#5611

The Effects of Smoking Policy on Indoor Air Quality and Sick Building Syndrome in 18 Air-Conditioned Offices

A. Hedge W.A. Erickson G. Rubin

ABSTRACT

A study of the effects of smoking policy on indoor air quality and sick building syndrome symptoms among 3,155 workers in 18 private sector air-conditioned office buildings is described. Five smoking policies were investigated: smoking prohibited, smoking restricted to rooms with local filtration, smoking restricted to rooms with no local air treatment, smoking restricted to rooms with separate ventilation, and smoking restricted to the open-plan cubicle workstations and enclosed offices. Levels of carbon monoxide, carbon dioxide, respirable particulates, formaldehyde, ultraviolet particulate mass, nicotine, air temperature, and relative humidity were measured at eight sample sites in each building. Approximately 30 workers at each of the eight sample sites completed an extensive questionnaire on environmental conditions, sick building syndrome symptoms, job satisfaction, job stress, smoking history, and personal details. Indoor air quality measures met the current ASHRAE 62-1989 standard. Comparison of all open-office sites between policies showed no significant differences in levels of carbon monoxide, carbon dioxide, formaldehyde, or respirable particulates. Levels of ultraviolet particulate mass and relative humidity were significantly lower in buildings where smoking is prohibited, and air temperature was significantly higher in these buildings, although on average this was <1°C. Among all buildings, air temperature was the only physical measure that was significantly correlated with SBS symptoms. Smoking policy had no significant effect on sick building syndrome symptoms.

INTRODUCTION

Tobacco smoking indoors has been identified as a source of a number of indoor air contaminants, especially particulate matter (Hodgson 1989; Van DeWiel et al. 1989) and combustion products (Godish 1990). Burning tobacco releases several thousand pollutants into the air, of which about 400 have been quantified (U.S. Surgeon General 1986). Environmental tobacco smoke (ETS) is an aerosol comprising vapor and particulate phases, both of which contain many organic and inorganic compounds (Eatough et al. 1988). ETS is a combination of sidestream smoke (SS) from the burning cigarette and exhaled mainstream smoke (MS) from the smoker (Guerin et al. 1987; Reasor 1987). The exposure of nonsmokers to second-hand smoke is termed "passive smoking." Passive smoking has been linked to a variety of health problems, including lung cancer and cardiovascular disease (OTA 1986; Samet et al. 1987).

Throughout the past decade, concerns have grown about the association between indoor air quality (IAQ) in the workplace and a variety of health complaints, including symptoms of the "sick building" syndrome. The sick building syndrome (SBS) describes a collection of nonspecific symptoms, including eye, nose, and throat irritation, mental fatigue, headaches, nausea, dizziness, and skin irritation, which seem to be linked with occupancy of certain workplaces (WHO 1983; Burge et al. 1987). SBS symptoms are experienced at work but are alleviated when away from work for any period of time. SBS complaints among office workers are thought to be caused by poor IAQ, but substantial empirical evidence suggests that SBS problems arise from the combined effects of a variety of environmental and nonenvironmental risk factors (Hedge 1989; Hedge et al. 1989).

Tentative evidence of an association between passive smoking and SBS complaints in U.K. offices has been reported (Robertson et al. 1987), but this has not been systematically investigated. Indeed, SBS complaints are more frequent among smokers (Hodgson and Collopy 1989). In recent years, many companies have introduced a smoking-prohibited policy, but since up to 30% of workers may be smokers, implementing such a policy may not be the most cost-effective alternative. To balance the requirements of nonsmokers and smokers, other companies have implemented spatially restrictive smoking policies, which confine smoking to certain areas of the building. Such policies attempt to minimize any widespread air pollution from cigarette smoking through dilution ventilation, localized filtration, or separate ventilation.

This paper summarizes findings from an ongoing research project investigating the effects of different smoking policies on IAQ and SBS complaints in air-conditioned private sector office buildings. Results for 18 office buildings using five different smoking policies are described.

Alan Hedge and **William A. Erickson** are in the Department of Design and Environmental Analysis, Cornell University, Ithaca, NY. **Gail Rubin** is in the Biometrics Unit, Cornell University.

METHODS

Office Buildings

Eighteen air-conditioned buildings with either variable-air-volume or constant-air-volume ventilation systems were studied. The buildings were occupied by 10 private companies, all doing typical office work. Whether or not a building had an indoor air quality problem was unknown to the investigators. All buildings were in the eastern U.S.: Alabama, Georgia, Indiana, Kentucky, Massachusetts, Michigan, New York State, Ohio, and Virginia.

Smoking Policies

Five smoking policies were investigated (see Table 1). These policies were smoking prohibited (SP), smoking restricted to rooms with local filtration (RF), smoking restricted to areas with no local air treatment (RNT), smoking restricted to rooms with separate ventilation (RSV), and smoking restricted to open-plan cubicle workstations and enclosed offices (RWS).

Indoor Air Quality Study: Site Selection

Each building was sampled over a consecutive two-workday period in the winter heating season with the exception of building L, which was sampled for one day. On each day, two sites were sampled in the morning and two more in the afternoon (Table 2). All sites were in the open-plan office areas in the SP and RWS buildings. In the RSV buildings, morning and afternoon measurements were taken at four sites in the nonsmoking open offices. At one building, the remaining sites were in the separately ventilated space (cafeteria) and included two sites where smoking was allowed and two sites where this was prohibited. At the other RSV building, the remaining four sites measured were in the cafeteria area where smoking was permitted. In all but one of the RF buildings, morning and afternoon measurements were taken at four sites in the open offices and at four sites in the designated smoking lounges. In one building (J), two sites were located in smoking lounges, two in nonsmoking lounges, and the remaining four in the open office areas (Table 3). In the RNT buildings, all the sites sampled were in open office areas. In the case of building K, smoking was allowed in six of the eight areas surveyed. In this building, the choice of policy was made by the department occupying the space. Only one day was spent sampling in building L because a census sample had been achieved. Of the four sites sampled in building L, three were on smoking-prohibited floors and the other site was on a floor occupied by another company that permitted smoking. We were not allowed to survey the occupants of this smoking area.

