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Effectiveness of Auxiliary Air Cleaners In Reducing ETS Components in Offices

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A field study was conducted to evaluate the effectiveness of several auxiliary air cleaning devices in reducing components of environmental tobacco smoke (ETS) within a designated smoking lounge and ambient areas in an office suite. Monitoring was performed for the ETS components nicotine, respirable particulate and carbon monoxide.

Nicotine and RSP samples were collected in a smoking lounge for two eight-hour periods for each of the following conditions: (1) no smoking in the office suite with no air cleaning devices operating; (2) smoking in the smoking lounge with no clean air devices operating; and (3) smoking in the smoking lounge with one of four air cleaning devices operating. Eight-hour general area and personal samples were also collected to determine levels of nicotine and RSP in ambient, non-smoking areas.

Continuous monitoring, with one minute averaging, was performed for carbon monoxide using a direct reading air quality monitor.

Introduction

Few issues create as heated a debate as defining the health consequences of environmental or "second hand" tobacco smoke. Conflicting health research studies continue to polarize views concerning the health consequences of ETS. To err on the side of caution, many local and county governments, as well as the Department of Defense, have established strict regulations banning smoking inside public buildings within their jurisdictions. Still others remain uncommitted to a smoking policy or require the establishment of separate smoking and non-smoking areas within public buildings.

In 1994, the Occupational Safety and Health Administration (OSHA) released a proposed indoor air quality standard that would require employers to install separate, ventilated smoking lounges or implement a no smoking policy.

As the debate over the health consequences of ETS continues, it is clearly evident that an environment where the smoker and non-smoker may coexist is sorely needed. One solution is the creation of designated smoking lounges. The preferred solution is the use of dedicated, non-recirculating exhaust systems in these lounges. The major disadvantages of this solution are the energy costs, distance to the outside, reluctance of owners to allow penetration of the building shell and lack of portability.

An alternative solution is the creation of designated smoking areas where contaminated air is simultaneously diluted with supply air and filtered by auxiliary air cleaning devices before being recirculated within the general building ventilation system. These devices are available for the commercial and residential markets and are stand-alone or ceiling mounted. Air cleaning devices designed to remove ETS must be capable of removing a combination of gases and particles less than one *um* in size.

This study's objective was to determine the effectiveness of several commercial auxiliary air cleaning devices in reducing components of ETS in a designated smoking lounge and ambient, non-smoking areas.

Principles of Air Cleaning

Auxiliary air cleaning devices use a combined system of control mechanisms to effectively remove vapor and particle components of ETS. Generally, air cleaning devices use filtration, electrostatic precipitation and gas-solid adsorption techniques in some combination for contaminant removal.

Media filtration removes particulate matter from an airstream by forcing the airstream through a porous media where particulate matter is deposited in and around the media structure by impaction and diffusion. Filter media may be constructed of any of a number of natural and man-made materials including fabric and fibrous glass.

High efficiency particulate air (HEPA) filter media is commonly used because of

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its ability to trap particulate in the submicrometer range with a minimum efficiency of 99.97% for 0.3 μm particles. Electrostatic precipitation removes particulate matter from an airstream using electrostatic forces. Particles are first subjected to a high-intensity electrical field which induces a charge on their surface and are then directed by a voltage gradient to an alternately charged collecting surface where they are precipitated and removed from the airstream. Gas-solid adsorption involves retention of contaminant vapors on the surface of a porous media through which the gas stream passes. The most commonly used adsorption media in auxiliary air cleaning devices is activated carbon.

Four air cleaning devices were evaluated during this study and a brief description of each type follows:

Device #1: Contaminated air is drawn by a fan through a foam pre-filter, a 95% efficient HEPA-type filter and 43 pounds (19.35 k) of carbon, permanganate and zeolite media in series before exhausted from the unit. The unit measures 24 by 24 by 48 ins. (61 by 61 by 122 cm) and was suspended from the ceiling according to the manufacturer's instructions. The average flow rate is 1,050 cfm (493.5 L/s).

