Impacts of ventilation: studies on "environmental tobacco smoke"

A. J. Geens, H. Al-Madfai & D. G. Snelson
Faculty of Advanced Technology, University of Glamorgan, Wales, UK

Abstract

A number of legislative bodies in Europe have already made or are currently considering making policy decisions on the issue of smoking in public places. Policy alternatives have been discussed in Town & Country Planning (2004 and 2008). Scientific evidence relating to this debate has been reported in a diverse range of publications such as the British Medical Journal, Indoor Air and the Chartered Institution of Building Services Engineers Journal. On inspection much of this reporting concludes negatively on the performance of ventilation systems. In this paper a critical review is undertaken of three "Environmental tobacco smoke" study papers, to supplement the overview provided by the authors in their paper in the International Journal of Innovative Computing, Information and Control (IJICIC) in 2007.

Keywords: ventilation, environmental tobacco smoke, environmental chamber.

1 Introduction

A number of legislative bodies in Europe have already made or are currently considering making policy decisions on the issue of smoking in public places. Policy alternatives have been discussed in Town & Country Planning [1]. Scientific evidence relating to this debate has been reported in a diverse range of publications such as the BMJ, Indoor Air and the CIBSE Journal. On inspection much of this reporting concludes negatively on the performance of ventilation systems [2–7].

In the UK the smoking ban has allowed a number of exemptions, and it is important that these spaces are ventilated using the best techniques available in order to protect both user groups and staff employed in these buildings for

WIT Transactions on Ecology and the Environment, Vol 116, © 2008 WIT Press
www.witpress.com, ISSN 1743-3541 (on-line)
doi:10.2495/AIR080491

example residential care homes, hospices and mental health units where patients are held in secure conditions for more than six months [8]. The most immediate health and safety concern from smoking in this type of building is probably that of fire with the risk of smokers falling asleep in their rooms whilst smoking. This risk is reduced by providing a smoking room which is more easily monitored than individual rooms. The same strategy facilitates easier management of longer term health and safety concerns about the exposure of staff to environmental tobacco smoke (ETS). The use of ventilation to prevent migration of ETS through the building and to dilute ETS in the smoking room is more easily and economically managed if smoking is limited to one room. Ironically, many in the medical profession have dismissed the role of ventilation in limiting exposure to ETS in their campaign for the introduction of smoking bans, although this debate has highlighted the case that many hospitality venues do not use ventilation systems effectively, and that not all ventilation systems are equally effective. Ventilation systems are now being installed in hospitality venues to reduce smells that were originally masked by the tobacco smoke after the smoking ban came into force for example stale beer and food odours.

As a result of the negative reporting on ventilation in the debate leading up to the introduction of the ban, there is a possibility that the potential contribution from ventilation systems in managing such risks may be ignored. It would appear that the UK government unquestioningly accepted the argument that adequately ventilated rooms were not an alternative to a complete ban. Consequently it is now difficult for the government to offer advice to exempt building operators on how to ventilate their buildings to comply with Health and Safety requirements. Many of these buildings are government controlled and regulated.

2 Environmental tobacco smoke studies

To illustrate the dismissive behaviour towards the use of ventilation, three studies into environmental tobacco smoke are reviewed.

2.1 Impact of various air exchange rates on the levels of (ETS) components [9]

This is a report on experiments carried out in an environmental chamber. The chamber has a volume of 30 m^3. Measurements were taken at a number of air change rates. For this chamber these air change rates can be analysed as shown in Table 1. In other words the ventilation rate of the chamber at 2 air changes per hour was 16.67 l/s, adequate for 2 non smoking occupants. An experiment was conducted for air change rates of 0.2, 0.5 and 1, with 5 cigarettes being burnt in the chamber. A further experiment was conducted with 2 air changes per hour and 10 cigarettes being burnt. With 5 cigarettes being burnt in the hour long experiment, and allowing for 2 cigarettes per hour per smoker, this equates to 10 people in a room with 25% smoking room which according to CIBSE Guide B, Table 2.11, [10] requires 16 l/s/p or 160 l/s, and 1 air change per hour is 8.3 l/s.

The report states in its opening summary that changes in ventilation rates simulating conditions expected in residential and commercial buildings during

Table 1: Analysis of chamber air change rates.

