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Environmental Tobacco Smoke

Position Document
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The ASHRAE Position Document on Environmental Tobacco Smoke was developed by the Society's Environmental Tobacco Smoke Position Document Committee.

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Executive Summary

This position document has been written to provide the membership of the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) and other interested persons with information on the health consequences of exposure of nonsmokers to tobacco smoke in indoor environments, and on the implications of this knowledge for the design, installation and operation of heating, ventilating, and air-conditioning (HVAC) systems. ASHRAE's sole objective is to advance the arts and sciences of heating, refrigeration, air conditioning and ventilation, and their allied arts and sciences and related human factors, for the benefit of the public. Therefore, the health effects of indoor exposure to emissions from cigarettes, cigars, pipes, and other tobacco products have long been relevant to ASHRAE.

For more than three decades, researchers have investigated the health and irritant effects among non-smokers exposed to tobacco smoke in indoor environments. The preponderance of credible evidence links passive smoking to specific diseases and other adverse health effects in people. A number of national and global review groups and agencies have concluded that exposure of nonsmokers to tobacco smoke causes adverse effects to human health. No cognizant authorities have identified an acceptable level of environmental tobacco smoke (ETS) exposure, nor is there any expectation that further research will identify such a level.

International experience has been gained over several decades with using various strategies to reduce ETS exposure, including separation of smokers from nonsmokers, ventilation, air cleaning and filtration, and smoking bans. Only the last provides the lowest achievable exposures for nonsmokers and is the only effective control method recognized by cognizant authorities (see *Findings of Cognizant Authorities*). At the time of this writing, several nations, eleven states in the U.S. and hundreds of municipalities and other jurisdictions have banned tobacco smoking completely in all public buildings and workspaces. The U.S. government has banned smoking in its workplaces. Experience with such bans documents that they can be effective, practically eliminating ETS exposure of non-smokers. While exposure is decreasing internationally because of these smoking bans in public and private buildings, and a decrease in the prevalence of smoking, substantial portions of the population are still regularly exposed in workplaces, homes and public places, such as entertainment venues.

ASHRAE concludes that:

- It is the consensus of the medical community and its cognizant authorities that ETS is a health risk, causing lung cancer and heart disease in adults, and exacerbation of asthma, lower respiratory illnesses and other adverse effects on the respiratory health of children.
- At present, the only means of effectively eliminating health risk associated with indoor exposure is to ban smoking activity.
- Although complete separation and isolation of smoking rooms can control ETS exposure in non-smoking spaces in the same building, adverse health effects for the occupants of the smoking room cannot be controlled by ventilation.
- No other engineering approaches, including current and advanced dilution ventilation or air cleaning technologies, have been demonstrated or should be relied upon to control health risks from ETS exposure in spaces where smoking occurs. Some engineering measures may reduce that exposure and the corresponding risk to some degree while also addressing to some extent the comfort issues of odor and some forms of irritation.
- An increasing number of local and national governments, as well as many private building owners, are adopting and implementing bans on indoor smoking.
- At a minimum, ASHRAE members must abide by local regulations and building codes and stay aware of changes in areas where they practice, and should educate and inform their clients of the substantial limitations and the available benefits of engineering controls.
- Because of ASHRAE's mission to act for the benefit of the public, it encourages elimination of smoking in the indoor environment as the optimal way to minimize ETS exposure.

ASHRAE Position Document on Environmental Tobacco Smoke

1.0 INTRODUCTION

Providing healthful and comfortable indoor environments through the control of indoor air quality is a fundamental goal of building and HVAC design and operation. ASHRAE has long been active in providing engineering technology, standards and design guidance in support of this goal. These activities are consistent with the Society's Certificate of Consolidation, which states that ASHRAE's sole objective is "… to advance the arts and sciences of heating, refrigeration, air conditioning and ventilation, and their allied arts and sciences and related human factors, for the benefit of the public."

This position document has been written to provide the membership of ASHRAE and other interested persons with information on what is known about the health consequences to nonsmokers from exposure to tobacco smoke in indoor environments and on the implications of this knowledge for the design, installation and operation of HVAC systems. Because tobacco smoke is a source of both gaseous and particulate contaminants, the health effects of inhaling smoke from cigarettes, cigars, pipes, or other tobacco products in indoor environments have long been relevant to ASHRAE, and specifically to ASHRAE Standard 62.1, *Ventilation for Acceptable Indoor Air Quality*[1]. Recently, ASHRAE adopted a policy stating that while "ASHRAE does not make findings as to the health and safety impacts of environmental exposures," its document and activities "shall consider health and safety impacts." Therefore, it is important for ASHRAE to identify these impacts as they relate to the activities of its members and then to consider them in its documents, as it has done in ASHRAE Standard 62.1. ASHRAE also adopted a policy stating that ASHRAE standards and guidelines will not set ventilation requirements and will not claim to provide acceptable indoor air quality in smoking spaces. Note that this policy does not prevent ASHRAE from providing guidance for designing smoking spaces in other documents, but these documents would only address odor and other comfort goals.

Concerns regarding tobacco smoke in indoor environments have arisen from evidence of adverse health and irritation effects caused among nonsmokers exposed to tobacco smoke indoors. The relevant evidence comes from information on tobacco smoke and its components; from toxicologic studies of tobacco smoke and some of its specific components; from the substantial epidemiologic, pathologic, and clinical evidence that shows the health effects of active smoking; and from epidemiologic studies that have assessed the risks of passive smoking. The latter studies, carried out over the last three decades, have linked passive smoking to specific diseases and other adverse health effects in children and adults.