Device #2: Contaminlated air is drawn by a fan through a metal pre-filter and an ozone generator in series before exhausted from the unit. The unit measures 12 by 13 by 16 ins. (30 by 33 by 41 cm) and was positioned on a stand five feet (1.5 m) above the floor.

Device #3: Contaminated air is drawn by a fan through a electrostatic pre-filter; a 22 inch (59 cm), V-bag filter; and 12 pounds (5.4 kg) of carbon media in series before exhausted from the unit. The unit measures 15 by 20 by 48 ins. (38 by 51 by 122 cm) and was mounted to the ceiling according to the manufacturer's instructions. The average flow rate is 650 cfm (305.5 L/s).

Device #4: Contaminated air is drawn by a fan through a electrostatic pre-filter, a 99.999% efficient HEPA filter and 9 pounds (4 kg) of carbon media in series before exhausted from the unit. The unit measures 19 by 24 by 48 ins. (48 by 61 by 122 cm) and was positioned on a table in the smoking lounge. The average flow rate is 750 cfm (352.5 cm).

Study Background

The study was conducted in a 3,100 ft^2 (288 m^2) office suite located on the second floor of a three-story building. The office suite occupied approximately 20% of the available office space on the second floor and the remaining space was vacant. The suite was comprised of 12 separate offices, a conference room, a kitchen area, a reception area, a fax and printer area and a storage room. All floors were carpeted with the exception of the kitchen floor and all ceilings were composed of 2 by 2 ft. (61 by 61 cm) suspended ceiling tiles. The conference room, measuring approximately 14 by 20 ft. (4.3 by 6.1 m), served as the designated smoking lounge for this study.

Description	Nicotine Levels (ug/m^3)*	RSP Levels (ug/m^3)*	Average Carbon Monoxide (ppm)
Baseline - No Smoking & No Air Cleaning Device	**Inside Lounge** <0.49 **Outside Lounge** <0.49, <0.46 **Personals** <1.7, <2.2, <3.1, <1.6	**Inside Lounge** <12, <9.3 **Outside Lounge** <12, <20 **Outdoors** <20 **Personals** <15, <14, <20, 50	**Inside Lounge** 0, 0 **Outside Lounge** 0, 0
Smoking & No Air Cleaning Device	**Inside Lounge** 48, 54.2 **Outside Lounge** <0.46, <0.47 **Personals** <0.43, 0.66, <0.46, <0.47	**Inside Lounge** 155, 500 **Outside Lounge** <8.4, 30 **Outdoors** 12, 60 **Personals** <13, <12, 60, 60	**Inside Lounge** 6, 5 **Outside Lounge** 0, 1
Smoking & Air Cleaning Device #1	**Inside Lounge** 26.4, 24 **Outside Lounge** <0.44, <0.46 **Personals** 0.55, <0.44, <0.46, <0.46	**Inside Lounge** 50, 90 **Outside Lounge** 20, 20 **Outdoors** <5.6, 20 **Personals** 20, <20, 20, 20	**Inside Lounge** 5, 3 **Outside Lounge** 2, 0
Smoking & Air Cleaning Device #2	**Inside Lounge** 49.9, 36.8 **Outside Lounge** <0.57, <0.43 **Personals** 0.44, <0.72, <0.45, <0.44	**Inside Lounge** 540, 400 **Outside Lounge** <20, 30 **Outdoors** 150, <20 **Personals** 140, 50, 40, 40	**Inside Lounge** 5, 4 **Outside Lounge** 1, 1
Smoking & Air Cleaning Device #3	**Inside Lounge** 22.5, 19.8 **Outside Lounge** <0.45, <0.47 **Personals** <0.43, <0.44, <0.46, <0.46	**Inside Lounge** 380, 380 **Outside Lounge** 80, 30 **Outdoors** 70 **Personals** 50, 60, 30, 50	**Inside Lounge** 4, 4 **Outside Lounge** 1, 0
Smoking & Air Cleaning Device #4	**Inside Lounge** 25.7, 24.6 **Outside Lounge** <0.44, <0.47 **Personals** <0.44, <0.45, <0.45, <0.47	**Inside Lounge** 110, 100 **Outside Lounge** 30 **Outdoors** 50, 10 **Personals** 60, 30,10, <20	**Inside Lounge** 4, 4 **Outside Lounge** 1, 1

* Less than (<) indicates that the sample result was below detectable limits

Table 1: A summary of the results for nicotine, RSP (respirable suspended particulate) and carbon monoxide for all sampling periods.