Indoor Air Quality Study: Environmental Measures

Levels of carbon monoxide, carbon dioxide, respirable suspended particulates measured by a portable meter and by gravimetric weight, formaldehyde, ultraviolet particulate matter (UVPM), nicotine, air temperature, and relative humidity were measured at sample sites in each building. Nicotine and UVPM both are indicators of ETS (Conner et al. 1990). The levels of these indicators in indoor air may reflect the effects of different smoking policies on the relative contribution of cigarette smoke

TABLE 1
Summary Information on Building Features

Policy	Company	Building	Site	Age	Total sq.ft.	# of floors	HVAC	Design Air change rates	Humidification
SP									
	I	A	Office Park	6	145,000	4	VAV	8-9/hour	evaporative
	II	B	City, busy road	23	270,000	19	CAV	3-8/hour	none
	II	C	City, busy road	23	270,000	19	CAV	3-8/hour	none
RSV	III	D	City, quiet road	34	194,000	3	CAV	9/hour	none
	IV	E	Office Park	12	548,000	6	VAV	na	steam
RF	V	F	Office Park	5	75,000	2	VAV	na	none
	V	G	Office Park	5	75,000	2	VAV	na	none
	VI	H	Office Park	1	200,000	5	VAV	na	none
	VII	I	City,busy road	20	600,000	40	CAV	na	none
	V	J	Office Park	2	84,000	4	VAV	na	none
RNT									
	VIII	K	City, busy road	15	55,000	2	VAV	na	none
	I	L	Office Park	14	110,000	4	VAV	8-9/hour	none
RWS									
	IX	M	Greenfield	1	600,000	7	CAV	8/hour	steam
	X	N	Office Park	4	410,000	4	VAV	na	steam
	IX	O	City, busy road	24	155,000	3	CAV	6-8/hour	steam
	IX	P	City, busy road	8	375,000	4	CAV	6-8/hour	steam
	VIII	Q	City, busy road	17	175,000	14	VAV	na	none
	X	R	City, busy road	13	320,000	19	CAV	na	evaporative

to air pollution in offices. All sampling was conducted during normal office hours and on full working days. Air-sampling locations were selected following the EPA's guidelines for monitoring IAQ as closely as possible (Nagda and Rector 1983). In general, sites chosen for sampling in the office areas were in the most densely occupied areas with the least amount of full height walls/obstructions. Care was taken to avoid the following: exterior walls and corners, areas receiving direct sunlight, palpable drafts, direct influences of supply or return ducts, mounting heights below 3 feet or above 5 feet, high traffic locations, and direct impacts from possible contaminant sources, e.g., a photocopier.

Indoor Air Quality Survey: Integrated Measures

Two ordinary black briefcases lined with inert sound-insulating foam each contained three computer-controlled sample pumps. A single-stage inertial impactor for measuring respirable particulates was fastened to the edge of each briefcase. Two brass tubes protruded approximately 4 cm from the same end of the briefcase to allow the air samples for nicotine and formaldehyde to be drawn beyond the edge of the case and for the protection of the sample medium. Care was taken to ensure that the inlet ports were unobstructed while sampling. Exhaust lines ran out through the opposite end of the case from the inlet ports. A bubble flowmeter was used to calibrate the pumps prior to each sampling session and to check the post-sample flow rate. The flow rates used were the average of 10 consecutive measurements after the pump flow stabilized. Total volume was calculated using the average of the initial and final flow rates. Overall, the rates were quite consistent, with the final flow rates averaging 98% (±0.004%) of the initial settings.

TABLE 2
Location and Number of Air Quality Sample Sites for Each Policy

Policy	Number of Buildings	Open Office Areas Non-Smoking	Open Office Areas Smoking	Lounge Areas Non-Smoking	Lounge Areas Smoking
SP	3	8	—	—	—
RSV	1	4	—	2	2
	1	4	—	—	4
RF	4	4	—	—	4
	1	4	—	2	2
RNT	1	3	1	—	—
	1	2	6	—	—
RWS	6	—	8	—	—

TABLE 3
Summary Information on Questionnaire Survey

Policy	Company	Building	Questionnaires Distributed	Questionnaires Returned	Questionnaires %Returned		% Female	% Male	% Current Smokers	Adjusted BSS (±SE)
SP										
	I	A	364	259	71%		83	17	17	3.43 ±0.17
	II	B	208	170	82%		61	39	15	3.63 ±0.20
	II	C	225	183	81%		97	3	26	4.20 ±0.20
				612		Policy Means	81	19	19	3.75 ±0.40
RSV	III	D	228	173	76%		44	56	19	2.65 ±0.20
	IV	E	295	209	71%		65	35	25	3.79 ±0.19
				382		Policy Means	56	44	23	3.22 ±0.50
RF	V	F	181	159	88%		77	23	30	0.77 ±0.21
	V	G	120	87	73%		67	33	21	0.99 ±0.28
	VI	H	282	189	67%		82	18	29	3.09 ±0.20
	VII	I	236	143	61%		58	42	15	3.23 ±0.22
	V	J	110	70	64%		90	10	16	3.12 ±0.31
				648		Policy Means	75	26	24	2.24 ±0.40
RNT										
	VIII	K	219	132	60%		64	36	29	3.15 ±0.23
	I	L	101	78	77%		84	16	22	2.69 ±0.31
				210		Policy Means	71	29	26	2.92 ±0.70
RWS										
	IX	M	318	255	80%		28	72	10	2.19 ±0.16
	X	N	286	217	76%		15	85	11	2.04 ±0.17
	IX	O	227	192	85%		53	47	16	2.49 ±0.19
	IX	P	339	279	82%		61	39	20	2.92 ±0.16
	VIII	Q	163	110	67%		69	31	19	3.03 ±0.25
	X	R	309	250	81%		46	54	15	2.92 ±0.16
				1303		Policy Means	57	43	15	2.60 ±0.27
		Total	4211	3155	75%	Grand Mean	60	40	19	2.83 ±0.05

All sorbent tubes and filters were prepared/supplied by a laboratory, which also performed sample analysis. One field blank for each pollutant was taken per building by briefly exposing the sampling medium. The following pollutants were measured.

