Chapter 5

Environmental Tobacco Smoke

Technical Options and Solutions

Dr Matthias K. Schorp*

INTRODUCTION

In the European Union with an estimated 97 million smokers, the need of providing technical options and solutions for indoor spaces where smoking occurs continues to be an important issue. To select the appropriate technologies, an understanding of the characteristics of environmental tobacco smoke (ETS), its contribution to levels of indoor air constituents, and of smokers/non-smokers acceptability of ETS levels is required. This paper provides fundamental information on environmental tobacco smoke and suggests technical options and solutions to maintain acceptability in spaces where smoking is permitted.

CHARACTERISTICS OF ETS

Environmental tobacco smoke, or ETS, is the "aged" and diluted mixture of both side-stream smoke and exhaled mainstream smoke from combustion of tobacco products such as cigarettes and cigars (Rodgman 1992). Mainstream smoke is the smoke emitted from the mouth-end of a cigarette and inhaled by smokers; side-stream smoke is the smoke emitted from the lit-end of a cigarette during and between puffs.

* Matthias K. Schorp is Senior Scientist with Philip Morris Europe, Worldwide Scientific Affairs, CH-2003 Neuchâtel, Switzerland

ETS consists of materials in both the gas and particulate phase. Approximately 100-200 compounds have been quantified in ETS (Guerin 1992). Due to the chemical complexity, dynamics, and extreme dilution of ETS in indoor air, as well as the complexity of the indoor air background, it is impossible to ascertain the concentration level of ETS per se. However, ETS concentrations can be put into perspective by measuring selected ETS components which then can be used as markers or tracers for ETS as a whole.

Some of the criteria for an ideal marker are that it should be specific to tobacco smoke, should be in sufficient concentrations in indoor air to be readily quantified, and should remain in constant proportion to the other components of ETS over a variety of conditions (NRC 1986). No component of ETS appears to fully meet these criteria.

The particulate fraction of the ETS aerosol is generally thought to consist of small semi-liquid droplets, which are of respirable size with a mass median diameter of approximately 0.2 mm (Owen 1992). ETS "particles" belong, therefore, to the respirable fraction (ISO 7708-1995). However, respirable suspended particles (RSP) emanate from numerous sources (Owen 1992). Gravimetric determination, or other total estimates of respirable suspended particles (RSP) are inappropriate indicators of ETS-respirable suspended particle (ETS-RSP) levels in any environment, since they do not give an estimate of the particle fraction attributable to ETS. Apportionment of particles to ETS includes the use of particulate phase markers.

Quantification of particulate phase markers, which provide an upper estimate for the contribution of ETS to RSP concentrations in the indoor environment are referred to as the UVPM (ultraviolet particulate matter) and FPM (fluorescent particulate matter) Methods (Conner 1990, Ogden 1990, ASTM 1996a). These techniques have indicated that, in most cases, the combustion derived fraction of indoor RSP ranges from 10-50% (Guerin 1992). In addition to the UVPM/FPM method, the determination of solanesol has been suggested as a method to determine ETS-RSP (SolPM - solanesol particulate matter - Method) (Ogden 1989, Tang 1990). Airborne solanesol is unique in that it is specific to tobacco smoke and is found only in the particulate phase of ETS. The concentration of RSP attributable to ETS, referred to as SolPM, is calculated from the airborne concentration of solanesol and the experimentally determined weight ratio of solanesol to RSP in ETS (Phillips 1994, Heavner 1996, Phillips 1996, 1997a, 1997b). All three methods (UVPM, FPM, SolPM) are currently used and relied upon, but SolPM is considered to give the closest representation of the particulate phase of ETS (Guerin 1992), although recent results indicate that SolPM can overestimate ETS particle concentrations at high concentrations and may underestimate at low concentrations (Phillips 1997a, 1997b).

Gas and vapour-phase contributions to ETS of selected analytes have been determined for the 50 top-selling USA cigarette brand styles (Martin 1997). Nicotine in ETS is predominantly found in the vapour-phase, as opposed to mainstream smoke, where

nicotine is predominantly found in the particulate phase. Many of the gas-phase compounds associated with ETS have other sources in the environment. For example, of the most prevalent 60 individual volatile organic chemicals (VOCs) identified in the European Indoor Air Quality Audit Project in 56 Office Buildings, not a single compound had tobacco smoke as the only source (Bluyssen 1995). This has some important ramifications as to the determination of the contribution of ETS to gaseous indoor air contaminants, which may be best characterized by the quantification of unique or highly selective ETS gas-phase components, such as nicotine and 3-ethenylpyridine (3-EP) (Nelson 1992, ASTM 1996b). 3-EP has been found to better track the concentrations of other gas-phase ETS components than nicotine (Nelson 1992).

Results from ETS source apportionment studies based on 3-EP in homes and offices have been reported by Heavner et al. (1992, 1996), and in smoking lounges by Hodgson et al. (1996). Table 5.1 presents data from some of the analytes quantified.