The heating, ventilation and air-conditioning (HVAC) for the office suite was provided by a central system. Individual heating and air-conditioning fan-coil units were provided in each of the six exterior offices; however these units did not draw fresh supply air from the building's exterior.

All supply air from the central system was directed into the occupied spaces via ceiling diffusers. All return air from

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the suite was directed back to the central HVAC system, (located on the roof of the building) through ceiling diffusers leading to a common plenum above the ceiling.

The HVAC system supply air was a mixture of return air and outside air. The outside air intake was located on the roof. The HVAC unit had 1in. (2.54 cm) pleated filters with a nominal efficiency of 30%. Filtration was typical of small commercial HVAC equipment.

Study Methodology

Prior to the study, each employee's smoking habits were surveyed to establish a controlled amount of cigarettes to be smoked during each testing period. The results of the survey indicated that approximately 100 cigarettes were smoked during a typical day; therefore 100 cigarettes was established as a controlled variable for each testing period. To ensure 100 cigarettes were smoked each testing period, a specified amount of cigarettes was allocated to each employee and a smoking log was established to record the time that each cigarette was smoked. Cigarette butts were counted daily to verify the correct number of cigarettes smoked for the test period. All smoking was performed in the smoking lounge with the entrance door closed.

To estimate the levels of ETS components, eight-hour personal and general area air samples were collected inside the smoking lounge and in nonsmoking areas to determine the amount of nicotine and RSP. Carbon monoxide levels were measured continuously during each sampling period. Two sampling periods were performed for each of the following scenarios:

- Baseline conditions, no smoking anywhere within the office suite.
- Smoking in conference room with no air cleaning devices operating.
- Smoking in the conference room with air cleaning device #1 operating.
- Smoking in the conference room with air cleaning device #2 operating.
- Smoking in the conference room with air cleaning device #3 operating.
- Smoking in the conference room with air cleaning device #4 operating.

The sampling periods for each of the air cleaning devices were chosen randomly.

Description	UVPM Levels (ug/m³)	FPM Levels (ug/m³)
Baseline - No Smoking & No Air Cleaning Device	**Inside Lounge** <5.3, <4.1 **Outside Lounge** <5.2 <4.6 **Outdoors** <4.7 **Personals** <6.3, <6.2, <5.3, <7.0	**Inside Lounge** <5.6, <4.3 **Outside Lounge** <5.4, <4.9 **Outdoors** <4.9 **Personals** <6.6, <6.5, <5.6, <7.4
Smoking & No Air Cleaning Device	**Inside Lounge** 278, 541 **Outside Lounge** 4.7, 7.2 **Outdoors** <4.7, <5.6 **Personals** <5.7, <6.2, <6.6, 15	**Inside Lounge** 370, 446 **Outside Lounge** <3.9, 5.2 **Outdoors** <5.0, 1.6 **Personals** <5.9, <5.3, 3.6, 10.7
Smoking & Air Cleaning Device #1	**Inside Lounge** <5, 62 **Outside Lounge** <5.4, <5.7 **Outdoors** <5.6, <5.8 **Personals** <6.3, 72, <6.7, <6.7	**Inside Lounge** <1, 42 **Outside Lounge** 0.6, 0.8 **Outdoors** <0.6, 0.7 **Personals** 0.6, 57, 0.7, 1.6
Smoking & Air Cleaning Device #2	**Inside Lounge** 389, 371 **Outside Lounge** <5.1, 5.6 **Outdoors** <5.3, <5.1 **Personals** <5.9, 13, 7.0, 9.9	**Inside Lounge** 365, 349 **Outside Lounge** 3.3, 4.5 **Outdoors** 0.7, 0.7 **Personals** 2.4, 9.4, 3.2, 6.0
Smoking & Air Cleaning Device #3	**Inside Lounge** 280, 427 **Outside Lounge** <5.0, <5.6 **Outdoors** 7.6 **Personals** 6.2, 20, <5.6, 10	**Inside Lounge** 304, 329 **Outside Lounge** 3.6, 3.5 **Outdoors** <0.5 **Personals** 4.3, 16, 3.5, 7.3
Smoking & Air Cleaning Device #4	**Inside Lounge** 83, 82 **Outside Lounge** <5.2 **Outdoors** <5.3, <4.9 **Personals** <6.0, <6.1, <5.7, <5.7	**Inside Lounge** 72, 62 **Outside Lounge** 1.5 **Outdoors** 0.6, <0.5 **Personals** 1.4, 3.7, 1.2, 2.3

