An Evaluation of a Smoking Ban Ordinance in Bars in Austin, TX

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Summary: *On September 1, 2005, the city of Austin, TX, USA instituted a smoking ban in most indoor public places. In this paper, we present the results of the effects of this ban on indoor air quality and indicators of exposure to environmental tobacco smoke (ETS). We report measurements of* $PM_{2.5}$*, CO,* CO_2 *concentrations, number of smokers, and number of occupants taken at seventeen venues during the month-long periods before and after the ban. Additionally, VOCs were monitored before and after the ban at three venues. The results show a statistically significant decrease (*$P < 0.05$*) in* $PM_{2.5}$ *and CO concentrations after the ban in all compliant venues, except for one venue that was exempt from the ordinance. We found no significant change in the overall number of patrons before and after the ban.*

Keywords: *Environmental tobacco smoke (ETS), smoking ordinance, hospitality venues, indoor air quality*
Category: *Case Studies*

1 Introduction

Environmental tobacco smoke (ETS) has been determined to be a health hazard [1-5], and although smoking has been banned in all federal buildings in the United States, states and municipalities are left with the responsibility of controlling ETS in public spaces. On September 1, 2005, the city of Austin, TX, USA enacted an ordinance that banned smoking in public places, city buildings, enclosed areas in workplaces, and within 15 feet from an entrance or operable window of an enclosed area in which smoking is prohibited [6]. Bans such as this one are often controversial because owners of bars and restaurants claim to suffer economic losses due to a decrease in patronage. In Austin, this ban has been particularly contentious because the city prides itself on its live music and nightlife scene, and citizens worry about the effect of the ordinance on local bar and nightclub operation and culture. Thus, if municipalities are going to institute smoking bans, the effectiveness of a smoking ban ordinance in reducing exposure to ETS as well as the occupancy effects must be well understood.

In certain localities where indoor smoking bans have been instituted, researchers have been able to measure pre- and post-ban indicators of ETS exposure in the air in one or a sample of venues. Ott *et al.* [7] measured respirable suspended particles (RSP) in a large tavern in Menlo Park, CA, USA 26 times during the two-year period before a smoking ban and 50 times during the one-year period afterwards and found a drastic decline in indoor RSP concentrations after the ban took effect. Repace [8] 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, DE, 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. Mulcahy *et al.* [9] investigated the effectiveness of a total indoor smoking ban in Ireland and sampled nine pubs for $PM_{2.5}$ and PM_{10} in Galway City, Ireland. The authors found a post-ban decrease of 75 – 96% for $PM_{2.5}$ concentrations and 47 – 74% drop for PM_{10} concentrations relative to pre-ban levels.

This study evaluates the effect of the smoking ban ordinance in Austin, TX on reducing exposure to ETS by measuring indicators of ETS in hospitality venues around the city before and after the smoking ban took effect. The goal of this research is to quantify the indoor air quality benefits of the indoor smoking ban and to provide this information to decision makers.

2 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, TX, 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: room volume, mean number of occupants, mean number of lit cigarettes, temperature, relative humidity (RH), and $PM_{2.5}$, CO, and CO_2 concentrations. Additionally, at Venues 6, 7, and 8, volatile organic compound (VOC) concentration 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 fifteen minutes, and again upon exit. Occupancy levels were tested for statistically significant changes ($P < 0.05$) with regards to both pre- and post-ban mean occupancy over all venues and the percent change in occupants at each venue.

The temperature and RH 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. 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 seconds outside for five minutes before entering each venue, and then within each venue for at least 30 minutes and, in some cases, up to 90 minutes.