Table 5.1 Percent of selected VOC derived from ETS in smoking lounges, smoking homes, and smoking workplaces (adopted from Hodgson 1996, Heavner 1996).

	Hodgson 1996 Smoking lounges (N=4) $\%VOC_{ETS}$ median	Heavner 1996 Smoking Homes (N=29) $\%VOC_{ETS}$ median	Heavner 1996 Smoking Workplaces (N=29) $\%VOC_{ETS}$ median
Formaldehyde	62.6	n.m.	n.m.
Acetone	25.1	3.98	1.11
2-Butanone	53.3	n.m.	n.m.
Benzene	54.0	11.38	11.49
Toluene	31.8	4.11	1.75
Ethylbenzene	25.2	3.36	2.68
m-,p—Xylene	22.2	5.40	3.81
o-Xylene	15.4	3.40	2.93
Styrene	50.0	13.39	6.21
Limonene	12.0	5.07	1.14

n.m. = not measured

DILUTION VOLUMES FOR ACCEPTABILITY OF ETS

The concept of acceptability of indoor air has been used in the past by ASHRAE as a determinant of indoor air quality and is incorporated in the 62-1989 Standard (ASHRAE 1989). Due to inter-individual differences and other factors, a criterion of 80% acceptance is generally thought to be sufficient.

The acceptability of environmental tobacco smoke for smokers and non-smokers has been investigated in controlled laboratory environments (Cain 1983, 1987; Leaderer 1984; Clausen 1987; Gunnarsen 1991; Straub 1993; Walker 1997). Subjects have been exposed to a range of ETS concentrations, which were monitored through the determination of ETS-RSP and carbon monoxide. Walker (1997), Winneke (1996), Gunnarsen (1987), and Clausen (1985) reported relatively stable acceptability ratings of ETS over the course of their experiments. At a given ETS level, smokers tend to give higher acceptability ratings than non-smokers. Among non-smokers, 80% acceptability of air quality is generally achieved at ETS levels resulting in ETS-RSP concentrations of about 60-100 mg/m^3 (Walker 1997).

The results from controlled laboratory environments may be used to estimate the impact of ETS levels in "real-world" settings. However, individuals may be differently responsive to actual real-world environments than in laboratory exposures. For example, the results from Winneke (1984) suggest that at a given ETS concentration, acceptability of ETS in the "real-world" would be higher than in the laboratory. Sensharma et al. stress the predominance of "exogenous factors" (i.e., factors other than the physical environment being assessed) on human responses to the indoor environment and suggest to examine human responses in relation to a set of exposure and exogenous factors (Sensharma

Table 5.2 Dilution volumes for acceptability of ETS at about 80%

Range of Dilution Volumes	Applicability	Reference
116 m^3/cigarette	Non-smokers	Walker et al. 1997
110 m^3/cigarette	Non-smokers & smokers	Gunnarsen et al. 1991
120 m^3/cigarette	Non-smokers & smokers	Clausen et al. 1987
78-120 m^3/cigarette	Non-smokers & smokers	Cain et al. 1983
25-40 m^3/cigarette	Smokers	Straub et al. 1992
23 m^3/cigarette	Smokers	Cain et al. 1987
20-40 m^3/cigarette	Smokers	Leaderer et al. 1984

1996). Acceptability of indoor air quality as predicted from experimental settings did not correlate with occupants' acceptance of indoor air quality in the 56 offices of the European IAQ Audit (Bluyssen 1995).

From the laboratory environments, the volume of air that is required to dilute the ETS from one cigarette to approximately 80% acceptance can be derived. The results are summarized in Table 5.2.

These dilution volumes give the ventilation system designer guidance for determining ventilation rates for any type of space where smoking occurs, similar to the recommendations of the British Standard BS 5925 "Ventilation principles and designing for natural ventilation" (BSI 1991), suggesting a range of dilution volumes of 30 to 120 m^3/cigarette. Ventilation rates specified in Table 2 of ANSI/ASHRAE Standard 62-1989 are based on a dilution volume of 80 m3/cigarette to address "moderate amount of smoking" (Janssen, 1991). These rates have been found to effectively reduce and remove ETS constituents (Sterling 1996, Oldaker 1995, Turner 1992) and provide indoor air that is acceptable to individuals (Bohanon 1993, Bohanon 1996, Moschandreas 1997).

SEPARATION OF SMOKING AND NON-SMOKING SPACES

As indicated above, discretionary smoking may be allowed throughout a facility and can be accommodated by ventilation rates as described in British Standard BS 5925 (BSI 1991), or other applicable national standards throughout the European Union. If, however, physical grouping of smokers and non-smokers is desirable, buildings may have designated smoking and non-smoking areas. In such buildings, commonly used designs have been widely reported in the literature, with options ranging from systems designed to accommodate simple spatial separation of smokers and non-smokers to systems designed for dedicated smoking lounges. The effectiveness of properly functioning ventilation options under varied smoking conditions and venues has been reported by Sterling 1989; Vaughan 1990; Straub 1993; Lambert 1993; Light 1993; Alevantis 1994; Curl 1995; Willman 1995; Hodgson 1996; Sterling 1997.

