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An evaluation of the indoor air quality in bars before and after a smoking ban in Austin, Texas

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This study assessed differences in the indoor air quality and occupancy levels in seventeen bars due to a city-wide smoking ban that took effect on September 1, 2005 in Austin, Texas, USA. We measured the following in each venue before and after the smoking ban: mean number of occupants, mean number of lit cigarettes, temperature, relative humidity, room volume, and $PM_{2.5}$, CO, and CO_2 concentrations. Additionally, VOC measurements were conducted at three of the venues. There was not a statistically significant change in occupancy, but the best estimate $PM_{2.5}$ concentrations in the venues decreased 71–99%, a significant reduction in all venues, relative to the pre-ban levels; CO concentrations decreased significantly in all but one venue; and concentrations of VOCs known to be emitted from cigarettes decreased to below the detection limit for all but two common compounds. These results suggest that the smoking ban has effectively improved indoor air quality in Austin bars without an associated decrease in occupancy.
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Introduction

As noted by Repace (2004), environmental tobacco smoke (ETS) has been deemed a health hazard by the National Cancer Institute (1999), the U.S. Environmental Protection Agency (1992), the National Institute for Occupational Safety and Health (1991), the Surgeon General (1986), and the National Research Council (1986). Although smoking has been banned in all federal buildings, states and municipalities are left with the responsibility of controlling ETS in indoor public spaces. On September 1, 2005, an ordinance took effect in Austin, Texas, USA that banned smoking in public places, city buildings, enclosed areas in workplaces, and within 15 ft from an entrance or operable window of an enclosed area in which smoking is prohibited (Austin HHSD, 2006). According to the ordinance, the owner or operator of a public place commits an offense if he or she fails to take necessary steps to prevent or stop another person from smoking. The enactment of this smoking ban ordinance was the culmination of a 2-year battle between antismoking advocates and many local business owners. Smoking bans such as this one are often controversial because owners of hospitality venues such as bars and restaurants claim to suffer economic losses due to a decline in patronage. Thus, if other cities are going to institute similar smoking bans, the changes in indoor air quality in hospitality venues due to smoking prohibition as well as the occupancy effects must be well understood.

Researchers investigating the effects of smoking in hospitality venues have determined that hospitality workers are exposed to relatively high concentrations of the indicators of ETS. One study quantitatively determined the extent of exposure to ETS for hospitality workers by analyzing cotinine, a metabolite of nicotine, in saliva samples taken at the beginning and end of the shift and found that workers in smoking establishments had the highest cotinine levels of all sampled employees, at concentrations that have been associated with substantial risks for heart and lung disease (Bates et al., 2002). Moreover, restaurant and bar wait-staff and bartenders are exposed to concentrations of indicators of ETS that are at least as high as those for people in other smoking-permitted workplaces (Jenkins and Counts, 1999). Bartenders and bar wait-staff are exposed to the highest concentrations of indictors of ETS among hospitality workers (Jenkins and Counts, 1999; Johnsson et al., 2003), and bartenders that work in a single room bar are exposed to approximately 10 times more of the indicators of ETS than those that work in larger, multiroom bars (Maskarinec et al., 2000). In an additional study, employees working in the gaming areas in casinos were determined to be exposed to indicators of ETS at levels that were greater than those observed in a representative sample of the US population (Trout et al., 1998). Also, researchers have noted that flight

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attendants working in the smoking section of an aircraft may have significant exposure to indicators of ETS (Lindgren et al., 1999).

Studies have also focused on the effect of ETS on the indoor air quality of hospitality venues. Branis et al. (2002) measured fine particles (PM_1) in four different indoor environments—a lecture room, a restaurant, and two types of offices—and determined that the highest concentration was in the restaurant, which allowed smoking. Carrington et al. (2003) sampled particulate matter and nicotine in 60 pubs in Greater Manchester, UK and found that pubs without designated smoking sections had the highest particle concentrations; that the presence of non-smoking sections reduced particle concentrations even in the smoking areas; that some exposure to elevated particle concentrations still occurred in the non-smoking areas; and that ventilation systems did not have a significant effect on the particle concentrations. Another study in Perth, Western Australia involved air quality measurements in 20 social venues that permitted smoking and found elevated carbon monoxide (CO) and particulate matter concentrations (Dingle et al., 2002). Also, the authors found lesser concentrations behind the bars than in the public seating areas, implying that most buildings were not well-mixed.