Nicotine Nicotine is one of the few tobacco-specific compounds that can be measured to determine even relatively low levels of ETS. Nicotine was not measured in the SP buildings, although a sample was taken in one SP building to determine that nicotine was absent. Nicotine was not measured in the nonsmoking open-office areas in the RSV buildings. Nicotine samples were collected by pumping air at 1 L/min through sorbent tubes containing XAD-4 resin for three hours (Reynolds 1989). The sorbent sampling tubes were composed of a flame-sealed glass tube (70 × 6 mm outside diameter, 4 mm inside diameter) containing two sections of 20/40 mesh XAD-4 resin separated by a glass wool spacer. The front section contained 80 mg of resin and the backup portion contained 40 mg. This method is capable of sampling both gaseous and particulate phase nicotine at concentrations typically found in indoor environments (Eatough et al. 1988). After sampling, the tubes were capped and refrigerated. For analysis, the XAD-4 resin was removed and the nicotine was desorbed with ethyl acetate containing 0.01% triethylamine. An aliquot of the desorbed sample then was injected into a gas chromatograph equipped with a thermionic-specific (nitrogen/phosphorous) detector. The area of the resulting nicotine peak was divided by the area of the internal standard peak and compared with the area ratios from the injection of standards. The detection limit of this method was 0.56 $\mu g/m^3$ for a 180-litre sample (0.10 μg/sample).

Respirable Suspended Particulates (RSP) ETS is a component of RSP (Ingebrethsen et al. 1988; Conner et al. 1990). Levels of RSP were measured gravimetrically (RSPG). Samples were taken through an inertial single-stage impactor (2.5 μm cutoff) at a 4 L/min flow rate for three hours. Particles were deposited on a 1.0 μm pore size, 37-mm-diameter fluoropore membrane filter. A 37-mm, 100 mesh stainless steel support screen was used, because the resistance of the standard cellulose pads was too great for the personal sampling pumps running at 4 L/min. The individual filters were stored and transported in styrene filter cassette holders. For sampling, they were transferred with clean forceps from the holder into the impactor body. Only the extreme outside edge of the filter that was clamped in the impactor was contacted by the forceps. All filters were stored in a cool desiccator cabinet when not in use. After treatment of the filter for static charge with an alpha emitter, an automatic balance with a 20-mg range and readability of 0.001 mg was used to determine the weight of the filter. The difference between the tare weight and the weight of the filter after sampling was recorded as the mass of the RSP.

Ultraviolet Particulate Matter (UVPM) UVPM measures the ETS component of respirable particulates (Ingebrethsen et al. 1988; Conner et al. 1990). After RSPG analysis, the individual filters were extracted with methanol and the resulting solution was filtered. The UV absorbance of a 50 μL sample of the filtrate was measured at 325 nm, with a sensitivity of 0.05 AUFS, using a liquid chromatograph array detector at a flow rate of 0.5 mL/min. The particle mass on the filter then was calculated, using a calibration curve based upon ETS particulate matter collected in an environmental chamber. The detection limit for this method was 3.61 $\mu g/m^3$ for a typical 720-litre sample (2.6 μg/sample).

Formaldehyde Formaldehyde is known to irritate the eyes, nose, and throat and to cause respiratory problems. Samples were collected by pumping air at 0.25 L/min for three hours through a cartridge impregnated with 2,4-dinitro-phenylhydrazine (DNPH) reagent (EPA method TO-11, 1984). Cartridges were stored individually in screw-capped glass vials, which, in turn, were kept in lidded cans filled with a combination of vermiculite and carbon to reduce chances of contamination. The tubes were stored in a refrigerator and shipped in coolers to and from the laboratory. Analysis was performed using a liquid chromatograph coupled to an UV-variable wavelength detector.

Each briefcase was placed on either a desktop or a file cabinet, along with a small sign (3 in. by 3 in.) that read "Air sampling in progress please do not disturb—Office Environmental Quality Study." Workers who inquired about the air sampling were told that general environmental measurements were being taken, and no mention was made of ETS.

Indoor Air Quality Study: Point Measures

The following pollutants and environmental conditions were measured hourly with direct reading instruments at each sample site for the duration of the integrated sampling:

Carbon monoxide (CO): CO can be an ETS tracer, although it is not specific to ETS, and it can indicate any ingress of vehicle exhaust fumes from nearby streets or under-building garages. CO was measured with a portable monitor that utilizes an electrochemical sensor to detect CO in a range from 0 to 50 ppm ±1% full-scale accuracy. The instruments were zeroed as required and were calibrated three times a day with a certified span gas of 30 ppm CO in air. The detection limit was set at 0.5 ppm.

Carbon dioxide (CO_2): CO_2 often is used as an indicator of the ventilation rate. Levels were measured with a portable nondispersive infrared absorption gas analyzer with a measurement range of 50 to 9,950 ppm (±0.01%). The monitor was calibrated using 99.99% dry nitrogen as a zero gas in combination with a span gas of 1,000 ppm CO_2 in nitrogen. Calibration was performed three times daily: morning, early afternoon, and at the end of the day. As the instrument proved to be sensitive to orientation, i.e., vertical upright or horizontal orientation produced different readings, all calibration and measurements were performed in the vertical upright position. Once the monitor's reading was stabilized (~10 seconds), a one-minute average concentration was read. The detection limit was 50 ppm.

