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NICOTINE, RSP, AND CO_2 LEVELS IN BARS AND NIGHTCLUBS

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Vapor phase nicotine and respirable suspended particle (RSP) concentrations were measured in bars and nightclubs as indicators of exposure to environmental tobacco smoke (ETS). The CO_2 concentrations were continuously monitored to provide a gross indication of ventilation adequacy, and occupant activities were observed. Results showed higher nicotine and RSP concentrations than have been reported for other indoor environments. Levels of ETS-related constituents varied widely between different nightclubs, taverns, and neighborhood pubs, depending on type of establishment, occupancy levels, amount of smoking, and ventilation adequacy. Mean nicotine concentrations were 58 $\mu g/m^3$, 46.6 $\mu g/m^3$, and 38.6 $\mu g/m^3$ for nightclubs, taverns and neighborhood pubs, respectively. Mean RSP concentrations were 151 $\mu g/m^3$, 93 $\mu g/m^3$, and 95 $\mu g/m^3$. The higher ETS-related concentrations were associated with elevated CO_2 levels, the highest occupancy levels, and cigarette consumption. In all establishments, CO_2 concentrations exceeded the 1 mL/L criterion for acceptable indoor air quality used in ASHRAE Standard 62-1989.

INTRODUCTION

Nonsmokers may be exposed to environmental tobacco smoke (ETS) at work, at home, in public areas, and in different modes of transportation. Levels of exposure to ETS constituents in some indoor environments have been measured, though there is little reliable data on personal exposures. In addition, there is only limited information on exposure levels in bars and nightclubs. Time budget studies have indicated that ETS exposure in bars and nightclubs should make only a minor contribution to total population exposure (Moschandreas 1981). Nevertheless, data collected in these environments are important because it is possible that higher ETS levels may be encountered in bars and nightclubs than in other indoor environments. For example, Arundel et al. (1987) estimated a nonsmokers' average exposure to particulate ETS to be approximately three to five times higher in bars than in other indoor environments.

The results of other studies that have monitored nicotine and respirable suspended particles (RSPs) as indicators of ETS in bars and nightclubs are shown in Table 1. Reported nicotine concentrations have ranged from 7.4 to 150 $\mu g/m^3$ and reported RSP levels have ranged from 30 to 801 $\mu g/m^3$. These studies confirm that ETS-related concentrations in bars and nightclubs are higher than have been reported in other indoor environments, including offices and restaurants (Sterling et al. 1988; Oldaker et al. 1990) and commercial aircraft (Oldaker and Conrad 1987; Malmfors 1989).

The studies of ETS-related substances summarized in Table 1 have not generally related nicotine and RSP concentrations to ventilation conditions in the establishments under investigation. In addition, previous

WORKPLACE	LOCATION	NICOTINE ($\mu g/m^3$) Mean	NICOTINE ($\mu g/m^3$) Range	RSP ($\mu g/m^3$) Mean	RSP ($\mu g/m^3$) Range	SMOKING CONDITION	SOURCE
2 Pubs	United Kingdom		4.7–13.0		83–155	Permitted	Kirk et al. 1988
1 Bar	France	71				Permitted	Arfi et al. 1989
1 Coctail Lounge	U.S.A.	10.3				Permitted	Hinds and First. 1975
3 Pubs	Japan	31.0				Permitted	Muramatsu et al. 1987
6 Cafes	France	37.8	25–52			Permitted	Badre et al. 1978
3 Taverns	U.S.A.	43.0–84.6	6.1–108.6			Permitted	Oldaker and Conrad. 1989
1 Nightclub	U.S.A.	94.5	83–106	787.5	774–801	Permitted	Eatough et al. 1989
2 Taverns	U.S.A.			310 Total Particulate	233–986 Total Particulate	Permitted	Cuddeback et al. 1976
3 Bars	U.S.A.	7.4	1.1–13.1	85	30–140.9	Permitted	Miesner et al. 1989
4 Bars	U.S.A.				93–589	Permitted	Repace and Lowrey. 1980
1 Pub	Austria		82–150			Permitted	Klus et al. 1987

Table 1. ETS concentrations in bars and nightclubs.

research has rarely considered factors such as occupancy levels and the amount of smoking. Therefore, an important objective of the present study was to investigate the relationship between measured concentrations of ETS-related substances, ventilation (using carbon dioxide concentrations as an indirect indicator of ventilation adequacy), and occupancy conditions.