Ventilation systems can, when supply airflow rates are lower than the total extract (return and exhaust) airflow in a space, intentionally depressurize a space relative to the surrounding areas. It is not the depressurization of the space that is the desired result, but the resulting directional airflow into that space. One example of applications where separation is maintained using directional airflow and relative pressure relationships is in the United States Centers for Disease Control (CDC) Guidelines for isolation of TB patients. The room supply and exhaust airflows are balanced to achieve an exhaust flow of either 10% or 50 cubic feet per minute (cfm) greater than the supply (whichever is greater) (CDC 1994).

Physical grouping can take place within the same space or in separate spaces. The section below addresses the need for achieving directional airflow to prevent the spread of smoke from smoking to non-smoking areas.

- Spaces where there are no physical barriers - no walls or dividers – to separate smoking from non-smoking areas. These spaces rely on airflow to prevent the spread of smoke across the open area

  By arranging supply, return, and exhaust air terminal devices properly with respect to occupants and equipment in the space, ETS levels in the occupied space can be reduced (Sterling 1989; Lambert 1993; Light 1993; Curl 1995). By optimizing the arrangement of the air terminals, ventilation systems can induce localized directional airflow within a room or space (ASHRAE 1997). This directional airflow can help control ETS, odour, and emissions in occupied spaces such as those from office equipment. Keeping maximum velocities in occupied areas below 0.15 m/s in winter and 0.25 m/s in summer will help avoid thermal discomfort (ISO 7730-1984; ASHRAE 1993; ASHRAE 1995). Ventilation is most effective if this directional airflow in the general occupied space occurs at low to moderate velocities. At higher velocities, turbulence and excessive eddying may lead to undesired spread of ETS, odours, or emissions (ASHRAE 1995).

  In open spaces with physical grouping of smokers and non-smokers in discrete areas, airflow should be directed from non-smoking areas towards smoking areas (Hayward 1993; Alevantis 1994; ASHRAE 1995; Hodgson 1996; Sterling 1997). This can be achieved, for example, by locating supply diffusers or grilles predominantly in the non-smoking area, and selecting delivery patterns such as three-way diffusers that encourage horizontal plug flow in the space. In many spaces, the placement of supply air terminals can be much more important in terms of the resultant airflow patterns than the location of the extract terminals. This is particularly true when air supply rates are below 7.5 l/s m^2, as in typical office interior zones, and when adequate induction occurs at the supply air terminals (ASHRAE 1997). Placement of return or exhaust grilles can also influence airflow; location of these devices primarily over smoking areas can encourage desirable directional airflow.

- Spaces with a wall or other physical barrier to separate the area. In these cases, keeping smoke from spreading out of the door or opening between the spaces is the primary concern. This arrangement includes what are typically thought of as smoking lounges.

The effectiveness of directional airflow to prevent or minimize the spread of smoke from smoking towards non-smoking areas was reported by Light 1993, Hayward 1993, Alevantis 1994, and Sterling 1997. A door introduces a new dynamic to the pressure relationships maintained by the ventilation systems. Airflow across a doorway should be of sufficient velocity to help control disturbance of the flow patters by motion of doors and occupants (ASHRAE 1995). Sustaining the directional airflow even when the door is in use improves ventilation system performance with respect to ETS (Hayward 1993, Alevantis 1994, Hodgson 1996). The simplest, but frequently applied tool to verify that the airflow is going in the "right direction," is the smoke pencil test.

Maintaining the system balance to provide this directional airflow may be complicated by the closing of doors. Methods to avoid problems include louvred doors, substantial undercuts, and transfer "jumper" ducts to provide an alternate pathway for airflow when doors are closed. When using transfer air ducts, increased overall transfer airflow or a barometric damper in the transfer duct may help to sustain airflow when the door is open.

TECHNOLOGIES FOR ENHANCED EFFECTIVENESS

Four technology groups are presented here as examples of potential opportunities for improving indoor air quality while reducing operating costs. These four include:

- Energy recovery ventilation
- Displacement ventilation
- Demand control ventilation
- Source management

Energy recovery ventilation

Energy recovery ventilation (ERV) systems in typical HVAC applications use exhaust air to heat and humidify, or cool and dehumidify outdoor air intake, allowing increased outdoor air intake while minimizing energy impacts and often reducing overall capital costs for system components.

Rotary heat exchangers work by transferring energy from one air stream, sometimes called the regeneration air, to another, sometimes called the process air. In typical HVAC application, the regeneration air would be exhaust air, and the process air would be outdoor air. Applied effectiveness in terms of sensible (heat) and latent (moisture) transfer often ranges between 60% to 80%. Independent test results based on ASHRAE Standard 84-1991 allow comparison of ERV performance claims.