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 was a statistically significant decrease ($P < 0.05$) in concentrations after the ban. Due to the small sample size, the Behrens-Fisher test of the hypothesis that the mean $PM_{2.5}$ and CO concentrations were the same before and after the ban was conducted for each venue. Given that Jenkins *et al.* [10] has shown that the TSI Dust-Trak and Side-Pak overcount particulate matter concentrations, the $PM_{2.5}$ data were analyzed with three different correction factors from their study. The first method involved conducting the significance tests using the raw data from the instruments, which was taken as the upper bound of the particle concentrations. The second method of data analysis was to correct only the pre-ban data, using a correction factor of 4.41, obtained from chamber tests. This second method provided the smallest difference between pre- and post-ban particle measurements and is a lower bound. Finally, the third method was our best estimate and 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. For Venue 5, the post-ban lower bound and best estimate used correction factors of 4.41 and 3.24 respectively, since this venue was approximately equally smoky before and after the ban.

The VOC samples were taken with a SKC Air Check Sampler (model 224-PCXR8) at a flow rate of 1 L/min for 60 minutes onto activated carbon sorbent in two stage tubes, extracted with CS_2, and analyzed with GC/MS. All concentration, temperature, and RH data were collected as close to the center of the main area of each 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.

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

where V is the volume of the venue (m^3), Q is the ventilation flow rate (m^3/h), C_0 and C are the outdoor and indoor concentrations of CO_2 (mg/m^3) respectively, and E is the emission rate of CO_2 (mg/h), which is comprised of CO_2 emissions from both people and burning cigarettes. Equation 1 was assumed to be at steady state, and rearranged to yield an estimate of the ventilation rate in air changes per hour, λ (h^{-1}).

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

Assuming a typical human breathing rate is 0.78 m^3/h [11] and 4% of exhaled air is CO_2 [12], the typical human emits 51.9 g CO_2/h. Also, assuming that a typical cigarette emits 300 mg CO_2 [2] and that it takes on average 6.5 minutes to smoke a cigarette [13], a typical cigarette emits 2.77 g CO_2/hr. Given the assumptions inherent to Equation 2, particularly the assumptions of complete mixing and steady-state conditions, it should be regarded as an approximate estimate of the ventilation rate.

3 Results

A wide range of sizes of venues was sampled, and the range of volumes was 280 to 2500 m^3. The pre-ban range of occupants for all venues was 20 to 230 people, and the post-ban range was 20 to 307 people. The pre-ban range of lit cigarettes was 3.3 to 13 cigarettes, and the post-ban range was 0 to 1.3 cigarettes, excluding for Venue 5 which had an average of 9 smokers after the ban. 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. The pre-ban range of temperatures was 21 to 28 ^{o}C, and the post-ban range was 21 to 30 ^{o}C. The pre-ban range of RH was 41 to 59%, and the post-ban range was 40 to 55%. The mean temperature and RH did not change significantly after the ban. Table 1 lists the volume and number of occupants and lit cigarettes for all 17 venues sampled. Over all of the sites, the occupancy showed no significant difference before or after the ban when considering either the total number of occupants or the percentage change at each venue.

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

		Occupants (No.)		Lit Cigarettes (No.)	
Venue	Vol. (m^3)	Pre	Post	Pre	Post
1	284	23	20	5.0	0
2	1164	73	70	10.8	0
3	377	44	23	7.3	0.7
4	379	38	25	5.3	0
5	467	72	81	7.0	9.0
6	1167	89	54	9.4	0
7	826	69	53	9.2	0
8	419	20	25	4.0	0
9	351	204	195	8.8	0
10	532	90	131	7.2	0
11	816	99	106	3.3	0
12	626	230	237	9.7	0
13	521	190	202	9.7	1.0
14	1995	187	307	10.0	0.3
15	677	186	150	13.0	0
16	886	79	55	7.3	0
17	2508	105	108	12.0	1.3

In all of the $PM_{2.5}$ and CO concentration 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 standard deviation for all venues were 111 and 49 $\mu g/m^3$, and the respective post-ban mean and standard deviation were 29 and 33 $\mu g/m^3$. For the best estimate, the respective pre-ban $PM_{2.5}$ concentration mean and standard deviation for all venues were 151 and 67 $\mu g/m^3$, and the respective post-ban mean and standard deviation were 11 and 13 $\mu g/m^3$. For the upper bound, the respective pre-ban $PM_{2.5}$ concentration mean and standard deviation for all venues were 488 and 216 $\mu g/m^3$, and the respective post-ban mean and standard deviation were 29 and 33 $\mu g/m^3$. Excluding all venues with post-ban smoking, the respective best estimate pre-ban mean and standard deviation for the $PM_{2.5}$ concentrations were 144 $\mu g/m^3$ and 72 $\mu g/m^3$, and the post-ban mean and standard deviation were 6 $\mu g/m^3$ 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 standard deviations 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.

