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A Survey of Environmental Tobacco Smoke Controls in California Office Buildings

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Abstract A survey of environmental tobacco smoke (ETS) controls in California office buildings was carried out to obtain information on the type and distribution of ETS controls in office buildings and to evaluate the effectiveness of various ETS controls. A total of 118 smoking areas in 111 county and city buildings were inspected to collect information on the type of ETS controls. Only 31% of the smoking areas inspected were physically separated from nonsmoking areas with full floor-to-true-ceiling walls, 25% exhausted air to the outside, and 38% did not recirculate air to non-smoking areas. A total of 23 smoking areas and their adjacent non-smoking areas in 21 buildings were monitored for nicotine and fluorescent particulate matter (FPM). A tracer gas, sulfur hexafluoride (SF_6), was released in smoking areas to measure the air leakage from smoking areas to adjacent non-smoking areas. The measurements of nicotine, FPM, and SF_6 have shown large variations of the effectiveness of ETS controls. The least effective type of smoking area studied were open areas with no physical barriers between smoking and nonsmoking areas, no exhaust to the outside and no return air separation. On the contrary, smoking rooms with three ETS controls (i.e., physical separation, exhaust to outside, and no air recirculation) were the most effective design in containing ETS within smoking areas.

Key words Environmental tobacco smoke; Designated smoking area; Office building; Nicotine; Fluorescent particulate matter; Sulfur hexafluoride.

Practical Implications
Exposure to environmental tobacco smoke (ETS) has been linked to a variety of adverse health outcomes. Effective ETS controls in office buildings will minimize ETS exposures in office environments and, therefore, reduce the number of deaths caused by ETS. On-site inspection of 118 smoking areas in 111 buildings has provided us major information on the type and distribution of ETS controls. Effectiveness of various ETS controls were evaluated by intensive environmental measurements of 23 smoking areas in 21 buildings. Among different ETS controls, the most effective design is the combination of complete physical separation from non-smoking area, no air recirculation from smoking area to non-smoking area, and exhaust of air from smoking area directly to outside.

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Introduction

Based on mounting scientific findings on respiratory health effects of environmental tobacco smoke (ETS) to non-smokers, the U.S. Environmental Protection Agency (U.S. EPA, 1992) concluded that ETS is a human lung carcinogen, responsible for approximately 3,000 annual lung cancer deaths of U.S. nonsmokers. The U.S.EPA concluded further that ETS is a risk factor for childhood asthma and lower respiratory tract infections. The U.S. EPA report covered studies on respiratory effects of ETS up to 1992. In 1997, the California Environmental Protection Agency (Cal/EPA) conducted a literature review including articles beyond 1992 and incorporating developmental, carcinogenic, and cardiovascular effects (Cal/EPA, 1997). The Cal/EPA's literature review supports the major conclusions of the U.S.EPA's report. The Cal/EPA report has identified additional health effects not included in the U.S.EPA's report. In addition to lung cancer, nasal sinus cancer is also causally associated with ETS exposure. Other health effects caused by ETS exposure identified in the Cal/EPA report include coronary heart disease, low birth weight, and sudden infant death syndrome.

In recognition of the significant health effects of ETS, many governmental agencies have issued smoking policies for the workplace and public places. To protect nonsmokers from exposure to ETS, smoking is generally re-

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stricted or prohibited at the workplace. Restrictions may vary from a total ban on indoor smoking to allowing smoking only in designated indoor areas. Although a total ban on indoor smoking is now more common, for those buildings where smoking is allowed, the most common practice is to allow smoking only in designated smoking areas. However, no specific guidelines have been developed for designing smoking rooms to best protect non-smokers from exposure to ETS leaking from smoking rooms. The major objectives of this study were to obtain information on the type and distribution of ETS controls in office buildings and to evaluate the effectiveness of these controls.

Methods

This study was carried out from 1991 to 1994 prior to the passage of workplace-restricting legislation. The survey consisted of two phases: 1) an inspection phase; and 2) a monitoring phase. During the inspection phase, we visited 118 smoking areas in order to collect information on the type of ETS controls. During the monitoring phase, we measured the concentrations of nicotine, fluorescent particulate matter (FPM), and a tracer gas (sulfur hexafluoride, SF_6) in smoking and adjacent nonsmoking areas. The monitoring data were used to evaluate the efficiency of ETS controls.

In order to select smoking areas for our study, a list of office buildings was compiled by mailing 506 letters to 58 counties and 448 cities in California. Of the 506 letters mailed out, 39 counties and 270 cities responded. Among the respondents, 24 counties and 166 cities had a total smoking ban in their office buildings. We contacted 15 counties and 104 cities, in which smoking was still allowed, and compiled a list of 322 buildings. While we were contacting managers of the 322 buildings, we were informed that smoking policies of 37 buildings had changed to a total smoking ban. The list of candidate buildings was therefore reduced to 285. The 285 buildings consisted of 64 county buildings and 221 city buildings. These buildings were located in 35 of the 58 California counties and 119 of the 448 California cities. From the list of 285 buildings, we selected 111 buildings for on-site inspection. Because some buildings had more than one smoking area, the total number of smoking areas was 118. A detailed description of the building selection procedure can be found in an earlier publication (California Department of Health Services, 1995).