Respirable suspended particulates (RSP): RSP was measured using a piezoelectric microbalance with a 3.5 μm impactor. The instrument was factory calibrated with dilute welding fumes with a sensitivity of 180 mg/Hz. Sensor cleaning was performed every four measurements, and impactor and precipitator needle cleaning was done prior to sampling in each building. When run in the 120-second mode, the unit had a measurement range of 0.01 to 3.5 mg/m^3, and the detection limit was 10 $\mu g/m^3$.

Illumination: Horizontal illumination was measured at desk height using a digital illuminance meter (accuracy ±2%). Areas by windows were avoided, as these were not representative illumination levels for the majority of the workspaces sampled. The measurement range was 0.001 to 9,990 fc (0.01 to 99,900 lux).

Temperature and Relative Humidity (RH): Temperature and RH were measured with a digital hygro-thermometer that had a measurement range of 10% to 95% RH, with 0.1% resolution and an accuracy of ±2%. The temperature sensor has a measurement range of 0.0°C to 80.0°C with 0.1°C resolution and was accurate to ±0.1°C. As with all of the real-time measures, measurements were taken at desk level.

SBS Survey: Questionnaire Measures

At the same time as the indoor air quality measures were taken, a self-report questionnaire was distributed to approximately 30 workers in the close vicinity of each of the eight sample sites (~240 workers per building). The design of this questionnaire was based on previous research instruments for SBS investigations (Hedge et al. 1989). The core questionnaire remained unchanged for all buildings, but the final section on smoking behavior was slightly different according to the building's smoking policy. The questionnaire collected data on employee perceptions of ambient conditions (16 questions); occupational factors (12 questions: 6 job satisfaction, 5 job stress, and 1 general work environment question); work-related health and SBS symptoms (17 symptoms: 15 SBS symptoms and 2 unrelated symptoms); and personal information (sex, age, smoking status, allergies). Job stress and job satisfaction questions were answered on a five-point rating scale ("strongly agree" to "strongly disagree"). Job satisfaction was measured using six items adapted from a short version of the "Job Satisfaction Scale," and job stress was measured using five items adapted from previous studies of self-reported job stress effects (Hedge 1988). Questionnaire administration and collection were conducted by the researchers on the same day, except for buildings F, G, and J, where this was done by company employees. Return rates varied between 60% and 85% (average 75%). An SBS symptom was defined as a symptom experienced at work at least "1-3 times" in the past month that "got better" when the worker was away from the office.

Statistical Design and Analysis

The physical environment data were analyzed as a split unit design, with smoking policy as the whole unit treatment factor and time of day (morning or afternoon samples) and smoking designation of an area as the sub-unit treatment factors. The building was the experimental unit for smoking policy.* The effect of smoking policy was tested using the variation in mean response among the buildings within each policy as the error term. The location at which the pollutant and environmental measures were taken within each building was the experimental unit for the time-of-day/smoking designation (nonsmoking/smoking) treatment combinations. Effects of time of day, smoking designation, interactions between these factors, and interactions of these factors with smoking policy were tested, with the variation among locations in buildings as the error term. All interactions were tested at a liberal alpha level, $\alpha = 0.1$, whereas main effects and contrasts were evaluated at $\alpha = 0.05$ (Snedecor and Cochran 1980). When the effect of policy was significant for a pollutant, comparisons among the smoking policies were made using the following set of orthogonal contrasts: RSV vs. RF (separate ventilation vs. filtration); RNT vs. average of RSV and RF (dilution from smoking lounges vs. some form of air cleaning); SP vs. average of RNT, RSV, and RF (removal vs. some form of spatial restriction of smoking); and RWS vs. average of SP, RNT, RSV, and RF (dilution of dispersed sources vs. point or no sources). An orthogonal set is the most concise way of summarizing the policy differences using independent pieces of information (Snedecor and Cochran 1980). When the interaction between policy and time of day was significant for a pollutant, comparisons between morning and afternoon measures were made for each policy. When the interaction between policy and smoking designation was significant for a pollutant, comparison of measures between smoking and nonsmoking areas were made for each spatially restricted smoking policy (RSV, RF, RNT).

*An experimental unit is defined as the smallest size unit to which a treatment can be applied.

Where appropriate, these comparisons were made using unequal variance independent samples t-tests. The Cochran-Mantel-Haenszel (CMH) procedure was used to test for differences in the proportion of men and women that were smokers, controlling for buildings. All statistical analyses of the physical environment data were analyzed on a computer using a standard statistical package. The concentrations of CO, CO_2, and formaldehyde were transformed to the natural log scale, because the variance varied with the mean, indicating that these data were log normal. For computational purposes, a value of 10^{-4} was added to each CO reading because there were zero readings.

Questionnaire Survey Data

Answers to the ambient environment and the SBS symptoms were made on an identical scale of the same frequency (never; 1-3 times/month; 1-3 times/week; every day) applied to the previous month in the building. A building sickness score (BSS) was calculated, i.e., the mean number of SBS symptoms per building (Burge et al. 1987). BSS values, adjusted for differences in sample size, were correlated with the corresponding adjusted mean values for pollutants and environmental measures. For the questionnaire survey data, descriptive and correlational analyses were performed on a computer using the statistical package.

RESULTS

Analysis of IAQ Study

Smoking policy had a relatively small effect on IAQ for the pollutants measured. For most of these pollutants, there were no significant differences in concentration among offices in SP buildings, nonsmoking office areas in RF, RSV, and RNT buildings, and office areas in RWS buildings. There was a significant effect of smoking policy on UVPM and formaldehyde in these office areas, which was due primarily to higher levels in the RF and RSV policies. However, all concentrations of UVPM and formaldehyde were low. UVPM was not significantly correlated with gravimetric RSP, even though the UVPM samples were derived from these RSP samples. UVPM did correlate significantly with metered RSP ($r = 0.69$, $p = 0.0001$) and with nicotine ($r = 0.45$, $p = 0.002$), which suggests that UVPM is measuring particulates from ETS.

