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The Effectiveness of Designated Smoking Areas in Controlling Non-Smokers Exposure to Environmental Tobacco Smoke

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Abstract

Field monitoring was conducted in office buildings in Seattle and Dallas to assess the effectiveness of various workplace smoking configurations in controlling non-smokers exposure to environmental tobacco smoke (ETS). Simultaneous measurements of vapour-phase and particle-phase tracers of ETS were conducted in adjacent smoking and non-smoking areas. Pressure relationships between smoking and non-smoking areas were determined. The Seattle portion of the study focused on the direct infiltration of ETS from smoking to non-smoking areas, as minimal recirculation of return air was occurring. Negative pressurisation of smoking areas eliminated the direct migration of ETS. Tracers of ETS exposure were not detected in non-smoking areas adjacent to negatively pressurised smoking lounges. In the Dallas study buildings, the impact of recirculation of ETS through the heating, ventilation and air-conditioning systems was assessed. Vapour-phase ETS constituents were recirculated into non-smoking areas at diluted concentrations. However, elevated particle-phase constituents were not found in non-smoking areas. The overall results indicate that non-smokers exposure to ETS can be effectively reduced in the office workplace without regulations or policies that require either direct exhaust of air from smoking areas to the outdoors by dedicated ventilation systems or total prohibition of smoking within buildings.

Introduction

Building operators are increasingly faced with a dilemma of responding to the different needs of smoking and non-smoking occupants of their buildings. A range of options are available to the building operator to accommodate smoking in the workplace, while striving to reduce the exposure of non-smoking occupants to environmental tobacco smoke (ETS).

Options to accommodate smoking include (a) general dilution ventilation with outside air ventilation rates in accordance with current engineering standards, for which division of the workplace into smoking and non-smoking areas is not required; (b) spatial separation of smokers and

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non-smokers, as has been implemented in many hospitality industry environments, and (c) physical separation of smokers and non-smokers, most commonly through the restriction of smoking to designated areas; physically apart from non-smoking areas. Designated smoking areas may be configured without changes to a building's heating, ventilation and air-conditioning (HVAC) systems, with minor HVAC system adjustments, or with the addition of dedicated exhaust ventilation systems to exhaust air directly to the outdoors. Each of the available options has different impacts on capital and operating costs for a building.

The trend in workplace smoking regulation in North America has been to adopt the most restrictive approaches to control non-smokers exposure to ETS. For example, the US Occupational Safety and Health Administration (OSHA) issued proposed indoor air quality (IAQ) rules for US workplaces in April 1994, which required either total prohibition of smoking, or provision of designated smoking areas that must directly exhaust to the outside [1]. For building operators whose goal is to accommodate both smokers and non-smokers, total prohibition is not an acceptable alternative. Therefore, the provision of designated smoking areas with dedicated exhaust systems is their only option, given the proposed OSHA rules. However, costly retrofits will be required to provide the necessary exhaust systems in high-rise office buildings typically found in cities throughout North America.

The research conducted here focuses on the effectiveness of the less costly option of providing designated areas that do not directly exhaust to the outdoors in controlling non-smokers exposure to ETS in the workplace. The research was conducted in Seattle, Washington, and Dallas, Texas, during August and September, 1993.

Methods

Selection of Cities, Study Buildings and Study Areas

Seattle and Dallas were selected as the cities in which to conduct the research due to climatic differences between the two cities which dictate major differences in the design considerations and operational requirements for office buildings.

Typically moderate outdoor temperatures in Seattle provide opportunities for HVAC systems to supply large volumes of outside air into buildings for much of the operating year. Such operational conditions allow building operators to use free cooling through economiser ventilation, with little or no increase in energy costs. In contrast, higher temperatures for much of the operating year in Dallas dictate that HVAC systems are operated with mechanical cooling. Consequently, buildings in Dallas are frequently designed with lower outside air supply capabilities than buildings in Seattle and are operated using a high proportion of recirculated air.

A telephone survey of building owners in Seattle and Dallas was conducted to solicit participation in the study. Specific selection criteria were used to identify the study buildings. The selection criteria were developed to provide a cross-section of buildings that would be representative of 'typical' high-rise office buildings throughout North America, thereby allowing generalisation and extrapolation of the research findings from the case studies to the North American office building stock. Specific criteria included a central HVAC system; high-rise structure over 10 stories; constant volume or variable air volume systems; standard (i.e. not high efficiency) filtration equipment; typical (i.e. not energy efficient) building envelopes; and a range in age to cover the majority of high-rise buildings in North America.

Once the study buildings were identified, specific study areas were selected within each building using the following criteria: (1) that smoking was permitted in either: (a) designated areas without additional ventilation; (b) designated areas with additional ventilation, or (c) individual office areas; (2) a non-smoking office area adjacent to the smoking area was accessible for monitoring; (3) both smoking and non-smoking areas were served by the same HVAC system.

Upon selection of a study area, two sampling sites were defined; the first site in the smoking area, and the second site in the adjacent non-smoking area. Adjacent sites were selected in order to assess the potential for direct migration of ETS through the occupied space and recirculation of ETS through the HVAC systems.

Sampling and Analytical Procedures

In each study area, the following data were gathered at the smoking and non-smoking sampling sites: (1) ETS exposure data; (2) ventilation performance data; (3) occupant activity information, and (4) HVAC system description.

Data were gathered in each of the 15 study areas (8 in Seattle, 7 in Dallas) during 1 working day per study area. Each day of monitoring was divided into two 4-hour sampling periods, corresponding to the morning and afternoon working hours. During each 4-hour sampling period, data on ETS exposure, ventilation performance and occupant activities were simultaneously gathered at the adjacent smoking and non-smoking sampling sites. The descriptive information regarding the HVAC system was collected throughout the day of monitoring.

ETS Exposure. ETS is a dynamic and complex chemical mixture in high dilution in air, consisting of both vapour-phase and particle-phase compounds [2, 3]. Previous research suggests that ETS exposure may be best characterised through simultaneous monitoring of selective particulate-phase and vapour-phase tracers [3].

Five tracers of ETS exposure were simultaneously monitored at the adjacent smoking and non-smoking sampling sites in each study area. Tracers of particulate-phase ETS exposure included total respirable suspended particles (RSP) and ultraviolet particulate matter (UVPM). Vapour-phase tracers of ETS exposure included nicotine, 3-ethenylpyridine (3-EP) and carbon monoxide (CO).

RSP were determined gravimetrically, in accordance with the American Society for Testing and Materials (ASTM) Standard D4532-92 titled 'Standard Test Method for Respirable Dust in Workplace Atmospheres' [4]. The limit of analytical detection for a 4-hour sampling period was 17 $\mu g/m^3$ of air. Calibration of the pumps before and after sampling showed a variation of $\pm 2\%$ and calibration of the microbalance indicated a variation of $\pm 5\%$. Therefore, the calibration procedures result in an overall analytical uncertainty for the method of ±7%.

RSP concentrations have been widely used as an indicator of the presence of ETS in indoor environments [5]. Field monitoring data has shown that while RSP levels tend to be higher in smoking environments than in comparable non-smoking environments, not all of the RSP in smoking areas are attributable to ETS due to the presence of multiple sources in indoor environments [6]. Consequently, the use of total RSP as a tracer of particle-phase ETS leads to an overestimate of ETS-related particles. Therefore, in the research conducted in Seattle and Dallas, additional analysis was performed to obtain a more sensitive estimate of ETS-related particles.