Building Inspection

One or two members of a field team experienced in building investigations inspected the 118 smoking areas. During each inspection, a walkthrough data sheet was filled out and a floor plan was drawn by the inspector(s). Information provided in the data sheet included characteristics of the building, type of heating, ventilating, and air conditioning (HVAC) system(s), smoking area(s), and surrounding non-smoking areas. Parameters recorded for each inspected building were number of floors; average square feet per floor; construction type; number of hours in use; proximity of parking facility; and other potential sources of pollutants around the building. Parameters recorded about each building's HVAC system(s) included number, size, age, location, and access of these systems; location of supply, return, and exhaust openings; area thermal controls; operation, and maintenance of HVAC system(s); location of outside air intakes; and filtration/contaminant removal devices. Parameters recorded for each smoking area were type; size; physical separation; ventilation controls; particulate sources; ETS removal devices, if any; and potential smoking and non-smoking sampling sites.

A total of 26 smoking areas were selected to include a full range of the following characteristics: type of smoking area (e.g. open or closed area), number of smokers, presence of exhaust fan, recirculation of air from smoking area to non-smoking areas, door between smoking and non-smoking area, door to outside, presence of air cleaning device(s), and permission for intensive environmental monitoring (California Department of Health Services, 1995). Three smoking areas were used for a pilot study to test the field component of the study. Following the pilot study, we monitored the remaining 23 smoking areas intensively for ETS-related parameters in order to evaluate the effectiveness of various ETS controls.

Environmental Monitoring

Buildings and smoking areas chosen for environmental monitoring were studied over a 3- to 4-day period. During this time period we did the following: a) measured nicotine and FPM in one or two locations of the smoking area and in two or three locations of non-smoking areas (for a total of four locations); b) tagged the air in the smoking area with a tracer gas (SF_6) and then measured its concentration continuously at the four ETS sampling locations, and in the smoking room's supply, return and exhaust air, if any; c) measured each building's overall ventilation rate using the tracer gas decay method as described later in this section; d) measured supply, return, and exhaust airflow rates in the smoking and non-smoking areas using a flowhood and/or a hot wire anemometer; e) measured pressure differences across entry doors of enclosed smoking areas using a digital micromanometer; and f) recorded by observation the number of cigarettes smoked in 2.5-h ETS sampling period. During each sampling period, we set the outdoor air dampers to a fixed position to reduce variations in the building's mechanical ventilation rate. In order to determine the effectiveness of existing ETS controls, we varied the following parameters in smoking areas when it was possible: a) operation of the exhaust fan (on or off); b) amount of outside air (dampers at maximum or minimum position); c) opening of the entry door (closed or open); d) operation of air cleaning device (on or off).

Nicotine was collected by drawing air for 150 min at 1.0 L/min. through XAD-4 sorbent tubes (diameter: 6 mm, length: 70 mm). Each sorbent tube consisted of a front section with 80 mg XAD-4 resin and a back-up section with 40 mg XAD-4 resin. The collected samples were analyzed with a gas chromatograph equipped with a thermionic-specific (nitrogen-phosphorus) detector and a 30-m coiled capillary column as described in ASTM (1990). The limit of quantitation (LOQ) based on the lowest calibration standard for the 150-min sampling period was 0.33 $\mu g/m^3$.

FPM was sampled by drawing air at a rate of 1.9 L/min for 150 min through an aluminum cyclone, which had a 50% cutpoint for particles with an aerodynamic diameter of 5 μm at the sampling flow rate. The particles were collected on a Teflon® filter, which had a 37-mm diameter and a pore size of 1 μm. The filter was then extracted with 4 ml of methanol (HPLC grade) in a 2 g (approx. 10 μL) vial with a Teflon® septum and was agitated for 1 h. The solution was then transferred to a cuvette, and the particles were measured by fluorescence spectrophotometry as described in Ogden et al. (1990). The LOQ based on the lowest calibration standard for the 150-min period was 0.35 μg/m^3.