Table 2: A summary of the results for the UVPM (ultraviolet particulate matter) and FPM (fluorescent particulate matter) analyses.

Monitoring

To estimate the levels of ETS components during the study, air monitoring was performed for nicotine, RSP and carbon monoxide. A description of the monitoring performed for each ETS component is provided below.

Nicotine: One eight-hour general area sample was collected inside the smoking lounge (Sample Area 1 - smoking area) and one eight-hour general area sample was collected outside the smoking lounge (Sample Area 2 - non-smoking area). Two eight-hour personal samples were collected for two non-smoking employees in Sample Area 2. All nicotine samples were collected using sampling pumps equipped with XAD-4 sorbent tubes.

Respirable Suspended Particles (RSP): One eight-hour general area sample was collected inside the smoking lounge (Sample Area 1 - smoking area), one eight-hour general area sample was collected outside the smoking lounge (Sample Area 2 - non-smoking area), and one eight-hour general area sample was collected outside the building. Two eight-hour personal samples were collected for two non-smoking employees in Sample Area 2. All RSP samples were collected on a teflon membrane filter with a one *um*

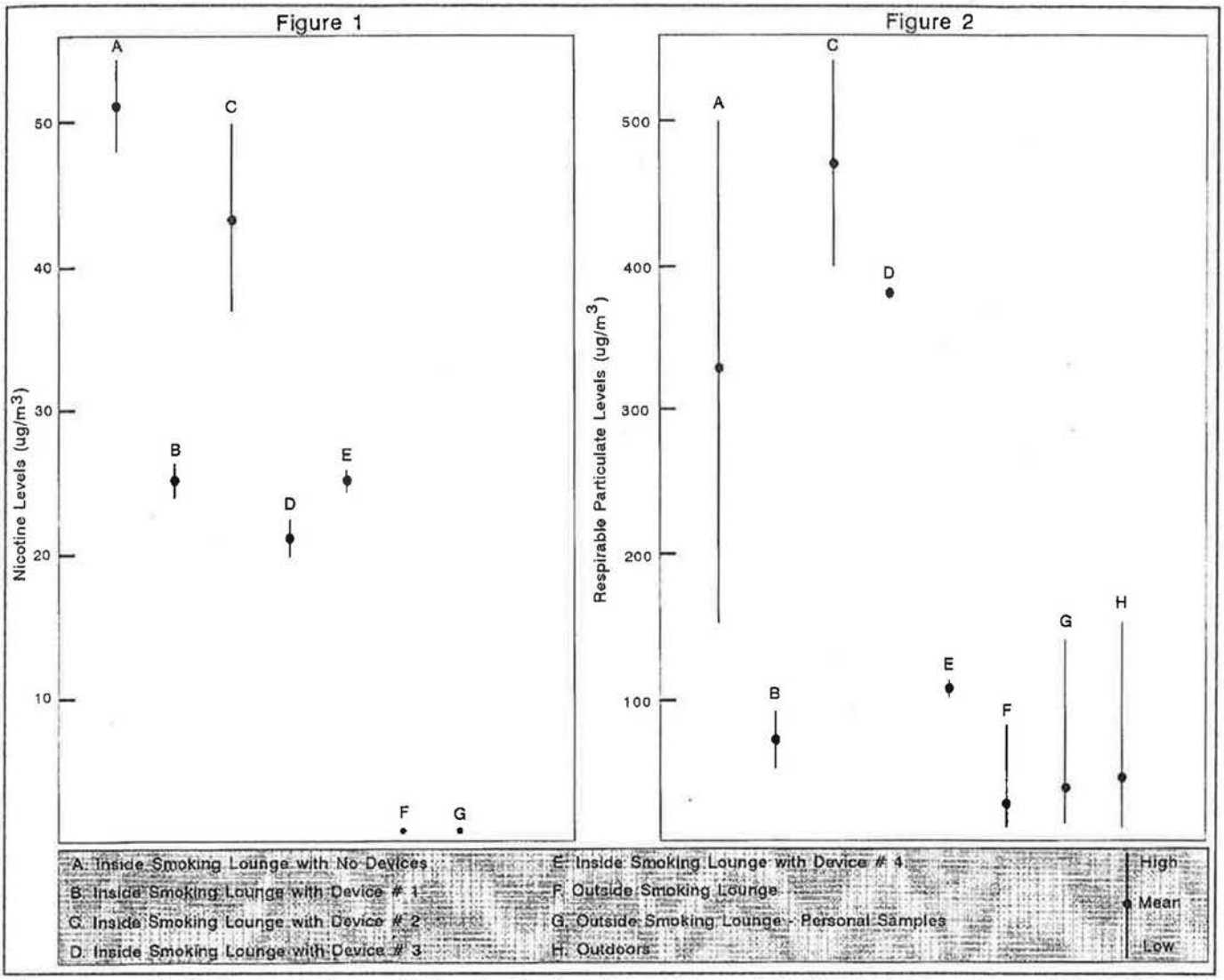

Figure 1 graphically illustrates the results for nicotine for all sampling periods. Figure 2 shows the result for RSP for all sampling periods.

pore. A cyclone assembly or an impactor was also used to separate respirable particles (<10 *u*m) from larger particles.