Overall Effects of Smoking Policy

The overall mean values of the pollutants and environmental measures for each smoking policy are given in Table 4. Notice that these mean pollutant concentrations are averaged across all areas of all buildings, regardless of the smoking designation of the area. For the smoking-restricted policies, pollutant concentrations were averaged across smoking and nonsmoking areas within buildings. There were no significant differences between smoking policies for levels of CO, RSPG, or illumination. There were marginally significant differences between smoking policies for levels of CO_2 ($p = 0.06$), UVPM ($p = 0.09$), and RH ($p = 0.06$). There were significant differences between smoking policies for levels of RSP ($p = 0.01$), formaldehyde ($p = 0.02$), and air temperature ($p = 0.03$). All significant effects were due primarily to differences between the SP and other smoking-restricted policies.

Effects of Spatially Restrictive Smoking Policies on IAQ

Table 5 gives the mean values of the pollutants and environmental measures for nonsmoking and smoking areas of the three spatially restrictive smoking policies. There were no significant differences between smoking policies for levels of CO,

CO_2, RSPG, RSP, UVPM, RH, or illumination. There were marginally significant differences among restricted smoking policies for air temperature ($p = 0.07$) and for nicotine ($p = 0.06$), and these were driven by differences between the RSV and RF policies ($p = 0.03$ for each pollutant). There were significant differences between policies for formaldehyde ($p = 0.05$), which was due to a difference between the RSV and RF buildings ($p = 0.05$).

There were no significant differences between nonsmoking and smoking areas for CO_2, RSPG, air temperature, RH, or illumination. There were significant differences between nonsmoking and smoking areas for CO ($p = 0.0001$), RSP ($p = 0.0001$), UVPM ($p = 0.0005$), and formaldehyde ($p = 0.0002$). The effect of a smoking area on nicotine levels could only be assessed for the RF and RNT policies, and a significant difference was found for the RF policy ($p = 0.0001$),

TABLE 4
IAQ Measurements for All Smoking Policies

Pollutant	Prohibited (3 Buildings)		R: Separate Vent. (2 Buildings)		R: Filtration (5 Buildings)		R: No Treatment (2 Buildings)		R: Workstation (6 Buildings)	
CO (ppm)*	0.0	(0.0-0.1)	0.3	(0.0-3.8)	0.3	(0.1-1.6)	0.3	(0.0-4.6)	0.1	(0.0-0.5)
CO2 (ppm)*	516	(414-643)	630	(481-825)	693	(584-821)	822	(628-1076)	573	(490-669)
Formaldehyde (ppm)*	0.01	(0.00-0.01)	0.01	(0.01-0.03)	0.02	(0.01-0.04)	0.04	(0.02-0.08)	0.01	(0.01-0.02)
RSP (µg/m3)	30	± 16	58	± 20	87	± 12	63	± 20	23	± 11
RSPG (µg/m3)†	199.4	± 101.6	153.2	± 124.4	67.6	± 78.7	-284.9	± 124.4	-38.3	± 71.8
UVPM (µg/m3)	0.0	± 39.5	38.4	± 48.3	127.8	± 30.6	42.5	± 48.3	10.2	± 27.9
Nicotine (µg/m3)	N.M.	N.M.	3.08	4.77**	21.62	± 3.02	4.11	± 4.77	2.36	± 2.75

Environmental Measures										
Temperature (°C)	24.7	± 0.3	24.3	± 0.4	23.4	± 0.2	23.7	± 0.4	23.6	± 0.2
RH (%)	21.9	± 3.7	36.9	± 4.5	32.4	± 2.9	38.2	± 4.5	35.9	± 2.6
Illumination (f.c.)	39.0	± 7.6	55.0	± 9.3	51.5	± 5.9	45.7	± 9.3	52.5	± 5.4

* - Adjusted means are backtransformed from natural log values.
** - nicotine only measured in smoking areas in these buildings
95% confidence intervals in parentheses
N.M. – no measurement taken
RSP - RSP levels were measured by meter
RSPG - RSP levels measured by laboratory analysis using gravimetric method
† - negative values from negative gravimetric weights

TABLE 5
IAQ Measurements in Smoking and Nonsmoking Areas for Restricted Smoking Policies

Pollutant	R: Separate Vent. (2 Buildings) Non-Smoking		R: Separate Vent. (2 Buildings) Smoking		R: Filtration (5 Buildings) Non-Smoking		R: Filtration (5 Buildings) Smoking		R: No Treatment (2 Buildings) Non-Smoking		R: No Treatment (2 Buildings) Smoking	
CO (ppm)*	0.1	(0.0–0.2)	1.0	(0.2–3.9)	0.1	(0.1–0.2)	1.0	(0.5–2.3)	0.2	(0.0–0.8)	0.6	(0.1–2.8)
CO2 (ppm)*	582	(496–682)	669	(554–807)	688	(624–758)	697	(626–777)	732	(595–901)	870	(704–1073)
Formaldehyde (ppm)*	0.01	(0.01–0.01)	0.02	(0.01–0.03)	0.02	(0.01–0.02)	0.04	(0.03–0.05)	0.03	(0.02–0.05)	0.04	(0.03–0.07)
RSP (µg/m3)	24	± 16	107	± 19	36	± 10	154	± 11	40	± 21	85	± 21
RSPG (µg/m3)†	107.8	± 129.5	210.9	± 153.3	-12.8	± 79.1	161.1	± 88.2	-99.9	± 168.7	-443.6	± 171.5
UVPM (µg/m3)	2.5	± 41.1	95.2	± 48.6	16.3	± 25.1	269.1	± 28.0	14.0	± 53.5	73.4	± 54.4
Nicotine (µg/m3)	N.M.	N.M.	3.08	± 4.77	1.09	± 4.40	46.27	± 4.90	1.38	± 9.38	6.98	± 9.54

Environmental Measures												
Temperature (°C)	24.3	± 0.2	24.3	± 0.2	23.4	± 0.1	23.4	± 0.1	23.7	± 0.2	23.6	± 0.2
RH (%)	35.8	± 2.4	37.5	± 2.8	32.4	± 1.4	32.5	± 1.6	38.3	± 3.1	38.0	± 3.1
Illumination (f.c.)	56.7	± 6.4	63.0	± 7.5	50.4	± 3.9	53.4	± 4.3	42.4	± 8.3	46.9	± 8.4

* - Adjusted means backtransformed from natural log values.
95% confidence intervals in parentheses
N.M. – no measurement taken
RSP - RSP levels were measured by meter
RSPG - RSP levels measured by laboratory analysis using gravimetric method
† - negative values from negative gravimetric weights

but there was no significant difference for the RNT policy. Levels of all pollutants generally were significantly higher in the smoking areas than in the nonsmoking areas.