Air change rate (air change/h)	0.2	0.5	1	2
Supply rate (l/s)	1.67	4.17	8.3	16.67
Number of people (no smoking 8 l/s/p)	0.21	0.52	1.04	2.08
Number of people (some smoking 16 l/s/p)	0.1	0.26	0.52	1.04

smoking do not have a significant influence on ETS levels. The air flow rates in the chamber underestimate likely rates in a mechanically ventilated building by a factor of approximately 20. The only place that these ventilation rates and ETS levels are likely to occur is in a domestic dwelling (with only infiltration to dilute ETS) with 5 or ten cigarettes being smoked per hour in one room. One useful outcome of this study, although not commented on by the author is that the results show that all contaminants measured behaved in the same way, demonstrating Dalton's Law of Partial Pressures [11], negating the need to measure large numbers of different ETS markers. The key points from the paper are summarised in Table 2 below.

2.2 Environmental tobacco smoke exposure in public places of European cities [7]

This paper reports that nicotine levels are lower in no smoking areas than where smoking is permitted (see Table 3). In the abstract the authors argue that policies should be implemented that would effectively reduce levels of tobacco smoke in public places. The authors do not make any policy suggestions, but improved ventilation would substantially meet many of their demands/suggestions. Despite the scale of the study the authors make no strong conclusions and refer to the work as a pilot study pointing the way for further investigation. The key points from the paper are summarised in Table 3 below.

2.3 An international study of indoor air quality, ventilation and smoking activity in restaurants: a pilot study [12]

This paper offers an attempt at estimating ventilation rates and delivering a consistent methodology across a large number of studies, however there are a great many assumptions, and unnecessary variations in the methodology to be overly confident in the analysis and the findings. For example different cigarette counting methods were used in different locations. The key points from the paper are summarised in Table 4 below.

Table 2: Summary of Nebot et al [9] 2005 study.

Reference	Setting	Air tightness of building measured	Type of ventilation	Description of venues	Length of Measurements	Measured pollutants	Measured outdoor air quality	Weather conditions recorded	Number of active smokers recorded	Measured area/volume of venue	Findings	Remarks
Nebot et al. (2005)	Europe against cancer initiative - seven European cities: Vienna (Austria), Paris (France), Athens (Greece), Florence (Italy), Oporto (Portugal), Barcelona (Spain), and Orebro (Sweden). Public places that were sampled are an airport, train station, hospital, restaurant, schools, university and disco. The study was carried out from October 2001 to October 2002.	Not specified	Yes: The data was recorded but not included in this paper	Sampling location and smoking policy	4 hours, 2 days, 7 days and 14 days	Nicotine vapour phase - ETS passive samplers (diameter 37 mm) comprising of a plastic cassette (with a windscreen on one side) containing a filter treated with sodium bisulfate. Samplers placed in both non-smoking and smoking areas. The samplers had to hang freely in the air, not be placed within 1 metre of an area where smokers regularly smoke, where air does not circulate, or under a shelf, or buried in curtains. The sampler used for personal samples had to be clipped to a shirt collar or lapel, with the windscreen facing away from the clothes. The study has a limitation regarding the placement of the samplers, which may result in differences between countries unrelated to actual exposure. The filters were analysed at the laboratory of the Public Health Agency of Barcelona, by gas chromatography / mass spectrometry (GM/MS) method.	No	No	No	Yes: The data was recorded but not included in this paper	In areas where smoking is prohibited, concentrations of nicotine are lower than in areas where smoking is allowed but they are not zero. The study showed that 22% of the samples had nicotine concentrations greater than 6.8 μg/m3; concentrations associated with lung cancer risk of one in 1000 assuming 45 years of working life, this is equivalent to the "significant harm" action level defined by the US Occupational Safety and Health administration. The results indicate that well implemented smoke-free polices are necessary to eliminate exposure to tobacco smoke in public areas.	In the abstract the authors argue that policies should be implemented that would effectively reduce levels of tobacco smoke in public places. The authors do not make any policy suggestions, but improved ventilation would substantially meet many of their demands/suggestions.

Table 3: Summary of Kotzias et al [7] 2004 study.

