smoking area, three in the smoking area and one at the interface between the two areas. There were also three annular supply air vents at ceiling level behind that bar counter. Air is extracted through 14 grilles (four of these located in the non-smoking area) at a rate of about 7 ac h^{-1} (air changes per hour). The bar is open Monday to Friday from 1200 h to 1430 h and from 1715 h to 2230 h.

Equipment and monitoring schedule

The CO and CO_2 monitoring equipment were installed on a Monday and continuous (10 minutes average) monitoring took place for five days. Eight sampling points were located in the smoking and non-smoking areas at a height of about 2.5 m plus one external point.

Ventilation rates were determined by discharging SF_6, mixing thoroughly and recording the decay rate. The mechanical ventilation system ensured that mixing was maintained. Air supply and extraction rates were measured using a hot-wire anemometer placed in front of the grilles. Air movement was visualised using cigarettes placed in various locations in the smoking areas (smoke detectors precluded the use of smoke pellets in the bar).

Four tests were carried out in the space as described below. Tests 2 to 4 were designed to improve the ETS separation between smoking and non-smoking areas. For each test condition, data were recorded every ten minutes for at least one day:

1 As found.
2 With partitions. A series of polycarbonate panels were placed (concertina fashion) against the handrail at the interface between the smoking and non-smoking areas. This was a barrier effectively 1.75 m high by 4 m wide.
3 With modified ventilation. The extract grilles in the non-smoking area were sealed with polythene in order to increase pressurisation in the zone.
4 With modified ventilation and partitions.

Results and discussion

The CO data for the four test conditions are summarised in Figure 3. The variations in CO and CO_2 concentrations are shown in Figure 4. A first observation is the generally low level of CO as a result of cigarette smoking in the bar. This contrasts with the much higher levels seen in the public houses measured as part of the preliminary study and others reported later. The main reason for this is thought to be the relatively higher air change rate for the occupancy, which is also supported by the CO_2 levels.

Figure 3 indicates a 30–40% reduction of CO level in the 'as found' conditions (day 23). When partitions were added, the reduction is similar (37–44%) (day 26). Similar reductions were recorded during the other two intervention periods (days 24 and 25). The results from the ventilation tests showed that air change rate did not vary for the different test conditions and was about 7 ac h^{-1}.

To get an indication of the broad pattern of air movement within the spaces, individual lighted cigarettes were located at nine positions in a vertical plane at the interface of the two zones. The vertical spacing was 750 mm and the horizontal spacing was 1220 mm. The cigarettes were positioned on

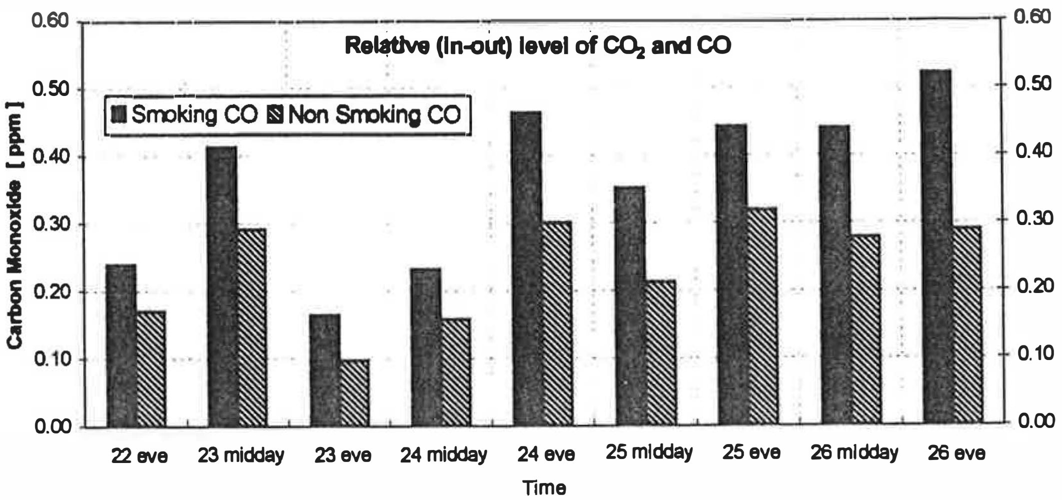

Figure 3 Averaged carbon monoxide levels in the smoking and non-smoking areas of a restaurant during four testing conditions (23) as found, (24) with partitions (25) with modified ventilation and (26) with partitions and modified ventilation. In all cases, CO levels were reduced by about 30–40% in the non-smoking area

