Monitoring pollutants in occupied spaces

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ABSTRACT
There is increasing evidence of a causal link between airborne particles and ill health and this study monitored the exposure to both airborne particles and the gas phase contaminants of environmental tobacco smoke (ETS) in a nightclub.

The present study followed a number of pilot studies in which the human exposure to airborne particles in a nightclub was assessed and the spatio-temporal distribution of gas phase pollutants was evaluated in restaurants and pubs. The work reported here re-examined the nightclub environment and utilized concurrent and continuous monitoring using optical scattering samplers to measure particulates (PM_{10}) together with multi-gas analysers.

The analysis illustrated the highly episodic nature of both gaseous and particulate concentrations in both the dance floor and in the bar area but levels were well below the maximum recommended exposure levels. Short-term exposure to high concentrations may however be relevant when considering the possible toxic effects on biological systems.

The results give an indication of the problems associated with achieving acceptable indoor air quality (IAQ) in a complex space and identified some of the problems inherent in the design and operation of ventilation systems for such spaces.

INDEX TERMS
IAQ assessment; Particulate matter; PM_{10}; ETS; carbon monoxide

INTRODUCTION
The possible health effects of exposure to ETS have been subjected to considerable investigation. The UK Scientific Committee on Tobacco and Health (SCTH, 1998) indicated that: ‘exposure to ETS is a cause of ischaemic heart disease’ and that ‘such exposure represents a substantial public health hazard’. The Fourth Report of the ISCSH (ISCSH, 1988) concluded that there was an increase in the risk of lung cancer from exposure to ETS in the range of 10–30% and stated that smoking in public places should be restricted on the grounds of public health.

ETS is comprised of exhaled mainstream smoke (MS) from the smoker, sidestream smoke (SS) emitted from the smouldering tobacco between puffs, contaminants emitted into the air during the puff and contaminants that diffuse through the cigarette paper and filter tip between puffs (EPA, 1992). Analysis of smoke generated from a standard cigarette shows it is made up from three main physical classes of chemicals: a gas phase containing nitrogen, nitrogen oxides, Carbon Monoxide (CO) and Carbon Dioxide (CO_2), and unused oxygen; a vapour phase containing a large number of volatile organic molecules produced by burning; and an aerosol of particles.

One of the main aims of the study was to compare and contrast the spatio-temporal levels of the gas phase and particulate components of ETS by measuring CO and PM_{10}. The intention was however to consider ETS as a whole as a potential hazard to health even though each component presents an individual health risk. CO contributes nothing to the flavour or satisfaction of smoking but is a component of the slow combustion process and raised

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carboxyhaemoglobin levels in the blood are widely used as a test for recent smoking. The particulates contain all the tar products and most of the carcinogenic components (Samet and Spengler, 1991). The Technical Advisory Group of the UK Scientific Committee on Tobacco and Health (SCTH, 1998) concluded that the tar content of cigarette smoke is the single most important factor in terms of health risk.

ETS concentrations depend on the number and activity of smokers, on room characteristics, including volume, and on ventilation patterns. Human exposure to the individual chemical components in ETS will also be affected by interrelated factors including chemical transformation, dispersal, removal and resuspension from surfaces and human activity patterns. This study examined a building that would have challenged any designer with a brief to provide a healthy internal environment. The building is a student union, of a complex shape and a large population during a concentrated time period with a high percentage of smokers (The Health Education Board for Scotland (HEBS, 2000) estimate that 35% of the 16–34 year olds are smokers).

METHODS

The Property

The property studied is a nightclub, operated by the University Students Association, which operates on Wednesday, Friday and Saturday nights between 9 p.m. and 3 a.m. There are between twenty and thirty employees and the venue holds a maximum of 1200 customers who are predominantly students, between 17 and 25 years of age.

