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# Indoor Air Quality in Restaurants With and Without Designated Smoking Rooms

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*Indoor air quality in restaurants was studied in two cities in northwest Ohio after clean indoor air ordinances had been enacted. Carbon dioxide and ultrafine particles were measured in two restaurants in Toledo and two restaurants in Bowling Green. One restaurant in each city was smoke free, and one restaurant in each city contained a dedicated smoking room. A smoke free office space was also assessed as a reference site. Measurements were collected with datalogging instrumentation simultaneously in both the designated smoking room, if present, and in the nonsmoking section. For smoke free establishments, datalogging instrumentation was also used. Carbon dioxide levels were elevated in all four restaurants, with only 32% of the measurements meeting the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) criterion level of 1000 ppm. Ultrafine particles currently do not have any formal standard or guideline. Statistically significant differences were evident between all four restaurants and the reference site. The largest differences were found between the two designated smoking rooms and the reference site ( $p < 0.001$ ), with the mean levels in the smoking rooms up to 43 times higher than in the reference site. The results from this study indicate inadequate fresh air supply in all four restaurants, particularly in the designated smoking rooms, and the possibility that the designated smoking rooms were not containing the environment tobacco smoke, based on the ultrafine particle concentrations measured in the nonsmoking areas of the smoking restaurants.*

**Keywords** environmental tobacco smoke, indoor air quality, restaurants, ultrafine particles

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## INTRODUCTION

The American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) defines acceptable IAQ as “air in which there are no known contaminants at harmful concentrations as determined by cognizant authorities and with which a substantial majority (80% or more) of the people exposed do not express dissatisfaction.”<sup>(1, p.399)</sup> In the hospitality industry (which includes restaurants) as in other nonindustrial environments, the concentrations of known contaminants are expected not to be at harmful levels because chemicals are not routinely used, and sources of biological and physical agents are generally not present. Therefore, only the second part of the ASHRAE definition can be used by restaurants to determine if air quality is acceptable.<sup>(1)</sup>

Indoor contaminants that may create IAQ problems come from a variety of sources, which can include inadequate ventilation, temperature and humidity extremes, water infusion, combustion products, soil gases, and environmental tobacco smoke (ETS). Contaminants that are often considered problems when assessing IAQ include volatile organic compounds (VOCs) such as formaldehyde, biological agents, radon, pesticides, particles, and fibers. The health effects from these contaminants are varied and can range from discomfort and irritation to cancer.<sup>(1)</sup> ETS could be considered the most important of these contaminants in terms of both health effects and engineering controls.<sup>(2)</sup>

Carbon dioxide (CO<sub>2</sub>) is frequently measured during IAQ investigations to assess building ventilation. An increase in CO<sub>2</sub> concentration is generally considered an indicator of inadequate fresh air supply. Humans are the main source of CO<sub>2</sub> through exhaled air, but unvented combustion processes and ETS may also contribute.<sup>(1)</sup>

Particles of various sizes may also be measured during IAQ investigations. Particle sources may include smoking, other

combustion processes, material deterioration, construction and renovation projects, and housekeeping activities such as vacuuming.<sup>(1)</sup> Particles of different sizes such as ultrafine particles (UFPs) and respirable suspended particulate matter (RSP) can be monitored using various sampling techniques. In indoor environments, UFPs, which have been defined as particles <0.1  $\mu\text{m}$  in diameter, have been highly correlated with IAQ complaint areas.<sup>(3)</sup> UFPs are predominately man-made<sup>(3)</sup> and a principal source is smoking.<sup>(1)</sup> There is no occupational exposure limit for UFPs at this time. RSP, which contain particles <10  $\mu\text{m}$  in diameter, have established occupational exposure limits for personal protection.<sup>(4)</sup>