There are now several decades of international experience with the use of various strategies to reduce ETS exposure, including separation of smokers and nonsmokers, ventilation, air cleaning and filtration, and bans. Only the last provides the lowest achievable exposures for nonsmokers and experience with such bans documents that they can be effective[2]. While exposure is decreasing nationally because of these smoking bans in public and private buildings, and because of decreases in the prevalence of smoking, substantial portions of the population are still regularly exposed in workplaces, homes and public places, such as entertainment venues.

2.0 TOBACCO SMOKE IN INDOOR SPACES: CHARACTERISTICS AND CONCENTRATIONS

2.1 Characteristics of Tobacco Smoke in Indoor Spaces

While tobacco may be smoked in other forms (e.g., pipes and cigars), the cigarette is the principal source of exposure of nonsmokers to tobacco smoke in the United States and other countries. The burning cigarette produces smoke primarily in the form of mainstream smoke (MS) – that smoke inhaled by the smoker during puffing – and sidestream smoke (SS) – that smoke released by the smoldering cigarette while not being actively smoked. Because of the lower temperature in the burning cone of the smoldering cigarette, many tobacco combustion products are enriched in SS compared to MS.

Nonsmokers are exposed to the combination of diluted SS that is released from the cigarette's burning end and the MS exhaled by the active smoker[3]. This mixture of diluted SS and exhaled MS has been referred to as secondhand smoke or environmental tobacco smoke (ETS); the term used in this position document. Exposure to ETS is also commonly referred to as passive or involuntary smoking.

Tobacco smoke consists of a complex mixture of particles and gases, with thousands of individual chemical components. The particles in ETS are in the submicron size range, and as such, penetrate deeply into the lung when inhaled. The respiratory tract (which extends from the nose to the alveoli) absorbs the gases in a manner dependent on their chemical and physical characteristics. For example, reactive and highly soluble gases, such as formaldehyde, are adsorbed in the upper respiratory tract, while less soluble and more inert gases, such as carbon monoxide, reach the alveoli and may be systemically absorbed. Additionally, these particles and gases also impact the mucous membranes of the eyes. While exposures of involuntary and active smoking differ quantitatively and, to some extent, qualitatively[4-9], involuntary smoking results in exposure to multiple toxic agents, including known human carcinogens generated by tobacco combustion[4-9].

2.2 Exposure to Tobacco Smoke in Indoor Spaces

The concentration of the various ETS constituents in an indoor space depends on the number of smokers and their pattern of smoking, the volume of the space, the ventilation rate and the effectiveness of the air distribution, the rate of removal of ETS from the indoor air by air cleaners, deposition of particles onto surfaces, and surface adsorption and re-emission of gaseous components. Because ETS is a complex mixture, measurements of single components are of varying specificity and none alone is considered to indicate the potential toxicity of ETS at a particular concentration. Therefore, measurements of multiple surrogates have been used as indicators of the concentration of the mixture for research and public health purposes. These measures include respirable suspended particles (RSP), nicotine, benzene, solanesol, 3-ethenyl pyridine (3-EP) and carbon monoxide. Such measurements have demonstrated contamination of indoor air wherever smoking takes place. Biomarkers of ETS exposure, i.e., indicators in biological materials such as nicotine in saliva and blood, have also been measured; measurable concentrations of these biomarkers (e.g. cotinine) have been found in the bodies of exposed nonsmokers, indicating uptake of ETS.

3.0 HEALTH EFFECTS OF INVOLUNTARY SMOKING

3.1 Cognizant Authorities

Following the same approach used in the landmark 1964 report of the U.S. Surgeon General on smoking and health[10], the finding that involuntary smoking causes disease or other adverse effects has been based in systematic review of the evidence and the application of criteria for evaluating the strength of evidence in support of causality. The principles for causal inference were set out in the 1964 report and revisited in the 2004 report of the Surgeon General[11]. This approach for evidence evaluation involves systematically gathering and assessing the quality of individual research studies, and then evaluating the overall strength of evidence using accepted causal criteria as guidelines. The term *causal criteria* refers to a set of principles for evaluating evidence for causal inference. These criteria include the consistency of the evidence, the strength of the association of involuntary smoking with the health outcome of concern, the specificity of that association, proper temporality of the association (i.e., involuntary smoking proceeds onset of the health outcome), and the coherence of the evidence.

Using this general approach, the scientific evidence on the health consequences of exposure to ETS has been extensively reviewed by a number of independent expert groups (cognizant authorities) in the United States and internationally, with similar conclusions over the last two decades (Table 1). In the United States, five major cognizant authorities have examined the evidence, including the U.S. Surgeon General[8], the U.S. Environmental Protection Agency[9], the National Research Council[6], the California Environmental Protection Agency[12, 13], and the National Toxicology Program [14]. The first major reviews were published in 1986. As the evidence has expanded, further reviews have been carried out in the United States and internationally. These conclusions are also supported by positions of major health organizations, such as the American Cancer Society, the American Heart Association, the American Lung Association, the American Medical Association, and the British Medical Association, and many professional societies, such as the American Public Health Association, the American Thoracic Society, the American College of Preventive Medicine, the American Academy of Pediatrics and others.

The validity of the conclusions from these cognizant authorities is largely based on the integrity of the processes used to ensure that the reviews and conclusions are free of bias. Factors used to assess the potential role of bias in these processes include the expertise and independence of the report's authors and reviewers, the comprehensiveness of the approach to reviewing the scientific evidence, and the process for peer-review of the report.