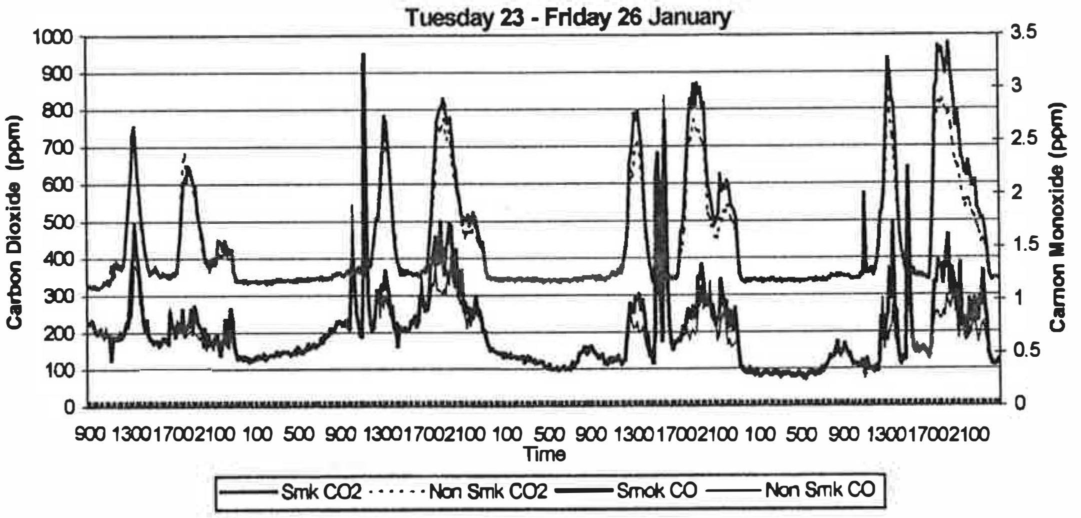

Figure 4 Carbon monoxide and carbon dioxide levels over four days in a restaurant in smoking and non-smoking areas. A small reduction in CO levels is observed in the non-smoking area

ash trays supported on stacked bar tables. The observation of the smoke movement was made under two conditions of segregation: as found and with partitions in place. In the 'as found' condition, the smoke movement indicated that air at the lower level was flowing away from the non-smoking area, but at high level there was migration towards the non-smoking area. Visual observations indicated a general circulation current. With the partition in place, the low-level air movement from the non-smoking area was not repeated and the smoke rose vertically to the higher level when it drifted, as previously, towards the non-smoking area.

4.2 Modern pub with children's area

Description of the pub

This is a large public house serving food and having a local children's licence and with smoking prohibited in the food area. Ventilation is by means of a ducted warm air heating and ventilating system. There are extraction fans in the windows of the raised food/children's area as well as ceiling extraction fans

Equipment and monitoring schedule

CO and CO_2 concentrations were monitored at eight sampling points placed across the room at heights between 2.0 and 2.5 m above floor levels; three in the drinking area, one adjacent to the toilet (smoking area), one in the entrance lobby, two in the seating/children's area (non-smoking) and one near the food servery (non-smoking). Monitoring took place over a busy weekend and ventilation measurements with the mechanical system switched off were carried out. Natural air infiltration levels were measured to be around 0.2 ac h^{-1}. It was not possible to carry out any intervention studies in the pub and monitoring concentrated on the spatial distribution of pollutants in the 'as found' condition.

Results and discussion

Figure 5 shows the profile of CO over the weekend and shows an occupancy-related pattern with increased levels at lunchtimes and evenings and with occasional peaks rising to about 2200 h. Figure 6 shows a profile for CO over a 24-hour period in two locations. Location 4 is representative of non-smoking food area and location 12 is the general bar/smoking area. It can be seen that CO levels are higher in the non-smoking area. Further analysis of measurements indicated little spatial distribution variations. The effect of the extract fans was to reduce the overall average concentrations of CO throughout the property and to alter the spatial concentrations in a manner that did not encourage lower smoke levels in the children's area. This is demonstrated by consideration of the results at one sampling point at the children's areas and one sampling point at