EXPERIMENTAL METHODS

Surveys were conducted in six nightclubs, four taverns, and five neighborhood pubs during October and November 1991 in Vancouver, Canada. The study differentiated between nightclubs, taverns and neighborhood pubs because each type of establishment has unique characteristics. Nightclubs are characterized by high occupant densities, dancing, and live entertainment. Taverns and neighborhood pubs typically have lower occupancy levels. Neighborhood pubs differ from taverns primarily by type of decor and furnishings, and by type of food service. A neighborhood pub typically has more elaborate furnishings than a tavern and offers a more extensive menu, similar to that found in a restaurant.

All 15 establishments in which data were gathered are served by mechanical ventilation systems. At each location, vapor phase nicotine and RSP concentrations were measured during two (and in one case, three) consecutive sampling periods. During each sampling period, the number of occupants and cigarettes smoked within a predefined observation area were recorded. In addition, CO_2 concentrations were continuously monitored for 24 h, within which time the nicotine and RSP samples were collected.

Sample collection and analysis

Instrumentation for sampling nicotine and RSP were housed in a regular briefcase. The sampling apparatus was designed to be unobtrusive because of a previously noted effect of air sampling on occupant behavior (Sterling and Mueller 1988). Similar unobtrusive equipment has been used by many other researchers monitoring ETS in public indoor environments. Samples were collected at central locations within each establishment. The briefcase was placed on a table or chair adjacent to a technician in a way that avoided direct exhalation of ETS into the sampling ports.

Nicotine samples were collected by drawing air at 1 L/min through sorbent tubes containing XAD-4, a styrene divinylbenzene copolymer. Samples were collected for two consecutive 1-h periods, allowing a lower limit of analytical detection of 1.6 $\mu g/m^3$. Collected samples were analyzed using a gas chromatograph equipped with a nitrogen phosphorous detector. This method is an enhancement of an approach employed by the U.S. National Institute for Occupational Safety and Health (Ogden et al. 1986).

The RSP concentrations were determined using a direct reading instrument fitted with a 3.5-micron impactor which quantifies the particle mass passing through a sensing chamber by deflected side scattered light. The RSP levels were simultaneously measured alongside the nicotine sample for each 1-h period, and a time-weighted average RSP concentration was determined. Research has shown discrepancies between RSP concentrations determined using light scattering instruments and gravimetric analysis (Ingebrethsen et al. 1988; Miesner et al. 1989; Reynolds et al. 1990). To address this concern, the RSP monitor had previously been calibrated for ETS-related research through simultaneous comparison with gravimetric analysis under different levels of smoking (Sterling et al. 1990).

Continuous CO_2 concentrations were recorded using a nondispersive infrared analyzer combined with a data logger, which measures CO_2 concentrations to a maximum of 3 mL/L. The monitor was set up to gather data for approximately 24 h, within which time the nicotine and RSP samples were collected. The CO_2 monitor was situated as close as possible to the sampling location for nicotine and RSP, either on a wall or column. The monitor was set up during the morning prior to an establishment's opening. The nicotine and RSP samples were collected during the evening. The monitor was picked up the following morning and data were downloaded into a computerized data file. Time-weighted average CO_2 concentrations were calculated for the corresponding nicotine and RSP sampling periods, and peak CO_2 concentrations during the 24-h monitoring period were determined.

During each 1-h sampling period, the number of occupants and the number of cigarettes smoked in a predefined observation area surrounding the sampling location were recorded. Observations were made every 10 min and averaged for each of the 1-h periods.

RESULTS

Table 2 summarizes the results from the nightclubs, taverns, and neighborhood pubs. The table shows the location, the time-weighted mean standard deviation, and range of values for nicotine, RSP, and CO_2, and the mean number of occupants and number of cigarettes smoked standardized by floor area.

Table 2. Nicotine, RSP, and CO_2 levels and observations in nightclubs, taverns, and neighborhood pubs.