3.2 Findings of Cognizant Authorities

Scientific evidence indicates adverse health effects from passive smoking throughout the life-span (Table 1). Some of the first epidemiological studies on ETS and health were reported in the late 1960s[15-17], and since then there have been hundreds of scientific papers on the health effects of ETS exposure. Exposure to ETS in actual indoor spaces has since been linked to numerous adverse effects in infants and children. The adverse effects may even extend to gestation, as ETS components and metabolites reach the fetus of pregnant mothers who are exposed. There is evidence suggesting that ETS exposure of the mother reduces birth weight and that child development and behavior are adversely affected by parental smoking[18-19]. ETS exposure causes increased risk for more severe lower respiratory infections, middle ear disease, chronic respiratory symptoms and asthma, and reduces the rate of lung function growth during childhood. There is no strong evidence at present that ETS exposure increases childhood cancer risk[20].

The first major studies on passive smoking and lung cancer in non-smoking adults were reported in 1981[21-22] and by 1986 the evidence supported the conclusion that passive smoking was a cause of lung cancer in non-smokers. Subsequent evidence has continued to identify other diseases and adverse effects of passive smoking in adults, and the conclusion has been reached that coronary heart disease is caused by ETS exposure (Table 1). The number of coronary heart disease deaths caused by ETS greatly exceeds the number of ETS-caused lung cancer deaths.

Thus, the epidemiological evidence, along with the other relevant lines of evidence, has been reviewed periodically by cognizant authorities with an increasingly lengthy list of diseases and other adverse effects associated with ETS exposure in the nearly two decades since the first causal conclusions were reached in 1986. Notably, conclusions offered by the cognizant authorities have converged and no conclusions have ever been reversed. The conclusions of these studies refer to ETS exposure in general since the biological action does not depend on the particular type of indoor environments.

The reports and their conclusions have not indicated that thresholds can be identified below which effects would not be anticipated, and in general, risks tend to increase with the level of exposure and conversely to decrease with a reduction in exposure. On a biological basis, a threshold would not be anticipated for the carcinogens in ETS[20, 23]. Additionally, the scientific evidence recognizes substantial subpopulations potentially susceptible to ETS, such as children and adults with asthma or heart disease, whose disease may be exacerbated by ETS exposure.

In the absence of a quantitative criterion for acceptable exposure, the only protective measure for effective control that has been recognized by cognizant authorities is an indoor smoking ban, leading to near zero exposure.

4.0 CONSIDERATIONS RELATED TO HVAC SYSTEM DESIGN AND OPERATION

4.1 General Principles

Societal recognition of the public health risks to children and adults of ETS exposure has motivated the use of strategies to reduce or eliminate exposure to ETS. Exposure to ETS has been reduced through a variety of strategies, including those that reduce, but do not eliminate, exposure to ETS. Others, such as banning or restricting smoking, result in a complete or nearly complete reduction of exposure to ETS. The specific strategies may be regulatory or voluntary in their application. Because smoking is a strong localized source of a complex mixture of hazardous agents with different physical and chemical characteristics, multiple engineering techniques need to be employed to minimize ETS exposure in non-smoking areas, absent a smoking ban. There is no target for such reduction, as no cognizant authority has defined a safe level of ETS exposure because of the complex nature of ETS, the multiple health and irritation hazards, and varying individual susceptibility to ETS.

Practitioners must always follow the laws and regulations in laws, regulations and directives at all levels of government, as well as industry codes and standards. Even where permitted by law, many developers, building owners, and operators do not allow smoking. For instance, BOMA International has taken the position that secondhand smoke should not be allowed in buildings and supports legislation to ban smoking in buildings[24]. In the U.S. and many other countries as well, smoking has been banned in most office buildings, shopping center common areas and in most retail sales areas. Many operators of restaurants and other hospitality venues have voluntarily done the same. Therefore, it is recommended that engineers work with their clients to define their intent for addressing ETS exposure in their building. In working with their clients, engineers need to take account of all laws and regulations relevant to ETS, and with their clients develop a strategy that will result in the lowest ETS exposure to building occupants within the context of a building's intended use.

4.2 Design and Operation Approaches

There are four general cases of space-use and smoking activity that lead to different engineering approaches to addressing ETS exposure in buildings: 1) banning smoking indoors; 2) allowing smoking only in isolated rooms; 3) allowing smoking in separate but not isolated spaces; and 4) totally mixing occupancy of smokers and nonsmokers. These approaches do not necessarily account for all circumstances, but are in a sequence from most to least effective in controlling ETS exposure.

1. Banning Smoking Indoors: A total ban on indoor smoking is the only effective means of controlling the health risks associated with ETS exposure. This approach has been implemented by many governments and private building owners. While there are no system design issues related to this approach, the existence of outdoor smoking areas near the building and their potential impacts on entryway exposure and outdoor air intake locations should be discussed with the developer, building owner and/or building operator.

2. Smoking Only in Isolated Rooms: Allowing smoking only in separate and isolated rooms, typically dedicated to smoking, can control ETS exposure in non-smoking spaces in the same building. Effective isolation is achievable through airflow and pressure control including location of supply outlets and return and exhaust air inlets to preserve desirable airflow directions at doorways, as well as the use of separate ventilation systems serving the smoking spaces. When using this approach, the design and operation need to address entrainment of exhaust air containing ETS into the non-smoking area's system through the air intake, windows, and other airflow paths. In addition, the airtightness of the physical barriers between the smoking and nonsmoking areas, as well as of the connecting doorways, requires special attention. Some smoking lounges in airports or office buildings exemplify use of this control approach. The risk of adverse health effects for the occupants of the smoking room cannot be controlled by ventilation. Engineering techniques to reduce odor and irritation in the smoking room include dilution ventilation, and air cleaning and filtration techniques.

