The Use of Fabric Diffusers to Control Environmental Tobacco Smoke

A. J. Geens, D.G. Snelson and J. R. Littlewood

Abstract - Smoking in public places is a hot debate presently in Europe. A number of legislative bodies in Europe have already made policy decisions on the issue of smoking in public places. Scientific evidence relating to this debate has been reported in a diverse range of publications such as BMJ, Indoor air and the BSJ. On inspection much of the reporting concludes negatively on the performance of ventilation systems. How are buildings that are exempt from this legislation, which will include a number of health care premises, going to protect both staff and employees and smokers? Can fabric diffusers reduce Environmental Tobacco Smoke (ETS) to a level that is as low as reasonably practical as required by health and safety legislation?

Index terms - fabric diffusers, ventilation, environmental tobacco smoke (ETS), smoking in public places, indoor air quality (IAQ)

1. Introduction

Fabric or textile ductwork is often used in situations where metal ductwork is difficult to install, for example in heavily racked storage buildings [1]. The same ductwork often serves the additional function of supply diffuser especially in food preparation/manufacturing facilities where its ability to be easily removed and washed is an asset.

Following tests carried out at the BSRIA laboratories in Crowthorne, [2] proposed that fabric diffusers installed at low level could serve as displacement ventilation supply diffusers and facilitate high air flow rates and hence high cooling capacity without draught or noise risk. It was demonstrated that this technique could increase cooling capacity to 50 W/m^2 [3]. Geens (2000) [4] also concluded that this displacement technique would be useful where high flow rates were required to deal with specific contaminant concerns, i.e. flow rate for air quality rather than cooling. In this case the increased ventilation effectiveness available with displacement ventilation would help to mitigate the need for such high flow rates with an associated energy benefit. The work at the BSRIA laboratories was repeated by Butler (2002) [5] at the BRE laboratories re-affirming the findings of Geens [4].

1.1 Ventilation in licensed premises

Buildings should be adequately ventilated as defined by the Buildings Regulations 2000, Part F 2006 [6] and the Management of Health and Safety at Work Regulations 1999 [7]. In 2003 Geens began a series of ventilation effectiveness surveys of new or upgraded ventilation systems installed in pubs that had been designed to provide improved air quality, specifically in the bar serving area, but also for the whole building as a consequence. The ventilation system would reduce the exposure of bar staff and customers to environmental tobacco smoke (ETS). This work introduced the opportunity for discussions with the system designers and consequently to the inclusion of fabric diffusers for the ventilation systems in pubs. The results form one of these pubs, the

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Hairy Canary in Brussels, Belgium are presented in this paper.

2 Method

There were no restrictions on smoking in the premises at the time of the research. Smoking was allowed at the bar counter. The airborne contaminants that were measured can be harmful in high concentrations. The levels of acceptable worker exposure are set out below:

OSHA (1994 [8]**, 1998):** Enforceable maximum exposures for industrial environments developed by OSHA (US Department of Labour) through a formal rule-making process. Once an exposure limit has been set, levels can be changed only through reopening the rule-making process. These permissible exposure limits (PELs) are not selected to protect the most sensitive individuals.

MAK: Recommended maximum exposures for industrial environments developed by the Deutsche Forschungs-Gemeinschaft, a German institution similar to the U.S. National Institute for Occupational Safety and Health (NIOSH). Levels are set on a regular basis, with annual reviews and periodic republication of criteria levels. These levels are enforceable in Germany and are not selected to protect the most sensitive individuals.

HSE EH40 (2005) [9]**:** Recommended maximum exposures for industrial environments developed by Health and Safety Commission, which is responsible for health and safety regulation in the United Kingdom. Levels and limits, which are regularly reviewed and updated, are enforceable in the United Kingdom and are not selected to protect the most sensitive individuals.

The European Standard EN 13779:2004 (E) [10]**:** further sets out a basic classification for indoor air quality (IDA) based upon the average level of carbon dioxide in the air over an 8 hour period.

This study was arranged to coincide with busy times of the week. Continuous real-time monitoring was carried out to ensure that peak exposure conditions were captured and to measure baseline levels of markers during the overnight period of no occupancy. The results from the instruments will be used to demonstrate the ventilation effectiveness. Additionally Drager smoke tubes were used during the set-up procedure to visualise and confirm the expected air flow patterns in the room. The sampling devices were located in the bar serving area at a height approximating to the breathing zone. A seating plan, layout of the pubs and where the ventilation grilles were positioned was recorded.