Carbon Monoxide: Continuous general area monitoring, with one-minute averaging, was performed inside the smoking lounge (Sample Area 1 - smoking area) and outside the smoking lounge (Sample Area 2 - non-smoking area). Two ten-minute samples, with one minute averaging, were collected outside the building during the morning and afternoon. Carbon monoxide was monitored using a direct reading air quality monitor.

Sample Analyses

All samples were analyzed by an American Industrial Hygiene Association (AIHA) accredited laboratory. Each RSP filter membrane was weighed prior and subsequent to sampling to determine the quantity of RSP collected over the sampling period.

In addition, each RSP sample was further analyzed using ultraviolet particulate matter (UVPM) and fluorescent particulate matter (FPM) techniques to determine the contribution of combustion products including ETS to RSP. All nicotine samples were analyzed in accordance with ASTM Method IP-2A.

Results

Table 1. summarizes the results for nicotine, RSP and carbon monoxide for all sampling periods.

Table 2. summarizes the results for the UVPM and FPM analyses. Results for nicotine and RSP for all sampling periods are summarized graphically in *Figure 1* and *Figure 2*, respectively. UVPM and FPM estimates of the contribution of combustion products such as ETS to RSP levels are illustrated in *Figure 3* and *Figure 4*, respectively.

Baseline Results

The baseline conditions established for this study consisted of a smoke-free office suite with normal dilution ventilation supplied by the building's general ventilation system. All baseline samples collected for nicotine in the smoking lounge and ambient non-smoking areas during the baseline test periods were below detectable limits. All samples for RSP were below detectable limits with the exception of one personal sample collected in the ambient non-smoking area which measured 50 $\mu g/m^3$.