Displacement ventilation

In proper displacement ventilation applications, ventilation effectiveness is improved (EV > 1.2), and less outdoor air intake and cooling capacity is required. Air is supplied at or near the floor level, at lower than design room air temperatures (usually around 19 °C) and at low velocities, while warm air is extracted at the ceiling level. The driving force in displacement ventilation is the internal heat sources, resulting in a vertical temperature gradient in a space that encourages warm, buoyant air to rise. The vertical temperature gradient divides the room into two zones, separated by the so-called "stratification level": a lower zone with unidirectional airflow of "clean" air and an upper recirculation zone. Sufficient ceiling height is required to minimize mixing between the two zones.

The resulting thermal convection helps lift indoor air constituents up and away from the occupied space, where they are exhausted. One argument for displacement ventilation is potentially better air quality in the occupied zone. A number of studies have reported that occupants will experience a better air quality in the breathing zone than that of the surrounding air, even if the interface is below the occupants' head (Styme 1991, Goodfellow 1992, Sateri 1992, Breum 1992, Krühne 1994, Hatton 1998). Consistent results with these studies were reported for displacement ventilation systems in rooms where smoking occurred (Nickel 1990, Bjørn 1996). Examination of different ventilation strategies to minimize migration of tobacco smoke from smoking into non-smoking areas found displacement ventilation to give superior results when compared to mixing systems (Kolokotroni 1995)

If thermal loads in a space are very high, the required temperature or velocity of supply air can exceed the range within which displacement ventilation is effective. The comfort criterion of a maximum vertical temperature gradient equal to 3K/m limits the maximum possible cooling load at about 25 W/m² floor area (Sandberg 1989). In some cases with high thermal loads, chilled beam or radiant cooling panels have been used in conjunction with displacement ventilation. Care must be taken to avoid disrupting the desired upward lamina airflow by creating convective airflow from chilled beam or radiant cooling panels. For similar reasons, use of local air cleaners, ceiling fans, or other devices that will result in downward airflow must be avoided in displacement ventilation system designs.

Demand control ventilation

The outside air flow rate for a ventilation system is normally designed for maximum occupancy. For a more rational use of energy, the outside air flow rate may be reduced in rooms which are not fully occupied. For example, carbon-dioxide-based Demand Controlled Ventilation (DCV) controls energy costs while maintaining target per person ventilation rates.

Carbon dioxide-based DCV systems use CO^2 as an occupancy indicator to reduce

ventilation below the maximum total outdoor air intake rate. Carbon dioxide is used as an indictor of occupancy, and not evaluated as a contaminant or used as a surrogate for body odour as a pass/fail benchmark for indoor air quality. In some applications, such as restaurants, mixed-gas sensors have been used to indicate loading of volatile organic compounds and to control ventilation on that parameter (Meier 1995).

Carbon dioxide-based DCV systems often control outdoor air intake using proportional control or other control strategies (VDMA 1998). Proportional control starts to open a damper or otherwise increase outdoor air flow rate when CO^2 levels are a certain amount above outdoor levels, often 100 to 150 ppm above actual outdoor levels. Outdoor airflow rate is increased further as indoor CO^2 levels continue to rise. Once CO^2 levels reach the upper set point, the damper position provides the design ventilation rate for full occupancy. The upper set point is often set close to a steady-state concentration of CO^2 corresponding to the design ventilation rate per person, for example, for about 10 l/s per person, about 850 ppm with outdoor CO^2 levels of 350 ppm.

Sensor location should be selected to accurately reflect CO^2 levels in the space. The control strategy should address any appreciable build up of contaminants that might occur during unoccupied hours. During occupied hours, maintaining a base ventilation rate will help control levels of general odours or contaminants not directly related to occupants.

Source Management

Mechanical or natural ventilation may not always be present or sufficient as designed or as actually provided. For example, due to smoking policy implementations, so-called coffee corners in office buildings may have a higher smoker density today than in the past, but the ventilation system has not been adapted to the new situation. For such conditions, practical and inexpensive technical options are needed.

Portable and ceiling-mounted "air cleaners" have found a niche in this market. To evaluate the effectiveness of such devices, a trade association of home appliances has issued a standard based upon the equivalent volume of clean air produced by the air cleaner, the "clean air delivery rate" CADR (AHAM 1986). Using this concept a number of air cleaners and filters have been tested. (Offermann 1985, Nelson 1993a, 1993b, Shaughnessy 1994, Niu 1997). The use of air cleaners to effectively remove ETS in a conference room has been reported by Pierce et al. (1996).

"Air cleaners" are not designed to capture the emissions directly from a source, but rather to treat the air of the entire space. On the other hand, the concept of "Source Management" would include the additional feature of capturing emissions at or close to a source, thereby reducing the distribution of emissions to the space. Devices with this aim are commercially available, ranging from "active ashtrays" to tables with integrated air treatment systems. High-end systems incorporate technology using vortex air distribution around the table smoking areas, with the effect to essentially prevent tobacco smoke leaving that area. Test reports on "active ashtrays" have been published by Wampler et al. (1994).