LOCATION		NICOTINE ($\mu g/m^3$)	RSP ($\mu g/m^3$)	CO_2 ($\mu L/L$)	OCC/AREA (#/100 m^2)	CIGS/AREA (#/100 m^2)
Nightclubs	mean	58.0	151	2285*	70	33
(n=13)	standard dev	30.4	47	880	37	15
	range	(21.8–119.5)	(92–246)	(915–>3000)	(28–158)	(16–61)
Taverns	mean	46.6	93	1164	37	27
(n=8)	standard dev	11.3	11	171	13	5
	range	(29.5–68.6)	(80–110)	(847–1289)	(15–68)	(17–33)
Neigh. Pubs	mean	38.6	95	1296	41	19
(n=10)	standard dev	18.1	49	498	25	7
	range	(6.3–63.9)	(25–180)	(740–2000)	(5–67)	(2–35)

n = number of samples;
* : underestimate of true mean, because calculation assumed CO_2 level of 3 mL/L (3 000 $\mu L/L$) for values > 3 mL/L (3 000 $\mu L/L$).

Nicotine and RSP concentrations were highest in the nightclubs. Nicotine concentrations ranged from 21.8 $\mu g/m^3$ to 119.5 $\mu g/m^3$, with a mean concentration of 58.0 $\mu g/m^3$. The RSP levels ranged between 92 $\mu g/m^3$ to 246 $\mu g/m^3$, with a mean of 151 $\mu g/m^3$. The higher nicotine and RSP concentrations in nightclubs coincided with the highest occupant densities (mean: 70 occupants/100 m^2) and greatest number of cigarettes smoked (mean: 33 cigarettes /100 m^2).

The CO_2 concentrations were substantially higher in nightclubs compared with the taverns and neighborhood pubs. In four of the six nightclubs, peak CO_2 concentrations exceeded the 3 mL/L maximum measurable level for the CO_2 monitor. In 5 of the 13 1-h sampling periods in nightclubs, time-weighted average CO_2 concentrations exceeded 3 mL/L. The mean CO_2 concentration of 2.28 mL/L given in Table 2 is an underestimate of the true mean, because an assumed value of 3 mL/L was used in the calculation for any point that exceeded the calibrated range. The actual CO_2 concentration for those sampling periods would have been higher.

Nicotine, RSP, and CO_2 concentrations were lower both in taverns and neighborhood pubs. Mean nicotine concentrations were 46.6 $\mu g/m^3$ in taverns and 38.6 $\mu g/m^3$ in neighborhood pubs. The RSP levels were similar in both types of establishments, with mean concentrations of 93 $\mu g/m^3$ in taverns and 95 $\mu g/m^3$ in neighborhood pubs. The lower nicotine and RSP concentrations coincided with lower occupancy levels and fewer cigarettes smoked.

The CO_2 concentrations were slightly higher in neighborhood pubs (mean: 1.30 mL/L) compared to taverns (mean: 1.16 mL/L), although these levels were substantially below those found in the nightclubs. The lower CO_2 concentrations in the taverns and neighborhood pubs reflected lower occupancy levels.

The CO_2 concentrations have been widely used as an indicator of ventilation adequacy in indoor air quality research. North American ventilation standards developed by the American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE) recommend outside-air ventilation rates to control CO_2 and other substances to acceptable levels. The ventilation rates described in ASHRAE Standard 62-1989 have been developed to control CO_2 concentrations to below 1 mL/L (ASHRAE 1989). A CO_2 concentration exceeding 1 mL/L therefore provides a gross indicator of poor ventilation (Collett and Sterling 1988; Rajhans 1983).

The impact of ventilation (as indicated by elevated CO_2 levels) upon nicotine and RSP concentrations is shown in Table 3. Combining data from the nightclubs, taverns, and neighborhood pubs, nicotine and RSP concentrations are shown in those establishments where mean CO_2 concentrations were (a) less than 1 mL/L; (b) between 1 and 2 mL/L; and (c) above 2 m L/L.

Table 3. Nicotine and RSP levels and observations by mean CO_2 concentration.

CO_2 CONCENTRATION		NICOTINE ($\mu g/m^3$)	RSP ($\mu g/m^3$)	OCC/AREA (#/100 m^2)	CIGS/AREA (#/100 m^2)
<1000 µL/L (n=8)	mean	25.6	73	26	17
	standard dev	11.5	29	12	6
	range	(6.3–42.5)	(25–111)	(5–44)	(2–26)
1000–2000 µL/L (n=14)	mean	52.9	116	48	27
	standard dev	14.0	35	15	8
	range	(29.5–77.0)	(82–188)	(22–69)	(16–36)
>2000 µL/L (n=9)	mean	63.0	161	82	37
	standard dev	30.4	49	38	17
	range	(32.2–119.5)	(92–246)	(33–158)	(16–61)

n = number of samples.