To facilitate comparison with other buildings this data was converted to cigarettes per hour per m^3 of building volume and is presented graphically with the monitoring results in this way.

Table 1 Levels of recommended worker exposure

		OSHA	**MAK**	**HSE**
		USA	**Germany**	**UK**
Carbon Dioxide	CO_2	5000 ppm	5000 ppm	5000 ppm
Carbon Monoxide	CO	50 ppm	30 ppm	30 ppm
Respirable Particles < 2.5 µm	PM 2.5	5 mg/m^3	1.5* mg/m^3	4 mg/m^3

*Note: this standard applies to < 4 µm. The level would be lower for PM 2.5.

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Table 2 Indoor air quality

Category	Description Indoor air quality	CO_2 level in room (above ambient external)
IDA 1	High	< 400 ppm
IDA 2	Medium	400 – 600 ppm
IDA 3	Moderate	600 – 1000 ppm
IDA 4	Low	> 1000 ppm

Three ETS markers were used in the studies, carbon dioxide (CO_2), carbon monoxide (CO), Respirable Suspended Particles (PM2.5), and temperature. CO_2 was recorded as this is the contaminant most usually used to control the operation of variable speed ventilation systems and is a useful indicator that the ventilation system is operating correctly at the outset. These markers are simple and inexpensive to monitor which was an important consideration when undertaking a series of investigations over a period of time. Although other markers have been used in other studies, the selection of markers is actually unimportant when assessing ventilation performance, as according to Dalton's Law of Partial Pressure [11]:

"A gas mixture behaves in exactly the same fashion as a pure gas"

The sampling devices used were the Dustrak Aerosol Monitor Model 8520 by TSI Inc, using the 2.5 µm inlet conditioner and a flow rate of 1.7 l/min, and the Q-Trak Plus IAQ Monitor Model 8554 by TSI Inc [12]. During the busy periods an hourly cigarette count was taken. Levels of Respirable Suspended Particles (PM 2.5), carbon monoxide, carbon dioxide and temperature were recorded. The rationale for this is as follows:

2.1 Respirable Suspended Particles (PM 2.5)

Respirable suspended particles (PM 2.5) are a constituent of environmental tobacco smoke and serve as a marker, although they are produced from other sources in buildings as well. The workplace exposure limit (8 hour time weighted average) for respirable particles is typically 4 mg/m^3 [9], however there is no ETS specific figure provided. A number of other particle phase or vapour phase markers may be monitored when assessing ventilation performance in dealing with ETS, but to do so in this study would have extended the timescale and costs unacceptably. The aim of this study was to demonstrate the effectiveness of a fabric diffuser in dealing with ETS and by monitoring a solid, (PM 2.5), and a gaseous, (CO) constituent it is possible to indicate the likely effectiveness of the system for a wider range of constituents. Reference to workplace exposure limits is appropriate in these studies as the monitoring is taking place behind the bar.

2.2 Carbon monoxide

Carbon monoxide is a constituent of environmental tobacco smoke (ETS) but is sometimes considered unsuitable as an ETS marker, as it has other sources for example combustion of petrol and diesel from cars and lorries. The advantages of ease of real-time recording and the existence of recognised occupational exposure standards for carbon monoxide outweighed this concern. Additionally any carbon monoxide from other sources will make the test conditions more onerous, not less. The workplace exposure limit (8 hour time weighted average) for carbon monoxide is 30 ppm [9]. Guidance on workplace exposure limits for carbon monoxide is not consistent however, for example Department of Health Committee on the Medical Effects of Air Pollutants (DOH COMEAP) has an indoor guideline value of 10 ppm for an 8 hour time weighted average.

2.3 Carbon dioxide

Carbon dioxide is produced wherever people are present in buildings, as a product of respiration as well as being an ETS constituent. It is therefore usual to use carbon dioxide as an indication of the effectiveness of the ventilation system. For the purposes of this study it is important to establish that the ventilation is performing effectively at the outset. Levels of CO_2 are not likely to reach levels of health concern for a building in normal use. A figure of 5000 ppm is identified in EH40/2005 [9] as the recommended 8 hour average exposure limit. For comfort level/odour dilution, a CO_2 limit of 1000 ppm is recommended in BSRIA Technical Note 2/2002 [13]. It is worth noting that carbon dioxide is present in fresh air at around 400ppm and so unlike the other indicators, carbon dioxide will not tend towards zero.