The building is of relatively complex design comprising a main dance area and bar. The dance area is a large rectangular space with a high barrel-shaped ceiling and the bar area is located to the west side and has a semi-circular plan form. The ventilation system in the nightclub is separated into two different sections for the two areas. The air conditioning for the main dance area comprises eighteen linear supply terminals and extract grilles, located in the vaulted ceiling. The maximum designed operating capacity is 6.3 m^3/s and the volume of the space is approximately 1300 m^3. In the bar area, the ventilation comprises 10 supply terminals and seven extract grilles (maximum capacity 2.4 m^3/s with a volume of 550 m^3).

Instrumentation

Our previous studies (Currie and Capper, 1994) and earlier work in the nightclub (Lindsay, 2000) suggested that the main sources of particulate material would be ETS, artificial smoke from the smoke generating devices (as in many other venues, this nightclub has smoke generating devices installed around the dance floor and smoke is generated throughout the night to provide a visual effect and ensure the venue remains atmospheric), human derived particulate material and particulate matter originating from outdoor sources.

The measuring of particulates was undertaken using TSI Dustrak monitors, which are real-time optical scattering instruments in which the concentration of particulate matter in a sample airflow is detected by the extent of the forward scattering of an infrared diode laser beam. The instrument measures particles in the range 0.1–10 µm and records concentrations every second and stores 1-min averages in memory.

The internal CO levels are a function of background/outside levels, the number and activity of smokers as well as the ventilation system and its operation. The monitoring of the gas phase was carried out using Brüel and Kjær multi-gas monitors, Type 1302, which work on the photoacoustic infrared detection principle. The gases monitored were CO, together with Carbon Dioxide (CO_2) as an overall measure of IAQ. Measurements were recorded with 2-min intervals between each sampling point.

Two Dustraks and two multi-gas monitors were used in this study. Equipment was located at either end of the nightclub. The locations chosen were a compromise between measurement of actual human exposure and practicality/security, i.e. it was not possible to place all equipment within the 'breathing zone' (height representative of the head height of the average individual).

In addition, a Grant Squirrel data logger was used to measure air temperature in the bar area, relative humidity and the temperature of the ventilation supply grilles. This was undertaken to identify the control strategy, in particular the on- and off-periods, for the air conditioning in the bar area.

Recordings were made of persons entering and leaving the venue at 30-min intervals in order to estimate numbers in the bar and on the dance floor and to consider likely CO_2 evolution.

RESULTS

The nightclub was continuously monitored on a number of occasions over a 3-month period, with varying occupancies. The figures below indicate some typical profiles.

Figure 1 indicates a typical occupancy profile over a 12-h period from 9 p.m. on a Friday evening through to 9 a.m. on Saturday morning. Occupancy numbers increase from less than 200 at 11 p.m. to over 900 at 2 a.m. CO_2 levels rise over the period from a background level of 450 ppm to a peak of approximately 2800 ppm in the early morning. Despite the continuous increase in numbers, and the resultant evolution of CO_2, the profile shows temporal differences due to operation of the ventilation system. The CO_2 levels for the main occupied period from 11.30 p.m. until 3.00 a.m. is above the BSRIA postulated control level for acceptable indoor air of 800 ppm and the WHO short-term exposure of 1000 ppm (WHO, 2000).