Controlling exposure to ETS, and therefore UFPs, is problematic.<sup>(5)</sup> Control of UFPs indoors is most effective when smoking is either banned or restricted to separately ventilated smoking rooms.<sup>(1)</sup> Although ventilation systems can reduce ETS concentrations, these systems may also contribute to the distribution of ETS components throughout a facility.<sup>(6)</sup> Liu et al.<sup>(7)</sup> recognized the most effective control methods in smoking areas as being physical separation, exhaust to the outside, and no air recirculation. The least effective control methods in smoking areas are open areas with no physical separation, no outside exhaust, and combined air recirculation. The option of banning smoking from facilities brings the benefits of less need for dilution air, less cleaning, less maintenance on air handling equipment, and lower operating costs for the HVAC system.<sup>(8)</sup> Repace and Lowrey<sup>(9)</sup> demonstrated both theoretically and experimentally that particulate matter generated from smoking contributes to air pollution by overwhelming the effects of ventilation systems and concluded that increasing ventilation rates would not correct the problem. Carrington et al.<sup>(10)</sup> supported this finding by reporting that the use of ventilation systems did not have a statistically significant effect on ETS-related contaminants either in smoking areas or in nonsmoking areas.

Differences in ETS constituents, but not in IAQ parameters, between smoking and nonsmoking areas have been reported. Moschandreas and Vuilleumier<sup>(11)</sup> reported a statistically significant difference in measured concentrations of ETS constituents between indoor smoking and indoor nonsmoking areas. Akbar-Khanzadeh et al.<sup>(12)</sup> reported no significant difference in CO<sub>2</sub> concentrations between smoking and nonsmoking areas of restaurants. However, this study reported that the CO<sub>2</sub> concentrations were significantly correlated with the number of dining patrons ( $p < 0.02$ ) and that in four of the eight restaurants studied, there was a gradual accumulation of CO<sub>2</sub> over time.

Because ETS is one of the most frequent causes of IAQ complaints<sup>(1)</sup> as well as the second most prevalent cause of indoor air contamination,<sup>(13)</sup> many municipalities and states have enacted clean indoor air ordinances. According to the American Nonsmokers' Rights Foundation<sup>(14)</sup> as of January 3, 2006, 6011 municipalities were covered by either a local or state 100% smoke free law. In nine states, all workplaces are 100% smoke free, contributing to the 25.3% of the U.S. population covered by 100% smoke free workplace laws.<sup>(14)</sup> Additionally, 39.6% of the U.S. population is covered by some

type of 100% smoke free law.<sup>(14)</sup> Two cities in Northwest Ohio (Toledo and Bowling Green) are among the municipalities that have enacted clean indoor air ordinances, although neither ordinance is 100% smoke free. The clean indoor air ordinances in both cities at the time of the study required that smoking be contained in entirely enclosed rooms with separate ventilation systems. In January 2004, the Ohio Tobacco Use Prevention and Control Foundation (TUPCF) provided 6 months' of funding for an exploratory study to assess the level of control of ETS components and indoor air quality parameters in restaurants complying with the new ordinances. The study was initiated a short time after the Toledo ordinance had originally been enacted and during a period when efforts were under way to weaken the ordinance. The exposure assessment portion of this study was designed to measure ETS constituents as well as IAQ parameters in a small sample of restaurants in Toledo and Bowling Green. This report presents the finding related to the specific IAQ parameters of CO<sub>2</sub> and UFPs. The results for the ETS constituents have been published elsewhere.<sup>(15)</sup>

## METHODS

### Restaurants

Two restaurants, containing both a restaurant and a bar area, were recruited in each of the two cities, Toledo and Bowling Green. One restaurant in each city was entirely smoke free. The second restaurant in each city needed to contain a nonsmoking area along with a designated smoking room. As required by each city's ordinance, the designated smoking room was required to be entirely enclosed with a separate ventilation system. The two smoke free restaurants were Restaurant A and Restaurant C. The two restaurants with designated smoking rooms were Restaurant B and Restaurant D. In addition, one smoke free office space located in Toledo was recruited as a reference site. The small number of restaurants sampled was due to the exploratory nature of the study and to the study requirement that all sampling be completed on a Friday or Saturday night (times expected to provide the highest weekly patron loads), the time allotted for the actual sampling (2 months), and the recharging time (a minimum of 12 hours) needed for instrumentation necessary for other parts of the study.