2.4 Temperature

There are requirements under Health Safety legislation relating to the provision of a satisfactory thermal environment. Monitoring of these parameters satisfies two objectives, firstly to establish that in improving the air quality the ventilation is not having a negative impact on thermal comfort, and secondly to establish whether it is actually enhancing thermal comfort. Ideally temperatures should be maintained between 19 ^{o}C and 24 ^{o}C, and relative humidity between 40 and 70% [14].

2.5 Cigarette Count

The number of cigarettes consumed was measured on an hourly basis through a count of the cigarette butts collected in ashtrays; to produce a measure of cigarettes/hour. To obtain a consistent comparison with other studies in venues of different sizes the cigarette count has been normalised by dividing by the volume of the premises, to provide a measure of cigarettes/m^3/hour. From earlier studies [15] in a number of countries and situations, all in venues where smoking is permitted and on the busiest evenings of the week, we have categorised the levels of smoke released in Table 3 below:

Table 3 Levels of smoke release

Smoking	8-hr average cig/m^3/hr
Very Heavy	0.31+
Heavy	0.16-0.30
Moderate	0.06-0.15
Light	< 0.05

For reference, the highest hourly level of smoking/m^3 recorded in our field research was 0.69 cigarettes/m^3/hour. This was exceptionally high and was only sustained for one hour.

2.6 Ventilation system interruption

When customers were smoking heavily the ventilation system was turned off for approximately 10 minutes. This was to highlight the effectiveness of the ventilation system on air quality inside the premises, and replicate conditions experienced before the installation of the systems.

2.7 Conditions

For reference the outside air quality was also measured. A log was kept of conditions in the outlets that may have affected the results.

3 Results

The external air quality was tested at 1pm on 6th April 2006. This showed an average air quality:

Carbon Dioxide: 430 ppm
Carbon Monoxide: 0.0 ppm
Respirable Particles (PM 2.5): 0.08 mg/m^3

The standards used are 8 hour averages; so to exceed the standard the level of contamination must be on average above the line. Peaks or

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"spikes" in the data are usually caused by occupants blowing smoke directly at the equipment to see what effect it has. These should generally be ignored.

3.1 Carbon Monoxide

The results of the monitoring for CO can be seen in Figs. 1 and 4. Fig. 1 shows that, with the ventilation running, the CO levels are kept close to 0 ppm. The figure shows that when the ventilation system was switched off, the CO levels quickly rose to approximately 3.5 ppm. Almost immediately after the ventilation system was switched back on, the CO readings dropped to their previous levels close to 0, which demonstrates the effectiveness of the ventilation system. The workplace exposure limit noted above is an average of 50 ppm (OSHA) or 30 ppm (MAK and HSE) over an eight-hour period.

3.2 Carbon Dioxide

The results of the monitoring for CO_2 can be seen in Figs. 1 and 3. Fig. 1 shows that, with the ventilation running, the CO_2 levels were limited to below 700 ppm. When the ventilation system was switched off, the CO_2 levels rose, on this occasion to approximately 1500 ppm, but when the ventilation was switched back on, the readings return very quickly to their earlier levels, demonstrating the effectiveness of the ventilation system. Readings taken outside the pub on the day of the ventilation effectiveness study indicate that outdoor level of CO_2 was approximately 430 ppm. Therefore the relevant European air quality standards are:

Thus a value of 5 on the CO_2 scale represents 500 ppm. The carbon dioxide readings indicated that for the entire measured period there was 'High Air Quality' (IDA1) except for the brief period with the ventilation switched off and immediately afterwards.

3.3 Particulate (PM 2.5)

The results of the monitoring for Respirable Suspended Particles (PM 2.5) can be seen in Figs. 2 and 4. Fig. 2 shows that with the ventilation equipment running particulate is limited to below 0.5 mg/m^3. The figure shows that when the ventilation unit is out of service, the particulate level rapidly rises, on this occasion to almost 2.5 mg/m^3. When the systems are re-instated, the readings return very quickly to their earlier levels. The workplace exposure limit noted above is an average 5 mg/m^3 (OSHA) or 4 mg/m^3 (HSE) over an eight-hour period.