3. Smoking in Separate But Not Isolated Spaces: In the third situation, smoking is allowed in separate spaces that are not physically isolated from non-smoking areas. This approach includes spaces where smokers and non-smokers are separated but still occupy a single space or a collection of smoking and non-smoking spaces served by the same air handler. Examples can be found in restaurants and bars with smoking and non-smoking areas, or buildings where smoking is restricted to specific rooms but a common, recirculating air handler serves both the smoking and non-smoking rooms. This situation also includes spaces where a common air handler does not recirculate from the smoking to the nonsmoking area and spaces with multiple air handlers.

Engineering techniques to reduce odor and irritation include, directional airflow patterns achieved through selective location of supply and exhaust vents, and air cleaning and filtration. These techniques may reduce ETS exposure in non-smoking areas but limited evidence is available on their effectiveness. Movement of people between non-smoking and smoking areas may disrupt intended airflow patterns, degrading the effectiveness of exposure reduction for the non-smoking occupants (including workers).

4. Mixed Occupancy of Smokers and Nonsmokers: If smoking is allowed throughout a space or a collection of spaces served by the same air handler, with no effort to isolate or separate the smokers and nonsmokers, there is no currently available or reasonably anticipated ventilation or air cleaning system that can adequately control or significantly reduce the health risks of ETS. For example, this situation includes unrestricted smoking in homes, dormitories, casinos, bingo parlors, small workplaces, and open plan office spaces. Air cleaning, ordinary dilution ventilation and displacement ventilation can provide some reduction in exposure but they cannot minimize adverse health effects, nor odor and sensory irritation for nonsmokers in general.

5.0 CONCLUSIONS

- There is a consensus among cognizant medical authorities that ETS is a health risk, causing lung cancer and heart disease in adults, and causing adverse effects on the respiratory health of children, including exacerbating asthma and increasing risk for lower respiratory tract infection.
- At present, the only means of eliminating health risks associated with indoor exposure is to ban all smoking activity.
- Although complete separation and isolation of smoking rooms can control ETS exposure in non-smoking spaces in the same building, adverse health effects for the occupants of the smoking room cannot be controlled by ventilation.
- No other engineering approaches, including current and advanced dilution ventilation, "air curtains" or air cleaning technologies, have been demonstrated or should be relied upon to control health risks from ETS exposure in spaces where smoking occurs, though some approaches may reduce that exposure and address odor and some forms of irritation.
- An increasing number of local and national governments, as well as many private building owners, are implementing/adopting bans on indoor smoking.

- At a minimum, ASHRAE members must abide by local regulations and building codes and stay aware of changes where they practice; they should also educate/inform their clients of the limits of engineering controls in regard to ETS.
- Because of ASHRAE's mission to act for the benefit of the public, it encourages elimination of smoking in the indoor environment as the optimal way to control ETS exposure.

Table 1. Adverse Effects from ETS Throughout the Life Span

Health Effect	SG 1984[1]	SG 1986[2]	EPA 1992[3]	CalEPA 1997[4]	UK 1998[5]	WHO 1999[6]	IARC 2002[7]
Children							
Risk factor for SIDS				Yes/c	Yes/a	Yes/c	
Increased prevalence of respiratory illnesses	Yes/a	Yes/a	Yes/c	Yes/c	Yes/c	Yes/c	
Decrement in pulmonary function	Yes/a	Yes/a	Yes/a	Yes/a		Yes/c	
Increased frequency of bronchitis, pneumonia	Yes/a	Yes/a	Yes/a	Yes/c		Yes/c	
Increase in chronic cough, phlegm		Yes/a				Yes/c	
Increased frequency of middle ear effusion		Yes/a	Yes/c	Yes/c	Yes/c	Yes/c	
Increased severity of asthma episodes and symptoms			Yes/c	Yes/c		Yes/c	
Risk factor for new asthma			Yes/a	Yes/c			
Adults							
Risk factor for lung cancer		Yes/c	Yes/c	Yes/c	Yes/c	Not addressed	Yes/c
Risk factor for heart disease				Yes/c	Yes/c	Yes/a	
Respiratory symptoms and lung function	Yes/a						
Increased severity of asthma episodes and symptoms				Yes/c			

Yes/a = association
Yes/c = cause

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Following the U.S. Environmental Protection Agency's classification of Environmental Tobacco Smoke (ETS) as a Group A carcinogen in 1992, California passed legislation in 1994 (Assembly Bill 13[1]) prohibiting most employers from exposing nonsmoking workers to ETS. As a result of this legislation, workplace smoking restrictions were added to the California Labor Code.[2] This statute prohibits any employer from knowingly or intentionally permitting the smoking of tobacco products in enclosed places of employment.

Prohibition of smoking at the workplace does not apply to breakrooms designated by employers for smoking, under specified conditions. There are additional exemptions to specific workplaces that are not related to the subject matter in this article.

Smoking Breakrooms

Smoking is allowed in specially designed and operated breakrooms that meet the following criteria:

a. Air from the room is exhausted directly to the outside by an exhaust fan;

b. No smoking room air is recirculated to other parts of the building; and

c. Smoking rooms are in a non-work area where employees are not required to be present as part of their work responsibilities other than custodial or maintenance work when the room is unoccupied.