To recruit participants, lists of restaurants were compiled separately for Toledo and Bowling Green. Each list was further categorized into either smoke free establishments or establishments with designated smoking rooms. The restaurants on each list were then ranked according to the size (square footage) of the restaurant. Starting with the largest restaurants, investigators visited each restaurant to ensure that it had both a restaurant and a bar, to describe the study, and to request participation. Recruiting was terminated once four restaurants agreed to participate. For a restaurant to be included in the study, the restaurant owner/manager agreed to the sampling event occurring during an entire Friday or Saturday evening shift, five restaurant staff being willing to wear sampling pumps for the ETS quantification portion of the study during their shift, and collecting area samples throughout the restaurant.

## Data Collection

A unique approach was used to collect data. Datalogging instruments were used for the entire shift at each of the five establishments. Monitoring lasted 6 hours at Restaurant C and Restaurant D, 7 hours at Restaurant A and Restaurant B, and 8 hours at the reference site. For the two sites with designated smoking rooms, Restaurant B and Restaurant D, two identical sets of datalogging instruments were used simultaneously. Each datalogging instrument was placed in a suitable location as close as possible to the middle of the sampled space. A suitable location was deemed to be out of the way of the restaurant staff and patrons but in an area where one of the investigators could access the meter periodically to confirm equipment operation. Suitable locations were on the top of half walls with large ledges, on shelves at drink stations, and in front of a fireplace.

### Carbon Dioxide

Carbon dioxide (CO<sub>2</sub>) concentrations were measured with two Q-Trak Model 8554s (TSI, Inc., Shoreview, Minn.). The Q-Trak measured temperature in degrees Fahrenheit (°F), relative humidity in percent (%), and CO<sub>2</sub> concentration in parts per million (ppm). The Q-Traks were pre- and postcalibrated each sampling day in accordance with manufacturer's instructions.

The monitoring strategy was designed to measure the CO<sub>2</sub> concentration during an entire evening shift on one of the busiest nights of the week. To accomplish this, the Q-Trak was placed in a suitable location and set in the datalogging mode to record CO<sub>2</sub> concentrations every second. Additionally, in the two establishments with designated smoking rooms (Restaurant B and Restaurant D), the second Q-Trak was placed in a suitable location and set in the datalogging mode to record CO<sub>2</sub> concentrations every second.

### Ultrafine Particles

Ultrafine particle (UFP) concentrations were measured with two P-Trak Model 8525s (TSI, Inc.). The P-Traks measured UFPs as a particle number concentration. The P-Traks were zeroed in accordance with manufacturer's instructions before and after each sampling event. Field calibration of P-Traks is not required according to the manufacturer. Each P-Trak was paired with a Q-Trak, and the same sampling strategy was used for both CO<sub>2</sub> and UFP concentrations.

### Patron Counts

The number of patrons at each establishment was determined every 20 min for the entire evening shift, beginning at the top of the hour. For the two establishments with designated smoking rooms, patron counts were recorded separately for the designated smoking room and for the nonsmoking areas.

## Data Analysis

Descriptive statistics were calculated for all five sites. The mean and standard deviation for the CO<sub>2</sub> and UFP concentrations were calculated separately for each instrument

within each site. Therefore, for the two sites with designated smoking rooms (Restaurant B and Restaurant D), the mean and standard deviation of the CO<sub>2</sub> and UFP concentrations were calculated separately for the designated smoking room and for the nonsmoking area. The minimum recorded concentration and maximum recorded concentration were also determined for each instrument within each site. Finally, the percentage of measured CO<sub>2</sub> concentrations that exceeded the ASHRAE criterion for acceptable indoor air quality of 1000 ppm was determined (700 ppm above the background level of 300 ppm).<sup>(16)</sup> Concentrations were recorded every second resulting in approximately 21,600 measurements for Restaurants C and D, approximately 25,200 measurements for Restaurants A and B, and approximately 28,800 measurements for the reference site.

Mann-Whitney nonparametric tests were then performed to determine whether the CO<sub>2</sub> and UFP concentrations differed between the designated smoking rooms and the combined nonsmoking area in Restaurants B and D. Additionally, Mann-Whitney nonparametric tests were performed to compare the four restaurants with the reference site. For the two establishments with a designated smoking room, the Mann-Whitney tests were performed separately for the designated smoking room and for the combined nonsmoking area. Nonparametric methods were used to avoid assumptions about the distributions of the measured concentrations.