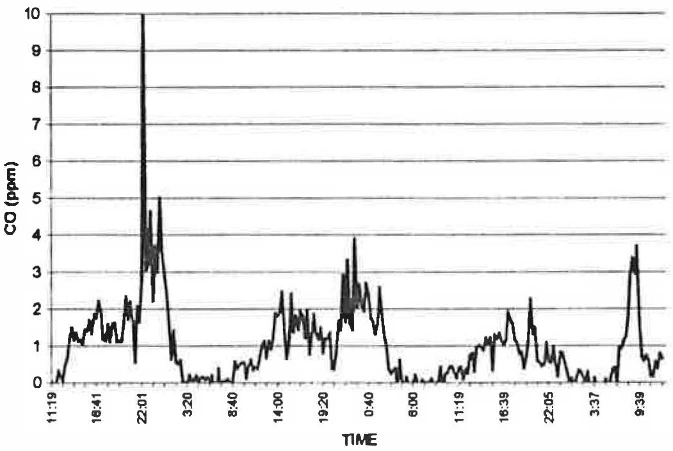

Figure 5 Carbon monoxide profile over a weekend in a pub in the smoking area

the bar. The concentration at the first point was increased 24%, whereas at the second point it was reduced by 16%.

4.3 Restaurant

Description of the restaurant

A staff restaurant was selected for monitoring because it comprised two areas of seating, a large open area with servery and a 'separate' smoking area, divided by a 1.8 m high partition from the larger main area. The restaurant is at the first floor of a three-storey 1960s block. Mechanical ventilation is by means of two window-mounted supply and extraction fans. The intended mode of operation is for supply into the main area and extraction from the smoking areas. In practice, the supply fan is rarely used as it results in considerable discomfort to the occupants and balance air is mostly drawn from the entrance area.

Equipment and monitoring schedule

The equipment used for monitoring was as described in section 4.2 above. Two tests were carried out as follows:

— Ventilation through mechanical means as described above and providing 3.3 ac h^{-1}

— Mechanical ventilation system switched off and natural ventilation provided at a measured value of 0.45 ac h^{1}.

The sampling points were located approximately 1.8 m above floor level; three in the smoking area, four in the non-smoking area and one in the entrance doorway; two additional sample points were measured in the vertical plane.

Results and discussion

Figure 7 shows CO levels during a typical weekday with natural ventilation only and Figure 8 shows levels with mechanical ventilation. The profiles indicate general occupancy-related patterns and clearly demonstrate differences between smoking and non-smoking areas (point 3 non-smoking and point 5 smoking). The vertical distribution of CO during a typical occupied period showed a slightly higher average concentration (10%) from floor to ceiling. The levels of CO measured in the non-smoking area were low but, relative to the smoking area, were higher than expected (at best, 54% lower, at worst 23%). This would indicate that neither the ventilation nor partitioning strategies were fully effective. With the mechanical ventilation switched on, 'smoke' diffusing into the non-smoking area was halved.

5 Conclusions

The data gathered during the measurements in one bar, one restaurant and three public houses indicate that CO appeared to be a useful indicator of ETS with the levels recorded matching the observed intensity of smoking. These data were gathered to assess the effectiveness of ventilation and partitioning and not to estimate the effects of personal exposure to ETS. Patterns are also consistent with occupancy patterns with peaks occurring at busy times.

In general, from the measurements it can be concluded that ventilation strategies alone, while being able to reduce the ETS levels, are generally insufficient in reducing the migration of ETS into an arbitrarily selected non-smoking space. Similar conclusions from field measurements have been reported elsewhere[10].

The introduction of open partitioning may reduce CO in the non-smoking area by a further small percentage, but