To provide an estimation of ETS-related RSP, the filter samples used in the determination of total RSP were analysed by the UVPM method developed for estimation of the contribution of ETS to the total RSP concentration [7]. For the 4-hour sampling period, the limit of detection was 5 μg/m^3. Based on the calibration of the sampling pumps and the chromatograph, the analytical uncertainty for the method was ±7%. As the UVPM technique specifically measures all combustion-related particulate matter, including ETS-related particles, UVPM concentrations may be considered a 'better' estimate of ETS-related particles than total RSP, which also include non-combustion-related particulate matter. However, as the method does not differentiate between combustion particles from ETS and from other combustion processes, UVPM concentrations may still be an overestimation of the ETS-related particles [6, 8].

To assess exposure to vapour-phase ETS, nicotine concentrations were determined in accordance with ASTM Standard D5075-90 titled 'Standard Test Method for Nicotine in Indoor Air' [9]. The limit of analytical detection for the method was 0.2 μg/m^3. Based on the calibration of the sampling pumps and the chromatograph, the analytical uncertainty for the method was ±7%.

Nicotine has been widely used in field research as a vapour-phase tracer because it is nearly unique to ETS in indoor environments [6]. However, chamber-based experimental research has questioned the appropriateness of nicotine as an ETS tracer because of unpredictable decay kinetics [3, 10]. Consequently, 3-EP was measured as an alternative vapour-phase tracer. This compound is the second most abundant tobacco smoke specific alkaloid in vapour-phase ETS after nicotine. 3-EP concentrations were determined using a modified analysis from the ASTM D5075-90 Method for Nicotine in Air [11, 12]. The limit of analytical detection for 3-EP was 0.2 μg/m^3. Based on the calibration of the sampling pumps and the chromatograph, the analytical uncertainty for the method was ±7%.

Carbon monoxide was also monitored as a vapour-phase tracer. Research investigations of ETS exposure conducted prior to the 1980s relied extensively on the use of CO as an ETS tracer, because it can be easily quantified with real time measurements using relatively inexpensive equipment [13]. However, the usefulness of CO as a tracer for ETS exposure is limited because it is produced by all combustion-related processes [5, 6]. Instantaneous CO concentrations were determined every 30 min with a portable electrochemical analyser. The lower limit of detection of the instrument was 0.1 ppm. The data collected every 30 min were averaged to obtain a mean CO concentration for the total sampling period.

Ventilation Performance. Ventilation system performance was assessed by continuous monitoring of carbon dioxide (CO_2), and determination of pressurisation relationships between the adjacent smoking and non-smoking areas.

Continuous CO_2 Monitoring. For continuous monitoring integrated monitors/dataloggers were installed in the adjacent smoking and non-smoking areas to continuously monitor CO_2 levels throughout the working day. Mean CO_2 concentrations corresponding to the 4-hour sampling periods for the collection of the tracers of ETS exposure were calculated.

In the proposed OSHA IAQ regulations for US workplaces, indoor CO_2 concentrations are described as 'indicator measurements for the effectiveness of building ventilation', with CO_2 data providing a gross indication of an HVAC system's ability to dilute and remove occupant generated contaminants [1]. A similar application of CO_2 data has also been applied to proposed IAQ regulations for workplaces in British Columbia [14]. The current ASHRAE/ANSI Ventilation Standard 62-1989, titled 'Ventilation for Acceptable Air Quality' describes minimum outside air ventilation rates based on the control of indoor CO_2 concentrations to less than 1,000 ppm, thereby using the 1,000 ppm concentration as a surrogate for adequate outside air supply [15]. However, CO_2 data cannot be used to accurately quantify outside air ventilation rates [16]. The accuracy of CO_2 as a tracer gas for calculating ventilation rates is limited by a series of assumptions associated with a CO_2 mass balance model which are frequently not fulfilled under real world conditions [17]. Consequently, calculation of outside air ventilation rates using CO_2 has been shown to significantly overestimate actual ventilation rates [18]. Therefore, in the analysis of data collected in the Seattle and Dallas study areas, CO_2 concentrations were interpreted to provide a gross indication of HVAC system performance relative to the ASHRAE/ANSI Standard 62-1989 indicator level of 1,000 ppm, not to directly quantify outside air ventilation rates.

Pressurisation Determination. Patterns of air movement between the adjacent smoking and non-smoking sampling sites were assessed through smoke pencil testing. An easily observable white smoke was injected into the air adjacent to the entrance to each smoking area and the direction of air flow was observed. If the air was observed to be moving out of the smoking area towards the adjacent non-smoking area, the smoking area was qualitatively categorised as 'positively pressurised'. If the smoke-laden air was observed to be infiltrating into the smoking area, it was categorised as 'negatively pressurised'. This procedure was repeated several times in each sampling area during the day of monitoring to determine the consistency of the pressurisation relationships within the space. Patterns of air movement were assessed with doors closed (smoke was observed moving underneath the closed doors) and with doors open. When the doors were open, smoke was introduced at varying heights within the door space to determine whether the direction of air movement varied by height. Consistent directions of air flow were observed at various heights. Research has also shown that pressure balances may change over the course of a day, particularly in buildings served by variable air volume (VAV) ventilation systems [19]. However, observed pressure balances (as indicated by the direction of air movement) remained consistent over the day in all study areas in the Seattle and Dallas buildings.

Occupant Activity. During the 4-hour sampling periods in each of the smoking areas, the number of cigarettes smoked was estimated by either (a) direct observation throughout the entire sampling period, or (b) counting of finished cigarettes in ashtrays.

HVAC System Information. General information regarding the design and operation of the study buildings, and specific details about the HVAC systems serving each study area were obtained from a review of engineering plans, walk-through inspection of HVAC components, and interviews with operations personnel.

Table 1. Description of Seattle study buildings

Building	Construction date	Number of storeys	Type of HVAC system	HVAC system description	Percent outside air at time of evaluation	Study areas in building
A	1960	24	CV	Central AHU on 24th floor; two fan systems: interior and perimeter; high-pressure induction in perimeter, ceiling based system in interior; return air drawn back to central AHUs	90–100	S1
B	1980	37	VAV	Separate supply fan systems serving floors 1–19 and 20–36; air supplied to AHUs on each floor, and distributed through ceiling-based VAV system; electric reheat for perimeter VAV; return air drawn back to mechanical room on each floor	90–100	S2
C	1971	27	CV	Central AHUs on 27th floor penthouse; independent fan systems: serve floors 1–14 and 15–28; air supplied by interior and perimeter systems; high-pressure induction in perimeter, ceiling based system in interior; return air drawn to central AHUs.	90–100	S3, S4
D	1963	21	CV	Central AHUs rooftop penthouse serving all floors; two fan systems: interior and perimeter; high-pressure induction in perimeter, ceiling based system in interior; return air drawn back to central AHUs	90–100	S5, S6
E	1988	59	VAV	Separate supply fan systems serving floors 4–24 and 25–59; air supplied to AHUs on each floor and distributed to ceiling based VAV system; electric reheat for perimeter VAV; return air drawn back to mechanical room on each floor	90–100	S7
F	1975	41	CV	Central AHU on 41st floor serving all floors; two systems: interior and perimeter; high-pressure induction in perimeter, ceiling-based system in interior; return air drawn back to central AHUs	90–100	S8

Results

Seattle Buildings

Study Building HVAC and Workplace Smoking Configurations

Data were collected in 8 study areas (identified as S1 through S8) in 6 high-rise office buildings (identified as Buildings A through F) in downtown Seattle. Table 1 summarises the characteristics of the study buildings.