Criteria a and b are the major focus of this article, and in particular, we consider the level of negative pressurization and other separation techniques that are effective in achieving the "no air … is recirculated…" criterion of b. This article does not consider any of the ventilation goals in the smoking breakrooms themselves. Rather, our focus is on minimizing ETS leakage from these breakrooms to nonsmoking areas.

California Study of Smoking Rooms

Phase I. From 1991 to 1994, prior to the passage of AB13, we studied the effectiveness of various smoking-area de-

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signs in containing ETS within smoking areas in 23 public buildings.[11,12] The designs studied ranged from open, adjacent, and/or contiguous smoking/nonsmoking areas to smoking rooms that were completely isolated from adjoining areas with walls and doors. We measured nicotine in the smoking and nonsmoking areas, pressure differentials between smoking and nonsmoking areas, smoking room airflow rates, and building ventilation rates. In addition, we tagged the air in the smoking room with a tracer gas (sulfur hexafluoride [SF_6]) and measured its concentration in the smoking and nonsmoking areas.

Among the designs studied, we found that enclosed areas with no air recirculation to nonsmoking areas and with exhaust to the outside were clearly the most effective in reducing exposure of non-smokers to ETS. Although only a small number (4 out of 23) of the smoking areas met the restrictions currently in AB13, the study indicated that the most important variables relevant to smoking room performance were room de-pressurization, door opening patterns, and in the case of open ceiling plenums between smoking and nonsmoking areas, leakage into the return air ceiling plenum above the smoking room.

Phase II. The purpose of this study was to quantify the effect of the variables identified during Phase I of the study relevant to smoking room performance under controlled laboratory conditions. This study was conducted from 1999 to 2002.

Twenty-seven experiments were conducted in a simulated smoking room with a smoking machine and an automatic door opener. The characteristics of the test chamber are described in *Table 1.* Smoking room performance was quantified primarily by tagging smoking room air with SF_6 and monitoring its concentration in both the smoking and nonsmoking areas. Because the dynamics and transport of the various ETS components can differ substantially from that of SF_6 and from each other, we measured three particle and two gas phase ETS tracers in a subset of these experiments. The particle-phase ETS tracers measured were: total particulate matter (PM), PM-phase scopoletin, and optical absorption of PM at 370nm (UVPM). The two gas-phase tracers measured were: nicotine and 3-ethenylpyridine (3-EP).

Three potential air leakage mechanisms were investigated in the chamber tests:

a. Through the gap under the door and wall cracks when the smoking room was pressurized relative to the nonsmoking area;

b. Around the ceiling tiles in an open plenum that connected with the nonsmoking area when the smoking room was pressurized relative to the plenum; and

c. Via the pumping action of the door as occupants enter and exit the smoking room.

Data collected from the 27 laboratory experiments allowed us to quantify the various types of leakage flows, the effect of these leaks on smoking room performance and nonsmoker exposure, and the relative importance of each leakage mechanism.

The most important findings of interest to designers of smoking rooms are summarized next. A detailed discussion of all the experimental findings has been published elsewhere.[13]

Smoking Room Effectiveness

The impact of each leakage mechanism on smoking room effectiveness was evaluated using the following performance

Existing Design Guidelines for Containment Rooms

Many organizations have issued guidelines for negatively pressurized rooms. These guidelines are based on field experience using smoke test methods.

1. A "rule of thumb" for designing negatively pressurized rooms has been that a 10% differential between a room's supply and exhaust (or return) airflow is adequate to prevent room air leakage to adjoining spaces.[3] Guttman[4] reported that this 10% rule of thumb "is a hangover from an old ASHRAE guide."
2. The Francis J. Curry National Tuberculosis Center[5] recommends that the negative pressure differential across Tuberculosis isolation rooms be approximately –7.5 Pa (0.03 in. H_2O). The same Center recommends that exhaust should exceed supply by at least 47 L/s (100 cfm).
3. CDC[6] recommends 0.25 Pa (0.001 in. w.c.) negative pressure for TB isolation rooms and that the exhaust should be 10% or 24 L/s (50 cfm) greater than the supply.
4. The California Office of Statewide Health Planning and Development (OSHPD[7]) and the California Mechanical Code recommend for TB isolation rooms the same pressure differential as CDC, but also specify that the exhaust should be 35 L/s (75 cfm) greater than the supply, that the room should be under negative pressure, and that the velocity at the "transfer opening" be 0.51 m/s (100 fpm).
5. For laboratories, the *American National Standard for Laboratory Ventilation*[8] specifies that where air must be contained, the exhaust and supply airflow rates must be maintained through any opening between the controlled space and adjoining areas, including open doorways, so that the following velocities be achieved at the opening:
   a. minimum velocity: 0.25 m/s (50 fpm); and
   b. preferred velocity: 0.51 m/s (100 fpm).
6. For areas undergoing asbestos containment, OSHA[9] recommends that these areas be negatively pressurized at 5 Pa (0.02 in. w.c.).
7. Wiseman[10] recommends a minimum negative pressure of 2.5 Pa (0.01 in. w.c.) and advices a pressure 12 Pa (0.05 in. w.c.) or higher for "critical areas."

California Smoking Ordinances

In 2001 our group conducted a telephone survey of all 62 local tobacco control jurisdictions in California regarding their ordinances for the operation of smoking rooms. The results indicated that 29% (N=18) have ordinances prohibiting smoking anywhere at the workplace, including smoking rooms, while the remainder do not have any specific ordinances more strict than the California Labor Code and, therefore, do not prohibit the operation of smoking rooms.