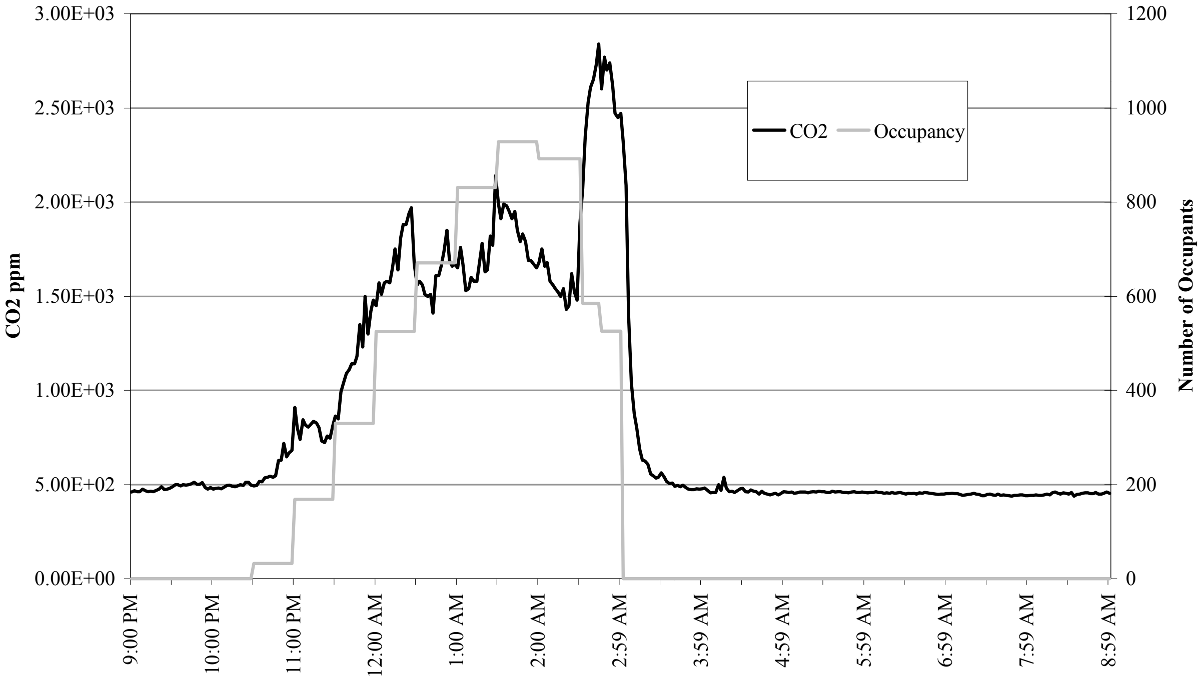

Figure 1 CO_2 and occupancy levels.

Figure 2 shows the particulate and CO profiles for the same period of time. The particulate profile indicates a maximum of approximately 10 mg/m^3 in the early morning but has clear, large, spikes that are the result of the operation of the smoke machine. Despite the contribution of the smoke machine the overall levels are low, compared to the UK Health and Safety Executive (HSE) occupational limit of 5 mg/m^3 for an 8-h period. CO peaks at approximately 4.5 ppm but is more typically between 1 and 3 ppm for the duration of the evening. Between 11 p.m. and 3 a.m., when occupancy levels reached over 900, the average CO level was only 2.2 ppm.

From data obtained using the temperature recorders the boost ventilation/extraction system was shown to be in operation between 12.20 a.m. and 2.30 p.m. The effect of this on particulates can be clearly seen in Figure 2; where the level drops below 2 mg/m^3. No commensurate reduction was observed with the CO levels, implying that ventilation has a significant impact on particulate concentrations. Further work is presently being undertaken to establish the effective dilution rates for the gas phase constituents at this boost ventilation; such that the relative effectiveness of ventilation in mitigating exposure to both particle and gas phase constituents can be assimilated.