Correlations between CO<sub>2</sub> and the number of patrons were determined along with correlations between CO<sub>2</sub> concentrations and elapsed monitoring time. These correlations were performed separately for each of the four restaurants. Ten-second average concentrations were calculated at the top of each hour, 20 min after the hour, and 40 min after the hour for each instrument. The 10-second average was chosen because the sample mode, as opposed to the datalogging mode, of both the Q-Trak and the P-Trak collects 10-second average concentrations. The times these averages were calculated coincided with the times when patron counts were collected.

## RESULTS

### Descriptive Statistics

The results from CO<sub>2</sub> sampling are summarized in Table I. The number of CO<sub>2</sub> measurements ranged from 19,307 at Restaurant C (duration 5:21:47) to 27,608 at the reference site (duration 7:40:08). The average CO<sub>2</sub> concentration ranged from 600 ppm at the reference site to 3800 ppm in the designated smoking room at Restaurant B. The minimum CO<sub>2</sub> concentration measured ranged from 250 ppm in Restaurant A to 1700 ppm in the designated smoking room of Restaurant B. The maximum CO<sub>2</sub> concentration measured ranged from 950 ppm at the reference site to 4600 ppm in the designated smoking room at Restaurant B.

All CO<sub>2</sub> measurements were compared with the 1000 ppm criterion limit for acceptable indoor air quality.<sup>(16)</sup> As shown in Table I, the percentage of measurements meeting this criterion ranged from 0 in the designated smoking room at Restaurant B

**TABLE I. Results from CO<sub>2</sub> Sampling**

Site <sup>A</sup>	Mean (ppm)	Minimum (ppm)	Maximum (ppm)	Duration (hr:min:sec)	% < 1000 ppm
Restaurant A	1300	250	2400	6:47:41	44.0
Restaurant B nonsmoking	2550	900	3900	5:48:10	0.8
Restaurant B smoking	3800	1700	4600	6:20:50	0
Restaurant C	1300	650	1850	5:21:47	25.6
Restaurant D nonsmoking	1000	700	1300	6:14:25	53.4
Restaurant D smoking	950	600	1400	6:15:27	63.9
Reference	600	300	950	7:40:08	100.0

Note: Q-Trak accuracy was + (3% + 50 ppm).

<sup>A</sup>Restaurants A and C were smoke free; Restaurants B and D contained designated smoking rooms.

to 100% at the reference site. Summarizing the five sites together, 41.1% of the measurements met the criterion limit.

The results from UFP sampling are summarized in Table II. The number of measurements ranged from 19,314 (duration 5:21:54) in the nonsmoking area of Restaurant B to 27,556 (duration 7:39:16) at the reference site. The average UFP concentration ranged from  $2.49 \times 10^3$  pt/cm<sup>3</sup> at the reference site to  $1.09 \times 10^5$  pt/cm<sup>3</sup> in the designated smoking room at Restaurant B. The maximum concentrations did not follow the same pattern and ranged from  $4.36 \times 10^4$  pt/cm<sup>3</sup> at the reference site to  $3.72 \times 10^5$  pt/cm<sup>3</sup> in the designated smoking room at Restaurant D. The minimum concentrations ranged from 250 pt/cm<sup>3</sup> at the reference site to  $5.89 \times 10^4$  pt/cm<sup>3</sup> in the designated smoking room of Restaurant D.

UFPs currently have no recommended guidelines. However, Figure 1 displays obvious differences by type of site (e.g., reference site, nonsmoking restaurant, nonsmoking area in smoking restaurant, and designated smoking room in smoking restaurant). Most notably is the difference between the reference site and the four restaurants. The mean UFP concentration in the smoke free restaurants was 6 times that of the mean UFP concentration in the reference site. The mean UFP in the nonsmoking area of the smoking restaurants was 6 times that of the mean UFP concentration in the smoke free restaurants and 33 times that of the mean UFP concentration in the reference site. The mean UFP concentration in the designated smoking

rooms of the smoking restaurants was 1.3 times that of the mean UFP concentration in the nonsmoking area of the smoking restaurants, 7 times that of the mean UFP concentration in the smoke free restaurants, and 43 times that of the mean UFP concentration in the reference site.