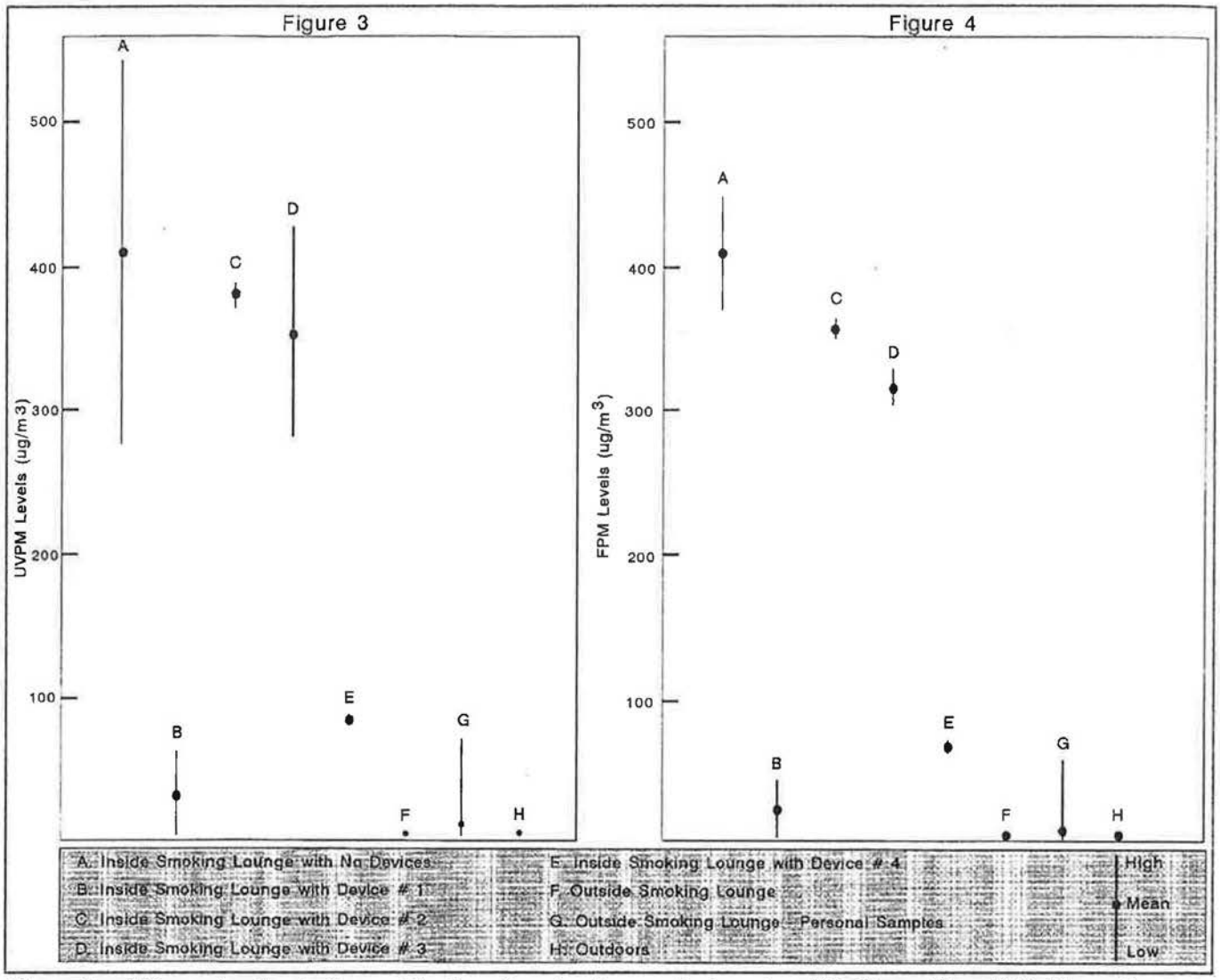

Figure 3 and Figure 4 estimate the contribution of combustion products such as ETS (Figure 3) and RSP (Figure 4).

Outdoor RSP Results

RSP levels outdoors were below detectable limits for three of the ten RSP samples collected and ranged between 10 and 70 $\mu g/m^3$ for six of the ten samples. One outdoor RSP sample level was 150 $\mu g/m^3$.

Smoking Lounge Results

In the smoking lounge, when dilution ventilation was used exclusively (no auxiliary air cleaning devices operating) and cigarettes were smoked, nicotine levels were 48 and 54 $\mu g/m^3$ and RSP levels were 155 and 500 $\mu g/m^3$. When auxiliary air cleaning devices and dilution ventilation were used concurrently in the smoking lounge, nicotine levels ranged between 20 and 50 $\mu g/m^3$ and RSP levels ranged between 50 and 540 $\mu g/m^3$. Average carbon monoxide levels inside the smoking lounge ranged between 5 and 6 ppm when dilution ventilation was used exclusively and between 3 and 5 ppm with air cleaning devices and dilution ventilation used concurrently.