Four of the study buildings were constructed prior to 1975 (Buildings A, C, D and F) and are all similar in HVAC system design. The buildings are served by constant volume systems with large capacity central air handling units (AHUs) in mechanical penthouses located either in the basement or at the rooftop. The systems are equipped with single stage filtration on the main AHUs, consisting of synthetic fibre bag filters, with a 30–40% effectiveness. This type of HVAC system supplies a constant volume of ventilation air at varying temperatures to satisfy occupant thermal requirements. Ventilation air is distributed to each floor through a central shaft and delivered through ceiling-based ductwork. Air is supplied to perimeter areas through high pressure induction units on the outer walls. Air is supplied to interior areas through ceiling-based ductwork and delivered to the occupied space through rectangular or slot diffusers. Return air is exhausted from the occupied space through openings into the ceiling plenum and drawn back through a vertical shaft to the central AHU.

Air exhausted from smoking areas within the 4 buildings built between 1960 and 1975 (Buildings A, C, D and

F) cannot therefore be recirculated within a floor through the mechanical system. Return air containing ETS is drawn back to the central AHU, diluted with outside air and return air from non-smoking areas, filtered and tempered (as necessary) and redistributed throughout the building, although during the period of research in Seattle, minimal recirculation of return air was occurring.

The 2 study buildings constructed since 1980 (Buildings B and E) are served by VAV systems in which thermal control of the indoor environment is achieved by varying the amount of air supplied to the occupied space. In both buildings, outside air is provided by central supply air fans to mechanical rooms on each floor. Each mechanical room contains an AHU which delivers ventilation air through ceiling-based ductwork to a series of VAV boxes. These boxes are equipped with dampers which modulate to vary the amount of air supplied to the occupied space, as a function of the space thermal requirements. Return air is exhausted from the occupied space into the ceiling plenum where a portion is drawn back to the mechanical room on the floor and a portion is exhausted to the outdoors. The VAV system in Buildings B and E are equipped with two-stage filtration. Synthetic fibre bag filters (efficiency 30–40%) are installed on the main AHUs, and low efficiency (10–20%) panel filters are installed on the AHUs on every floor.

This design configuration creates the potential for air exhausted from a smoking area to be recirculated within a floor, particularly under HVAC operational conditions requiring a high degree of recirculation of return air. However, such operational conditions were not observed during the sampling periods in Buildings B and E.

Minimal recirculation of return air was a common operational characteristic of the HVAC systems serving all 6 Seattle buildings during the period of research in August 1993. The moderate outdoor temperatures provided appropriate conditions for the HVAC systems to be operated to take advantage of free cooling using 'economiser' ventilation strategies. In all 6 buildings, 90–100% outside air (i.e. little or no circulation) was being used to ventilate the indoor environment. The use of economiser ventilation to provide free cooling during periods of moderate outdoor temperatures is a commonly used energy management strategy in temperate climatic zones in North America. In Seattle, HVAC system operation using economiser ventilation represents a critical operational mode. For example, the chief operating engineers in each building estimated that they operate their HVAC systems with economiser ventilation for approximately 70% of the operating year, without excessive increases in energy costs.

Given the HVAC operating conditions of minimal recirculation of air from smoking areas within the Seattle buildings during the period of research, the data collected simultaneously in adjacent smoking and non-smoking areas were particularly relevant for assessing the impact of direct infiltration of ETS from smoking areas into non-smoking areas, rather than through recirculation by HVAC systems.

Table 2 summarises the configuration of the adjacent smoking and non-smoking sampling sites in each of the 8 study areas, including the floor areas of the smoking and non-smoking locations. The workplace smoking configurations were categorised as either (a) smoking restricted to a designated area without additional ventilation; (b) designated smoking area with additional ventilation; or (c) division of workplace into smoking and non-smoking offices.

Study areas S1 and S7 included designated smoking lounges that were not equipped with additional ventilation to supplement the central HVAC system. Despite the absence of additional ventilation, the smoking sites in study areas S1 and S7 were negatively pressurised relative to the adjacent non-smoking sites.

Study areas S3 and S8 included designated smoking lounges in which additional ventilation had been provided. The smoking lounge in study area S3 included a food preparation area equipped with exhaust hoods. The smoking lounge in study area S8 had been retrofitted with a local exhaust fan which draws air from the room and discharges into the ceiling plenum (i.e. not exhausted directly to the outdoors). The smoking lounges in study areas S3 and S8 were both negatively pressurised relative to the adjacent non-smoking sampling locations.

Study areas S2, S4, S5 and S6 were workplaces divided into smoking and non-smoking offices. In study area S2, the enclosed smoking office was equipped with a local exhaust fan to discharge exhaust air into the ceiling plenum. The fan operation provided a negative pressurisation of the smoking area. In contrast, the smoking sites in study areas S4, S5 and S6 were all positively pressurised relative to the adjacent non-smoking work areas. In all 3 cases, no changes or additions had been made to the air distribution system in the study areas.

ETS Exposure and Ventilation Performance Monitoring

The results from the simultaneous monitoring of ETS-related substances and HVAC performance at the adjacent smoking and non-smoking areas in the Seattle buildings were analysed to examine the effectiveness of differ-

Table 2. Workplace smoking configurations in Seattle study buildings (August 1993)

Building	Study area	Workplace smoking configuration	Description of smoking area	Additional ventilation and air cleaning equipment	Description of non-smoking area	Pressurisation of smoking area
A	S1	Smoking restricted to a designated area	Staff lounge (416 ft^2)	Ceiling-mounted electrostatic precipitator	Meeting room (400 ft^2)	Negative
B	S2	Workplace divided into smoking and non-smoking offices	Enclosed office (320 ft^2)	Exhaust fan installed in ceiling to increase return air flow to plenum	Secretarial/ reception area (150 ft^2)	Negative
C	S3	Smoking restricted to a designated area	Coffee shop (1,260 ft^2)	Local exhaust fans in food preparation area	Meeting room (360 ft^2)	Negative
C	S4	Workplace divided into smoking and non-smoking offices	Enclosed office (168 ft^2)	Unitary electrostatic precipitator (small residential unit)	Enclosed office (120 ft^2)	Positive
D	S5	Workplace divided into smoking and non-smoking offices	Reception/ Clerical area (336 ft^2)	Unitary electrostatic precipitator	Enclosed office (112 ft^2)	Positive
D	S6	Workplace divided into smoking and non-smoking offices	Open plan office (280 ft^2)s	None	Enclosed Office (120 ft^2)e	Positive
E	S7	Smoking restricted to a designated smoking area	Smoking lounge (115 ft^2)	None	Open plan office (1,500 ft^2)	Negative
F	S8	Smoking restricted to a designated smoking area	Smoking lounge/ meeting room (350 ft^2)	Exhaust fan installed in ceiling to increase return air flow to plenum	Open plan office (800 ft^2)	Negative

ent workplace smoking configurations, and to assess the impact of pressurisation of the smoking areas.

Given the HVAC operating conditions of minimal recirculation of air from smoking areas within the Seattle buildings, the data collected simultaneously in adjacent smoking and non-smoking areas are particularly relevant for assessing the impact of direct infiltration of ETS from smoking areas into non-smoking areas, rather than through recirculation by HVAC systems.

Workplace Smoking Configuration. Table 3 compares the levels of ETS-related substances, cigarette consumption rates (standardised to number of cigarettes per 100 ft^2) and CO_2 concentrations under the three workplace smoking configurations. Means for the measured parameters are presented at the bottom of each data set. To calculate the mean values, if a data point was reported as less than the detection limit (e.g., nicotine concentrations of less than 0.2 μg/m^3 of air), the detection limit (i.e. 0.2 μg/m^3) was used as the representative value for the calculation of the mean.