3.4 Temperature

The results of the monitoring for temperature can be seen in Fig. 3. Temperature was reasonably constant during the monitoring period and was within the acceptable range for comfort. During the period when the equipment was off and overnight, there was a marked increase in temperature, indicating that the temperature control was not satisfactory.

3.5 Cigarette Count

Peak consumption per hour was 56 (0.20 cigarettes/m^3/hour). This is considered a heavy level of smoking for the space.

Table 4 European air quality standards

Category	**Description** **Indoor air quality**	**CO_2 level in room**
IDA 1	High	< 830 ppm
IDA 2	Medium	830 – 1030 ppm
IDA 3	Moderate	1030 – 1430 ppm
IDA 4	Low	> 1430 ppm

Note: the scale in the charts is divided by 100 for CO_2 to enable scaling with carbon monoxide.

Fig. 1 The Hairy Canary Gases Thursday 6th April 2006

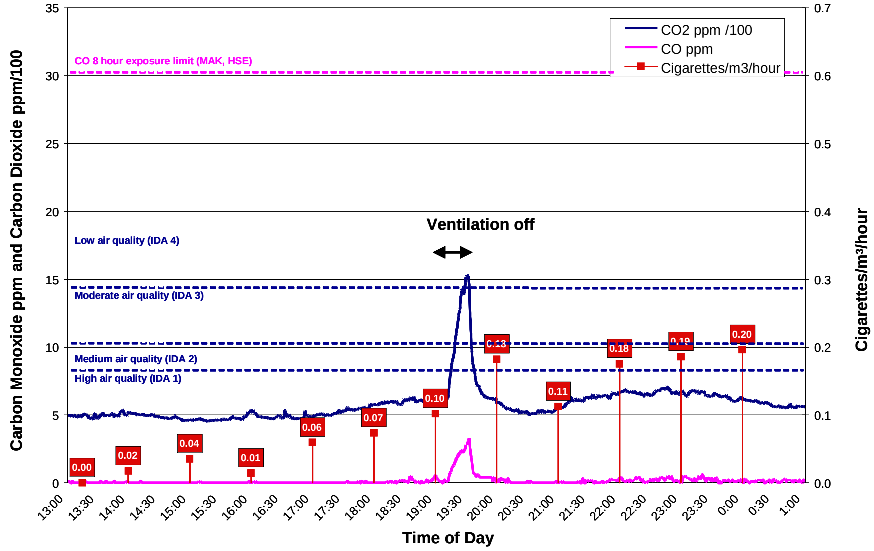
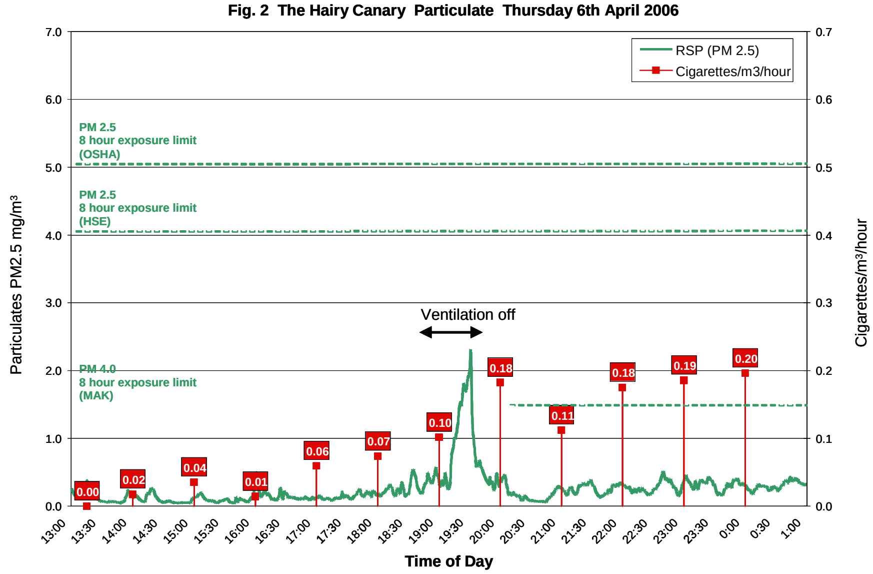
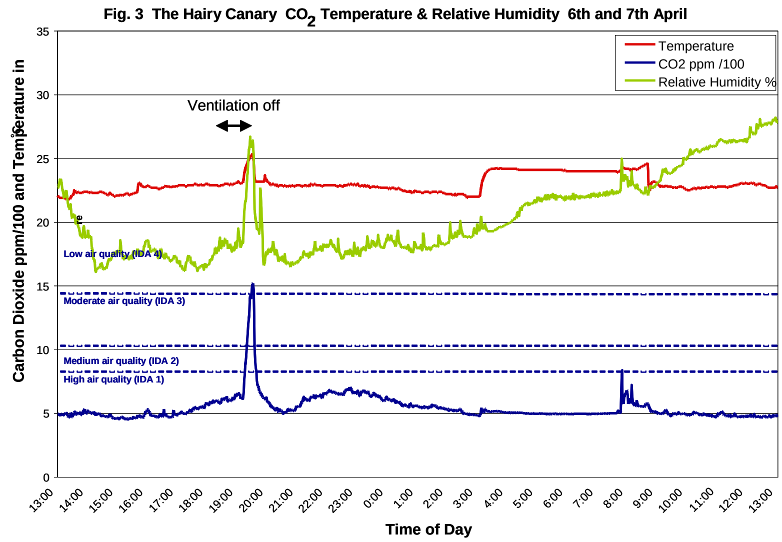