SUMMARY

Estimation of the contribution of ETS to particle and gas-phase indoor air constituents is a prerequisite to successfully design for spaces where smoking occurs. The majority of the compounds identified in ETS have other indoor or outdoor sources. To apportion the contribution of smoking to these compounds, the measurement of vapour-phase markers (e.g., 3-ethenylpyridine, nicotine) and/or particulate phase markers (e.g., UVPM, FPM, SolPM) is required.

Data from laboratory experiments indicate that smokers can be accommodated by providing dilution ventilation of about 25-40 m^3 per cigarette, and non-smokers of about 78-120 m^3 per cigarette, giving guidance to the ventilation system designer for determining ventilation rates for any type of space where smoking occurs.

Directional airflow arrangements from the non-smoking to the smoking zone are options directed at additionally minimizing ETS exposures to non-smokers. "Technologies for Enhanced Effectiveness" have demonstrated their capabilities in research and should provide reasonable solutions in practice.

REFERENCES

AHAM Standard AC-1-1986. Method of measuring performance of portable household electric cord-connected room air cleaners. Association of Home Appliance Manufacturers, Chicago, 1986.

Alevantis L.E., Liu K.-S., Hayward S.B., Shah K.B., Leiserson K., Tsao E., Huang Y., Offermann F.J. Effectiveness of ventilation in 23 designated smoking areas in California office buildings. In Proceedings of ASHRAE IAQ '94: Engineering Indoor Environments: pp 89-103, 1994.

ASHRAE 62-1989. Ventilation for Acceptable Indoor Air Quality. American Society of Heating, Refrigerating and Air-conditioning Engineers (ASHRAE), Atlanta, GA, 1989

ASHRAE 84-1991. Method of Testing Air-to-Air Heat Exchangers. American Society of Heating, Refrigerating and Air-conditioning Engineers (ASHRAE), Atlanta, GA, 1991.

ASHRAE. Air-Conditioning Systems Design Manual. ASHRAE Publications, Atlanta, 1993.

ASHRAE. 1995 ASHRAE Handbook – HVAC Applications. ASHRAE Publications, Atlanta, 1995.

ASHRAE. 1997 ASHRAE Handbook-Fundamentals. ASHRAE Publications, Atlanta, CH. 31, 1997.

ASTM Standard D 5955-96. Standard Test Methods for Estimating the Contribution of Environmental Tobacco Smoke to Respirable Suspended Particles Based on UVPM and FPM. 1996 Annual Book of ASTM Standards, Philadelphia, American Society for Testing and Materials; Vol. 11.03: 1996a.

ASTM Standard D 5075-96. Standard Test Method for Nicotine and 3-Ethenylpyridine in Indoor Air. 1996 Annual Book of ASTM Standards, Philadelphia, American Society for Testing and Materials; Vol. 11.03: 1996b.

Bjørn E., Nielsen P.V. Passive smoking in a displacement ventilated room. In: Proceedings of 7th International Conference on Indoor Air Quality and Climate - Indoor Air '96, Nagoya, Japan, July 21-26, 1996 1: 887-892, 1996.

Bluyssen P.M., De Oliveira Fernandes E., Fanger P.O., Groes L., Clausen G., Roulet C.A., Bernhard C.A., Valbjorn O. European Audit Project to Optimize Indoor Air Quality and Energy Consumption in Office Buildings, Final Report. Contract JOU2-CT92-022, TNO Building and Construction Research, Delft, The Netherlands, March 1995.

Bohanon H. Curl S. Operations and maintenance procedures and resultant air quality in one 630.000 ft2 office building. In: Proceedings of ASHRAE IAQ '93: Operating and Maintaining Buildings for Health, Comfort, and Productivity, Philadelphia, Nov. 7-10, 1993, pp. 61-70, 1993.

Bohanon H., Walker J.C., Morgan W.T., Cole S.K. Effect of ventilation rate on air quality perception in a 55.000 square meter office building. In: Proceedings of 7th International Conference on Indoor Air Quality and Climate - Indoor Air '96, Nagoya, Japan, July 21-26, 1996 4: pp. 39-44, 1996.

Breum N.O. Ventilation efficiency in an occupied office with displacement ventilation – a laboratory study. Environ Int 18: pp. 353-361, 1992.

BS 5925:1991 "Code of practice for ventilation principles and designing for natural ventilation" British Standards Institution (BSI), London, 1991

Cain W.S., Leaderer B.P., Isseroff R., Berglund L.G., Huey R.J., Lipsitt E.D., Perlman D. Ventilation requirements in buildings I. Control of occupancy odor and tobacco smoke odor. Atmos Environ 17: pp. 1183-1197, 1983.