The tracer gas (SF_6) was used in this study to monitor the air movement from smoking area to non-smoking areas and to measure local and overall ventilation rates of each building. To trace air movement from smoking to non-smoking areas, SF_6 was released near the ETS sources at a constant flow rate using a mass flow controller. The release point was either in a supply register in the smoking room, or in the absence of a supply register, next to a small portable mixing fan approximately 4 feet above the floor. The amount of SF_6 released in the smoking room varied depending upon the room size and ventilation rate. SF_6 concentrations were monitored in the smoking room, exhaust air stream (if present), and non-smoking areas. A pollutant removal efficiency based on the total amount of SF_6 released in the smoking area and amount of SF_6 removed via the exhaust fan was presented in an earlier publication (Alevantis et al., 1994). The SF_6 samples were drawn through Tygon® tubing (non-absorbent to SF_6) to a central location where monitoring was done automatically using a computer-controlled, 8-location sampling system. This system used an unheated molecular sieve column and an unheated electron capture detector. The column was automatically back-flushed after elution of each SF_6 peak (Alevantis, 1989). Sample sequencing using this system was once every 90 s. Calibration was done manually at the beginning and end of each day, using Tedlar® sample bags filled with four calibration gases (0.515, 0.961, 4.91 and 71.9 ppb). The LOQ of SF_6 was 0.1 ppb. To measure the overall ventilation rates of each building, SF_6 was released at a constant rate into the HVAC system's main supply air stream. SF_6 was monitored at several locations in the building during the build-up, steady-state and decay periods. Measurements of the building air change rates and smoking room leakage rates were made on separate days, since the single tracer gas can be used for only one type of measurement at a time. Interzonal and unplanned airflows were not measured. A detailed description of the measurement of smoking leakage rates is given in an earlier publication (Alevantis et al., 1993).

Results

Characteristics of 118 Smoking Areas Inspected

The results of the walkthrough inspections of the 118 smoking areas revealed that 42 (36%) of the smoking areas were enclosed smoking lounges, 27 (23%) were private offices, 26 (22%) were break rooms, 13 (11%) were areas within cafeterias, and 10 (8%) were areas within hallway or foyers (see Table 1). Among the different means of physical separations, we found that 48 (41%) of the 118 smoking areas were not separated from the adjacent nonsmoking areas. Five (4.2%) were partially separated from non-smoking areas by movable partitions or other barriers. Twenty-six (22%) were partially separated from adjoining non-smoking areas by floor-to-suspended-ceiling walls. Thirty-six (31%) were completely separated from adjoining non-smoking areas by full floor-to-true-ceiling walls.

Eighty-five (72%) of the 118 inspected smoking areas had no exhaust fan. Thirty-two (27%) equipped with exhaust fans. One exhausted to the hallway, one exhausted to the ceiling plenum, and 30 (25%) exhausted to the outside. As to the type of return air from smoking areas, we found that the return air from 50 (42%) of the smoking areas was ducted. The air from 25 (21%) smoking areas returned through a common open ceiling plenum. There was no return at all in 43 (36%) smoking areas. The air from 75 (63%) smoking areas returned to the main air-handling system, which served both smoking and non-smoking areas. Only two of the 118 smoking areas were served by separate ventilation systems. Thirteen (11%) smoking areas were not equipped with any ventilation system. Constant air volume (CAV) was the most common (71%)

Table 1 Characteristics of the 118 inspected smoking areas

	Frequency	Percentage (%) (N=118)
Type of Smoking Area		
Smoking Lounge	42	36
Private Office	27	23
Breakroom	26	22
Cafeteria	13	11
Hallway	10	8
Type of Physical Barrier		
No Physical Barrier	48	41
Partial Dividers (e.g. portable partitions)	5	4
Partial Walls[a]	26	22
Full Walls[b]	36	31
Other	3	2
Type of Air Exhaust		
No Exhaust Fan	85	72
Exhaust to Outside	30	25
Exhaust to Plenum	1	1
Exhaust to Hallway	1	1
Other	1	1
Type of Return Air		
Ducted	50	42
Ceiling Plenum	25	21
No Return	43	36
Type of Ventilation		
Constant Air Volume	84	71
Variable Air Volume	18	15
Separate Ventilation System	2	2
No Mechanic Ventilation	13	11
Unknown	1	1

[a] Walls from floor to suspended ceiling
[b] Walls from floor through suspended ceiling to true ceiling

type of building ventilation system. Eighteen (15%) smoking areas were served by variable air volume (VAV) ventilation systems.

The joint probabilities of various ETS controls (i.e. the combination of physical barrier, exhaust to outside and return air separation) are presented in Table 2. This table shows that only 8 smoking areas (7%) had the most efficient ETS controls with a combination of full floor-to-true-ceiling walls, exhaust to outside and no return air to the main system. Forty-five smoking areas (40%) had inadequate ETS controls: which a) were not separated from the adjoining non-smoking areas by full walls; b) did not exhaust to the outside the building; and c) recirculated ETS-containing air into the building.