Reference	Setting	Air tightness of building measured	Type of ventilation	Description of venues	Length of Measurements	Measured pollutants	Measured outdoor air quality	Weather conditions recorded	Number of active smokers recorded	Measured area/volume of venue	Findings	Remarks
Kotzias (2004)	INDOORTRON walk-in type environmental chamber, temperature control (15-40 °C), relative humidity (20-90%) and air exchange rates 0.1-2 ach ("climate model"). Under non-controlled climatic conditions ("rising mode") air exchange rates can be increased up to 5 ach (air exchange rates per hour). Commercial smoking machine was used in these experiments. Cigarettes had nicotine content of 0.6 mg and tar of 7.0 mg.	Air exchange rates were set as the experiment was carried out in a walk-in environmental chamber	Dilution ventilation Air exchange rates were determined by using a tracer gas. Stagnant air conditions for Experiment one 3 different ventilation rates 0.2, 0.5 & 1 and experiment two five different ventilation rates 0.5, 1, 2, 3.5 & 5. Homogeneity is 100% in climate mode and 75% in the rising mode.	Yes: walk-in environment chamber	100 minutes	Volatile Organic Compounds (VOC): benzene, toluline, pyridine, m+p-Xylene, limonene and nicotine (1st and 2nd series of experiments at stagnant air conditions, 0.5, 1 and 2 ach). Carbonyl compounds: formaldehyde and acetaldehyde 2nd series of experiments at 0.5, 1 &5 ach). Inorganic gases: NOx (NO + NO2) and carbon monoxide (CO) all experiments. Air samples were taken at distinct time intervals to follow changes occurring in concentrations of the compounds formed during the burning of the tobacco. VOC concentrations were measured using TENAX TA tubes, analysis was done by thermal desorption and gas chromatography with Mass Selective Detector. Carbonyl compounds concentrations were measured using Sep-Pak DNPH-Silica cartridges.	No	No	Yes: Experiment 1 - five cigarettes (RH at 50%, temperature 23 °C) and experiment 2 - five cigarettes smoked simultaneously five times (RH at 50% (at 5 ach dropped down to 23%) and temperature 23 °C)	Yes (volume 30-m^3)	The chemicals (volatile hydrocarbons, carbonyls, polycyclic aromatic hydrocarbons, inorganic gases and particles) emitted by smoking cigarettes are not rapidly and substantially eliminated from the indoor atmosphere, even when higher air exchange rates are applied. These results show that "wind tunnel" - like rates or other higher rates of dilution ventilation would be expected to be required to achieve pollutant levels close to ambient air limit values.	The report states in its opening summary that changes in ventilation rates simulating conditions expected in residential and commercial buildings during smoking do not have a significant influence on ETS levels. The air flow rates in the chamber underestimate likely rates in a mechanically ventilated building by a factor of approximately 20. The only place that these ventilation rates and ETS levels are likely to occur is in a domestic dwelling (with only infiltration to dilute ETS) with 5 or ten cigarettes being smoked per hour in one room. One useful outcome of this study, although not commented on by the author is that the results show that all contaminants measured behaved in the same way, demonstrating Dalton's Law of Partial Pressures, negating the need to measure large numbers of different ETS markers.
	Modelling of NOx and CO to show build-up and decay up to 120 minute experiment at different air exchange rates. An attempt was made to calculate at which air exchange rates CO and NOx concentrations reach levels comparable to those in ambient air [NO2: 200 ug/m^3 (one hour), CO: 10 mg/m^3 (8-hour average)].			Yes: modelling of conditions inside a walk-in environment chamber	Up to 120 minutes	Carbon monoxide (CO) and (NOx) A linear ODE (ordinary differential equation) was used to simulate mathematically the experimental setup. The concentration change of NOx and CO was attributed to emissions from smoking device, removal due to exchange and introduction of outdoor polluted air into the chamber (for the experiments in "rising mode"). No other sink source or sink terms for the two pollutants was considered. The assumption was that the chamber gases were well mixed.			Yes: The same emission rate was used to simulate both the first and second series of experiments, multiplied by 4 in the latter case.		Model and experimental date agree fairly well. The correlation coefficient between measured and calculated time series stays above 99% in all cases while the normalized bias is below 5% in all but one dataset.	

Table 4: Summary of Bohanon et al [12] 2003 study.