Smoking Policy Effects on IAQ in Open Office Areas

The effects of smoking policy on IAQ of all nonsmoking office areas was compared with that of the office areas in the RWS policy, where smoking at each desk was allowed (Table 6). There were no significant differences among policies for levels of CO, CO_2, RSPG, RSP, or illumination. There was a marginally significant difference among policies for air temperature ($p = 0.06$). There were significant differences among policies for levels of UVPM ($p = 0.05$), formaldehyde ($p = 0.05$), and RH ($p = 0.05$). All effects were driven by differences between the SP and the other smoking-restricted policies.

Comparison of the SP and RWS Policies

The effect on IAQ of prohibiting smoking vs. restricting smoking to office workstations was tested by comparing SP and RWS policies. No significant differences were found in CO, CO_2, RSP, RSPG, formaldehyde, and illumination. There were significant differences in temperature ($p = 0.04$), RH ($p = 0.03$), and UVPM ($p = 0.003$). Temperature was higher, although by less than 1°C, and RH and UVPM were lower for the SP policy.

Questionnaire Survey

There was a marginally significant difference in the average age of workers among policies ($p = 0.06$), but there was no difference in worker age among buildings within a policy. There were significant differences in the proportions of men and women who completed the survey who were smokers, nonsmokers, and former smokers (CMH $\chi^2 = 18.8$, $= 0.000$, see Table 3).

Estimates of the total number of cigarettes smoked during the workday under the RSV, RF, RNT, and RSW policies and the total number of person hours spent in smoking areas under the RSV, RF, and RNT policies were calculated from the survey data. More cigarettes were smoked daily in the RWS policy (345 ± 47) than in the RSV (234 ± 81) and the RF (179 ± 51) policies. There were complete data for only one building with the RNT policy (492).

The total number of person hours spent smoking was significantly correlated with CO ($r = 0.83$, $p = 0.04$) and with formaldehyde levels ($r = 0.89$, $p = 0.02$). The total number of cigarettes smoked per day was significantly correlated with formaldehyde levels ($r = 0.93$, $p = 0.007$), and there was a marginally significant correlation with CO ($r = 0.77$, $p = 0.08$). Covariate analyses were performed and showed the total number of cigarettes smoked per day and the number of person hours spent in smoking areas did not account for more variation in levels of CO, CO_2, UVPM, nicotine, and formaldehyde than did the study design variables. This was due to the colinearity of these smoking measures with the smoking designation of the office areas, i.e., smoking or nonsmoking.

Analysis of SBS Symptoms

Eye problems, fatigue and lethargy, headache, and irritability were among the most prevalent and most frequently experienced symptoms (Table 7). There is no accepted criterion of how prevalent symptoms must be before a building is classified as a "sick" building. It has been suggested that "the use of a questionnaire survey to get an impression of the extent of symptoms/complaints in the rest of the workforce is recommended. If the frequency of symptoms is high, above 20%, we have to deal with an epidemic, not only endemic symptoms, and the costs for a 'cure' may be high" (Levy 1990, p. 239). For the buildings surveyed in this study, most of the SBS symptoms exceed

TABLE 6
IAQ Measurements in Open Office Areas for All Smoking Policies

	POLICY									
	Prohibited (3 Buildings) (n=24)		R: Separate Vent. (2 Buildings) (n=8)		R: Filtration (5 Buildings) (n=22)		R: No Treatment (2 Buildings) (n=12)		R: Workstation (6 Buildings) (n=48)	
Pollutant										
CO (ppm)*	0.0	(0.0-0.1)	0.1	(0.0-1.2)	0.1	(0.0-0.8)	0.2	(0.0-3.7)	0.1	(0.0-0.6)
CO2 (ppm)*	516	(414-644)	582	(444-763)	688	(580-817)	738	(563-967)	573	(490-669)
Formaldehyde (ppm)*	0.01	(0.00-0.01)	0.01	(0.00-0.02)	0.02	(0.01-0.03)	0.03	(0.01-0.08)	0.01	(0.01-0.02)
RSP (μg/m3)	30	± 8	24	± 10	35	± 7	39	± 10	23	± 6
RSPG (μg/m3)†	199.4	± 99.6	107.8	± 122.0	-13.4	± 77.2	-152.1	± 122.0	-38.3	± 70.5
UVPM (μg/m3)	0.0	± 3.3	2.5	± 4.0	11.7	± 2.5	13.4	± 4.0	10.2	± 2.3
Nicotine (μg/m3)	N.M.	N.M.	N.M.	N.M.	0.45	± 0.86	1.38	± 1.85	2.36	± 0.58
Environmental Measures										
Temperature (°C)	24.7	± 0.3	24.3	± 0.4	23.4	± 0.3	23.7	± 0.4	23.6	± 0.2
RH (%)	21.9	± 3.7	35.8	± 4.6	32.4	± 2.9	38.6	± 4.6	35.9	± 2.6
Illumination (f.c.)	39.0	± 7.3	56.7	± 8.9	50.7	± 5.6	44.1	± 8.9	52.5	± 5.2

* - Adjusted means backtransformed from natural log values.
95% confidence intervals in parentheses
N.M. – no measurement taken
RSP - RSP levels were measured by meter
RSPG - RSP levels measured by laboratory analysis using gravimetric method
† - negative values from negative gravimetric weights

this 20% criterion. There was a small but significant difference ($p = .0001$) between the mean number of SBS symptoms reported by men (2.4 ± 0.1) and women (3.1 ± 0.1), which agrees with other research (Burge et al. 1987; Hedge et al. 1989; Skov and Valbjørn 1987).