In certain cities, states, or countries where indoor smoking bans have been instituted, researchers have been able to measure the pre- and post-ban indoor air quality in a sample of venues. Ott et al. (1996) measured respirable suspended particles (RSP) in a large tavern in Menlo Park, California, USA 26 times during the 2-year period before a smoking ban and 50 times during the 1-year period afterwards and found a decline of 77–90% of RSP after the ban. Repace (2004) conducted pre- and post-ban measurements of RSP and particulate polycyclic aromatic hydrocarbons (PPAH) in six bars, a casino, and a pool hall in Wilmington, Delaware, USA, and he concluded that ETS contributed to 90–95% of the RSP indoor air pollution and 85–95% of the carcinogenic PPAH when smoking was allowed. These values exceed levels of these contaminants found in major highways and city streets, and he concluded that the health of both workers and patrons is endangered by ETS. Mulcahy et al. (2005) investigated the effectiveness of a total indoor smoking ban for all of Ireland and sampled nine pubs for $PM_{2.5}$ and PM_{10} in Galway City. The authors found a post-ban decrease of 75–96% for $PM_{2.5}$ concentrations and 47–74% for PM_{10} concentrations relative to pre-ban levels.

The present study was conducted to evaluate the effect of the smoking ban ordinance in Austin on indoor air quality by measuring indicators of ETS exposure in hospitality venues in the city before and after the smoking ban took effect. The goal of this research was to quantify the indoor air quality benefits of the ordinance and to provide this information to decision makers. Building occupancy measurements were also conducted and are intended to provide insight into potential economic impacts of the ordinance. The results contained herein will help concerned parties understand the effects of an indoor smoking ban on hospitality venues.

Methods

Indicators of ETS exposure and indoor air quality were measured at 17 Austin-area bars during the month-long period before the ban was enacted and again on the same day of the week and approximately the same time of day during the month-long period after the ban. The venues surveyed were a sample of convenience, were selected over a geographic range in Austin, and were assessed by two different field teams. Eight venues (Venues 1–8) scattered throughout the city were evaluated by the first field team, and nine venues (Venues 9–17) located in an entertainment hub in the downtown area of the city were evaluated by the second field team. One selected venue (Venue 5) remained a smoking establishment after the ban because of a variance from the ordinance due to a recently upgraded ventilation system. Venue information and indicators of ETS exposure that were measured for this study were the following: room volume, mean number of occupants, mean number of lit cigarettes, temperature, relative humidity, and $PM_{2.5}$, CO, and carbon dioxide (CO_2) concentrations. Additionally, at Venues 6, 7, and 8, volatile organic compound (VOC) measurements were conducted before and after the smoking ban.

The room volume was estimated by visual and scaling methods for Venues 1–8, and with a Strait-Line Sonic Laser Tape ultrasonic ruler as well as with visual and scaling methods at Venues 9–17. The number of occupants and number of lit cigarettes were counted upon entry, then every 15 min, and again upon exit. As at least 30 min was spent at each venue, this method provided at least three observations for each count in all cases. Occupancy levels were tested for statistically significant changes with regards to both pre- and post-ban mean occupancy over all venues and the percent change in occupants for each venue.

All real-time measurements of temperature, relative humidity, and CO, CO_2, and $PM_{2.5}$ concentrations were made with instruments that fit into a small, portable pack. The temperature and relative humidity in all venues were measured with a TSI Q-Trak. The TSI Q-Trak malfunctioned during the pre-ban testing of Venues 9–11, so any pre-ban measurements utilizing this instrument were not recorded for these venues. The $PM_{2.5}$ concentrations were measured with a TSI Dust-Trak by the first field team at Venues 1–8 and with a TSI Side-Pak by the second field team at Venues 9–17, both of which were zero-calibrated before each use and configured to measure $PM_{2.5}$. The CO and CO_2 concentrations in all venues were also measured with the TSI Q-Trak. The TSI Q-Trak was calibrated according to the manufacturer's instructions for both CO and CO_2 before use. Data were collected every 30 s outside for 5 min before entering each venue, and then within each venue for at least 30 min, and, in some cases, up to 90 min. All data were collected as close to the center of the main area of the venue as possible.