In those workplaces in which smoking was restricted to a designated area with no additional ventilation (study areas S1 and S7), infiltration of vapour-phase ETS into the non-smoking area was not identified, as nicotine and 3-EP concentrations were below the analytical detection limits for 4-hour samples. Carbon monoxide concentrations were generally similar at all smoking and non-smoking sites, demonstrating the limited usefulness of CO as a tracer for ETS exposure. RSP and UVPM levels were lower in the non-smoking areas (means 30 and 7 μg/m^3 respectively) compared to the adjacent smoking areas (means 37 and 17 μg/m^3).

Similar results were also found in the 2 study areas in which additional ventilation has been provided to the designated smoking areas (S3 and S8). Nicotine concentrations were below detectable levels in the non-smoking areas. Measurable concentrations of 3-EP were not detected in the non-smoking area at site S8, but were detected in the non-smoking area at site S3 (mean 0.3 μg/m^3). This apparent anomaly between the nicotine and 3-EP data may reflect a difference in adsorbent properties of the two tracers, with nicotine more readily adsorbed on surfaces [11]. RSP and UVPM concentrations were substantially lower in the non-smoking areas (means 25 and 8 μg/m^3 respectively) compared to the designated smoking areas (means 53 and 12 μg/m^3).

In the 4 study areas in which smoking was restricted to designated areas (S1, S7, S3 and S8), the absence of ETS-related substances in the non-smoking areas appears to be related to the negative pressurisation of the adjacent smoking areas. The influence of pressurisation is further analysed in the following section.

Table 3. ETS-related substances and ventilation parameters in adjacent smoking and non-smoking areas, Seattle, August 1993, categorized by workplace smoking configuration

Building	Site	Time	Smoking area RSP µg/m^3	Smoking area UV-PM µg/m^3	Smoking area nicotine µg/m^3	Smoking area 3-EP µg/m^3	Smoking area CO ppm	Smoking area CO^2 ppm	Smoking area cigs per 100 ft^2	Non-smoking area RSP µg/m^3	Non-smoking area UV-PM µg/m^3	Non-smoking area nicotine µg/m^3	Non-smoking area 3-EP µg/m^3	Non-smoking area CO ppm	Non-smoking area CO^2 ppm	Smoking area pressurisation
Designated smoking area – no additional ventilation provided																
A	S1	AM	38	18	3.4	1.0	1.6	522	2.4	35	<5	<0.2	<0.2	1.3	377	Negative
		PM	23	14	5.6	1.7	1.8	617	3.6	30	11	<0.2	<0.2	1.4	461	
E	S7	AM	48	13	2.3	<0.2	1.2	452	7.8	20	<5	<0.2	<0.2	1.0	420	Negative
		PM	42	24	1.9	<0.2	1.4	433	5.2	34	<5	<0.2	<0.2	1.1	422	
Mean			37	17	3.3	0.8	1.5	506	4.8	30	7	<0.2	<0.2	1.2	420	
Designated smoking area – additional ventilation provided																
C	S3	AM	66	8	13.0	1.9	2.7	517	5.5	25	5	<0.2	0.4	2.0	390	Negative
		PM	52	23	4.8	0.5	2.2	508	4.0	30	15	<0.2	0.3	1.4	398	
F	S8	AM	49	6	1.5	<0.2	1.6	418	1.7	22	5	<0.2	<0.2	1.4	455	Negative
		PM	46	12	2.9	0.4	1.4	407	2.6	24	6	<0.2	<0.2	1.1	429	
Mean			53	12	5.6	0.8	2.0	463	3.5	25	8	<0.2	0.3	1.5	418	
Workplace divided into smoking and non-smoking offices																
B	S2	AM	33	9	2.6	<0.2	1.4	405	0.9	24	8	<0.2	<0.2	1.3	435	Negative
		PM	30	15	3.5	0.3	1.3	413	1.6	19	6	<0.2	<0.2	1.2	456	
C	S4	AM	39	16	2.2	0.4	2.2	433	5.4	22	8	0.8	0.5	2.0	455	Positive
		PM	27	15	2.2	1.0	2.3	421	5.9	19	5	0.5	0.5	2.1	446	
D	S5	AM	51	26	16.7	2.0	1.3	422	3.6	31	16	1.3	<0.2	1.5	432	Positive
		PM	55	14	16.1	2.7	1.7	416	3.0	31	18	1.4	<0.2	1.4	438	
D	S6	AM	33	6	2.5	0.8	1.3	488	4.3	18	8	2.0	1.2	1.3	472	Positive
		PM	26	13	2.9	0.5	1.4	456	3.9	24	12	0.6	<0.2	1.2	472	
Mean			37	14	6.1	1.0	1.6	432	3.6	23	10	0.9	0.4	1.5	451	

The data from the study areas which were divided into smoking and non-smoking offices indicate the presence of vapour-phase ETS in the non-smoking areas of 3 of the 4 study areas (S4, S5, S6). In all 3 cases, the offices in which smoking was permitted were positively pressurised and nicotine and 3-EP were quantified in the non-smoking areas due to direct migration of ETS through the space, albeit at concentrations substantially diluted compared to the smoking areas. Nicotine concentrations ranged between 2.2 and 16.7 µg/m^3 in the smoking offices, compared to 0.5 to 2.0 µg/m^3 in the non-smoking offices. 3-EP concentrations ranged between <0.2 and 2.7 µg/m^3 in the smoking offices, compared to <0.2–1.2 µg/m^3 in the non-smoking offices. In contrast, in the 1 study area in which the smoking office was negatively pressurised (S2), nicotine and 3-EP concentrations were not detected in the non-smoking area.

In all 4 study areas in which the workplace was divided into smoking and non-smoking offices, RSP and UVPM concentrations were higher in the smoking offices (means 37 and 14 µg/m^3 respectively) compared to the non-smoking offices (means 23 and 10 µg/m^3). This finding suggests that simple division of the workplace to accommodate smokers and non-smokers may reduce non-smokers' exposure to particle-phase ETS, regardless of pressure differentials between the smoking and non-smoking areas.

Throughout all study areas, the measured concentrations of both the vapour-phase and particle-phase tracers of ETS exposure in the smoking areas were related to the number of cigarettes consumed. Higher ETS-related constituent concentrations were observed in those study areas with the higher cigarette consumption rates.

The results of the carbon dioxide monitoring showed similar CO_2 concentrations in all study areas, regardless of workplace smoking configuration. Mean CO_2 concentrations at the smoking sites ranged from 400 to 600 ppm. CO_2 concentrations in the non-smoking areas were slight-

Table 4. ETS-related substances and ventilation parameters in adjacent smoking and non smoking areas, Seattle, August 1993, categorised by smoking area pressurisation