There was no significant difference between the mean number of SBS symptoms reported by smokers (3.7 ± 0.1) and nonsmokers or former smokers (3.5 ± 0.1). There were no significant effects of smoking policy on the building sickness score (BSS) (Table 3); however, there were significant differences in BSS among the buildings within smoking policies.

Office IAQ and SBS

There was a significant correlation between adjusted BSS values and air temperature ($r = 0.58$, $p < 0.01$) but no significant correlations between BSS and any of the IAQ or environmental measures.

DISCUSSION

The present research to date has found few differences in IAQ among the five smoking policies studied. Results show that workers in nonsmoking open offices are exposed to negligible additional pollution in restricted-smoking buildings compared with smoking-prohibited buildings, providing that they do not spend time in areas where smoking is concentrated, e.g., smoking lounges. However, this does not necessarily mean that individual workers in the immediate vicinity of a cigarette smoker in an office will not inhale elevated levels of pollutants, nor does it mean that nonsmokers will not be irritated by involuntary ETS exposure.

Although most of the IAQ measures taken met the current ASHRAE 62-1989 standard for acceptable IAQ (ASHRAE 1989), 74% percent of the workers reported at least one work-related SBS symptom! Smoking policy did not significantly affect SBS symptoms. Air temperature correlated with the BSS, even though most measures of air temperature fell within the winter comfort zone, i.e., air temperature 22.8 °C and 25 °C for a relative humidity of around 30% (ASHRAE 1981). This finding agrees with previous research showing a correlation between air temperature and SBS complaints (Jaakola et al. 1987; Skov et al. 1987).

Carbon dioxide is often used as an indicator of ventilation rate, and the ASHRAE 62-1989 ventilation standard sets a recommended upper limit of 1,000 ppm for worker comfort. Very few measures of carbon dioxide exceeded or even approached this level in the buildings sampled. Carbon dioxide levels did not correlate with the BSS, which is consistent with the null results for the relationship between CO_2 and SBS symptoms reported by Hodgson and Collopy (1989).

Formaldehyde is a known irritant, affecting the eyes, nose, throat, respiratory tract, and skin, and it sometimes induces asthma-like attacks even at low concentrations. Several studies have reported a dose-response relationship between formaldehyde and symptoms at levels as low as 0.1 ppm in sensitized people (Godish 1990). Formaldehyde can be outgassed from a number of building products, (e.g., particle board, adhesives, ceiling tiles), and it is also produced by cigarette smoking. Levels of formaldehyde generally were low in the buildings sampled, with the exception of building K, and there was no significant correlation between formaldehyde and the BSS values.

Gravimetric measurement of RSP was problematic because 18 field blanks showed some discrepancy from their initial mass: 5 with negative mass, 13 with positive mass. These problems were not encountered with RSP measures obtained using the portable piezobalance. It has been suggested that ETS is the major source of RSP in indoor air (Van De Wiel et al. 1989). Analysis of the RSP data confirmed significant differences between smoking and nonsmoking areas; however, office averages for metered RSP did not correlate with the BSS values.

Analysis of UVPM data confirmed significant differences between smoking and nonsmoking areas and between SP and restricted-smoking policies. UVPM was correlated with nicotine and metered RSP, which agrees with the suggestion by Conner et al. (1988) that it is a measure of particulates from ETS. However, UVPM was not significantly correlated with gravimetric RSP, even though the UVPM samples were derived from these RSP samples. UVPM levels in offices did not correlate with BSS values.

The ASHRAE 62-1989 ventilation standard recommends that, for worker comfort and health, RH should fall between 20% and 60% and preferably should exceed 30%. Most RH measures approached or exceeded 30%, except for buildings B

TABLE 7
Prevalence of Work-Related Sick Building Syndrome Symptoms

Symptoms	%Never	%1-3x/month	%1-3x/week	%Every day
Excessive mental fatigue	56.9	22.6	12.5	8.1
Headache across forehead	61.4	22.0	11.6	5.1
Dry eyes	62.9	13.9	11.6	11.6
Irritated, sore eyes	62.0	15.5	13.7	8.7
Nervousness, irritability	63.5	23.0	9.5	4.0
Unusual tiredness, lethargy	70.1	18.2	7.1	4.6
Stuffy, congested nose	72.0	11.4	8.3	8.3
Sore, irritated throat	77.8	13.3	5.9	3.1
Runny nose	80.8	10.7	5.2	3.3
Hoarseness	84.7	9.5	4.2	1.6
Dry skin	85.7	4.0	3.8	6.5
Dizziness	89.7	8.0	1.9	0.4
Wheezing, chest tightness	91.5	5.5	1.9	1.0
Nausea	92.3	6.5	1.0	0.3
Skin irritation, rashes	95.5	3.1	0.6	0.8

and C, where low RH was measured. Low RH has been suspected as a cause of SBS symptoms; SBS complaints were among the highest in buildings B and C, where RH was lowest. However, using data from all buildings, there was no significant correlation between RH and BSS values.

None of the IAQ measures, other than air temperature, was significantly correlated with BSS values, which suggests that physical measurement of indoor environmental conditions alone will not accurately gauge the prevalence of SBS complaints in the building. Similarly, results show that prohibiting smoking will not necessarily reduce the prevalence of SBS problems in offices.

ACKNOWLEDGMENTS

Research described in this interim project report is conducted under contract to the Center for Indoor Air Research, Linthicum, Maryland. We are grateful to Professor William Sims, Elizabeth Luke, Gretchen Barnes, and Susan Ulman for assistance with this work. We also thank all companies and workers who have participated in this project.