To quantify the effect of the indoor smoking ban on indicators of exposure to ETS, the $PM_{2.5}$ and CO data were analyzed to determine if there were statistically significant decreases ($P<0.05$) in concentrations after the ban. Owing to the small sample size, the Behrens-Fisher test of the hypotheses that the mean $PM_{2.5}$ and CO concentrations were the same before and after the ban were conducted for each venue. Given that the TSI Dust-Trak and Side-Pak have been shown to overcount particulate matter concentrations (Jenkins et al., 2004), the $PM_{2.5}$ data were analyzed with three different sets of correction factors. First, the raw data from the instruments were analyzed without a correction factor, which was taken as the upper bound of the particle concentrations. Second, only the pre-ban data was reduced by a correction factor of 4.41, which was obtained from chamber tests by Jenkins et al. (2004), which provided the smallest difference between pre- and post-ban particle measurements and was our lower bound. Finally, our best estimate used correction factors of 3.24 for the pre-ban data and 2.57 for the post-ban data, which were determined from tests in smoking and non-smoking areas of hospitality venues, also as described in Jenkins et al. (2004). For Venue 5, we used correction factors of 4.41 and 3.24 for the post-ban lower bound and best estimate, respectively, since this venue was approximately equally smoky before and after the ban. The VOC samples were drawn with a SKC Air Check Sampler (model 224-PCXR8) at a flow rate of 1 l/min for 60 min onto activated carbon sorbent in two stage tubes, extracted with CS_2, and analyzed with GC/MS. All VOC data were also collected as close to the center of the main area of the venue as possible.

Finally, the air exchange rate was estimated for each venue with the following mass balance for CO_2 that assumed a well-mixed space and that the only sources of indoor CO_2 were due to the ambient outdoor levels, occupants, and lit cigarettes in the venue:

$$V\frac{\mathrm{d}C}{\mathrm{d}t} = QC_0 - QC + E \qquad (1)$$

where V is the volume of the space (m^3), Q is the ventilation flow rate (m^3/h), C_0 and C are the respective outdoor and indoor concentrations of CO_2 (mg/m^3), and E is the emission rate of CO_2 (mg/h), which is comprised of CO_2 emissions from both occupants and burning cigarettes. Eq. (1) was divided through by the volume, V, assumed to be at steady state, and rearranged to yield the following equation for an estimate of the ventilation rate in number of air changes per hour (ACH), λ (h^{-1}):

$$\lambda = \frac{E}{V(C - C_0)} \qquad (2)$$

Assuming a typical human breathing rate is $0.78\,m^3/h$ (US EPA, 1997) and 4% of exhaled air is CO_2 (Meyer, 1983), the typical human emits 51.9 g CO_2/h. Also, assuming that a typical cigarette emits 300 mg CO_2 (National Research Council, 1986) and that it takes, on average, 6.5 min to smoke a cigarette (Klepis et al., 2003), a typical cigarette emits 2.77 g CO_2/h. Given the assumptions inherent to Eq. (2), particularly the assumptions of complete mixing and steady-state conditions, it should be regarded as an approximate estimate of the ventilation rate.

Results

Table 1 lists the venue information for all 17 venues sampled. A wide range of sizes of venues was sampled, and the range of volumes was 280–2500 m^3. The pre-ban range of occupants for all venues was 20–230 people, and the post-ban range was 20–307 people. The pre-ban range of average lit cigarettes was 3.3–13 cigarettes, and the post-ban range was 0–1.3 cigarettes, except for Venue 5, which had an average of nine smokers after the ban and was exempt from the ordinance. Other than Venue 5, the lit cigarettes observed during the post-ban assessment were at Venues 3, 13, 14, and 17, where there were occupants who did not comply with the ban. Over all of the sites, the occupancy showed no significant difference before or after the ban when considering either the mean number of occupants over all venues or the percentage change in occupancy for each venue. A lack of a significant difference in pre- vs. post-ban occupancy was also found when all sites with post-ban smoking were excluded (Venues 3, 5, 13, 14, and 17), as well as when only Venue 5 was excluded. The pre-ban range of temperatures was 21–28°C, and the post-ban range was 21–30°C. The pre-ban range of relative humidity was 41–59%, and the post-ban range was 40–55%. Also, the mean temperature and relative humidity did not change significantly after the ban.

Table 2 lists the mean and standard deviation (SD) of the lower bound, best estimate, and upper bound of the pre- and post-ban $PM_{2.5}$ concentrations that were measured in Venues 1–17. In all of the summary statistics reported below, Venue 5 is excluded because it was exempt from the ordinance. For the lower bound, the respective pre-ban $PM_{2.5}$ concentration mean and SD for all venues were 111 and 49 $\mu g/m^3$, and the respective post-ban mean and SD were 29 and 33 $\mu g/m^3$. For the best estimate, the respective pre-ban $PM_{2.5}$ concentration mean and SD for all venues were 151 and 67 $\mu g/m^3$, and the respective post-ban mean and SD were 11 and 13 $\mu g/m^3$. For the upper bound, the respective pre-ban $PM_{2.5}$ concentration mean and SD for all venues were 488 and 216 $\mu g/m^3$, and the respective post-ban mean and SD were 29 and 33 $\mu g/m^3$. Excluding all venues where there was post-ban smoking (Venues 3, 5, 13, 14, and 17), the respective best estimate pre-ban mean and SD for the $PM_{2.5}$ concentrations were 144 and