### Nonparametric Analysis

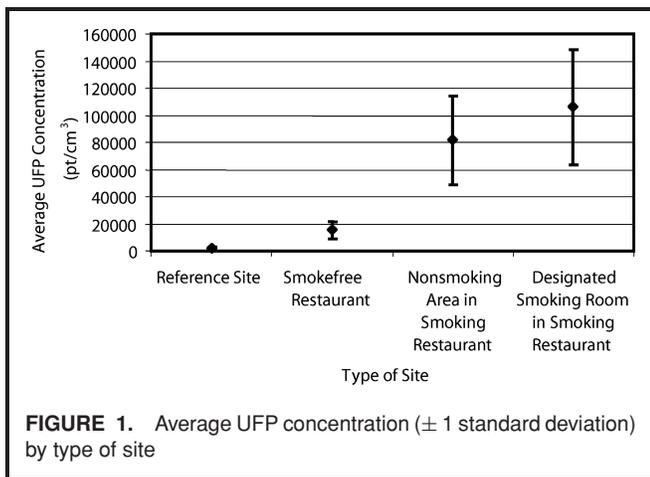
For the two restaurants with designated smoking rooms (Restaurant B and Restaurant D), Mann-Whitney tests were performed to determine whether the measured CO<sub>2</sub> and UFP concentrations were significantly different between the designated smoking room and the nonsmoking area. At Restaurant B, the CO<sub>2</sub> concentration was significantly different ( $p = 0.035$ ) with the nonsmoking area consistently recording a lower CO<sub>2</sub> concentration than in the designated smoking room (Figure 2). However, at Restaurant D, there was no statistical difference in recorded CO<sub>2</sub> concentrations ( $p = 0.937$ ). At both sites, the measured UFP concentrations were approaching statistical significance. The differences at Restaurant B ( $p = 0.073$ ) are shown in Figure 3, and the differences at Restaurant D ( $p = 0.065$ ) are shown in Figure 4.

The four restaurants were each compared individually with the reference site. All comparisons were highly statistically significant ( $p \leq 0.001$ ) indicating that CO<sub>2</sub> and UFP concentrations measured at the reference site were different from the concentrations measured in the four restaurants.

**TABLE II. Results from Ultrafine Particle Concentration Sampling**

Site <sup>A</sup>	Mean (pt/cm <sup>3</sup> )	Minimum (pt/cm <sup>3</sup> )	Maximum (pt/cm <sup>3</sup> )	Duration (hr:min:sec)	Data Points
Restaurant A	$1.32 \times 10^4$	$4.28 \times 10^3$	$1.75 \times 10^5$	6:43:14	24,194
Restaurant B nonsmoking	$8.03 \times 10^4$	$2.91 \times 10^4$	$1.67 \times 10^5$	5:47:41	20,861
Restaurant B smoking	$1.09 \times 10^5$	$1.28 \times 10^4$	$1.84 \times 10^5$	6:20:52	22,852
Restaurant C	$1.73 \times 10^4$	$6.13 \times 10^3$	$4.91 \times 10^4$	5:21:54	19,314
Restaurant D nonsmoking	$8.29 \times 10^4$	$4.23 \times 10^4$	$2.01 \times 10^5$	5:23:30	19,410
Restaurant D smoking	$1.03 \times 10^5$	$5.89 \times 10^4$	$3.72 \times 10^5$	6:08:20	22,100
Reference	$2.49 \times 10^3$	250	$4.36 \times 10^4$	7:39:16	27,556