Cain W.S., Tosun T., See L.-C., Leaderer B. Environmental tobacco smoke: Sensory reactions of occupants. Atmos Environ 21(2): pp. 347-353, 1987.

Centers for Disease Control and Prevention (CDC), Public Health Service, HHS "Guidelines for Preventing the Transmission of Mycobacterium Tuberculosis in Health-Care Facilities" Department of Health and Human Services Agency, Atlanta, GA, 1994.

Clausen G.H., Nielsen K.S., Sahin F., Fanger P.O. Sensory irritation from exposure to environmental tobacco smoke. In: Proceedings of 4th International Conference on Indoor Air Quality and Climate - Indoor Air '87, Berlin, Germany, 2: pp. 52-55, 1987.

Conner J.M., Oldaker G.B. III, Murphy J.J. Method for assessing the contribution of environmental tobacco smoke to respirable suspended particles in indoor environments. Environ Technol 11: pp. 189-196; 1990.

Curl S.C., Bohanon H.R., Jones M.T., Taylor W.D. Effects of ventilation and separation on environmental tobacco smoke concentration" In: Proceedings of ASHRAE IAQ '95 "Practical Engineering for IAQ," Denver, October 22-24, 1995, pp. 77-88, 1995.

Goodfellow H.D., Grebenc J. Comparison of dilution and displacement ventilation for thermal and contaminant control in a simulated office environment. In: Society of Heating Air Conditioning and Sanitary Engineers of Japan, International Symposium on Room Air Convection and Ventilation Effectiveness, Tokyo, Japan, July 2-24, 1992: pp. 171-176, 1992

Guerin M.R., Jenkins R.A., Tomkins B.A. The Chemistry of Environmental Tobacco Smoke: Composition and Measurement. Lewis Publishers, Inc., Chelsea, MI; 1992.

Gunnarsen L., Fanger P.O. Adaption to indoor air pollution. Environ Int 18: pp. 43-54, 1992.

Hatton A., Awbi H.B. A study of the air quality in the breathing zone. In: Roomvent 6th conference "Air Distribution in Rooms" Stockholm, Sweden, June 14-17, 1998 2: pp. 159-166, 1998.

Hayward S.B., Liu K-S., Alevantis L., Shah K., Loiselle S., Offermann F.J., Chang Y-L., Webber L. Effectiveness of ventilation and other controls in reducing exposure to ETS in office buildings. In: Proceedings of 6th International Conference on Indoor Air Quality and Climate - Indoor Air '93, Helsinki, Finland, July 4-8, 1993 5: pp. 509-514, 1993.

Heavner D.L., Morgan W.T., Ogden, M.W. Determination of volatile organic compounds and ETS apportionment in 49 homes. Environ Int 21: pp 3-21, 1994.

Heavner D.L., Morgan W.T., Ogden M.W. Determination of volatile organic compounds and respirable suspended particulate matter in New Jersey and Pennsylvania homes and workplaces. Environ Int 22 (2): pp 159-183, 1996.

Hodgson A.T., Daisey J.M., Mahanama K.R., Brinke J.T., Alevantis L.E. Use of volatile tracers to determine the contribution of environmental tobacco smoke to concentrations of volatile organic compounds in smoking environments. Environ Int 22(3): pp. 295-307, 1996.

ISO 7708-1995. Air Quality – Particle size fraction definitions for health-related sampling. International Organization for Standardization (ISO), Geneva, Switzerland, 1995.

ISO 7730-1984 Moderate thermal environments – Determination of the PMV and PPD indices and specification of the conditions for thermal comfort. International Organization for Standardization (ISO), Geneva, Switzerland, 1984.

Janssen, J.E. Written Statement of the American Society of Heating, Refrigerating, and Air-Conditioning Engineers. Presented to the US House Energy and Commerce Subcommittee on Health and Environment, Washington, D.C, April 10, 1991.

Kolokotroni M., Alamdari F., Salemi R., Eagles N., Smith M.G. Ventilation effectiveness and space partitioning to minimize migration of tobacco smoke in public buildings. In: Proceedings of Healthy Buildings '95 "International Conference on Healthy Buildings in Mild Climates" Milan, Italy, September 10-14, 1995 2: pp. 617-626, 1995.

Krühne H., Fitzner K. Air quality in the breathing zone in rooms with displacement flow. In: Roomvent 4th conference "Air Distribution in Rooms" Krakow, Poland, June 15-17, 1995 2: pp 93-102, 1994.

Lambert W.E., Samet J.M., Spengler J.D. Environmental tobacco smoke concentrations in no-smoking and smoking sections of restaurants. JAMA 83(9): pp. 1339-1341, 1993.

Leaderer B.P., Cain W.S., Isseroff R., Berglund L. Ventilation requirements in buildings-II. Particulate matter and carbon monoxide from cigarette smoking. Atmos Environ 18(1): pp. 99-106, 1984.