Table 1. Venue information, including volume, mean number of occupants and mean lit cigarettes, mean temperature, and mean relative humidity

Venue	Vol. (m^3)	Occupants (no.)		Lit cigarettes (no.)		Temp (°C)		RH (%)	
		Pre	Post	Pre	Post	Pre	Post	Pre	Post
1	284	23	20	5.0	0	27.0	25.9	46.6	47.8
2	1164	73	70	10.8	0	25.8	23.9	48.9	49.4
3	377	44	23	7.3	0.7	24.9	23.5	45.7	49.8
4	379	38	25	5.3	0	25.0	25.2	49.2	44.1
5	467	72	81	7.0	9.0	23.6	24.3	40.7	50.5
6	1167	89	54	9.4	0	24.5	24.8	50.0	46.7
7	826	69	53	9.2	0	20.9	21.4	57.6	50.9
8	419	20	25	4.0	0	22.4	24.3	46.1	54.8
9	351	204	195	8.8	0		26.4		51.0
10	532	90	131	7.2	0		28.3		43.9
11	816	99	106	3.3	0		26.6		40.0
12	626	230	237	9.7	0	27.3	28.3	51.6	40.6
13	521	190	202	9.7	1.0	27.4	28.9	59.3	47.8
14	1995	187	307	10.0	0.3	27.6	29.9	58.8	50.0
15	677	186	150	13.0	0	24.3	25.2	56.9	45.4
16	886	79	55	7.3	0	25.2	26.6	55.4	46.8
17	2508	105	108	12.0	1.3	27.2	29.9	54.8	47.2

Table 2. Lower bound, best estimate, and upper bound of mean pre- and post-ban $PM_{2.5}$ concentrations at all 17 venues

Venue	Lower bound ($\mu g/m^3$)		Best estimate ($\mu g/m^3$)		Upper bound ($\mu g/m^3$)	
	Pre Mean (SD)	Post Mean (SD)	Pre Mean (SD)	Post Mean (SD)	Pre Mean (SD)	Post Mean (SD)
1	48.7 (9.36)	1.09 (0.59)	66.2 (12.7)	0.42 (0.23)	215 (41.3)	1.09 (0.59)
2	46.3 (6.12)	2.03 (0.49)	63.0 (8.32)	0.79 (0.19)	204 (27.0)	2.03 (0.49)
3	109 (18.5)	111 (26.2)	148 (25.2)	43.1 (10.2)	479 (81.8)	111 (26.2)
4	53.3 (20.1)	19.5 (0.92)	72.5 (27.3)	7.57 (0.36)	235 (88.5)	19.5 (0.92)
5	53.2 (16.9)	53.2 (7.43)	72.4 (23.0)	72.5 (10.1)	235 (74.7)	235 (32.7)
6	137 (37.4)	3.02 (0.54)	187 (50.9)	1.18 (0.21)	606 (165)	3.02 (0.54)
7	85.5 (15.0)	2.36 (0.68)	116 (20.4)	0.92 (0.27)	377 (66.0)	2.36 (0.68)
8	141 (62.0)	11.8 (2.20)	191 (84.4)	4.60 (0.86)	620 (273)	11.8 (2.20)
9	119 (17.1)	22.0 (4.12)	162 (23.2)	8.56 (1.60)	525 (75.3)	22.0 (4.12)
10	88.6 (9.56)	13.1 (8.64)	121 (13.0)	5.08 (3.36)	391 (42.2)	13.1 (8.64)
11	66.2 (11.7)	5.32 (1.62)	90.2 (15.9)	2.07 (0.63)	292 (51.6)	5.32 (1.62)
12	125 (19.2)	32.8 (12.4)	170 (26.1)	12.7 (4.81)	552 (84.5)	32.8 (12.4)
13	78.0 (21.8)	41.8 (20.1)	106 (29.7)	16.3 (7.81)	344 (96.3)	41.8 (20.1)
14	163 (26.2)	36.4 (24.1)	222 (35.7)	14.2 (9.39)	719 (116)	36.4 (24.1)
15	228 (21.3)	31.2 (3.75)	311 (29.1)	12.1 (1.46)	1008 (94.1)	31.2 (3.75)
16	133 (12.1)	30.2 (10.8)	180 (16.4)	11.7 (4.21)	585 (53.2)	30.2 (10.8)
17	150 (15.5)	102 (32.3)	204 (21.2)	39.7 (12.6)	662 (68.6)	102 (32.3)

72 $\mu g/m^3$, and the respective best estimate post-ban mean and SD were 6 and 5 $\mu g/m^3$.

