Human exposure to particulate and gaseous pollutants in a bar

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ABSTRACT

There is increasing evidence of a causal link between airborne particles and ill health and this study examined the exposure to both airborne particles and the gas phase contaminants of environmental tobacco smoke (ETS) in a bar. The work reported here utilized concurrent and continuous monitoring using real-time optical scattering personal samplers to record particulate (PM_{10}) concentrations at two internal locations. Very high episodes were observed in seating areas compared with the bar area. A photo-acoustic multi-gas analyser was used to record the gas phases (CO and CO_2) at eight different locations throughout the bar and showed little spatial variation. This gave a clear indication of the problems associated with achieving acceptable Indoor Air Quality in a public space and identified a fundamental problem with the simplistic design approach taken to ventilate the space. Both gaseous and particulate concentrations within the bar were below maximum recommended levels although the time-series analysis illustrated the highly episodic nature of this exposure.

INDEX TERMS

Air quality; Ventilation effectiveness; ETS

INTRODUCTION

A proportion of public opposition to exposure to Environmental Tobacco Smoke (ETS) stems from its potential for causing irritation and annoyance but, for the most part the passive smoking debate relates to the health risks of exposure and the presence of several known or suspected human carcinogens in tobacco smoke (Walsh *et al.*, 1984; Weetman, 1992).

This research has its basis in the report by the UK Independent Scientific Committee on Smoking and Health (Froggatt, 1988), which concluded that there was 'a small increase in the risk of lung cancer from exposure to environmental tobacco smoke'. This increase is in the range of 10–30% and is calculated to amount to several hundred out of the current total of about 40 000 lung cancer deaths in the UK. More recently, the Scientific Committee on Tobacco and Health (1998) 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 have 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.

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For most buildings the only practical way of limiting the airborne concentration of the pollutants is by dilution with fresh air from outside the building. In public houses this is normally done by using mechanical ventilation, typically by the use of extract fans through windows and walls. If the systems are more complicated then there is a risk of introducing additional hazards due to duct contamination by viable organisms such as bacteria and fungi. The introduction of fresh air will also dilute the persistent smell associated with ETS.

Previously reported work (Currie and Capper, 1994) identified problems in respect of the traditional design approach to ventilated spaces and showed where improvements could be made to accommodate best environmental practice. The studies demonstrated the weaknesses of the traditional approach to perceived air quality problems, where mechanical extract ventilation is installed and operated on an ad-hoc basis.

METHODS

The ETS exposure of building occupants is now commonly referred to as Second-hand Smoke (SHS) and comprises the combustion products of tobacco from the burning ends of cigarettes, pipes and cigars (sidestream smoke) and exhaled smoke from smokers (mainstream smoke). Nearly 85% of the smoke in a room results from sidestream smoke (Wakeham, 1961). In order to monitor SHS/ETS levels it is normal to consider surrogates. The most commonly used surrogate, and the one monitored in this study, was CO. CO_2 levels were also measured, generally being regarded as a good indicator of overall indoor air quality relating to occupancy. In addition, continuous sampling of the respirable particulate fraction of ETS, measured as PM_{10}, was undertaken in an attempt to correlate the spatio-temporal distribution of the different component phases.

The equipment used to measure the gas concentrations was a Brüel & Kjær Gas Analyser Type 1302, whose detection principle is based on photoacoustic absorption. It allowed unattended monitoring of gas concentrations for up to six gases simultaneously and provided qualitative analysis measurements on-site. This was connected to a CBISS multi-point sampler unit. A notebook computer provided control and data logging functions using proprietary software. Compensation was made for barometric pressure and temperature fluctuations, water vapour interference and interference from other known gases.

Particulates were measured using real-time optical scattering instruments (Dustrak Aerosol Monitor 8520, TSI Inc., USA). This device draws air through a light scattering laser-photometer and the concentration of particles is determined from the forward scatter of the infrared diode laser beam. The instrument measures particles in the range 0.1–10 μm. The sample flow rate through the inlet orifice was adjusted to discriminate for the PM_{10} size fraction and the two devices were zero point and cross-calibrated.

Description of Space

The bar chosen for this study was a popular Student Union building situated on the ground floor of an old stone built house. The bar was open Monday through Saturday from 1100 h until 2300 h, opening later until 2400 h on a Thursday and Friday night. Food is served from 1100 h until 1930 h daily.