The California Department of Health Services conducts ongoing statewide surveys aimed at collecting information about Californians' smoking behaviors, including operation of smoking rooms. Based on these surveys, we estimated that about 122,000 California workers, or 0.8% of the workforce were working in buildings where smoking rooms were operating in 1999. For 2000, these estimates were slightly lower (100,000 workers or 0.6% of the workforce), indicating a decline in smoking at the workplace.

measure:

• The *smoking room exhaust efficiency* is the percentage of smoking room air that is successfully exhausted to the outdoors by the ventilation system serving the smoking room.[12,13] Smoking room air containing ETS that is not exhausted to the outdoors can be sorbed on smoking room surfaces and/or leak into adjoining, nonsmoking areas. The steady-state exhaust efficiency, $h_{exh,}$ is given by

$$\eta_{exh} = Q_{exh,SR}\left[\mathrm{ETS}\right]_{SR}/S\times 100\% \tag{1}$$

where $Q_{exh,\,SR}$ is the smoking room exhaust flow in units of volume per time, $[\mathrm{ETS}]_{SR}$ is the ETS or SF_6 concentration in the smoking room exhaust duct at steady-state in units of mass per volume, and S is the generation rate of ETS or SF_6 in units of mass per time. Higher exhaust efficiencies indicate that most of the smoking room air is removed by the smoking room's exhaust.

Flow Under Closed Door

We applied the data for the flow under the door and the data for the pressure differential between the smoking room and the adjoining nonsmoking room to the power law equation as described in the *2001 ASHRAE Handbook—Fundamentals*, Chapter 26:

$$Q = c(\Delta P)^n \tag{2}$$

where Q is the flow under the door in L/s, c is the flow coefficient in L/s/(Pa)^n, and n is a dimensionless pressure exponent.

Fitting our data to the above equation resulted in $c = 6.10$ L/s/(Pa)$^{0.573}$ and $n = 0.573$.

Assuming that the flow coefficient is linearly proportional to the gap under the door (6 mm or 0.25 in. for our experiment), we produced the following equation:

	Smoking Room	Non-Smoking Room
Room Dimensions	2.2 m × 4.6 m × 2.4 m (7.2 ft × 15 ft × 7.9 ft)	2.2 m × 4.6 m × 2.4 m (7.2 ft × 15 ft × 7.9 ft)
Room Floor Area	10.2 m^2 (110 ft^2)	10.2 m^2 (110 ft^2)
Room Volume	25 m^3 (870 ft^3)	25 m^3 (870 ft^3)
Door Size	2.1 m × 0.89 m (6.9 ft × 2.9 ft)	
Gap Under Door	0.64 cm (0.25 in.)	
Supply Flow Rate	3 – 54 L/s (6.3 – 114 cfm)	26 – 100 L/s (Outside Plus Recirculated) (55 – 212 cfm)
Supply Flow Per Floor Area	0.05 – 1.1 cfm/ft^2	0.5 – 1.9 cfm/ft^2
Exhaust Flow	13 – 99 L/s (27.5 – 210 cfm)	11 – 61 L/s (23 – 130 cfm)
Exhaust Flow Per Floor Area	0.25 – 1.9 cfm/ft^2	0.21 – 1.2 cfm/ft^2
Percentage of Outside Air	100%	30 to 70%
ACH	0.4 to 7.9 hr^{-1}	1.9 to 15 hr^{-1}
Calculated Velocity at Door Opening with Door Open (@99 L/s or 210 cfm Exhaust)	0.053 m/s (10 fpm)	
Ceiling Plenum Height	23 cm (9 in.)	
Linear Feet of Ceiling Tiles	61 m (200 ft)	

Table 1: Experimental parameters.

$$Q_{under\ door} = 1{,}100\,A_{gap}\left(\Delta P_{SR}\right)^{0.573} \tag{3}$$

where $Q_{under\ door}$ is flow under the door in L/s, ΔP_{SR} is the pressure differential between the smoking room and the adjoining nonsmoking area(s) in Pa, and A_{gap} is the area of the door gap in m^2.

Flow Around the Perimeter of Ceiling Tiles

Similarly, using Equation 2 and fitting the data for the experiments where the ceiling plenum was open between the smoking and nonsmoking areas, we obtained $c = 28.5$ L/s/(Pa)$^{0.484}$ and $n = 0.484$ for flow from the smoking room to the plenum.

Assuming that the flow coefficient is linearly proportional to the total perimeter of ceiling tiles installed in a smoking room (200 linear feet for our experiment), we produced the following equation:

$$Q_{SR\text{-}cp} = 0.142\,L_{cp}\left(\Delta P_{cp}\right)^{0.484} \tag{4}$$

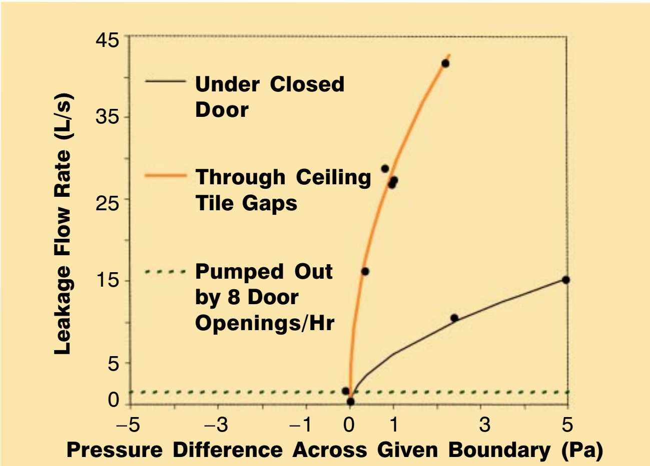

Figure 1: Leakage flow from smoking room to nonsmoking room as a function of pressure differentials across the smoking room's door and ceiling plenum.