Figure 1 shows the best estimate of the mean pre- and post-ban $PM_{2.5}$ concentrations measured in all 17 venues, and the error bars represent the SD for each sampled venue. $PM_{2.5}$ concentrations decreased for all venues except Venue 5, which had approximately equal concentrations of $PM_{2.5}$ before and after the ban because it had approximately the same number of smokers before and after the ban.

Table 3 shows the mean CO concentrations that were measured at each venue during the pre- and post-ban sampling, as well as the outdoor CO concentrations and the difference between the indoor and outdoor concentrations. Venues 9, 10, and 11 were not tested for CO during the pre-ban sampling due to equipment failure. CO concentrations decreased after the smoking ban for all venues except Venues 5 (which retained its smoking status) and 17. The respective pre-ban mean and SD for the CO concentrations, again excluding Venue 5, were 5.9 and 2.2 ppm, and the respective post-ban mean and SD were 2.5 and 2.0 ppm. Excluding all venues where there was post-ban smoking (Venues 3, 5, 13, 14, and 17), the respective pre-ban mean and SD for the CO concentrations were 5.8 and 2.2 ppm, and the respective post-ban mean and SD were 1.8 and 1.0 ppm.

There was a statistically significant decrease ($P < 0.05$) in $PM_{2.5}$ concentrations for all cases except for the lower bound case for Venue 3, which had occupant non-compliance after the ban and Venue 5, which remained a smoking venue.

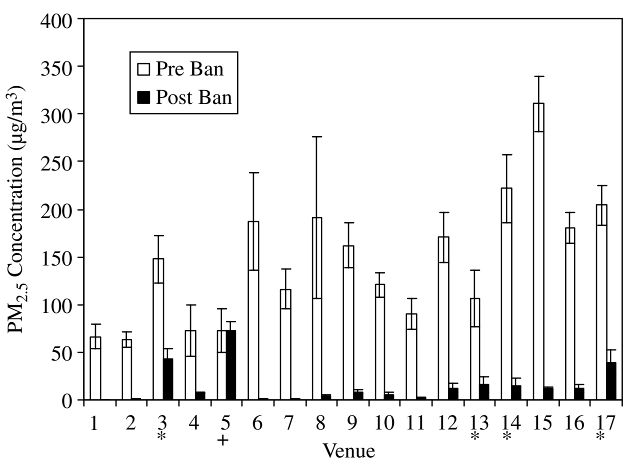

Figure 1. Best estimate pre- and post-ban $PM_{2.5}$ concentrations for all venues: *indicates occupant non-compliance and +indicates venues exempt from the ordinance.

All venues except Venues 5 and 17 exhibited a statistically significant decrease ($P < 0.05$) in CO concentrations as well. Venue 17 had high outdoor CO (7.2 ppm) levels post-ban, likely due to its proximity to a busy street. Even though Venues 3, 13, and 14 had non-compliant occupants, there were fewer burning cigarettes than before the ban, so there was still a statistically significant decrease. Also, there was a statistical decrease in the mean difference between indoor and outdoor CO concentrations over all venues after the ban excluding those for Venues 7–9, where there was equipment failure during the pre-ban testing.

Table 4 lists the results for the pre- and post-ban concentrations of VOCs that were detected at Venues 6–8. A value of b.d. listed in the table indicates that the concentration was below the detection limit of $8\,\mu g/m^3$. Compounds listed in bold on Table 4 are all known to be emitted from sidestream tobacco smoke (Baek and Jenkins, 2004), as well as from other sources. For the three tested venues, all of the compounds that cigarettes are known to emit, with the exception of acetone and limonene, decreased to below detection limit after the ban. Although not listed in the table, ethanol was also detected at breakthrough levels at all venues before and after the ban.

Table 5 lists the outdoor and indoor concentrations of CO_2 for the venues, as well as the estimated ventilation rates in air changes per hour (h^{-1}). Outdoor and indoor CO_2 concentrations were not measured during the pre-ban testing for Venues 9 to 11, and consequently, pre-ban ventilation rates were not estimated for those venues. The mean estimated ventilation rate for all venues was $2.4\,h^{-1}$ before the ban and $3.8\,h^{-1}$ after the ban, excluding Venues 9–11.