The bar is entered through a door in the lower hallway, this door provides the only exit/entrance for the public and the bar is located along one end of the space. The total volume of space in the bar is 195 m^3 with no single areas being designated as non-smoking or for eating only.

A plan view of the bar can be seen in Figure 1.

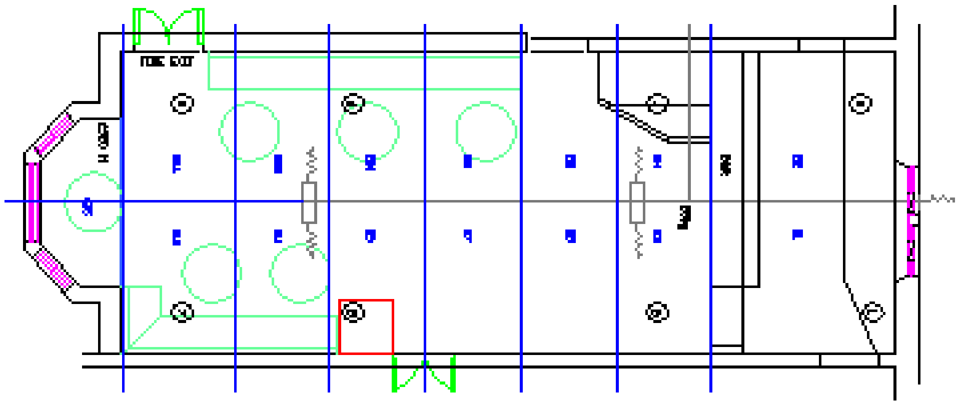

Figure 1 Plan view of Student Bar showing position of extract ductwork.

Description of Ventilation System

Ventilation was provided by a single extract duct running approximately two-thirds of the length of the space and exiting through a wall behind the bar area. An in-line axial flow fan fitted with a variable speed controller is located behind the bar. The operation of this was normally set at one-third full speed (full speed capacity 1.48 m^3/s) and adjusted up or down by staff according to the perceived air quality in the bar.

RESULTS

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. PM_{10} levels were recorded at two points; one within the bar area, the other next to the bay window at the opposite end of the bar coincident with points 2 and 8 of the gas phase sampler. Monitoring took place over a number of weeks and ventilation measurements with the mechanical system at different settings carried out. Natural air infiltration levels were measured to be around 0.2 ach. It was not possible to carry out any intervention studies in the bar and monitoring concentrated on the spatial distribution of pollutants in the 'as found' condition.

Figure 2 shows the CO_2 profiles at a mid-point in the seated area of the bar over a 3-day period, from a Tuesday through to Thursday.