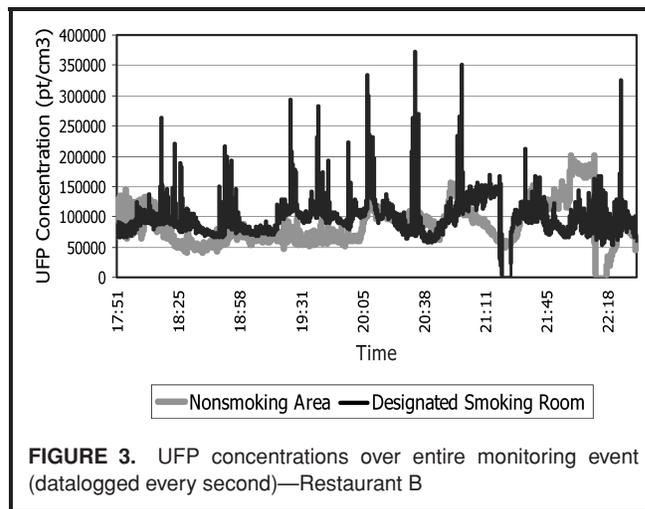
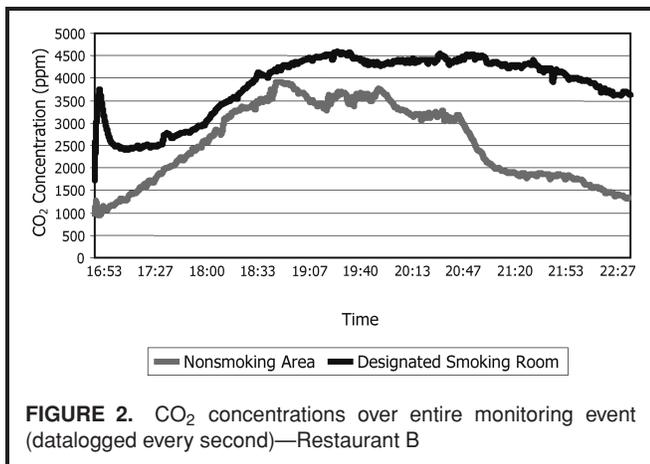
<sup>A</sup>Restaurants A and C were smoke free; Restaurants B and D contained designated smoking rooms.



### Correlations

Correlations between CO<sub>2</sub> concentrations and patron count were tested for the four restaurants. Statistically significant correlations were found only at Restaurant A ( $p < 0.0001$ ) and in the nonsmoking area of Restaurant B ( $p < 0.0001$ ). However, when the correlation between CO<sub>2</sub> concentration and patron count was controlled for elapsed time of monitoring, statistically significant correlations were found at Restaurant A ( $p < 0.0001$ ), the nonsmoking area of Restaurant B ( $p < 0.0001$ ), the designated smoking room of Restaurant B ( $p = 0.0030$ ), and at Restaurant C ( $p = 0.0005$ ). Only the CO<sub>2</sub> concentrations measured at Restaurant D were not significantly related to patron count.

Similarly, correlations between CO<sub>2</sub> concentrations and elapsed monitoring time were tested for the four restaurants. Statistically significant correlations were found at the designated smoking room of Restaurant B ( $p = 0.0413$ ), at Restaurant C ( $p = 0.0166$ ), and the designated smoking room of Restaurant D ( $p = 0.0037$ ). However, when the correlation between CO<sub>2</sub> concentration and elapsed monitoring time was controlled for patron count, statistically significant correlations were found at Restaurant A ( $p = 0.0326$ ), the nonsmoking area at Restaurant B ( $p = 0.0218$ ), the designated smoking room of

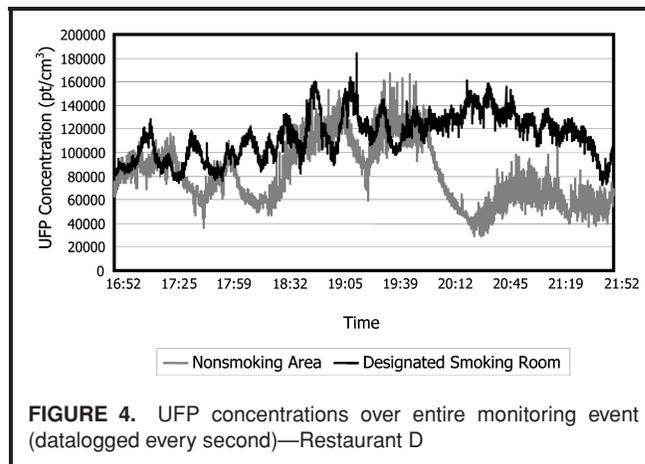


Restaurant B ( $p = 0.0011$ ), at Restaurant C ( $p = 0.0006$ ), and in the designated smoking room of Restaurant D ( $p = 0.0044$ ).