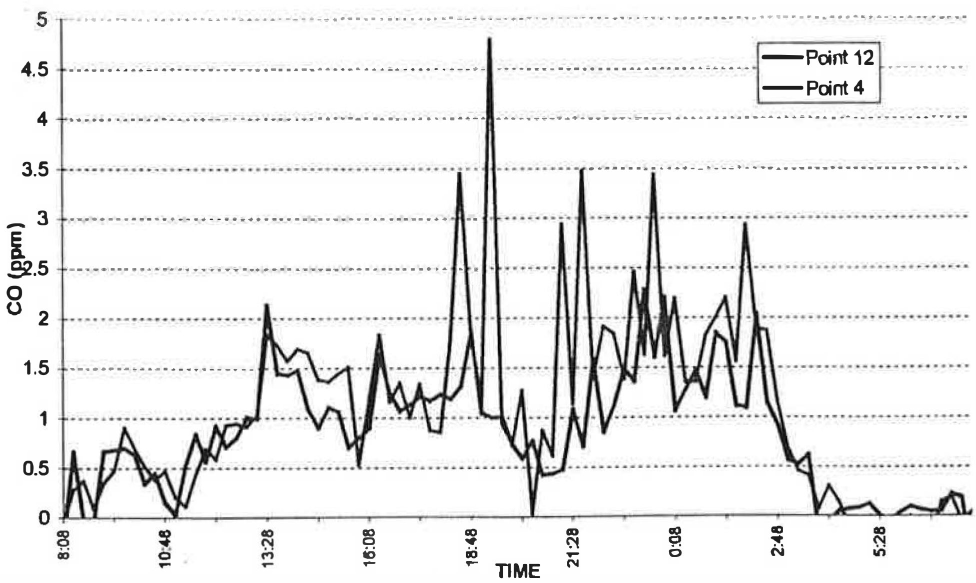

Figure 6 Carbon monoxide profile over 24 hours in a pub. Point 4 is representative of non-smoking areas and point 12 is located in the general bar smoking area. It can be seen that CO levels are higher in the non-smoking area

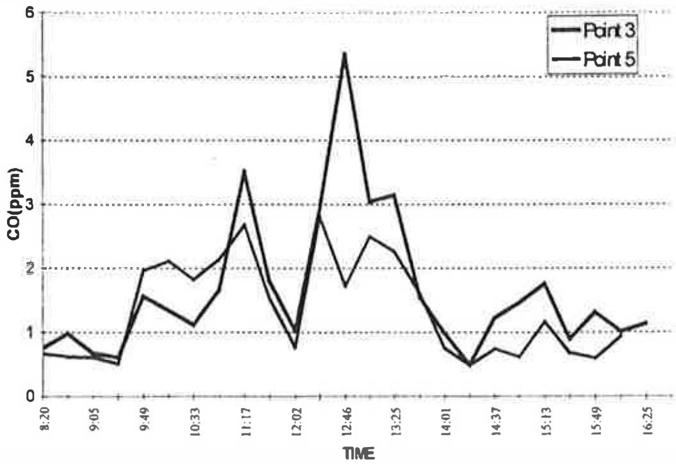

Figure 7 Carbon monoxide levels in a naturally ventilated restaurant (0.5 ac h^{-1}). Point 3 is in the smoking areas and point 5 is in the non-smoking area

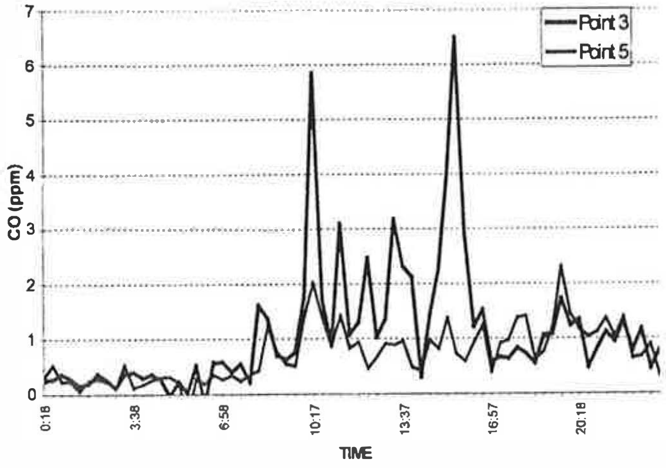

Figure 8 Carbon monoxide levels in a mechanically ventilated restaurant (3.3 ac h^{-1}); same restaurant as in Figure 7. Point 3 is in the smoking areas and point 5 is in the non-smoking area

this depends on many parameters and cannot be generalised.

However, the following general guidelines have been derived:

— Maximise the distance between smokers and non-smokers, ensuring that there is limited foot traffic between the zones.
— Increase air change rates in both zones.
— Install barriers between the zones.
— When circulation routes divide two zones, install barriers adjacent to the smoking area so that the circulation route is through the non-smoking area.
— Check, particularly in establishments with kitchens, that separate air extraction from an adjacent space is not undermining attempts to contain ETS in the public area.

Our view is that the only possible and practicable solution is to physically separate the smoking area and provide a separate ventilation system.

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