Intensive Field Monitoring Results

Characteristics of Smoking Areas Monitored

Of the 23 smoking areas we studied intensively, 13 were smoking lounges, seven were cafeterias, and three were break rooms (see Table 3). The floor sizes of smoking areas varied from 7.8 to 120 m^2. Building air change rates varied from 0.43 to 9.3 h^{-1}. Supply air flow rates ranged from 35 to 540 L/s in the 18 smoking areas where we took these measurements. Among the 23 smoking areas monitored, ten were equipped with exhaust fans of which eight exhausted to outdoors and two exhausted indoors. The air in five of the 23 smoking areas were separated from the main return air systems. Seven of the 23 smoking areas were equipped with air-cleaning devices. We measured pressure dif-

Table 2 Number and proportion of smoking areas with different combinations of physical barrier, exhaust to outside, and return air separation

Separated by full floor-to-true-ceiling walls 36 (32%)				Not separated by full floor-to-true-ceiling walls 78 (68%)			
Exhausted to outside 10 (9%)		Not exhausted to outside 26 (23%)		Exhausted to outside 20 (17%)		Not exhausted to outside 58 (51%)	
Not returned	Returned	Not returned	Returned	Not returned	Returned	Not returned	Returned
8 (7%)	2 (2%)	14 (12%)	12 (11%)	8 (7%)	12 (10%)	13 (11%)	45 (40%)

Four observations did not meet the criteria of any of the above categories.

Table 3 Characteristics of the 23 monitored smoking areas

ID	Type	Area (m^2)	Barrier	Supply Airflow (L/s)	Bldg. ACH h^{-1}	Separate Return Air	Exhaust	Air Cleaner
1	cafeteria	32	none	71	0.72	no	no	2 E.P.[d]
2	smoking lounge	19	full walls[a]	120	3.8–5.5	yes	to outside	none
3	cafeteria	39	none	300	0.93	no	to hallway	none
4	cafeteria	110	partial divider	–[c]	9.3	no	to outside	none
5	smoking lounge	28	full walls[a]	300	1.4	yes	no	none
6	smoking lounge	62	partial walls[b]	540	2.6	no	to outside	none
7	smoking lounge	16	partial divider	220	1.1–2.3	no	no	2 E.P.[d]
8	smoking lounge	24	full walls[a]	220	1.5	no	no	1 E.P.[d]
9	smoking lounge	54	partial walls[b]	250	0.43	no	to outside	none
10	cafeteria	80	none	190	1.5	no	no	none
11	smoking lounge	74	partial walls[b]	220	0.76–2.1	no	to outside	1 E.P.[d]
12	breakroom	28	none	180	0.61–4.1	no	no	none
13	smoking lounge	16	full walls[a]	120	0.59	yes	no	1 E.P.[d]
14	cafeteria	44	none	170	3.1–3.8	no	no	none
15	cafeteria	120	none	–[c]	1.6–2.0	no	no	none
16	breakroom	35	partial walls[b]	260	0.7–1.3	no	no	none
17	smoking lounge	29	partial divider	0	–[c]	no	to outside	none
18	smoking lounge	7.9	full walls[a]	9.4	0.7–2.0	no	to plenum	none
19	breakroom	67	none	–[c]	0.98	no	no	none
20	cafeteria	100	none	–[c]	1.1	no	no	3 charc[e]
21	smoking lounge	7.8	partial walls[b]	35	0.76	no	to outside	2 port.[f]
22	smoking lounge	9.3	full walls[a]	40	2.1	yes	no	none
23	smoking lounge	19	partial walls[b]	190	1.1–2.7	yes	to outside	none

[a] Walls from floor through suspended ceiling to true ceiling
[b] Walls from floor to suspended ceiling
[c] Not measured
[d] Electrostatic precipitator
[e] Activated charcoal
[f] Portable air cleaner

ferentials in 8 smoking areas, of which only three were operating under negative pressures considered sufficient to contain ETS within the smoking areas, i.e., greater than 7 Pascal (Pa). Further discussion of these three smoking areas and the rationale for choosing 7 Pa are provided by Alevantis et al. (1996).

During each monitoring day, the number of cigarettes smoked was recorded every 30 min for the morning and afternoon sessions each lasting 2.5 h. A total of 176 sessions were recorded for the 23 smoking areas. Eight sessions were monitored in 19 smoking areas and six sessions were monitored in four smoking areas. The number of cigarettes smoked per session varied from 0.5 to 114 with an average of 24.7. The range and average number of cigarettes smoked of all sessions in the 23 smoking areas are presented in Table 4. The least average number of cigarettes (3.3) was smoked in smoking area #16 and the most average number of cigarettes (71.6) was smoked in smoking area #14.

Environmental Measurements

Nicotine: Nicotine concentrations ranged from below the limit of quantitation (LOQ) of 0.33 $\mu g/m^3$ to 140 $\mu g/m^3$ in smoking areas and from below the LOQ to 120 $\mu g/m^3$ in non-smoking areas. To calculate average nicotine concentrations, we used half of the LOQ, i.e., 0.17 $\mu g/m^3$ for the concentrations below the LOQ. The range and average nicotine concentrations of the 23 smoking and adjacent non-smoking areas are presented in Table 4. Adjacent non-smoking areas were areas closest to the smoking areas and generally occupied by non-smokers. Of the 23 adjacent non-smoking areas listed in Table 4, only one (#21) was located across the hallway of the smoking area. The remaining 22 adjacent non-smoking areas were each physically next to the smoking areas, either without or with a physical barrier, i.e., a common wall. Excluding area #8, which was lacking valid nicotine measurements in the smoking area due to sampling and analysis failure, the average concentrations of the 22 smoking areas ranged from 2.2 to 112 $\mu g/m^3$ with a mean value of 19.1 $\mu g/m^3$. The average concentrations of the 23 adjacent non-smoking areas ranged from below the LOQ to 48.4 $\mu g/m^3$ with a mean value of 7.6 $\mu g/m^3$. Excluding #8, the mean value of the 22 non-smoking areas was 5.8 $\mu g/m^3$, which is about 30% of the mean concentration of the 22 adjacent smoking areas.