Building	Site	Time	Smoking area							Non-smoking area						Smoking area pressurisation
			RSP µg/m³	UV-PM µg/m³	nicotine µg/m³	3-EP µg/m³	CO ppm	CO_2 ppm	cigs per 100 ft²	RSP µg/m³	UV-PM µg/m³	nicotine µg/m³	3-EP µg/m³	CO ppm	CO_2 ppm	
Smoking area negatively pressurised relative to adjacent non-smoking area																
A	S1	AM	38	18	3.4	1.0	1.6	522	2.4	35	<5	<0.2	<0.2	1.3	377	Negative
		PM	23	14	5.6	1.7	1.8	617	3.6	30	11	<0.2	<0.2	1.4	461	
B	S2	AM	33	9	2.6	<0.2	1.4	405	0.9	24	8	<0.2	0.3	1.3	435	Negative
		PM	30	15	3.5	0.3	1.3	413	1.6	19	6	<0.2	<0.2	1.2	456	
C	S3	AM	66	8	13.0	1.9	2.7	517	5.5	25	5	<0.2	0.4	2.0	390	Negative
		PM	52	23	4.8	0.5	2.2	508	4.0	30	15	<0.2	0.3	1.4	398	
E	S7	AM	48	13	2.3	<0.2	1.2	452	7.8	20	<5	<0.2	<0.2	1.0	420	Negative
		PM	42	24	1.9	<0.2	1.4	433	5.2	34	5	<0.2	<0.2	1.1	422	
F	S8	AM	49	6	1.5	<0.2	1.6	418	1.7	22	5	<0.2	<0.2	1.4	455	Negative
		PM	46	12	2.9	0.4	1.4	407	2.6	24	6	<0.2	<0.2	1.1	429	
Mean			43	14	4.2	0.7	1.7	469	3.5	26	6	<0.2	<0.2	1.3	424	
Smoking area positively pressurised relative to adjacent non-smoking area																
C	S4	AM	39	16	2.2	0.4	2.2	433	5.4	21	8	0.8	0.5	2.0	455	Positive
		PM	27	15	2.2	1.0	2.3	421	5.9	19	5	0.5	0.5	2.1	446	
D	S5	AM	51	26	16.7	2.0	1.3	422	3.6	31	16	1.3	<0.2	1.5	432	Positive
		PM	55	14	16.1	2.7	1.7	416	3.0	31	18	1.4	<0.2	1.4	438	
D	S6	AM	33	6	2.5	0.8	1.3	488	4.3	18	8	2.0	1.2	1.3	472	Positive
		PM	26	13	2.9	0.5	1.4	456	3.9	24	12	0.6	<0.2	1.2	472	
Mean			39	15	7.1	1.2	1.7	439	4.4	24	11	1.1	0.4	1.6	453	

ly lower, ranging from 375 to 500 ppm. The lower levels in the non-smoking areas generally reflect lower occupant densities compared to the smoking areas.

ASHRAE Standard 62-1989 describes minimum ventilation requirements for indoor environments based on the control of CO_2 concentrations to less than 1,000 ppm, thereby using CO_2 as a surrogate for ventilation adequacy. The low CO_2 concentrations in the Seattle buildings suggest that the study areas were being supplied with high volumes of outside air (probably in excess of the minimum outside air requirements described in ASHRAE Standard 62-1989). This finding is unsurprising given the 'economiser' ventilation configurations in the study buildings at the time of evaluation.

Smoking Area Pressurisation. Table 4 focuses on the differences in measured ETS-related substances between those study areas in which the smoking area was negatively or positively pressurised relative to the adjacent non-smoking sampling site.

The results from the 5 study areas in which the smoking area was negatively pressurised (S1, S2, S3, S7, S8) indicate minimal infiltration of ETS-related substances into the non-smoking areas. During all sampling periods, nicotine was not detected in the non-smoking areas. However, measurable 3-EP concentrations were determined in 2 of the non-smoking areas (S2 and S3). Total RSP and UVPM concentrations in the non-smoking areas were substantially lower (means 26 and 6 µg/m³, respectively) than the adjacent smoking areas that were negatively pressurised (means 43 and 14 µg/m³).

In the 3 study areas in which the smoking site was positively pressurised (S4, S5, S6), vapour-phase ETS was measured in the non-smoking areas. Nicotine and 3-EP concentrations were detected in all 3 non-smoking locations adjacent to positively pressurised smoking rooms. While the vapour-phase concentrations in the non-smoking areas are substantially less than those determined in the smoking areas, the results confirm the presence of diluted vapour-phase ETS in the non-smoking areas. Given the HVAC system operating conditions in which minimal recirculation was taking place, the source of ETS in the non-smoking areas is the direct flow of air through the occupied space, and not recirculation through the HVAC systems.

Table 5. Description of Dallas study buildings

Building	Construction date	Number of storeys	Type of HVAC system	HVAC system description	Percent outside air at time of evaluation	Study areas in building
G	1982	33	VAV	One supply fan system drawing outside air from 2nd floor level; air supplied to AHU in mechanical rooms on every other floor, each serving two floors; ventilation air distributed through ceiling based VAV system; electrical reheat for perimeter VAV; return air drawn back to AHUs on every other floor	10	D1, D2, D3
H	1972	40	CV	One supply fan system drawing outside air from 4th floor; air supplied to east and west AHUs on every other floor; dual duct multizone (constant volume) system distributes air through ceiling based ductwork; return air drawn back to AHUs on every other floor	10	D4, D5
I	1987	55	VAV	Separate supply fan systems serving floors 1–38 and 39–55; air supplied to AHUs on every other floor, each serving two floors; ventilation air distributed through VAV system; electrical reheat for perimeter VAV; return air drawn back to AHUs on every other floor	10	D6
J	1983	18	VAV	Separate supply fan systems serving floors 1–12 and 13–18; central AHUs in basement and rooftop; air supplied from central AHUs to ceiling based VAV boxes on each floor; electrical reheat for perimeter VAV; return air drawn back to central AHUs	15–20	D7

However, the identified infiltration of diluted vapour-phase ETS into the non-smoking areas adjacent to the positively pressurised smoking rooms did not lead to an elevation in RSP concentrations. Mean RSP concentrations in the non-smoking areas adjacent to the positively pressurised smoking areas were 24 μg/m^3, compared to 26 μg/m^3 in the non-smoking areas adjacent to the negatively pressurised smoking areas.

Dallas Buildings

Study Building HVAC and Workplace Smoking Configurations

Data were collected in 7 study areas (identified as D1 through D7) in 4 high-rise buildings in Dallas (Buildings G through J) during September 1993. The study buildings varied in date of construction from 1972 to 1987. Table 5 summarises the characteristics of each study building. The 3 buildings constructed in the mid-1980s (Buildings G, I and J) are all served by VAV systems, whereas the 1 building constructed earlier in the 1970s (Building H) is served by a constant volume HVAC system. The 3 buildings with VAV systems varied by HVAC design. In buildings G and I, a fixed volume of outside air is supplied to each building throughout the operating year (approximately 10% of the total ventilation air). The outside air is delivered by main AHUs in basement and rooftop rooms through vertical shafts to mechanical rooms on every other floor. Synthetic bag filters (efficiency 30–40%) are installed in the main AHUs to filter the ventilation air. Each mechanical room houses a smaller AHU, which supplies air to two floors. Within each mechanical room, the outdoor air is mixed with return air recirculated from the occupied space. The mixed air is filtered, cooled, and distributed to VAV boxes in the suspended ceiling. Low efficiency panel filters are installed on each AHU. The VAV boxes in perimeter areas are equipped with electrical duct heaters, for supplemental heating during the winter months. Return air is exhausted from the occupied space through openings in the ceiling plenum and is drawn back to the floor-based mechanical room where mixing with outdoor air occurs. Given this HVAC system configuration, air exhausted from areas where smoking is occurring is drawn back to the mechanical room, where it is tempered and redistributed within the two floors served by the individual AHU.

The VAV system serving Building J is different in HVAC design. The building is equipped with two central AHUs, rather than a series of smaller fan systems on every other floor. The two central AHUs serve floors 1 through 12, and 13 through 18 respectively. Fibreglass bag filters are installed in the central AHUs. At the time of monitoring, approximately 15–20% of outside air was being supplied to Building J. At other times of the year, during periods of lower outdoor temperatures, a larger proportion of outside air is supplied to the building.