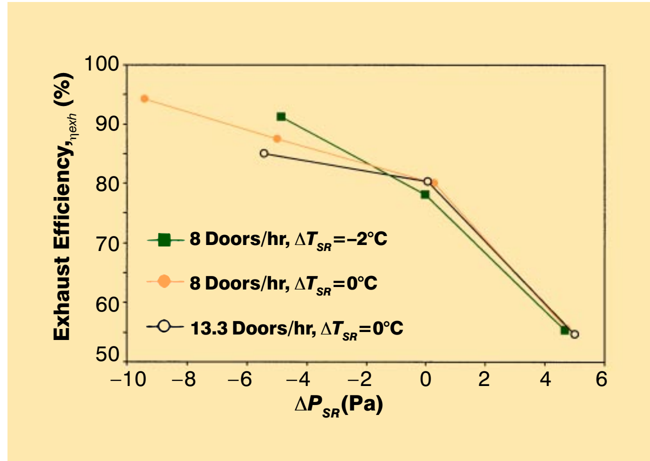

Figure 2: Exhaust efficiency as a function of the pressure differential between smoking and nonsmoking rooms.

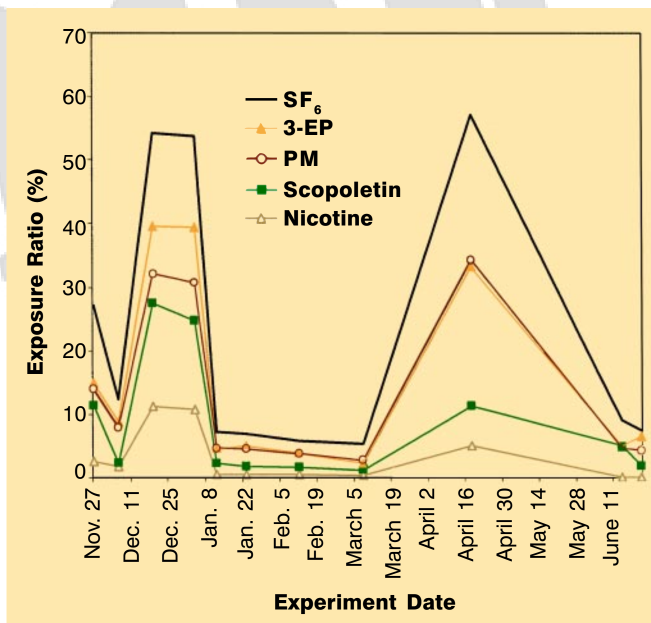

Figure 3: Exposure ratios (ratio of concentrations in nonsmoking and smoking rooms) for five tracers.

where $Q_{SR\text{-}cp}$ is the flow through the perimeter of the ceiling plenum tiles in units of L/s, L_{cp} is the perimeter of the ceiling tiles in m, and ΔP_{cp} is the pressure differential between the smoking room and ceiling plenum in Pa. The proportion of ETS contaminants in this leakage flow that enters the nonsmoking area of a building will depend on whether the plenum air is recirculated or leaks into the nonsmoking areas, the percentage that is recirculated, and on the extent to which the contaminants deposit on surfaces in the return or leakage air path or are removed by filters.

Pumping of ETS-Laden Air by Opening and Closing of the Smoking Room Door

Each opening and closing of the smoking room swing-type door transferred approximately 24 ft^3 (670 L) of ETS-laden air from the smoking room to the adjacent nonsmoking area. The effective leakage rate in units of L/s can be determined by multiplying this volume by the number of door openings per unit time, D

$$Q_{door\text{-}pumping} = 670\ \mathrm{L} \times D[openings/hr] \times 2.8\times10^{-4}\ hr/s \quad (5)$$

This volume was measured when door pumping was the only leakage mechanism of the smoking room, i.e., the room was not ventilated and not depressurized.

We anticipate that this leakage rate would scale approximately linearly with door size.

Equations 3 and 4 allow a designer to specify exhaust airflows for a smoking room based on target values for ΔP_{SR} and ΔP_{cp} (target values are discussed later in this article). These equations apply for the experimental setup that we studied and may not fully describe other rooms with considerably different leakage mechanisms.

Leakage Mechanisms and Pressure Gradient

Plotting the various leakage flows as a function of the appropriate pressure drop (*Figure 1*) indicates that:

a. Depressurization eliminates undesirable leakages under door gaps and around ceiling tiles (instead, the leakage goes from nonsmoking to smoking area);

b. Pumping of smoking room air via door opening is the only leakage mechanism in depressurized smoking rooms; and

c. In our experiments, leakage to the ceiling plenum was a stronger function of ΔP than leakage through the door.