FPM: FPM concentrations ranged from below the LOQ (0.35 $\mu g/m^3$) to 35 $\mu g/m^3$ in smoking areas and from below the LOQ to 30 $\mu g/m^3$ in the non-smoking areas. To calculate average FPM concentrations, we used half of the LOQ, i.e., 0.18 $\mu g/m^3$ for the concentrations below the LOQ. The average and range of the FPM concentrations of the 23 smoking and adjacent non-smoking areas are presented in Table 4. The average FPM concentrations measured in the 23 smoking areas ranged from 0.3 $\mu g/m^3$ to 19.1 $\mu g/m^3$ with a mean value of 4.1 $\mu g/m^3$. The average FPM concentrations measured in the adjacent non-smoking areas ranged from the 0.18 $\mu g/m^3$ to 15.4 $\mu g/m^3$ with a mean value of 2.1 $\mu g/m^3$, which is about 50% of the mean concentration of smoking areas.

SF_6: SF_6 concentrations ranged from 4.5 ppb to 128 ppb in smoking areas and from below the LOQ (0.1 ppb) to 58.3 ppb in non-smoking areas. To calculate average SF_6 concentrations, we used half of the LOQ, i.e., 0.05 ppb for the concentrations below the LOQ. The average and range of SF_6 concentrations of the 23 smoking and adjacent non-smoking areas are presented in Table 4. The average SF_6 concentrations of the 23 smoking areas ranged from 10.9 to 88 ppb with a mean value of 41.8 ppb. The average SF_6 concentrations of the 23 non-smoking areas ranged from 0.05 to 35.1 ppb with a mean value of 12.8 ppb, which is about 30% of the mean concentration of smoking areas.

Effectiveness of ETS controls

To evaluate the effectiveness of ETS controls, the ratios of the mean concentration of nicotine, FPM, and SF in adjacent non-smoking area versus smoking area were calculated. Table 5 shows the differences of ratios, *t*-test statistics and p-values between the presence and absences of three ETS controls: total physical separation of smoking area from non-smoking area by full floor-to-true-ceiling walls, return air separation, and exhaust to outside. This table shows that all three ETS controls provide various degrees of reducing ETS in non-smoking areas. With only one exception, all differences are statistically significant ($p<0.05$). For nicotine ratios, the mean difference between exhaust to outside and not exhaust to outside is not significant ($t=0.61$, $p=0.55$).

In order to contrast the most-efficient and least-efficient ETS controls, ratios of SF_6 in non-smoking area versus smoking areas were calculated and ranked. The four lowest ratios and four highest ratios are listed in Table 6, along with the specific ETS controls employed. As expected, the four worst cases were all open cafeterias with no physical barriers between smoking and adjacent non-smoking areas. Air from these four smoking areas was not exhausted to outside but mixed with the building return air. All the best cases were smoking areas with at least two ETS controls. The means of the SF_6, nicotine and FPM ratios are 0.4%, 2.4% and 19% respectively for high-efficient ETS controls and 90%, 54% and 127%, respectively, for the low-efficient ETS

Table 4 Average and range of ETS-related measurements in smoking and adjacent non-smoking areas