The Chief Building Engineer for Building J estimated that the HVAC systems can be operated at 80% or more outside air for approximately 3 months during the winter in Dallas. During the hot summer months, the building typically operates at the minimum outside air setting (15–20% outside air) that was occurring during the period of monitoring in September 1993. The outdoor air is mixed with return air recirculated from the occupied space. The mixed air is filtered, cooled and distributed through vertical shafts to ductwork in the suspended ceiling and supplied to the occupied space through a network of VAV boxes. Unlike the other two buildings with VAV systems, the HVAC configuration of Building J prevents air exhausted from smoking areas from being recirculated within specific floors. Air exhausted from any one smoking location is diluted with return air from other floors and returned to the central fan systems, where it is mixed with outside air, tempered and redistributed throughout multiple floors.

Building H (constructed in 1972), is the only one of the Dallas study buildings to be served by a dual duct, constant volume HVAC system. A fixed volume of outside air (approximately 10% of the total ventilation air) is supplied through vertical shafts to two mechanical rooms on every other floor. In each mechanical room, the outside air is mixed with return air from two floors of the occupied space. The mixed air is filtered with low efficiency (10–20%) panel filters and cooled then redistributed to a series of 'zones' throughout the two floors served by the particular AHU. This design configuration creates the potential for air exhausted from smoking areas to be recirculated within the two floors served by a particular AHU.

In contrast to the Seattle study buildings where minimal recirculation of return air was observed, the high proportion of recirculated air of between 80 and 90% was a common characteristic of the operation of the HVAC systems serving all 4 Dallas buildings during September 1993. Given the high degree of recirculation, the data collected simultaneously in adjacent smoking and non-smoking areas in the Dallas buildings can be used to assess the extent of recirculation of ETS through the mechanical air handling systems, in addition to the impact of direct infiltration of ETS into non-smoking areas through the occupied space.

Table 6 describes the workplace smoking configuration of each study area within the study buildings, including floor areas of the smoking and non-smoking areas. In all 7 study areas, the pressurisation of the smoking sampling site was found to be consistent throughout the period of monitoring.

Study areas D3 and D6 included designated smoking areas with no additional ventilation to supplement the buildings HVAC system. In both cases, the smoking sites were positively pressurised relative to the adjacent non-smoking offices.

Study area D7 included a designated smoking lounge in which additional ventilation had been installed. All return air from the smoking lounge was exhausted to an air cleaning unit located in the suspended ceiling. The air cleaning unit consists of a fan blower to draw in the exhaust air, high efficiency filtration designed to remove particulate matter and activated carbon panels to remove gaseous substances. The treated air exiting the air cleaner was discharged into the ceiling plenum. The smoking lounge was negatively pressurised relative to the adjacent non-smoking area.

Study areas D1, D2, D4 and D5 were all workplaces divided into smoking and non-smoking offices. Retrofits to the air distribution system had been implemented in only one of the study areas (D5). An exhaust fan had been installed in the ceiling to increase the return air flow from the office. The exhaust air from the smoking area discharged into the ceiling plenum, rather than being ducted directly outdoors.

ETS Exposure and Ventilation Performance Monitoring

The results from the air quality monitoring in Dallas are presented in a similar format to the findings from the Seattle buildings.

Workplace Smoking Configuration. Table 7 compares the levels of ETS-related substances under the 3 different workplace smoking configurations. In those study areas in which smoking was restricted to designated smoking rooms without additional ventilation (D3 and D6), vapour-phase ETS was identified at the non-smoking sampling site at substantially diluted levels relative to the adjacent smoking areas. Mean nicotine and 3-EP concentrations in the smoking areas were 20.4 and 2.9 μg/m^3 respectively, compared to 0.5 and 0.6 μg/m^3 in the non-smoking areas. However, the presence of vapour-phase ETS constituents in the non-smoking areas did not coincide with a significant elevation in particle-phase concentrations. Total RSP and UVPM concentrations in the non-smoking areas were substantially lower (means 26 and 5 μg/m^3 respectively), compared to the smoking areas (means 74 and 37 μg/m^3).

In the one study area (D7) in which additional ventilation and air cleaning technology had been installed, vapour phase ETS was not found at the non-smoking sam-

Table 6. Workplace smoking configurations in Dallas study buildings (September 1993)

Building	Study area	Workplace smoking configuration	Description of smoking area	Additional ventilation and air cleaning equipment	Description of non-smoking area	Pressurisation of smoking area
G	D1	Workplace divided into smoking and non-smoking offices	Enclosed office (225 ft²)	Unitary electrostatic precipitator (including carbon filter)	Open plan office (450 ft²)	Positive
G	D2	Workplace divided into smoking and non-smoking offices	Enclosed office (120 ft²)	Unitary electrostatic precipitator (including carbon filter)	Enclosed office (130 ft²)	Negative
G	D3	Smoking restricted to a designated area	Staff lounge (720 ft²)	Ceiling mounted electrostatic precipitator	Open plan office (750 ft²)	Positive
H	D4	Workplace divided into smoking and non-smoking offices	Open plan Reception area (800 ft²)	None	Enclosed office (250 ft²)	Negative
H	D5	Workplace divided into smoking and non-smoking offices	Open plan offices (650 ft²)	Exhaust fan installed in ceiling to increase return air flow to plenum	Open plan offices (1,000 ft²)	Negative
I	D6	Smoking restricted to a designated area (enclosed office)	Enclosed office/ smoking lounge (220 ft²)	None	Open plan offices (800 ft²)	Positive
J	D7	Smoking restricted to a designated area	Dedicated smoking lounge (700 ft²)	Fan unit and filtration installed in ceiling, filtered air delivered to plenum	Enclosed office (360 ft²)	Negative

Table 7. ETS-related substances and ventilation parameters in adjacent smoking and non-smoking areas, Dallas, September 1993, categorized by workplace smoking configuration

Building	Site	Time	Smoking area							Non-smoking area						Smoking area pressurisation
			RSP μg/m³	UV-PM μg/m³	nicotine μg/m³	3-EP μg/m³	CO ppm	CO_2 ppm	cigs per 100 ft²	RSP μg/m³	UV-PM μg/m³	nicotine μg/m³	3-EP μg/m³	CO ppm	CO_2 ppm	
Designated smoking area – no additional ventilation																
G	D3	AM	80	16	33.7	4.2	2.2	572	2.8	23	<5	0.4	0.9	2.1	619	Positive
		PM	91	48	24.2	4.7	1.7	708	2.4	25	5	0.9	1.0	1.9	726	
I	D6	AM	58	39	12.1	2.5	1.9	592	10.0	22	6	0.5	0.4	2.3	630	Positive
		PM	67	47	11.7	0.3	1.7	590	10.5	35	5	<0.2	<0.2	2.3	640	
Mean			74	37	20.4	2.9	1.9	616	6.4	26	5	0.5	0.6	2.2	654	
Designated smoking area – additional ventilation provided																
J	D7	AM	132	43	25.6	3.3	3.3	675	3.6	21	<5	<0.2	<0.2	2.0	650	Negative
		PM	111	57	22.3	2.7	2.8	725	5.3	21	6	<0.2	<0.2	1.8	658	
Mean			122	50	24.0	3.0	3.1	700	4.5	21	5	<0.2	<0.2	1.9	654	
Workplace divided into smoking and non-smoking offices																
G	D1	AM	36	6	9.8	1.4	1.8	765	3.1	23	8	2.1	1.5	1.6	661	Positive
		PM	31	<5	5.5	1.7	2.0	935	2.2	25	7	2.7	1.3	1.7	782	
G	D2	AM	58	9	15.1	1.7	1.9	760	6.6	22	<5	0.4	0.6	2.0	638	Negative
		PM	25	10	7.5	1.6	2.1	913	4.2	30	<5	0.8	0.7	2.3	771	
H	D4	AM	32	8	0.3	0.4	1.2	486	0.8	24	5	0.2	0.4	1.4	425	Negative
		PM	39	8	0.2	0.4	1.8	515	0.8	22	6	0.2	0.4	1.9	456	
H	D5	AM	48	5	0.5	0.5	1.6	664	1.4	33	<5	0.4	0.5	1.4	574	Negative
		PM	31	12	1.5	0.4	1.7	795	1.4	25	<5	0.2	0.4	1.6	650	
Mean			38	8	5.1	1.0	1.8	729	2.6	25	6	0.9	0.7	1.7	620	