Table 3. Outdoor and indoor CO concentrations for each venue

Venue	Outdoor CO (ppm)		Indoor CO (ppm)		Indoor–Outdoor CO difference (ppm)	
	Pre Mean	Post Mean	Pre Mean (SD)	Post Mean (SD)	Pre Mean	Post Mean
1	1.0	1.0	8.3 (1.4)	2.1 (0.3)	7.3	1.1
2	3.8	2.2	7.8 (0.7)	2.1 (0.3)	4.0	−0.1
3	4.0	2.2	9.6 (0.7)	3.0 (0.2)	5.6	0.8
4	1.1	2.0	2.1 (0.3)	1.2 (0.4)	1.0	−0.9
5	1.6	1.9	2.9 (0.5)	4.0 (0.2)	1.3	2.1
6	2.0	1.8	6.8 (0.6)	2.0 (0.0)	4.8	0.2
7	4.5	3.0	5.9 (0.6)	3.0 (0.3)	1.5	0.0
8	4.2	4.7	8.4 (0.9)	4.1 (0.2)	4.2	−0.6
9		0.0		1.1 (0.2)		1.1
10		2.3		2.2 (0.2)		−0.1
11		1.0		1.2 (0.6)		0.2
12	1.0	1.1	3.4 (0.5)	1.0 (0.5)	2.4	−0.1
13	2.0	0.5	3.9 (0.3)	1.4 (0.3)	1.9	0.9
14	3.0	1.8	6.8 (0.7)	6.0 (1.5)	3.8	4.3
15	1.0	0.0	5.1 (0.9)	0.4 (0.3)	4.1	0.4
16	3.0	1.0	4.3 (0.5)	1.8 (0.1)	1.3	0.8
17	3.0	7.2	4.5 (0.5)	7.9 (0.7)	1.5	0.7

Table 4. VOC concentrations detected before and after the ban

VOC	Venue 6		Venue 7		Venue 8	
	Pre ($\mu g/m^3$)	Post ($\mu g/m^3$)	Pre ($\mu g/m^3$)	Post ($\mu g/m^3$)	Pre ($\mu g/m^3$)	Post ($\mu g/m^3$)
1,2,4-Trimethyl benzene	8.33	b.d.	b.d.	b.d.	10.0	b.d.
1,4-Dichlorobenzene	11.7	132	b.d.	b.d.	b.d.	b.d.
2-Propanol	45.0	73.3	18.3	28.3	b.d.	60.0
α-Pinene	10.0	11.7	b.d.	10.0	b.d.	b.d.
Acetone	45.0	25.0	46.7	31.7	250	b.d.
Benzene	31.7	b.d.	30.0	b.d.	31.7	b.d.
Ethyl Acetate	55.0	46.7	51.7	86.7	86.7	38.3
Heptane	13.3	b.d.	b.d.	b.d.	8.33	b.d.
iso-Butanol	13.3	b.d.	10.0	15.0	16.7	b.d.
Limonene	217	200	66.7	83.3	283	85.0
m/p-Xylene	26.7	b.d.	25.0	b.d.	25.0	b.d.
Methyl ethyl ketone	15.0	b.d.	16.7	b.d.	18.3	b.d.
Tetrachloroethylene	b.d.	b.d.	b.d.	b.d.	11.7	b.d.
Toluene	58.3	b.d.	53.3	b.d.	60.0	b.d.

Compounds in bold are known to be emitted from sidestream tobacco smoke (Baek and Jenkins, 2004).

Table 5. Outdoor and indoor CO_2 concentrations and estimated ventilation rates for each venue

Venue	Outdoor CO_2 (ppm)		Indoor CO_2 (ppm)		Estimated ventilation (h^{-1})	
	Pre Mean	Post Mean	Pre Mean (SD)	Post Mean (SD)	Pre Mean	Post Mean
1	468	452	2255 (71)	2538 (183)	1.3	1.0
2	457	502	2279 (126)	1895 (207)	1.0	1.2
3	453	423	2235 (198)	1208 (202)	1.9	2.2
4	417	480	1017 (57)	699 (41)	4.8	8.5
5	450	463	1251 (55)	1414 (37)	5.4	5.2
6	452	436	2256 (376)	1854 (56)	1.2	0.9
7	457	480	1889 (111)	3104 (225)	1.7	0.7
8	520	552	2057 (112)	1041 (84)	0.9	3.5
9		477		1605 (134)		14
10		478		2005 (69)		4.6
11		788		2979 (565)		1.7
12	716	446	3356 (338)	1821 (269)	3.9	7.8
13	736	442	2328 (118)	1297 (168)	6.5	13
14	722	419	5388 (549)	3838 (593)	0.6	1.3
15	668	437	5294 (541)	2647 (272)	1.7	2.8
16	767	589	2333 (63)	1038 (59)	1.6	3.9
17	654	533	1990 (99)	1563 (133)	0.9	1.2