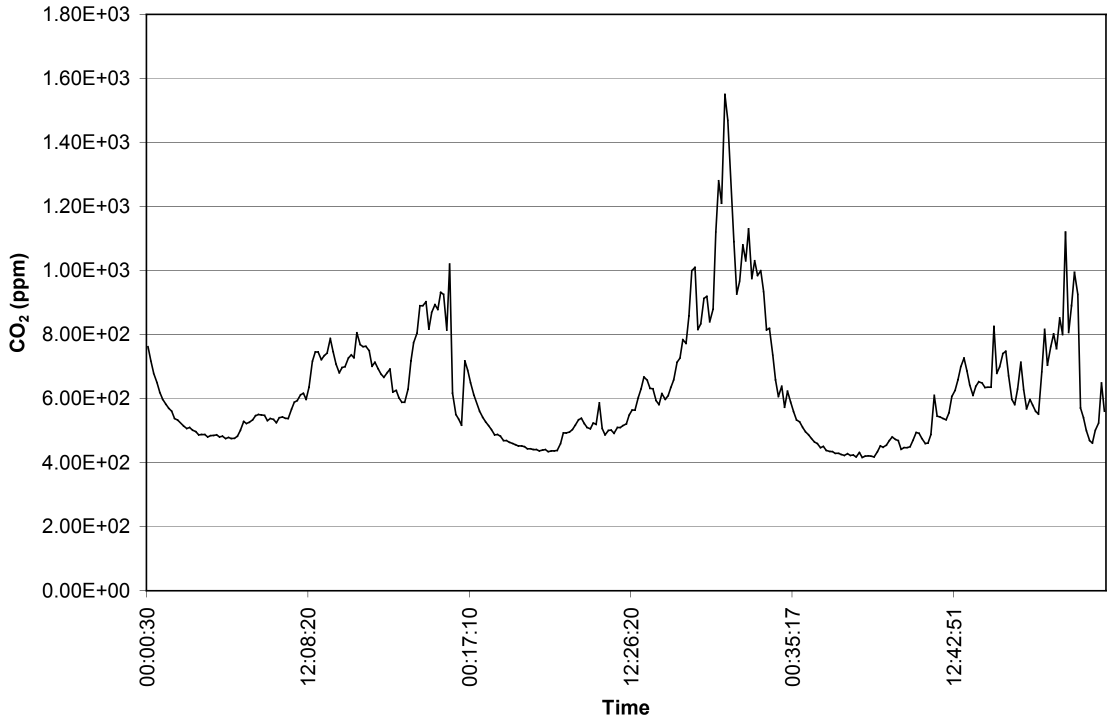

Figure 2 CO_2 profile showing occupancy related evolution.

The CO_2 profile indicates, as expected, an occupancy related pattern with increased levels at lunchtime, an early evening peak and a build-up towards late evening/closing time. Using the CO_2 decay concentration at the end of the occupied period the ventilation air exchange rate for the space can be calculated. This confirmed the measured ventilation rates.

Figure 3 shows a CO profile over the same time period for two of the eight monitored locations; the bar area and the window area at the opposite end of the occupied space. It can be seen that the CO levels show little spatial variation considering the majority of smoking activity was taking place in the seated areas near the window sampling point. The mechanical ventilation system was being operated in its normal mode (one-third operating volume) during this monitoring period and would appear to have little or no effect on the spatial distribution of gas phase constituents in ETS as evidenced by the CO marker.

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 number of smokers.

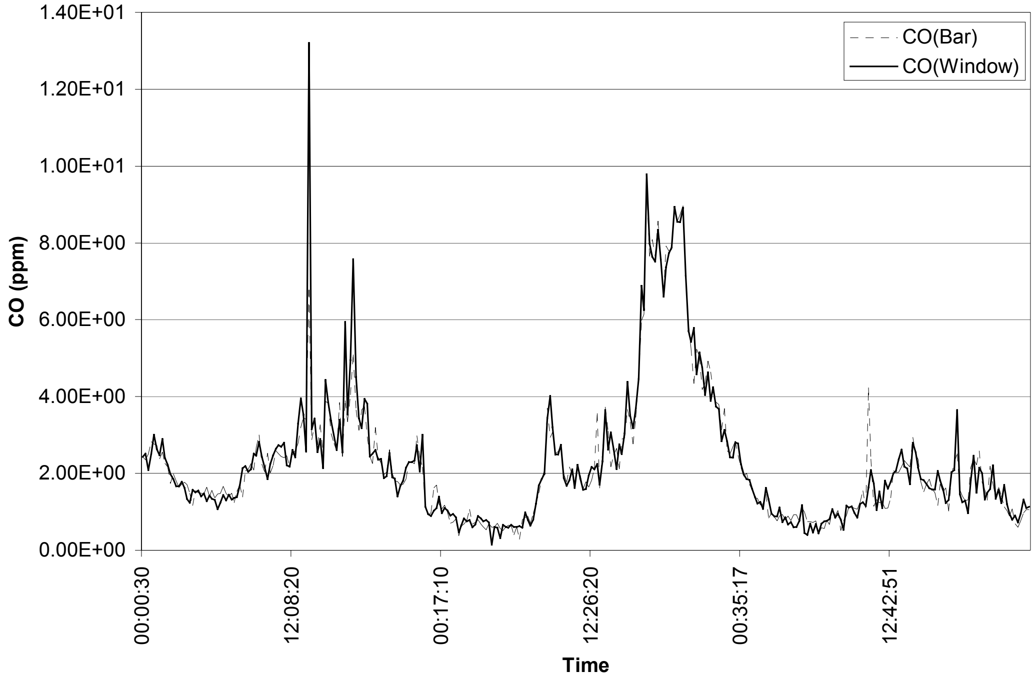

Figure 3 CO levels measured at bar and window locations.