### DISCUSSION

The results of this study indicate that designated smoking rooms in smoking restaurants may have poorer air quality than either the nonsmoking area in smoking restaurants or in smoke free restaurants. The mean CO<sub>2</sub> concentration was significantly higher in the designated smoking room at Restaurant B than in the nonsmoking area ( $p = 0.035$ ), although at Restaurant D there was no statistical difference in the CO<sub>2</sub> concentrations between the designated smoking room and the nonsmoking area. The results from Restaurant B are consistent with those reported by Moschandreas and Vuilleumier.<sup>(11)</sup>

Further results indicating the inadequacy of the ventilation in the four restaurants comes from the correlations between CO<sub>2</sub> concentrations and patron count and between CO<sub>2</sub> concentrations and elapsed monitoring time. The CO<sub>2</sub> concentration was significantly correlated with patron count at Restaurants A, B, and C, even while controlling for elapsed



monitoring time. In other words, as the number of people increased in these three sites, so did the CO<sub>2</sub> concentrations. Additionally, at the same three sites, the CO<sub>2</sub> concentration was significantly correlated with the elapsed monitoring time, even when controlling for the patron count. Therefore, the ventilation systems in these three establishments were not adequate to limit CO<sub>2</sub> concentrations with an increasing number of people present or even with an increasing amount of time elapsed from the beginning of the work shift.

These results are further supported by the proportion of hourly readings meeting the ASHRAE criterion for acceptable indoor air quality. At Restaurant D, the only site where CO<sub>2</sub> concentrations were not correlated with patron count or elapsed monitoring time, 53.4% of the CO<sub>2</sub> concentrations measured in the nonsmoking area met the criterion, and 63.9% of the CO<sub>2</sub> concentrations measured in the designated smoking room met the criterion. At Restaurants A, B, and C combined, none of the CO<sub>2</sub> concentrations measured in the designated smoking room met the criterion, and only 23.5% of the CO<sub>2</sub> concentrations measured in the nonsmoking area met the criterion.

In terms of the UFP concentrations, obvious differences were noted between the four restaurants and the reference site. The lowest UFP concentrations were measured at the reference site and the highest UFP concentrations were measured in the designated smoking rooms of the smoking sites, possibly indicating that the ventilation systems in the designated smoking rooms in the smoking restaurants were not containing the ETS. Other studies have measured particulate concentrations in the hospitality industry, although none have reported UFP concentrations. Moschandreas and Vuilleumier<sup>(11)</sup> reported statistically significant differences in respirable suspended particles (RSP) measured in the smoking section and nonsmoking sections of two restaurants, a billiard hall, and a casino. Carrington et al.<sup>(10)</sup> also measured RSP concentrations and reported significantly higher ( $p < 0.05$ ) concentrations in the smoking areas compared with the nonsmoking areas of 60 pubs in the United Kingdom. Similarly, Lambert et al.<sup>(17)</sup> reported higher RSP concentrations in smoking sections compared with nonsmoking sections in six of the seven restaurants they tested. Finally, Cains et al.<sup>(18)</sup> reported lower PM<sub>10</sub> concentrations in the majority of clubs studied. Therefore, the UFP results reported in this study are consistent with other particulate measures reported in other studies.

This study had many limitations. Time constraints established by the funding agency limited the study to four restaurants and resulted in the exploratory nature of the study. Additionally, previous measurements of IAQ parameters were not collected prior to enacting the clean indoor air ordinances and, therefore, improvements in air quality could not be determined. However, these limitations should not detract from the unique features of this study, namely, the use of datalogging instruments to simultaneously measure IAQ parameters in both designated smoking rooms as well as in the nonsmoking area in restaurants that allowed smoking.

## CONCLUSIONS

The results of this study indicate that differences exist between smoke free restaurants and restaurants with designated smoking rooms in terms of air quality. UFP concentrations were higher in the restaurants with designated smoking rooms than in either the smoke free restaurants or the reference site. The higher UFP concentrations in the combined nonsmoking area in the restaurants with designated smoking rooms may indicate that the designated smoking rooms did not contain the ETS.

In terms of the effect of clean indoor air ordinances on air quality, differences were evident between smoke free restaurants and restaurants with designated smoking rooms. Therefore, by banning smoking in most restaurants, the clean indoor air ordinances contributed to cleaner air in the smoke free restaurants by removing ETS. Consequently, the air quality in restaurants with designated smoking rooms was not as good as in the smoke free restaurants, based on CO<sub>2</sub> and UFP concentrations.

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