Since the quasi-steady state concentration of a pollutant originating in an enclosed space is roughly inversely proportional to the space's pollutant-free ventilation rate, a higher ventilation rate in a smoking room reduces concentrations of ETS contaminants in the smoking room air, which, in turn, diminishes the adverse effects of leakage from the smoking room to the nonsmoking room. To first order, for the high ventilation rates in smoking rooms, the concentrations of ETS constituents in the smoking room air will increase in direct proportion to ETS constituent production rate and decrease in proportion to the reciprocal of the smoking room's ventilation rate. A more complete discussion of ETS concentrations during and after smoking can be found elsewhere.[14,15]

Comparing Leakages

We conducted the majority of our experiments with a swing-type entry door to the smoking room. In addition, we conducted a limited number of experiments with a sliding-type entry door as well as with an open doorway (no door) in order to compare the leakages of ETS-laden air to the nonsmoking area of these configurations.

The "pumped out by eight door openings/hr" curve in *Figure 1* was determined using a swing-type door. When we replaced this type of smoking room door with a sliding door, the volume of air pumped out per opening was reduced by 77%. Therefore, the volume shown in Equation 5 is reduced to only 5.4 ft^3 (150 L) in the case of a sliding door.

Intuitively, using a smoking room with a fixed, open doorway would be a way to completely eliminate smoking room air leakage via door pumping. However, thermally-induced circulation flows through the doorway can cause air from the smoking room to leak into the nonsmoking room, even when the net flow across the doorway is towards the smoking room. In our "open doorway" test, SF_6 concentrations in the nonsmoking room were comparable to those found in our tests with a door in place, but it required ventilation rates that were two to four times higher to achieve the same results. Thus, using a door and maintaining the smoking room depressurized was a much more effective way to control leakage from the smoking room. Open doorways with higher face velocities than ours may be more protective, though they presumably would require even higher exhaust flows.

In our experiments, we were able to achieve 99 L/s (210 cfm) of exhaust flow or velocities of 0.053 m/s (10 fpm) through the open doorway. As was mentioned previously, for a laboratory with open doorways, the American National Standard for Laboratory Ventilation[8] recommends a minimum velocity of 0.25 m/s (50 fpm) with 0.51 m/s (100 fpm) being the desired velocity. For a standard size door, these velocity requirements translate into exhaust airflows of 470 L/s and 940 L/s respectively (1,000 and 2,000 cfm). These exhaust flows are unrealistically high, especially for smaller size rooms. For large smoking rooms with large numbers of users, such as in some airports, the open-door smoking room may possibly be more practical and superior to a smoking room with a swinging door. It should be pointed out that the open doorway may be perceived as a hazard by some nonsmokers.

Recommended Pressure Differential

Figure 2 shows the η_{exh} as a function of the pressure differential between the smoking and nonsmoking room. The graph shows that for pressure differentials of –5 to –7 Pa (–0.02 to –0.03 in. W.C.), exhaust efficiencies of at least 90% were achieved. This pressure difference will vary with the total amount of leakage in the smoking room's envelope. Temperature differentials of 2°C (3.6°F) did not result in measurable additional leakages.

Correlation Between SF_6 and Other ETS Markers

We used the *exposure ratio* to correlate SF_6 to the other ETS tracers. The exposure ratio is the ratio of ETS or SF_6 concentration in the nonsmoking area divided by the corresponding concentration in the smoking area. Lower exposure ratios indicate better protection for occupants of nonsmoking areas

As shown in *Figure 3,* all ETS tracer exposure ratios showed good correlation with SF_6 (i.e., all fluctuated together in response to the various smoking room configurations). However, all ETS tracers exhibited lower-*magnitude* exposure ratios than SF_6, implying less leakage to nonsmoking-room air. 3-EP showed the highest levels in nonsmoking room air, whereas nicotine showed the lowest.

Other Considerations

There were many issues related to the health and comfort of non-smokers occupying areas adjoining smoking rooms that our research did not intent to address. Some of these issues include:

a. Health effects associated with low-level ETS exposures in the nonsmoking areas;

b. Leakage of residual and sorbed ETS from a smoking room when the room is unoccupied and its ventilation is turned off;

c. Ventilation rates for odor control in the smoking rooms; and

d. Transfer of ETS from smoking areas to nonsmoking areas by occupant clothing.

Conclusions

Our test results indicate that designers of smoking rooms should consider the following:

1. Maintain smoking rooms depressurized relative to the adjoining nonsmoking areas. Our results showed that for pressure differentials between –5 to –7 Pa (–0.02 to –0.03 in. w.c.), exhaust efficiencies of at least 90% were achieved.

2. Air from the smoking rooms should be exhausted to the outside without recirculation to other occupied spaces.

3. *Figure 2* may be used to estimate the pressure differential to maintain a desired level of smoking room efficiency. Equations 3 and 4 can then be used to estimate exhaust airflow requirements to maintain the pressure differential.

4. Increasing the smoking room ventilation rate will dimin-

ish the concentration of ETS contaminants in any air that happens to leak from the smoking room to the nonsmoking area.

5. If a smoking room shares a common plenum with adjacent nonsmoking spaces, either block off plenum or ensure that the smoking room is under slightly negative pressure relative to the ceiling plenum.

6. Even when smoking rooms are maintained under negative pressure, operating swing-type entry doors to enter and exit smoking rooms results in pumping of smoking room air into adjoining nonsmoking areas.

7. Sliding-type entry doors minimize leakage due to the "pumping" effect.

8. Automatic closure mechanisms are recommended for swing-type and sliding-type doors to avoid leakage through an open doorway.

9. An open doorway requires high exhaust flows to ensure that air flows from the nonsmoking area to the smoking area and is unlikely to be a practical configuration for the most common, smaller size smoking rooms.

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