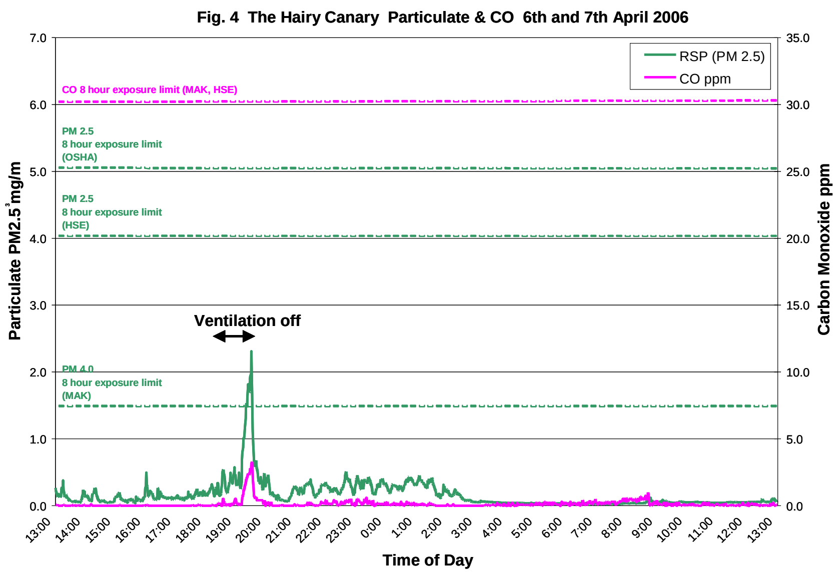
Fig. 2 The Hairy Canary Particulate Thursday 6th April 2006



4 Analysis of results

This study clearly demonstrates the ability of the ventilation system in this building to limit and control the concentrations of the parameters under consideration. The results presented are from instruments located close to the breathing zone of the bar staff. Measurements from the customer area have proved difficult in terms of securing the instruments for continuous monitoring and finding neutral positions that will not be influenced by the proximity of the cigarettes being smoked. The three air quality constituents recorded appear to fluctuate in tandem with the level of ventilation intervention. The results show that the ventilation equipment controls contaminant levels for the markers recorded and that when the equipment is turned off the levels rapidly increase until ventilation is re-instated. When the ventilation is re-instated the levels fall back very quickly to their earlier levels. This appears as a very steep curve on the chart. During this monitoring period, all parameters were well within recognised workplace exposure limits as noted.





5 Conclusion

These studies clearly demonstrate the ability of the ventilation system to limit and control the concentrations of the parameters under consideration to within recommended workplace exposure limits. The results are consistent with similar earlier studies, and are in fact at the better end of the range of results obtained from earlier studies, adding weight to the argument that appropriately designed ventilation systems significantly improve the air quality in buildings where smoking is taking place, meeting all available workplace exposure limits.

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