Light E., Gay R. Preliminary assessment of designated smoking areas for nonsmoker exposure to environmental tobacco smoke. In: Proceedings of ASHRAE IAQ '93: Operating and Maintaining Buildings for Health, Comfort, and Productivity, Philadelphia, Nov. 7-10, 1993, pp. 19-25, 1993.

Martin P., Heavner D.L., Nelson P.R., Maiolo K.C., Risner C.H., Simmons P.S., Morgan W.T., Ogden M.W. Environmental tobacco smoke (ETS): A market cigarette study. Environ Int 23(1): pp. 75-90, 1997.

Moschandreas D.J., Vuilleumier K.L. Satisfaction of ASHRAE Standard 62-1989 leads to attainment of acceptable IAQ in hospitality environments. In: Proceedings of Healthy Buildings/IAQ '97 "Global Issues and Regional Solutions" Bethesda, MD, September 27- October 2, 1997 2: pp. 517-522, 1997.

Meier S. Demand-based ventilation: indoor comfort at lower costs. In: Proceedings of Healthy Buildings '95 "International Conference on Healthy Buildings in Mild Climates" Milan, Italy, September 10-14, 1995 3: pp. 1743-1750, 1995.

National Research Council (NRC), Environmental Tobacco Smoke – Measuring Exposures and Assessing Health Effects, National Academy Press, Washington, DC, p. 70, 1986.

Nelson P.R., Heavner D.L., Collie B.B., Maiolo K.C., Ogden M.W. Effect of ventilation and sampling time on environmental tobacco smoke component ratios. Environ Sci Technol 26(10): pp. 1909-1915, 1992.

Nelson P.R., Sears S.B., Heavner D.L. Application of methods for evaluating air cleaner performance. Indoor Environ 2: pp. 111-117, 1993a.

Nelson P.R., Hege R.B., Conrad F.W., Coleman W.M. Removal of gaseous indoor air contaminants by commercial air filters. In: Proceedings of the 1993 EPA/A&WMA International Symposium on measurement of toxic and related air pollutants. Pittsburgh: Air & Waste Management Association pp. 249-254, 1993b.

Nelson P.R., Conrad F.W., Kelly S.P., Maiolo K.C., Richardson J.D., Ogden M.W. Composition of environmental tobacco smoke (ETS) from international cigarettes and determination of ETS-RSP : particulate marker ratios. Environ Int 23: pp. 47-52, 1997.

Nickel J. Air quality in a conference room with tobacco smoking ventilated with mixed or displacement ventilation. In: Proceedings of Roomvent 2nd conference "Air distribution in Rooms" Oslo, Norway, June 13-15, 1990, paper 64, 14pp, 1990.

Niu J., Tung C.-W., Burnett J. The functions of air-cleaners in indoor air quality control. In: Proceedings of ISBE Indoor & Built Environment Problems in Asia, Kuala Lumpur, Malaysia Sept. 4-5, 1997, pp. 133-139, 1997.

Offermann F.J., Sextro R.G., Fisk W.J., Grimsrud D.T., Nazaroff W.W., Nero A.V., Revzan K.L., Yater J. Control of respirable particles in indoor air with portable air cleaners. Atmos Environ 19(11): pp. 1761-1771, 1985.

Ogden M.W., Maiolo K.C. Collection and determination of solanesol as a tracer of environmental tobacco smoke in indoor air. Environ Sci Technol 23: pp. 1148-1154, 1989.

Ogden M.W., Maiolo K.C., Oldaker G.B. III, Conrad F.W. Evaluation of methods for estimating the contribution of ETS to respirable suspended particles. In: Proc. 5th International Conference of Indoor air Quality and Climate, Toronto, Canada 2: pp. 415-420, 1990.

Oldaker G.B., Taylor W.D., Parrish K. Investigations of ventilation rate, smoking activity and indoor air quality at four large office buildings" Environ Technol 16: pp. 173-180, 1995.

Owen M.K., Ensor D.S., Sparks L.E. Airborne particle sizes and sources found in indoor air. Atmos Environ 26 (12): pp. 2149-2162, 1992.

Phillips K., Howard D.A., Browne D., Lewsley J.M. Assessment of personal exposures to environmental tobacco smoke in British nonsmokers. Environ Int 20(6): pp. 693-712, 1994.

Phillips K., Bentley M.C., Howard D.A., Alván G. Assessment of air quality in Stockholm by personal monitoring of nonsmokers for respirable suspended particles and environmental tobacco smoke. Scand J Work Environ Health 22 Suppl. 1: pp. 1-24, 1996.

Phillips K., Bentley M.C., Howard D.A., Alván G., Huiol A. Assessment of air quality in Barcelona by personal monitoring of nonsmokers for respirable suspended particles and environmental tobacco smoke. Environ Int 23(2): pp. 173-196, 1997a.