The PM_{10} levels (Figure 4) for the same sampling points over the same period indicate a significant difference between bar and window areas.

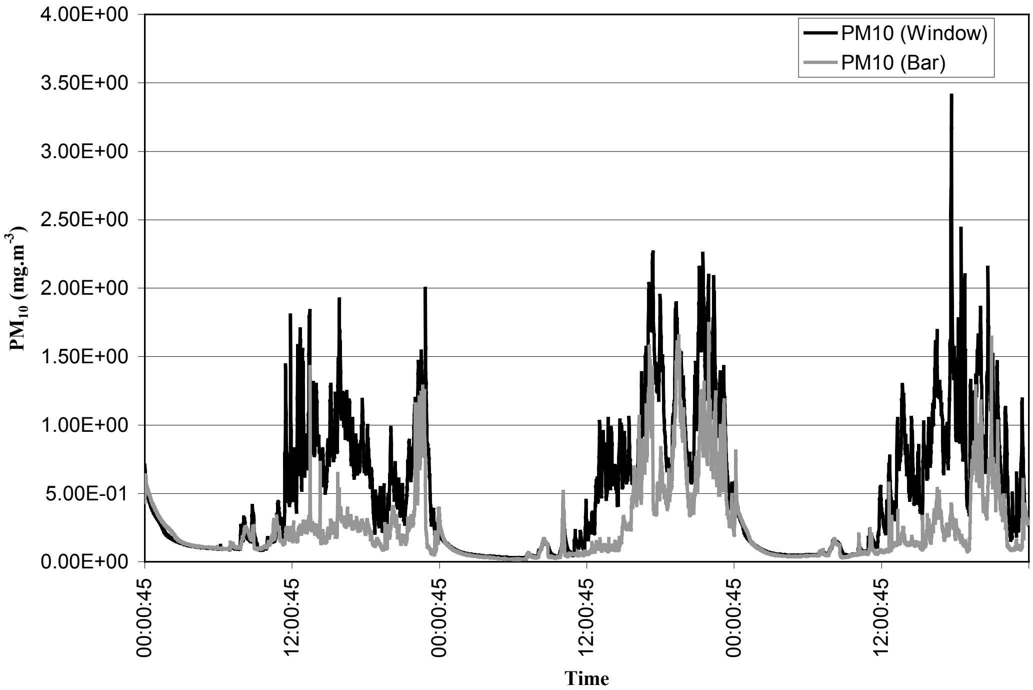

Figure 4 PM_{10} levels measured at bar and window locations.

At the window location, where smokers observed sitting in that area were generating a significant proportion of the ETS, particulate levels were on average 108% higher than the levels measured at the bar. This would indicate that, unlike the gas phase constituents of ETS, the particulate phases are significantly affected by spatial constraints and ventilation strategies. The exposure to ETS for occupants of a bar varies considerably between gas and particulate components.

CONCLUSIONS

The data gathered during this experiment indicate that CO appeared to be a useful indicator of ETS with the levels recorded matching the observed intensity of smoking. The time-series data from Dustrak devices illustrate the highly episodic nature of particulate pollution in the bar. This is relevant when considering health risks of short-term exposure to very high concentrations of particles. Both gaseous and particulate concentrations recorded within the bar (6 ppm CO and 0.99 mg m^{-3} PM_{10}) were below maximum recommended levels of 8.6 ppm CO and 5 mg m^{-3} PM_{10} (running 8 h mean for both).

The spatio-temporal distribution of, and therefore occupant exposure to, gas and particulate phase constituents in ETS differ considerably. The rapid diffusion and advection of the gas phase from burning cigarettes would appear to ensure a fairly uniform distribution throughout an occupied space and, neglecting the mainstream inhalation of smokers, would tend to average the exposure to all occupants. Ventilation strategies alone, while being able to reduce the overall ETS levels, are generally insufficient in reducing the migration of gas phase ETS in a shared occupancy space. Occupant exposure to the particulate phases in ETS would appear to be affected by proximity to the source and has the potential to be significantly influenced by the ventilation strategies employed. Interestingly, from observations made on the operation of the ventilation system controls in the bar they appeared to be adjusted to meet the thermal comfort needs of the occupants rather than air quality However the situation clearly exists where traditional ad-hoc ventilation designs do not achieve airflow distributions that mitigate the effects of ETS.

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