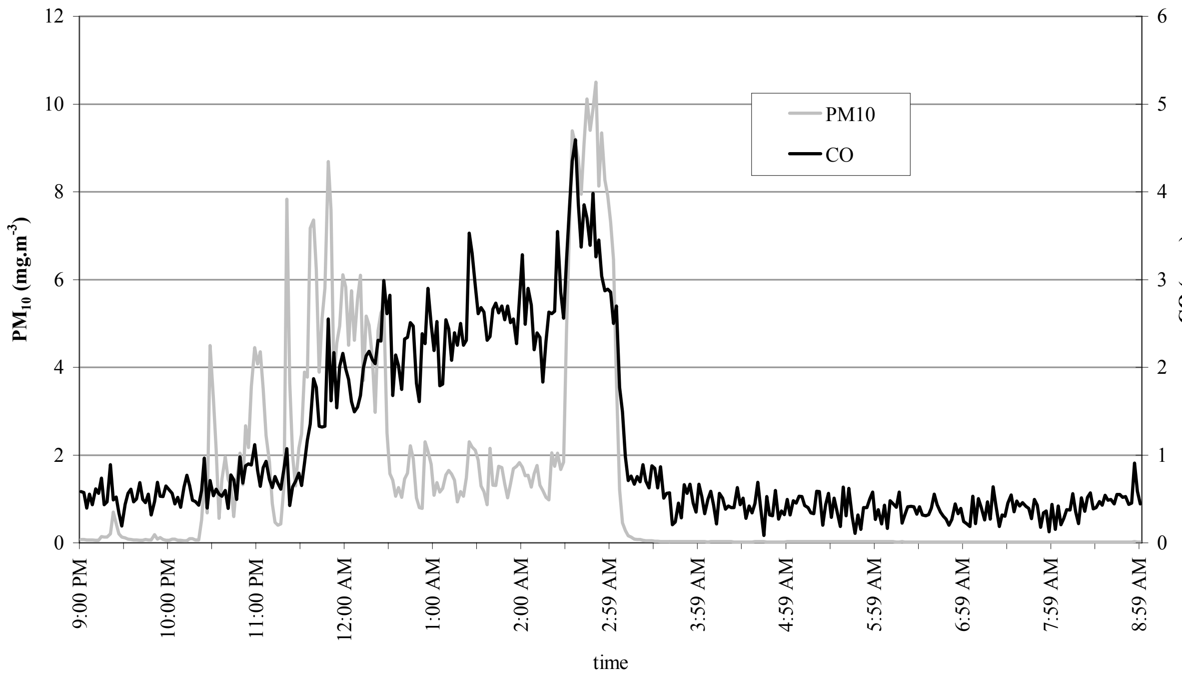

Figure 2 PM_{10} and CO levels measured in the bar area.

DISCUSSION

In addition to the practical difficulties of recording data in an occupied space, some statistical problems were also encountered during the analysis, though they were not unanticipated. From the objectives of this project the most serious is multi-collinearity. In investigating the relationship between PM_{10} and CO, both variables are functions of occupancy numbers, room and building services system characteristics and operation. Only limited data on occupancy was available—readings were taken at 30-min intervals—but data on CO_2 as a surrogate for occupancy was used. There is a correlation between CO and CO_2 (with, for example, an R^2 value of 0.89 for the occupied period illustrated in the above profile) but the relationship between PM_{10} and CO is less clear. The multi-collinearity manifests itself through large standard errors of the coefficient in a regression analysis and requires further work.

The levels of artificial smoke and the effect on the PM_{10}/CO relationship also requires further exploration by separation from the particulates associated with smoking. It is difficult to quantify the volume and rate of smoke production over the course of an evening as the operation of the smoke machine is arbitrary; the volume released is dependent on the operator.

CONCLUSION AND IMPLICATIONS

The profiles that are illustrated above are typical of the values recorded on a number of occasions and, in general, the levels of both CO and particulates were very low compared to the values reported in other studies in bars and pubs. Average concentrations of CO of 10-20 mg/m^3 have been recorded with peak values of up to 30 mg/m^3 (Marconi *et al.*, 1995).

Concentrations of ETS and artificial smoke were clearly not constant over the course of an evening and human exposure would have been highly episodic, often at very high concentrations. It is therefore important to consider how short-term episodes of very high particle concentrations influence health. The WHO also indicate that even though it is not clear whether particulate matter is the best single measure by which to characterize ETS, the large health impact at concentrations commonly found leads to the conclusion that no level above zero could be considered acceptable. It should also be borne in mind that exposure to ETS and other air pollutants can act synergistically to produce adverse health effects (WHO, 2000).

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