Phillips K., Bentley M.C., Howard D.A., Alván G. Assessment of air quality in Turin by personal monitoring of nonsmokers for respirable suspended particles and environmental tobacco smoke. Environ Int 23(6): pp. 851-871, 1997b.

Pierce W.M., Janczewski J.N., Roethlisberger B., Pelton M., Kunstel K., Effectiveness of auxiliary air cleaners in reducing ETS components in offices. ASHRAE J 38(9): pp. 51-57, 1996.

Rodgman A. Environmental tobacco smoke. Reg Toxicol Pharmacol 16: pp. 223-244, 1992.

Sandberg M., Blomquist C. Displacement ventilation systems in office rooms. ASHRAE Trans. 95 (2) 9pp, 1989.

Sateri J.O. Local ventilation effectiveness in the breathing zone. In: Society of Heating Air Conditioning and Sanitary Engineers of Japan, International Symposium on Room Air Convection and Ventilation Effectiveness, Tokyo, Japan, July 2-24, 1992: pp. 307-312, 1992.

Sensharma N.P., Woods J.E., Edwards P.K., Holbrook G.T. Simultaneous control of exposures and exogenous factors to achieve acceptability. In: Proceedings of 7th International Conference on Indoor Air Quality and Climate - Indoor Air '96, Nagoya, Japan, July 21-26, 1996 2: pp. 785-790, 1996.

Shaughnessy R.J., Levetin E., Blocker J., Sublette K.L. Effectiveness of portable indoor air cleaners: Sensory testing results. Indoor Air 4: pp. 179-188, 1994.

Sterling T.D., Collett C. Ross J. Levels of environmental tobacco smoke under different conditions of ventilation and smoking restriction. In: Combustion Process and the Quality of the Indoor environment, Air & Waste Management Association, Transaction, Suppl 15: pp. 223-235, 1989.

Sterling E.M., Collett C.W., Ross J.A. Assessment of non-smokers' exposure to environmental tobacco smoke using personal-exposure and fixed-location monitoring. Indoor Built Environ 5: pp. 112-125, 1996.

Sterling E., Collett C., Ross J. The effectiveness of designated smoking areas in controlling non-smokers exposure to environmental tobacco smoke. Indoor Built Environ 6: pp. 29-44, 1997.

Straub H.E., Nelson P.R., Toft H.R. Evaluation of smoking lounge ventilation designs ASHRAE Transactions 99(1): pp. 466-475, 1993.

Styme H., Sandberg M., Mattsson M. Dispersion pattern of contaminants in a displacement ventilated room – implications for demand control. In: AIVC 12th conference "Air Movement and Ventilation Control within Buildings" Ottawa, Canada, September 24-27, 1991 1: pp. 173-190, 1991.

Tang H., Richards G., Benner C.L., Tuominen J.P., Lee M.L., Lewis E.A., Hansen, L.D., Eatough, D.J. Solanesol – A tracer for environmental tobacco smoke particles. Environ Science Teclmol 24(6): pp. 848-852, 1990.

Turner S., Cyr L., Gross A.J. The measurement of environmental tobacco smoke in 585 office environments. Environ Int 18: pp. 19-28, 1992.

Vaughan W., Hammond S.K. Impact of "designated smoking area" policy on nicotine vapor and particle concentrations in a modern office building. J Air Waste Manage Assoc 40: pp. 1012-1017, 1990.

VDMA 24773. Demand-controlled ventilation – Definitions, requirements and control strategies (in german). Verband Deutscher Maschinen- und Anlagebau e.V. Frankfurt/ Main, Beuth-Verlag GmbH, Berlin, 1998.

Walker J.C., Nelson P.R., Cain W.S., Utell M.J., Joyce M.B., Morgan W.T., Steichen T.J., Pritchard W.S., Stancill M.W. Perceptual and psychophysiological responses of non-smokers to a range of environmental tobacco smoke concentrations. Indoor Air 7: pp. 173-188, 1997.

Wampler D.A., Litvak A., Miller-Leiden S., Gadgil A.J., Nazaroff W.W. Effectiveness of smokeless ashtrays. In: Proceedings of the 87th Annual Meeting & Exhibition, Air & Waste Management Association, Cincinnati, OH, June 19-24, 1994: pp. 1-10, 1994.

Willman A.J. Levels of ETS in contemporary office workplaces. In: Proceedings of Healthy Buildings '95 "International Conference on Healthy Buildings in Mild Climates" Milan, Italy, September 10-14, 1995 2: pp. 587-592, 1995.

Winneke G., Plischke K., Roscovanu A., Schlipkoeter H.-W. Patterns and determination of reactions to tobacco smoke in experimental exposure setting. In: Proceedings of 3rd International Conference on Indoor Air Quality and Climate - Indoor Air '84, Stockholm, Sweden 2: pp. 351-356, 1984.

Winneke G., Neuf M., Steinheider B. Separating the impact of exposure and personality in annoyance response to environmental stressors, particularly odors. Environ Int 22(1): pp. 73-81, 1996.