Reference	Setting	Air tightness of building measured	Type of ventilation	Description of venues	Length of Measurements	Measured pollutants	Measured outdoor air quality	Weather conditions recorded	Number of active smokers recorded	Measured area/volume of venue	Findings	Remarks
Bohanon et al. (2003)	Uniformed protocol used in 34 medium-priced restaurants where smoking took place in six countries (France, Korea, Japan, Switzerland, United Kingdom, and United States). Air samples and questionnaires were obtained during the lunch and /or dinner period on high occupancy days.	Not specified	Both natural and mechanical ventilated systems are mentioned in the paper but no further details are given. Two methods were used to determine the rate of outside air supply to the test space. An engineering estimated air exchange rates from the available mechanical ventilation paraters and in-duct air flow measurements and CO_2 measurements combined with counts of people in the space were used to estimate air exchange rates. The use of CO_2 to estimate restaurant ventilation rates is based on CO_2 exhalation at a rate of 31/min-person.	Sampling location and questionnaire that sort basic information from the occupants. The questionnaire assessed the perception of indoor environmental conditions: noise, temperature, draft, odours humidity, freshness, environmental tobacco smoke, and overall IAQ and/or indoor air quality (IEQ). The questionnaires were normally distributed by the waiting staff after they took the orders for the meal.	In duplicate over 3 to 4 hours and in most cases over 1 to 2 days	A protocol was devised to obtain quantitative information on the environmental conditions within the restaurants. Respirable suspended particulate matter, ultraviolet particulate matter, fluorescing particulate matter, solanesol particulate matter, nicotine, 3-ethenylpyridine, carbon dioxide, carbon monoxide, temperature and relative humidity were measured in this study. Two sampling locations were identified in each restaurant. The sampling equipment was at least 50 cm from any walls, and located approximately at head height of a seated person. The sampling would not be influenced by fans or ventilation system or direct exposure to sidestream or exhaled mainstream smoke plumes. Particulate matter samples were collected using 37-mm filters with opaque filter holders to ensure the stability of the solanesol collected on the filters. Gas-phase samples were collected with XAD-4 cartridges.	Yes: Outdoor concentration of CO_2 for the estimated ventilation rates but no details in the paper	No	Yes - Number of smokers were estimated from an average count every 30 minutes. Two methods were employed, the first method was collecting and counting the cigarette butts about every 30 minutes. The second method was frequent periodic visual observations and tabulation of occupant smoking. Regardless of the method used, the number of cigarettes smoked per hour was estimated.	Yes: Volume of room for the estimated ventilation rates but no detail in the paper	It is not necessary to measure a large number of constituents to gain insight into ETS levels in a restaurants facilities. It is necessary to measure at least one constituent in each of the vapour and particle phases. The most beneficial measurements are nicotine or 3-EP, and solanesol or Sol-PM. Carbon dioxide generated by occupants was found to be a viable tool to determine ventilation rates	This paper offers an attempt at estimating ventilation rates and delivering a consistent methodology across a large number of studies, however there are a great many assumptions, and variations in the methodology to be overly confident in the analysis and the findings.
	Indoor air modelling a simple model was used derived from the basic model, (ventilation estimation model) to calculate the steady-state concentrations of an indoor air pollutant. For 28 sessions in five Swiss restaurants nicotine and 3-EP concentrations were calculated.	Not applicable	(Q*F) becomes an effective ventilation rate	Not applicable	Not applicable	ETS yields of nicotine and 3-EP from cigarettes were taken to be 1585 and 334 μg/cig.	Not applicable	Not applicable	Yes - The number of cigarettes smoked per hour (cig/h).	Not applicable	The results appear to predict the measured concentrations, especially at higher concentrations. The simplicity and the potential uncertainties associated with the input parameters, the model predicts nicotine and 3_EP concentrations surprising well. Experimental errors in counting the number of cigarettes smoked are a potential factor. The study does demonstrate that there is significant potential for the use of carbon dioxide measurements to be used to estimate ventilation rates.	

3 Conclusion

In introducing smoking bans it can be argued that insufficient consideration has been given to the use of ventilation systems to control levels of environmental tobacco smoke or to provide segregation by pressurization / de-pressurization of zones. Effective use of ventilation is not straightforward and the evidence from the scientific community has not been helpful, however well intentioned and executed.

The summary of the Bohanon paper confirms the complexity of the problem, which is likely to deter the policy makers from further investigation, whilst the Nebot paper recommends further work, a point apparently overlooked by policy makers. The Kotzias paper provides technically concise and accurate findings, and it is unsurprising therefore that this paper is widely quoted as evidence that ventilation is ineffective in controlling environmental tobacco smoke. This is unfortunate, as although the Kotzias work is accurate and reliable, it was mainly testing using air exchange rates expected in non-mechanically ventilated buildings as those were the rates specified in the project brief.

It is perhaps unreasonable to expect policy makers to have spotted this simple but fundamental weakness in the experimental methodology in the past, but future decisions should now be better informed.

Acknowledgement

This study was commissioned by the Scottish Licensed Trade Association with funding support from the UK Tobacco Manufacturers' Association.

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