Inside the smoking lounge, devices 1 and 4 demonstrated the greatest reduction in RSP from baseline levels and device number 3 demonstrated the greatest reduction in nicotine from baseline levels. Devices 1 and 4 also significantly reduced the levels of nicotine in the smoking lounge.

Non-smoking Area Results

In nonsmoking areas, when dilution ventilation was used exclusively in the smoking lounge while cigarettes were smoked, both nicotine area samples were below detectable limits and one of two area RSP samples was below detectable limits. The remaining area RSP sample measured 30 $\mu g/m^3$. When dilution ventilation was operating concurrently with air cleaning devices, all eight nonsmoking area nicotine samples collected were less than detectable limits. The seven area RSP samples collected ranged from 20 to 80 $\mu g/m^3$. Average carbon monoxide levels in nonsmoking areas ranged between 0-2 ppm.

Results for RSP levels in nonsmoking areas outside the smoking lounge did not vary significantly from RSP levels outdoors indicating that measurable amounts of RSP were not migrating from inside the smoking lounge into nonsmoking areas. Nicotine levels in nonsmoking areas outside the smoking lounge were all below detectable limits, indicating that measurable amounts of nicotine were not migrating from the smoking lounge into non-

smoking areas. Although much lower than in the smoking area, there was a measurable amount of CO migrating from the smoking area into the nonsmoking area.

Personal Sample Results

Personal samples were collected for nonsmoking employees working in nonsmoking areas. When dilution ventilation was used exclusively (no auxiliary air cleaning devices operating) and cigarettes were smoked, three out of four personal samples for nicotine were below detectable limits and the remaining sample was 0.66 $\mu g/m^3$. For the four RSP personal samples, under the same conditions, two samples measured 20 $\mu g/m^3$ and two were below detectable limits.

When dilution ventilation and auxiliary air cleaning devices were operated concurrently during smoking test periods, personal samples for nonsmoking employees in nonsmoking areas, indicated that nicotine levels were below detectable limits in 14 of the 16 samples collected and were 0.44 and 0.55 $\mu g/m^3$ for the remaining two samples. RSP personal sample levels were below detectable limits for two out of the 16 samples collected and ranged between 10 and 60 $\mu g/m^3$ for 13 of the 16 samples collected. The remaining RSP personal sample level was 140 $\mu g/m^3$.

RSP levels for personal samples were well below levels measured inside the smoking area and were not significantly different from RSP levels outside the building indicating RSP was not migrating from inside the smoking lounge into ambient areas. Nicotine levels for personal samples were below detectable limits for all but three samples collected. The remaining three personal samples measured 0.66, 0.55 and 0.44 $\mu g/m^3$ while the levels of nicotine for the same periods were 48, 26.4 and 49.9 $\mu g/m^3$, respectively, inside the smoking lounge. These results indicate that nicotine was not migrating appreciably from the smoking lounge into ambient, nonsmoking areas.

Conclusions

Results of this study indicate that auxiliary air cleaning devices operating concurrently with dilution ventilation can be effective in reducing the levels of nicotine and RSP in a designated smoking area. These results indicate that air cleaning devices equipped with HEPA filters are most effective in reducing RSP levels. Devices equipped with carbon media are most effective in reducing levels of nicotine.

Results of the study also indicate that physical separation when combined with dilution ventilation is effective in controlling the migration of ETS components from a smoking lounge to nonsmoking areas.

In addition to the filtration technology used in the device, there are a number of other factors that should be considered when controlling the levels of ETS in a smoking lounge, including:

- the amount of outside air supplied to the lounge;
- the flow rate of the device;
- the size of the smoking lounge;
- the number of cigarettes being smoked; and
- the pressure differences between the smoking area and the surrounding areas.

It should also be noted that there are other filtration technologies that can control ETS, including electrostatic precipitation, that were not evaluated in this study.

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