REFERENCES

ASHRAE. 1981. *ASHRAE Standard 55-1981, Thermal environment conditions for human occupancy.* Atlanta: American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc.

ASHRAE. 1989. *ASHRAE Standard 62-1989, Ventilation for acceptable indoor air quality.* Atlanta: American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc.

Burge, P.S., A. Hedge, S. Wilson, et al. 1987. "Sick building syndrome: A study of 4373 office workers." *Annals of Occupational Hygiene*, Vol. 31, pp. 493-504.

Conner, M., G. Oldaker, and J. Murphy. 1990. "Method for assessing the contribution of environmental tobacco smoke to respirable suspended particulates in indoor environments." *Environmental Technology Letters*, March.

Eatough, D., L. Hansen, and E. Lewis. 1988. "Methods for assessing exposure to environmental tobacco smoke." *Transactions: Combustion Processes and the Quality of the Indoor Environment: An International Specialty Conference*, pp. 183-200.

EPA. 1984. EPA Method TO-11. *Compendium of methods for the determination of toxic organic compounds in ambient air.* EPA Document #600-484-041: TO11-1—TO11-38, April.

Godish, T. 1990. *Indoor air pollution control.* Michigan: Lewis Publishers.

Guerin, M.R., C.E. Higgins, and R.A. Jenkins. 1987. "Measuring environmental emissions from tobacco combustion: Sidestream cigarette smoke literature review." *Atmospheric Environment*, Vol. 21, pp. 291-297.

Hedge, A. 1988. "Job stress, job satisfaction, and work-related illness in offices." In *Proceedings of the 32nd Annual Meeting of the Human Factors Society*, Vol. 2, pp. 777-779.

Hedge, A. 1989. "Environmental conditions and health in offices." *International Reviews of Ergonomics*, Vol. 3, pp. 87-110.

Hedge, A., S. Wilson, P.S. Burge, et al. 1987. "Environmental, psychological and organizational correlates of employee health in offices: A proposed model." In *Proceedings of the 31st Annual Meeting of the Human Factors Society*, Vol. 2, pp. 736-740.

Hedge, A., P.S. Burge, A.S. Robertson, et al. 1989. "Work-related illness in offices: A proposed model of the 'sick building syndrome.'" *Environment International*, Vol. 15, pp. 143-158.

Hodgson, M.J. 1989. "The role of combustion products in building-associated illness." *Occupational Medicine: State of the Art Reviews*, Vol. 4, pp. 735-740.

Hodgson, M.J., and P. Collopy. 1989. "Symptoms and the microenvironment in the sick building syndrome: A pilot study." *The Human equation: Health and comfort.* Atlanta: American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc.

Ingebrethsen, B., D. Heavner, A. Angel, et al. 1988. "A comparative study of environmental tobacco smoke particulate mass measurements in an environmental chamber." *Journal of the Air Pollution Control Association*, Vol. 38, pp. 413-417.

Jaakola, J.J.K., O.P. Heinonen, and O. Seppänen. 1989. "Sick building syndrome, sensation of dryness and thermal comfort in relation to room temperature in an office building: Need for individual control of temperature." *Environment International*, Vol. 15, pp. 163-168.

Lenvik, K. 1990. "Comparisons of working conditions and 'sick building syndrome' symptoms among employees with different job functions." In *Indoor Air '90, Proc. 5th International Conference on Indoor Air Quality and Climate*, Toronto, Vol. 1, pp. 507-512.

Levy, F. 1990. "The medical approach to patients with IAQ problems." In *Indoor Air '90, Proc. 5th International Conference on Indoor Air Quality and Climate*, Toronto, Vol. 5, pp. 327-331.

Nagda, N.L., and H.E. Rector. 1983. *EPA guidelines for monitoring indoor air quality.* EPA-600/4-83-046, September.

Norbäck, D. 1990. "Environmental exposures and personal factors related to sick building syndrome." Doctoral thesis, Uppsala University.

OTA. 1986. *Passive smoking in the workplace: Selected issues.* Office of Technology Assessment.

Reasor, M.J. 1987. "The composition and dynamics of environmental tobacco smoke." *Journal of Environmental Health*, Vol. 50, pp. 2024.

Reynolds, R.J. 1989. *Portable air sampling system—Operator's manual*, Revision 4. Winston-Salem, NC: R.J. Reynolds Company.

Robertson, A.S., P.S. Burge, A. Hedge, et al. 1988. "Relation between passive cigarette smoke exposure and 'building sickness.'" *Thorax*, Vol. 43, p. 263.

Samet, J.M., M.C. Marbury, and J.D. Spengler. 1987. "Health effects and sources of indoor air pollution. Part 1." *American Review of Respiratory Disease*, Vol. 136, pp. 1486-1508.

Skov, P., O. Valbjørn, and DISG. 1987. "The sick building syndrome in the office environment: The Danish Town Hall study." *Environment International*, Vol. 13, pp. 339-349.

Skov, P., O. Valbjørn, B.V. Pedersen, and DISG. 1989. "Influence of personal characteristics, job-related factors and psychosocial factors on the sick building syndrome." *Scandinavian Journal of Work Environment & Health*, Vol. 15, pp. 286-295.

Snedecor, G.W., and W.G. Cochran. 1980. *Statistical methods*, 7th ed. Iowa State University Press.

U.S. Surgeon General. 1986. *The health consequences of involuntary smoking*, DHHS (CDC) 87-8398.

Van De Wiel, H.J., E. Lebret, H.C. Eeerens, et al. 1989. "Quantifying future trends of indoor air quality as a basis for government policy plans." In *Pilot study on indoor air quality: Managing indoor air quality risks*, Report on a Meeting Held in St. Michaels, Maryland, October 25-27. U.S. EPA.

WHO. 1983. *Indoor air pollutants: Exposure and health effects.* EURO Reports and Studies 78. World Health Organization.