Table 8. ETS-related substances and ventilation parameters in adjacent smoking and non-smoking areas, Dallas, September 1993, categorised by smoking area pressurisation

Building	Site	Time	Smoking area RSP µg/m³	UV-PM µg/m³	nicotine µg/m³	3-EP µg/m³	CO ppm	CO_2 ppm	cigs per 100 ft²	Non-smoking area RSP µg/m³	UV-PM µg/m³	nicotine µg/m³	3-EP µg/m³	CO ppm	CO_2 ppm	Smoking area pressurisation
Smoking area negatively pressurised relative to adjacent non-smoking area																
G	D2	AM	58	9	15.1	1.7	1.9	760	6.6	22	<5	0.4	0.6	2.0	638	Negative
		PM	25	10	7.5	1.6	2.1	913	4.2	30	<5	0.8	0.7	2.3	771	
H	D4	AM	32	8	0.3	0.4	1.2	486	0.8	24	5	0.2	0.4	1.4	425	Negative
		PM	39	8	0.2	0.4	1.8	515	0.8	22	6	0.2	0.4	1.9	456	
H	D5	AM	48	5	0.5	0.5	1.6	664	1.4	33	<5	0.4	0.5	1.4	574	Negative
		PM	31	12	1.5	0.4	1.7	795	1.4	25	<5	0.2	0.4	1.6	650	
J	D7	AM	132	43	25.6	3.3	3.3	675	3.6	21	<5	<0.2	<0.2	2.0	650	Negative
		PM	111	57	22.3	2.7	2.8	725	5.3	21	6	<0.2	<0.2	1.8	658	
Mean			60	19	9.1	1.4	2.1	692	3.0	25	5	0.3	0.4	1.8	603	
Smoking area positively pressurised relative to adjacent non-smoking area																
G	D1	AM	36	6	9.8	1.4	1.8	765	3.1	23	8	2.1	1.5	1.6	661	Positive
		PM	31	<5	5.5	1.7	2.0	935	2.2	25	7	2.7	1.3	1.7	782	
G	D3	AM	80	16	33.7	4.2	2.2	572	2.8	23	<5	0.4	0.9	2.1	619	Positive
		PM	91	48	24.2	4.7	1.7	708	2.4	25	5	0.9	1.0	1.9	726	
I	D6	AM	58	39	12.1	2.5	1.9	592	10.0	22	6	0.5	0.4	2.3	630	Positive
		PM	67	47	11.7	0.3	1.7	590	10.5	36	5	<0.2	<0.2	2.3	640	
Mean			61	26	16.2	2.5	1.9	694	5.2	25	6	1.1	0.9	2.0	676	

pling location, and particle-phase levels were similar to other non-smoking areas, despite elevated RSP levels in excess of 100 µg/m³ in the adjacent smoking area. In study area D7, air exhausted from the smoking lounge passed through HEPA filtration and activated carbon before being discharged into the ceiling plenum.

The data from the 4 study areas which were divided into smoking and non-smoking offices (D1, D2, D4 and D5) indicate the presence of vapour-phase ETS in the non-smoking areas. Higher nicotine and 3-EP concentrations were measured in the non-smoking area of study area D1, compared to the other 3 non-smoking areas. The differences in vapour-phase concentrations may be attributable to differences in pressurisation, with the smoking site in study D1 being positively pressurised relative to the non-smoking area, thereby allowing direct migration of ETS through the occupied space. In the other study areas (D2, D4, D5), the smoking areas were negatively pressurised relative to the adjacent non-smoking areas.

CO concentrations were generally similar at all smoking and non-smoking sites, regardless of workplace smoking configuration, demonstrating the limited usefulness of CO as a tracer for ETS exposure.

The measured concentrations of both the vapour-phase and particle-phase tracers of ETS exposure in the smoking areas in the Dallas buildings were related to the number of cigarettes consumed, as was also the case in the Seattle buildings. The highest ETS-related constituent concentrations were observed in the study areas with the highest cigarette consumption.

CO_2 concentrations were generally similar under all three workplace smoking configurations, with mean levels ranging from 486 to 935 ppm in smoking areas and from 425 and 782 ppm in the non-smoking areas. The higher CO_2 concentrations were associated with higher occupant densities. CO_2 levels were higher in the Dallas office buildings than in the Seattle office buildings. The variation in CO_2 concentrations between the two cities reflects the different HVAC design and operational configurations.

Interpretation of the CO_2 data as providing a gross indication of ventilation adequacy, the CO_2 levels in the

Dallas study areas suggest that all areas were being supplied with volumes of outside air adequate to dilute occupant generated CO_2 to less than the 1,000 ppm criterion for ventilation adequacy in ASHRAE Standard 62-1989.

Smoking Area Pressurisation. Table 8 compares those study areas in which the smoking sampling site was negatively pressurised relative to the adjacent non-smoking office area, with study areas where the smoking location was positively pressurised.

The results from the study areas in which the smoking locations were negatively pressurised (therefore eliminating the direct migration of ETS) identify the presence of diluted vapour-phase ETS in three of the four non-smoking areas (D2, D4, D5). The one exception was study area D7. The presence of nicotine and 3-EP in the non-smoking areas indicates that vapour-phase ETS was being recirculated through the HVAC system.

Despite the presence of vapour-phase ETS constituents in the non-smoking locations in study areas D2, D4 and D5 (which are attributed to recirculation through the HVAC system), the results do not show elevated particulate-phase ETS. Total RSP concentrations were substantially lower in the non-smoking areas (mean 26 μg/m^3 for sites D2, D4 and D5 combined) than in the corresponding smoking areas (mean 39 μg/m^3 for D2, D4 and D5 smoking areas combined). Similar results were also observed for the UVPM concentrations. The finding that the recirculation of diluted ETS does not lead to elevated particulate concentrations may be a function of the filtration of return air by the HVAC system prior to recirculation to the occupied space.

Recirculation of ETS-related substances was not occurring into the non-smoking sampling site in study area D7, despite elevated particulate-phase and vapour-phase components in the designated smoking area (the highest concentrations for all tracers of ETS exposure in the Dallas data set). The smoking location in study area D7 was the designated area that had been equipped with the above ceiling air cleaning unit, with technologies to remove both particulate and vapour constituents, before discharging the treated air into the plenum for recirculation. The results from study area D7 suggest that application of appropriate air cleaning technologies may be effective in minimising non-smokers' exposure to ETS, without requiring exhaust ventilation directly to the outdoors.