Nicotine and RSP concentrations increased with higher CO_2 levels, showing the effect of reduced outside air dilution. When CO_2 concentrations were less than 1 mL/L (the "acceptable" level according to ASHRAE Standard 62-1989), mean nicotine and RSP concentrations were 25.6 $\mu g/m^3$ and 73 $\mu g/m^3$, respectively. At CO_2 concentrations between 1 and 2 mL/L, mean nicotine concentrations more than doubled to 52.9 $\mu g/m^3$. RSP concentrations also increased to 116 $\mu g/m^3$. The highest nicotine and RSP concentrations were measured in establishments in which CO_2 levels exceeded 2 mL/L. Mean nicotine concentrations were 63.0 $\mu g/m^3$, and mean RSP levels were 161 $\mu g/m^3$.

The impact of occupancy upon CO_2 concentrations also is shown in Table 3. Elevated CO_2 concentrations were associated with higher occupancy levels. In locations where CO_2 concentrations were below 1 mL/L, occupancy levels ranged between 5 and 44 occupants per 100 m^2 (mean: 26/100 m^2). When CO_2 concentrations were between 1 and 2 mL/L, mean occupancy was 48 persons/100 m^2, and when CO_2 levels exceeded 2 mL/L, the mean occupancy was 82 persons/100 m^2.

DISCUSSION

This study shows higher nicotine and RSP concentrations in bars and nightclubs than have been reported in other indoor environments such as offices and restaurants (Sterling et al. 1988; Oldaker et al. 1990) and commercial aircraft (Oldaker and Conrad 1987; Malmfors 1989). The elevated nicotine and RSP concentrations are, in part, a function of higher cigarette consumption and occupant densities.

Inadequate ventilation substantially affected the level of ETS-related constituents. North American ventilation standards recommend outside air ventilation rates to control CO_2 concentrations below 1 mL/L to provide "acceptable indoor air quality" (ASHRAE 1989). ASHRAE Standard 62-1989 recommends a minimum outside air ventilation rate of 15 L/S·person for bars and cocktail lounges, and 13 L/S·person for discos and ballrooms. Based on the 1 mL/L CO_2 criterion, ventilation appears to be poor in most of the surveyed locations. Mean CO_2 concentrations exceeded 1 mL/L in 11 of 15 establishments, and peak CO_2 concentrations exceeded 1 mL/L in all except one location. These results show that outside-air ventilation rates supplied to the bars and nightclubs generally did not meet those recommended in ASHRAE Standard 62-1989. The supplied volumes of outside air were not able to adequately control occupant generated CO_2, particularly in locations with higher occupant densities. Low volumes of outside air supply also affect the ability of a ventilation system to dilute and remove indoor generated substances, including ETS.

The nicotine and RSP concentrations found in the present study are comparable to those reported by other studies. Nicotine concentrations in the studies cited in Table 1 range from 4.7 to 150 $\mu g/m^3$, com-

pared with 6.3 to 119.5 $\mu g/m^3$ in this study. The RSP concentrations in the present study (25 to 246 $\mu g/m^3$) are similar to those reported by Miesner et al. (1989) and Kirk et al. (1988), but are slightly lower than those measured elsewhere.

Further comparison with the findings of other researchers is not possible because of the general absence of reported information about ventilation conditions, occupancy, and amount of smoking. Miesner et al. (1989) reported that CO_2 concentrations exceeded 1 mL/L in bars, but specific values were not given. Similarly, Oldaker and Conrad (1989) described a tavern as "poorly ventilated", but did not report CO_2 concentrations or ventilation rates. They did, however, associate higher nicotine concentrations with increased occupancy levels and cigarette consumption.

Overall, the results of this study underline the critical importance of adequate ventilation for the dilution of indoor-generated substances, particularly in environments such as bars and nightclubs, characterized by short-term high occupancy levels. The outside ventilation rates recommended in current North American Ventilation Standards (ASHRAE Standard 62-1989) were clearly not being supplied to most of the bars and nightclubs participating in this study.

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