Discussion

This study analyzed the effects of the September 1, 2005 indoor smoking ban on the occupancy levels and indoor air quality for seventeen bars in Austin. Given that neither this study nor two others that were similarly conducted (Ott et al., 1996; Mulcahy et al., 2005) found evidence of a decrease in occupancy levels, a ban on smoking in hospitality venues does not appear to cause reductions in patronage. Furthermore, all venues were visited at the same day of the week and approximately same time of day during the pre- and post-ban testing in an effort to minimize occupancy variations. Nonetheless, we are aware that the methods of occupancy sampling used here are less than ideal and may not represent a true account of the economic effects on hospitality venue owners. Evaluations of occupancy based on alcohol sales tax data over a sufficient amount of time before and after the ban would provide a more accurate representation of the economic implications of the smoking ban.

Although there may not be unquestionable evidence regarding the economic impacts of the smoking ban on hospitality venue owners, the effects of the ban on indoor air quality are quite clear. There was much less smoking after the ban; four venues (25% of non-exempt venues) had minor issues with occupant non-compliance. Excluding Venue 5, for all three analyses of the pre- and post-ban $PM_{2.5}$ data, there was a statistically significant reduction in $PM_{2.5}$ concentrations for all but a single case out of the 48 cases analyzed: the lower bound case for Venue 3. This fact is not surprising, however, since Venue 3 had occupants that did not comply with the smoking ban. Since the data were analyzed with the three different sets of correction factors (Jenkins et al., 2004) and there was a statistically significant decrease for all cases over all venues in which there was no smoking after the ban, it is clear that the smoking ban ordinance reduced indoor $PM_{2.5}$ concentrations.

CO concentrations also decreased significantly for all relevant venues except Venue 17, which actually exhibited an increase in CO concentration due to the high outdoor CO concentration during the post-ban testing of that venue. Also, there was a statistically significant difference after the ban for the mean difference in indoor and outdoor CO concentrations across all venues, excluding those venues for which CO concentrations were not recorded during the pre-ban testing. Regarding the VOC concentrations, in the three tested venues all but two VOCs emitted by cigarettes—acetone and limonene—that were detected during the pre-ban sampling decreased to below detection limit in the post-ban sampling. Furthermore, acetone decreased by a factor of approximately 2 after the ban in Venues 6 and 7 and to below detection limit in Venue 8. Also, limonene is an extremely common terpene found in many cleaning agents and consumer products besides ETS so its presence after the ban is unsurprising. Thus, nearly all indicators of ETS exposure that we measured decreased considerably after the ban; the smoking ban ordinance can be judged a clear success from the viewpoint of indoor air quality. Awareness of the success is relevant both to those who want to evaluate the recent Austin smoking ban or those who want bolster the case for a smoking ban in another municipality.

Other studies that measured particulate matter concentrations as indicators of ETS exposure before and after smoking bans describe results similar to those found in this study. Using the best estimate of this investigation, $PM_{2.5}$ concentrations decreased in the range of 71–99% relative to the pre-ban levels, consistent with the findings of Ott et al. (1996), Repace (2004), and Mulcahy et al. (2005). Such large relative decreases suggest that ETS is the main source for fine particulate matter in hospitality venues where smoking is permitted. Moreover, the reductions in fine particulate matter concentrations are similar even when bans are enacted in geographically different parts of the world.

Reducing public exposure to ETS can have immediately noticeable effects on human health. Sargent et al. (2004) surveyed hospital admissions before and after an indoor smoking ban to determine if there was a change in the monthly number of hospital admissions for acute myocardial infarction, a form of heart disease for which there is an increased risk associated with ETS exposure. The ban and subsequent study occurred in Helena, Montana, a geographically isolated community with one hospital to serve approximately 68,000 people. During the 6 months for which there was a ban on indoor smoking, the number of monthly admissions for acute myocardial infarction fell significantly from a mean of 40 admissions to 24 admissions per month. Thus, laws that ban indoor smoking and enforce smoke-free public places may have the effect of decreasing morbidity due to heart disease.

Additionally, smoking bans can potentially reduce ETS exposure more generally than in hospitality venues alone, since smoking bans have the added effect of encouraging smokers to smoke less or even stop smoking altogether. Hopkins et al. (2001) surveyed the effectiveness of various interventions to reduce both pubic exposure to ETS and general tobacco use. Of the 10 sampled investigations of exposure and tobacco use after a smoking ban intervention, the authors reported that eight of the studies noted reductions in daily tobacco consumption and that three studies observed increases in tobacco use cessation.