In the 3 study areas in which the smoking locations were positively pressurised (D1, D3 and D6), nicotine and 3-EP were quantified in the non-smoking areas at levels slightly higher (means 1.1 and 0.9 μg/m^3, respectively) than had been measured in the non-smoking areas adjacent to the negatively pressurised smoking sites (means 0.3 and 0.4 μg/m^3). The higher vapour-phase levels reflect infiltration of ETS both through recirculation through the HVAC systems and direct migration through the space.

Discussion

The combined findings from the Seattle and Dallas case studies highlight a number of issues regarding the magnitude of non-smokers' exposure to ETS in the office workplace, under different smoking configurations and a range of HVAC operating conditions. While not representing the entire North American building stock, the 10 buildings included in the case study may be considered to be a typical sample of many high-rise office buildings with central HVAC systems in North America. The research findings may therefore be used to provide technical guidance to decision-makers involved with the development of workplace smoking policies and regulations, and building operators striving to accommodate smokers and non-smokers in their buildings.

The combined results from the two cities show that non-smokers' exposure to ETS can be reduced in the office workplace without the imposition of regulations requiring either the installation of dedicated exhaust ventilation systems or total prohibition of smoking within a building. The research has identified the importance of negative pressurisation of smoking locations relative to surrounding non-smoking areas. Negative pressurisation of smoking areas minimises the direct migration of ETS into non-smoking areas through the occupied space.

Technically, negative pressurisation of an area within the building is achieved when a greater volume of air is exhausted from a space than is supplied to the space. This may be achieved by actions other than the installation of an independent exhaust system to a smoking area, which discharges air directly to the outside. In the study buildings in Dallas and Seattle, negative pressurisation of smoking areas was accomplished by (a) the addition of exhaust fans in the suspended ceiling which discharge return air from the smoking location into the ceiling plenum; (b) increasing the number of return air openings in the suspended ceiling to allow a greater volume of return air to enter the plenum; and (c) installation of an air cleaner in the suspended ceiling equipped with an exhaust fan which draws air from the smoking area to the filtration unit.

When a smoking area (either a designated lounge or private office) is negatively pressurised, infiltration of

Table 9. Research investigations of the recirculation of ETS from designated smoking lounges to non-smoking areas

Sampling location	Smoking condition	Ventilation condition	Mean nicotine µg/m³	Mean RSP µg/m³	Source	Ref.
1 Office (USA) Smoking lounge	No smoking Permitted	Recirculation within floor Lounge positively pressurized	0.3–2.7 3.3–4.0		Hayward et al., 1993	20
1 Office (USA) Smoking lounge	No Smoking Permitted	Recirculation within floor Lounge negatively	<0.3–0.6 9.1–16.5		Hayward et al., 1993	20
2 Offices (USA) Smoking lounge	No smoking Permitted	No recirculation of ETS Separately ventilated		24 107	Hedge et al., 1991	23
2 Offices (USA) Smoking lounge	No smoking Permitted	Recirculation from lounge Not separately ventilated	1.38 6.98	40 85	Hedge et al., 1991	23
2 Offices (USA) remote from lounge 2 Offices adjacent to lounge Smoking lounge	 No smoking No smoking Permitted	 Recirculation within floor Recirculation within floor Separately ventilated; slight negative pressurisation	 All <0.7 0.7–4.3 No measurements taken in lounge		Light and Gay, 1993	19
2 Offices (USA) remote from lounge 2 Offices adjacent to lounge Smoking lounge	 No smoking No smoking Permitted	 Recirculation within floor Recirculation within floor Separately ventilated; strong negative	 All <0.7 All <0.7 No measurements taken in lounge		Light and Gay, 1993	19
2 Offices (USA) Smoking lounge	No smoking Permitted	No recirculation from Separately ventilated; negative pressurisation	All <0.2 No measurements taken in lounge	5–7	Oldaker et al., 1992	21
Offices (Canada) Offices Cafeteria Cafeteria	No smoking No smoking No smoking Smoking section	No recirculation of ETS Recirculation from cafeteria Not separately ventilated Not separately ventilated	<0.4 <0.4–1.0 6.2 14.0 Background corrected	6 7 32 70	Sterling and Mueller, 1988	24
Offices (Canada) Offices Smoking lounge	Permitted No smoking Permitted	Recirculation within floor Recirculation from lounge Not separately ventilated	4.9 <1.6–3.0 75.0		Sterling et al., 1987	5
Offices (Canada) Staff lounge Smoking lounge Outdoors	No smoking No smoking Permitted	No recirculation of ETS No recirculation of ETS Separately ventilated	 <0.4 16.2	17 15 119 21	Sterling et al., 1988	25
Staff room (Canada) Cafeteria Outdoors	No smoking Permitted	Recirculation from cafeteria Not separately ventilated	<0.4–0.8 5.8	21 60 15	Sterling et al., 1988	25
Offices (USA) Offices Snack bar	No smoking No smoking Permitted	No recirculation of ETS Recirculation from snack bar Not separately ventilated	0.1 0.2–0.3 85.4		Vaughan et al., 1989	26

ETS into adjacent non-smoking areas is most likely to occur by recirculation through the HVAC system. In the Seattle case study, where the HVAC operating conditions were such that minimal recirculation was taking place, ETS was not found in the non-smoking areas adjacent to negatively pressurised smoking areas.

In contrast, a high degree of recirculation of return air by the HVAC system was occurring in the Dallas study buildings. The results from Dallas showed the presence of diluted vapour-phase ETS constituents in the non-smoking areas adjacent to the negatively pressurised smoking locations, indicating recirculation of diluted ETS through the HVAC system. These findings suggest that, even under 'worst case' conditions where a high degree of return air within a building is recirculated, measured concentrations of ETS-related constituents in non-smoking areas were at or marginally above analytical detection limits. Recirculation of ETS was not detected in the Dallas study area in which the air cleaner had been installed in the suspended ceiling above the smoking lounge. Although only one example this suggests that the application of appropriate air cleaning technology (including media to remove both vapour-phase and particulate-phase components) may provide an effective option for eliminating the recirculation of diluted ETS within a building.

The research findings from the study buildings in Seattle and Dallas generally concur with the conclusions from other investigations that have undertaken simultaneous monitoring of ETS exposure in adjacent smoking and non-smoking areas. Table 9 summarises the research data reported in 8 other studies.

Light and Gay [19], Hayward et al. [20], and Oldaker et al. [21] all examined the relevance of pressurisation on controlling the transfer of air from smoking areas into adjacent non-smoking locations. Their findings highlight the importance of negative pressurisation of smoking areas to eliminate the direct migration of ETS through the workplace. In addition, their research shows that the magnitude of non-smokers exposure to ETS due to recirculation through the HVAC system is minimal. Similar findings have also been reported by Alevantis et al. [22] in research conducted in 23 designated smoking areas in Californian office buildings.

The other studies summarised in table 9 did not determine pressure relationships between smoking and non-smoking areas. However, the research by Hedge et al. [23], Sterling and Mueller [24], Sterling et al. [5, 25] and Vaughan and Hammond [26] have all demonstrated that while recirculation of ETS through HVAC systems can occur, the measured concentrations of ETS-related substances are diluted to levels at or below analytical detection limits.

The overall findings from the case studies presented here and other similar research suggest that the provision of designated smoking areas without dedicated exhaust systems can reduce non-smokers exposure to ETS. On the assumption that the HVAC system configurations and the operational characteristics of the 10 study buildings are typical of other high-rise buildings, the conclusions from this research study are applicable to high-rise office buildings throughout North America. Such conclusions confirm that smoking may be accommodated in the workplace and non-smokers exposure to ETS can be effectively controlled without the implementation of prohibitive actions such as bans or the costly requirements of installing dedicated exhaust ventilation systems.

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