ID of Smoking Area	# of Cigarettes Smoked (counted in 2.5 h)	Concentration of Nicotine (μg/m^3)		Concentration of FPM (μg/m^3)		Concentration of SF_6 (ppb)	
		Smoking Area	Non-smoking Area	Smoking Area	Non-smoking Area	Smoking Area	Non-smoking Area
1	17.9 (4–28)	9.9 (3.3–16)	3.2 (0.9–6.8)	2.5 (0.4–6.2)	4.3 (0.5–7.8)	16 (16)	5.95 (5.8–6.1)
2	6.6 (4–13)	3.3 (1.8–7.3)	0.5 (<0.33–2.7)	0.6 (<0.35–1.1)	0.18 (<0.35)	32 (13–51)	0.63 (0.2–1.05)
3	66 (41–114)	30.7 (9.2–55)	15.6 (1.1–32)	9.7 (1.4–19)	15.4 (7.7–30)	26.5 (26–27)	29.5 (27–32)
4	51.4 (30–82)	4.3 (1.5–9.1)	0.17 (<0.33)	1.7 (0.6–5.7)	0.3 (<0.35–0.5)	10.9 (4.5–15)	1.37 (0.75–2.41)
5	10 (5–14)	9.9 (3.3–17)	0.2 (<0.33–0.5)	2.1 (0.6–7.3)	0.5 (<0.35–1.1)	35 (33–36)	8.7 (3.1–14.4)
6	8.5 (2–30)	2.2 (0.17–10.9)	0.2 (<0.33–0.6)	1.5 (<0.35–6.9)	0.18 (<0.35)	52.6 (27.2–58.1)	13.5 (2.2–46.8)
7	9.4 (4.5–14)	7.2 (2.9–11)	4.5 (1.6–12)	0.6 (<0.35–1.4)	2.5 (1.0–4.2)	46.5 (43–50)	30.5 (30–31)
8	14 (10–18)	–[a]	48.4 (19–104)	12.4 (2.7–35)	5 (2.8–9.2)	31.8 (31.8)	11.4 (11.4)
9	56.1 (43–77)	47.8 (14–80)	47.4 (31–66)	19.1 (0.5–35)	1.3 (<0.35–2.2)	44.1 (23.2–76.8)	1.41 (0.76–1.89)
10	26.4 (15–36)	14.3 (6.5–18)	11.3 (5–18)	2.6 (0.6–8.3)	3.1 (1.4–4.9)	22.3 (7.84–31.2)	15.4 (5.9–21.2)
11	17.9 (10–36)	17.7 (9.8–31)	1.5 (<0.33–9)	3.4 (1.6–6.2)	1 (0.4–1.7)	24.7 (20.8–30.1)	3.55 (2.5–4.8)
12	8 (5–12)	2.4 (<0.33–4)	1.4 (<0.33–4.6)	0.3 (<0.35–0.5)	0.6 (<0.35–1.3)	28.3 (14.1–42.5)	27.6 (15.1–40)
13	19.4 (14–35)	47.8 (26–110)	3.4 (2.3–4.1)	3.1 (1.4–6.1)	1.7 (0.5–4.5)	46.7 (14.6–88.8)	6.29 (2.37–8.59)
14	71.6 (39–83)	19 (12–32)	7.6 (<0.33–22)	2.7 (0.4–8.9)	2.7 (<0.35–10)	43.9 (37.2–50.6)	27.3 (17.8–36.8)
15	67.1 (44–83)	7.2 (1.8–13)	2 (0.8–3.1)	1.3 (0.5–5.2)	2 (1.2–2.8)	57.6 (26.3–88.8)	28.9 (10.2–47.6)
16	3.3 (0.5–4)	3.9 (<0.33–6.4)	1.5 (<0.33–2)	0.4 (<0.35–1.2)	1.4 (<0.35–2.4)	55 (14.3–95.6)	35.1 (11.8–58.3)
17	28.3 (1–103)	34 (3.4–110)	22 (<0.33–120)	3.1 (<0.35–17)	0.18 (<0.35)	84 (67.3–128)	4.31 (1.1–11.1)
18	8.5 (2–18)	5.7 (2–12)	0.17 (<0.33)	0.5 (<0.35–1.2)	0.18 (<0.35)	30.5 (20.5–40.5)	0.05 (<0.1)
19	13.8 (13–15)	6.2 (3.6–8.7)	2 (1.1–3.7)	1.6 (1.1–2.8)	2.9 (2.1–3)	50 (46–55.1)	23.1 (17.4–31.8)
20	27.6 (24–34)	5.4 (2.7–6.6)	1.4 (0.63–3.9)	2.8 (1.1–5.5)	0.8 (<0.35–1.5)	24 (21–27)	19.7 (11–26)
21	15.3 (4–23)	112 (44–140)	0.6 (<0.33–1)	18.4 (5.2–25)	0.6 (<0.35–1.2)	82.3 (81.3–83.9)	0.76 (0.45–1.22)
22	6.3 (6–25)	8.3 (4.2–14)	0.4 (<0.33–1.2)	1.5 (0.7–2.7)	0.3 (<0.35–0.6)	88 (35.7–108)	0.26 (<0.1–0.65)
23	15.1 (11–20)	21.2 (5.4–42)	0.17 (<0.33)	1.4 (0.48–3.7)	0.18 (<0.35)	29.3 (12.3–46.2)	0.05 (<0.1)
Mean of 23 Monitored Areas	24.7 (3–72)	19.1 (2.2–112)	7.6 (0.17–48.4)	4.1 (0.3–19.1)	2.1 (0.18–15.4)	41.8 (10.9–88)	12.8 (0.05–35.1)

[a] No nicotine data for this site

Table 5 Effects of control measures on ratios of mean concentrations of nicotine, FPM and SF_6 in adjacent non-smoking areas versus mean concentrations in smoking areas