Reducing ETS exposure through typical ventilation means has been shown to be of limited effectiveness. Repace and Lowrey (1980) showed that under practical ranges of smoker densities and ventilation conditions, the indoor respirable particulate concentrations in venues that allowed smoking greatly exceed particle concentrations found in smoke-free places, outdoors, and vehicles on busy commuter highways. Moreover, as evidenced by the indoor CO_2 concentrations reported in Table 5, many bars investigated were inadequately ventilated according to ASHRAE Standard 62.1-2004, either presumably due to an effort to reduce costs or to ineffective HVAC system controls. These elevated CO_2 concentrations are evidence that ventilation rates are often below levels required to achieve acceptable indoor air quality, regardless of whether there is smoking in the venues or not. Our findings are supported by the ventilation study of Dingle et al. (2002), and of the 20 venues the authors investigated, none of the owners reported using their ventilation systems to maintain acceptable indoor air quality, instead using them only for maintaining thermal comfort.

Researchers have also examined ETS exposure in hospitality venues that have a non-smoking section that shares a ventilation system with the smoking section. In their study of 60 pubs in the UK, Carrington et al. (2003) noted that for pubs with non-smoking areas the median concentration of fine particulate matter is reduced only by 34% of that in the smoking areas. Another study evaluated the effectiveness of ventilation and partitioning to mitigate the effects of passive smoking, and measured CO concentrations as a marker of ETS, CO_2 as a general indoor air quality indicator, and air flow measurements to estimate ventilation and infiltration rates (Kolokotroni et al., 1999). The study determined that ventilation strategies alone, although reducing concentrations of indicators of ETS somewhat, are generally not sufficient to reduce migration of indicators of ETS into a non-smoking space. Additionally, Akbar-Khanzadeh (2003) examined how exposure to indicators of ETS corresponds to a non-smoking dining section that does not have a separate ventilation system from the smoking section. The author determined that there were statistically elevated levels of indicators of ETS in the non-smoking sections over the samples from control environments (although these levels were also statistically lower than those found in the smoking sections themselves). The study recommends that smoking sections be isolated physically and have separate ventilation systems or non-smoking policies should be enforced. Thus, since in most venues complete separation and ventilation systems are either not physically or economically feasible, an indoor smoking ban may be the only certain way to ensure that the health of workers and the public is optimally protected in all hospitality venues.

One venue we sampled, Venue 5, was an enclosed upstairs bar with an independent ventilation system, which allows it to retain its smoking status until 2012. Venue 5 had an estimated ventilation rate of approximately $5\,h^{-1}$, which was high enough to maintain comparatively low pre- and post-ban concentrations of CO_2 (between approximately 1200 and 1400 ppm). It had a best estimate pre-ban $PM_{2.5}$ concentration of $72\,\mu g/m^3$, approximately one-half of the best estimate pre-ban mean over all venues of $151\,\mu g/m^3$. Furthermore, Venue 5 had a best estimate post-ban concentration of $73\,\mu g/m^3$, which is approximately seven times the best estimate post-ban mean over all venues of $11\,\mu g/m^3$. Although Venue 5 did have a pre-ban mean concentration that was less than the pre-ban mean across all venues, the lower $PM_{2.5}$ concentration afforded by the ventilation system appears considerably less effective when compared to the reduction in $PM_{2.5}$ concentrations due to the smoking ban. Moreover, the 94% average reduction in best estimate $PM_{2.5}$ concentrations for all venues is considerably more than can be explained by the 37% average increase in estimated ventilation rate, indicating that the reduced smoking is the dominant contributor to the decreased indoor $PM_{2.5}$ concentrations.

In conclusion, this study assessed the air quality and occupancy levels in seventeen bars in Austin, Texas before and after a smoking ban that took effect on September 1, 2005. There was not a statistically significant decrease in occupancy, but indicators of ETS exposure did decrease significantly. The best estimate $PM_{2.5}$ concentrations in the venues decreased 71–99% relative to the pre-ban levels, which was similar to other studies of the same type; CO decreased significantly in all but one venue and the mean difference between indoor and outdoor CO concentrations decreased significantly after the ban; and concentrations of VOCs known to be found in cigarettes measured in three venues decreased to below detection limits for all but two common compounds. Owing to the reduction in ETS indicators due to the smoking ban, Austin's comprehensive ban on indoor smoking reduced the exposure to ETS of both workers of and the public who visit hospitality venues.

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