Control Measures	Nicotine Ratio (%) n, Mean (S.D.)	FPM Ratio (%) n, Mean (S.D.)	SF_6 Ratio (%) n, Mean (S.D.)
Full walls[a]			
Yes	6, 7 (3)	7, 32 (14)	7, 15 (14)
No	16, 39 (21)	16, 122 (125)	16, 45 (36)
t-value (p)	4.33 (0.0005)	2.84 (0.0118)	2.89 (0.0088)
Return air separation			
Yes	5, 6 (6)	5, 29 (16)	5, 8 (11)
No	17, 38 (29)	18, 113 (120)	18, 44 (34)
t-value (p)	4.27 (0.0004)	2.87 (0.0099)	3.75 (0.0012)
Exhaust to outside			
Yes	8, 25 (24)	8, 16 (19)	8, 8 (9)
No	14, 33 (36)	15, 137 (119)	15, 51 (33)
t-value (p)	0.61 (0.55)	3.94 (0.0014)	4.69 (0.0002)

[a] Walls from floor through suspended ceiling to true ceiling

Table 6 Contrast of low versus high ETS exposure ratios of adjacent non-smoking areas to smoking areas

Smoking Area ID	SF_6 Ratio (%)	Nicotine ratio (%)	FPM ratio (%)	Type of Smoking Area	Physical Barrier	Exhaust to Outside	Return Air Separation
18	0.16	3.5	40	Smoking Lounge	Full walls[a]	Yes	No
23	0.17	0.9	14	Smoking Lounge	Partial walls[b]	Yes	Yes
22[c]	0.29	4.8	20	Smoking Lounge	Full walls[a]	No	Yes
21	0.92	0.5	3.3	Smoking Lounge	Partial walls[b]	Yes	No
Mean	0.4	2.4	19				
10	69	79	119	Cafeteria	None	No	No
20	82	26	29	Cafeteria	None	No	No
12	97	58	200	Cafeteria	None	No	No
3	111	51	159	Cafeteria	None	No[d]	No
Mean	90	54	127				

[a] Walls from floor through suspended ceiling to true ceiling
[b] Walls from floor to suspended ceiling
[c] Door to outside open
[d] Exhaust to hallway

controls. It is noteworthy that in smoking area #3 with the highest exposure ratio, the average concentrations of both SF_6 and FPM were higher in the nonsmoking area than in the smoking area. In smoking area #3, two supply air registers were located in the smoking area resulting in air movement into the non-smoking area.

For the evaluation of the effectiveness of air cleaning devices in reducing ETS in smoking and non-smoking areas, changes of nicotine and FPM exposures were calculated (California Department of Health Services, 1995). Because air cleaning devices have no effect on SF_6 concentrations, no effort was made to compare the changes of SF_6 concentrations with the air cleaning devices on and off. However, the comparisons of nicotine and FPM changes, with air cleaning devices on and off, in smoking areas #1, #7, #8, #11, #13, and #21 and their corresponding adjacent non-smoking areas did not reveal a consistent pattern of ETS reductions. Approximately half of the changes were negative (decreased ETS), while the other half were positive (increased ETS).

Conclusions and Discussion

Of the 118 smoking areas inspected, only 31% were physically separated from non-smoking areas by full floor-to-true-ceiling walls. Forty-one percent of the designated smoking areas in open cafeterias had no physical barrier at all from adjacent non-smoking areas. While ETS should be exhausted directly from smoking areas to outside, only 25% did so. Seventy-two percent of the inspected smoking areas had no exhaust fans. There were two cases that ETS-containing air from smoking areas was exhausted directly into a hallway or a return air plenum. The air of 63% of the smoking areas was mixed with the building return air either through a return air duct or an open return air plenum, thus redistributing ETS-containing air to non-smoking areas served by the same air handling system. Only 7% of the inspected smoking areas had the best combination of ETS controls, i.e., full floor-to-true-ceiling walls, no return air from smoking area to non-smoking area, and exhaust from smoking area to outside.

With a response rate of 61%, the 111 buildings with 118 smoking areas inspected represent fairly well California public office buildings at the time of our survey. The 23 smoking areas selected for intensive environmental monitoring were not randomly chosen to represent the 118 inspected smoking areas. They were selected to include a wide spectrum of ETS relevant parameters and to evaluate the effectiveness of major ETS controls.

Since the conclusion of our study in 1994, the California legislature passed Assembly Bill 13 (AB13), entitled *Occupational Safety and Health: Tobacco Products,* prohibiting most employers from exposing non-smoking employees to ETS. In AB13, all smoking areas shall meet the following design specifications: a) air from the smoking room shall be exhausted directly to the outside by an exhaust fan, and b) air from the smoking room shall not be recirculated to other parts of the building. After AB13 was passed, a number of local governments enacted total bans on indoor smoking at the workplace in their jurisdictions. However, a wide range of smoking policies employing some of the ETS controls investigated in this study still exist outside California.

For the evaluation of ETS controls, the ratios of nicotine, FPM and SF_6 in non-smoking area versus smoking area were calculated. In general, the results were consistent in reflecting the effectiveness of various ETS controls. The average concentrations of nicotine, FPM, and SF_6 in nonsmoking areas were 30%, 50%, and 30% respectively of the concentrations in smoking areas. The contrast of low versus high ETS exposure ratios in Table 6 shows that all three marker compounds can differentiate between good and poor ETS controls. Among the three marker compounds studied, nicotine concentrations measured in non-smoking areas were always lower than those found in smoking areas. The average SF_6 concentration measured in one non-smoking area was higher than that in smoking area (#3). There were eight cases where we found higher average FPM concentrations in non-smoking areas than those of smoking areas (#1, 3, 7, 10, 12, 15, 16, 19). The discrepancies are probably due to a number of reasons including:

1. The three marker compounds have the following inherent differences: (a) nicotine is a unique ETS marker, but is very reactive and can be easily adsorbed onto indoor surfaces; (b) FPM is not as specific as nicotine due to interference from other sources such as cooking and diesel exhaust; and (c) SF_6 is a stable chemical that does not adsorb onto indoor surfaces and does not exist in the natural environment. Although SF_6 is not a constituent of ETS, it can be used to effectively trace the movement of air from the smoking area to the non-smoking area.
2. SF_6 was released at relatively constant rate from a single location, while cigarettes were smoked sporadically and at different locations within the smoking area.
3. Some smoking and non-smoking areas were located in open cafeterias or break rooms, where cooking, a source of FPM, was also taking place.
4. Although all sampling locations were chosen so that SF_6, nicotine and FPM sampling sites were as close as possible, effects of local ventilation and sources patterns on different samplers can not be expected to be entirely identical.

The three marker compounds monitored in this study have provided us a better understanding of different aspects of ETS's behavior than a single marker could. A quantitative comparison of the results of nicotine and SF_6 and its implications have been presented in an earlier publication by Alevantis et al. (1994).

The measurements of nicotine, FPM and SF_6 in the 23 smoking areas and adjacent non-smoking areas clearly show the variation of the effectiveness of various ETS controls. There were cases where non-smokers were exposed to equivalent or higher ETS concentrations in non-smoking areas than in the smoking areas. There were also situations where concentrations in non-smoking areas were less than 1% of those in smoking areas. ETS controls, such as complete physical separation from non-smoking areas, no air recirculation from smoking areas to non-smoking areas, and exhaust of air from smoking areas directly to outside, reduced significantly the spread of ETS into non-smoking areas.

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References

Alevantis, L.E. (1989) "A computer-controlled system for measuring air exchange rates of buil ings using sulfur hexafluoride as a tracer gas". In: Nagda, N.L. and Harper, J.P. (eds) *Design and protocol for monitoring indoor air quality*, Philadelphia, American Society for Testing and Materials (ASTM STP 1002). pp. 257–265.

Alevantis, L.E., Hayward, S.B., Shah, K.B., Loiselle, S. and Offermann, F.J. (1993) "Tracer gas techniques for the determination of the effectiveness of pollutant removal from localized sources". In: Teichman, K.Y. (ed.) *Proceedings of the American Society of Heating, Refrigerating and Air-Conditioning Engineers – IAQ'93 Conf.*, Philadelphia, PA.

Alevantis, L.E., Liu, K.-S., Hayward, S.B., Shah, K.B., Offermann, F.J. and Leiserson, K. (1994) "Effectiveness of ventilation in 23 designated smoking areas in California office buildings". In: *Proceedings of the American Society of Heating, Refrigerating and Air-Conditioning Engineers IAQ'94 Conf.*, St. Louis, MO, pp. 89–103.

Alevantis, L.E., Offermann, F.J., Loiselle, S. and Macher, J.M. (1996) "Pressure and ventilation requirements of hospital isolation rooms for tuberculosis (TB) patients: Existing guidelines in the United States and a method for measuring room leakage". In: Maroni, M. (ed) *Ventilation and Indoor Air Quality in Hospitals*, Kluwer Academic Publishers, pp. 101–116.

ASTM (1990) *ASTM method D 5075–90a, standard test method for nicotine in indoor air*, Philadephia, PA, American Society for Testing and Materials.

California Environmental Protection Agency (1997) *Health effects of exposure to environmental tobacco smoke*, Sacramento, California Environmental Protection Agency.

California Department of Health Services (1995) *Effectiveness of ventilation and other controls in reducing exposure to environmental tobacco smoke in office buildings*, Sacramento, California Department of Health Services.

Ogden, M.W., Maiolo, K.C., Oldaker, G.B. and Conrad, F.W. (1990) "Evaluation of methods for estimating the contribution of ETS to respirable suspended particles'.' In: *Proceedings of the Fifth International Conference on Indoor Air Quality and Climate.*

U.S. Environmental Protection Agency (1992) *Respiratory health effects of passive smoking: Lung cancer and other disorders*, Washington, DC, United States Environmental Protection Agency, Office of Research and Development.