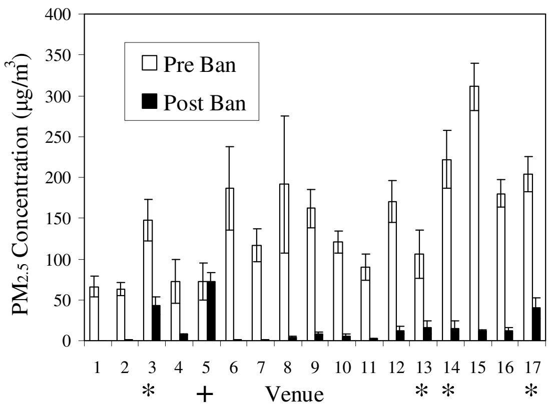

Fig. 1. Best estimate $PM_{2.5}$ concentrations for all venues. * represents occupant non-compliance, and + represents venues that did not have to comply with the ordinance.

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 all cases at Venue 5, which remained a smoking venue.

The respective pre-ban mean and standard deviation for the CO concentrations, again excluding Venue 5, were 5.9 and 2.2 ppm, and the respective post-ban mean and standard deviation were 2.5 and 2.0 ppm. Excluding all venues with post-ban smoking, the respective pre-ban mean and standard deviation for the CO concentrations were 5.8 ppm and 2.2 ppm, and the post-ban mean and standard deviation were 1.8 ppm and 1.0 ppm. CO concentrations decreased significantly (P < 0.05) after the smoking ban for all venues except Venues 5 (which retained its smoking status) and 17. 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.

Table 2 lists the results for the pre- and post-ban concentrations of VOCs that were detected at Venues 6 – 8. Compounds listed in bold in Table 2 are all known to be emitted from sidestream tobacco smoke [14]. 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 the detection limit after the ban. Though not listed in the table, ethanol was also detected at breakthrough levels at all venues before and after the ban.

Table 3 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 – 11, and consequently, those venues could not have ventilation rates estimated for the pre-ban sampling. 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 2. VOC concentrations detected before and after the ban. Bolded compounds are known to be emitted from sidestream tobacco smoke [14]. b.d. indicates below the detection limit (8.3 μg/m^3).

	Venue 6		Venue 7		Venue 8	
VOC (μg/m^3)	Pre	Post	Pre	Post	Pre	Post
1,2,4-Trimethyl benzene	8.3	b.d.	b.d.	b.d.	10	b.d.
1,4-Dichloro-benzene	12	132	b.d.	b.d.	b.d.	b.d.
2-Propanol	45	73	18	28	b.d.	60
α-Pinene	10	12	b.d.	10	b.d.	b.d.
Acetone	45	25	47	32	250	b.d.
Benzene	32	b.d.	30	b.d.	32	b.d.
Ethyl Acetate	55	47	52	87	87	38
Heptane	13	b.d.	b.d.	b.d.	8.3	b.d.
iso-Butanol	13	b.d.	10	15	17	b.d.
Limonene	217	200	67	83	283	85
m/p-Xylene	27	b.d.	25	b.d.	25	b.d.
Methyl ethyl ketone	15	b.d.	17	b.d.	18	b.d.
Tetrachloro-ethylene	b.d.	b.d.	b.d.	b.d.	12	b.d.
Toluene	58	b.d.	53	b.d.	60	b.d.

Table 3. Outdoor and indoor CO_2 concentrations (in ppm) and estimated ventilation rates for each venue.

	Outdoor CO_2		Indoor CO_2		Ventilation (h^{-1})	
Venue	Pre	Post	Pre	Post	Pre	Post
1	468	452	2255	2538	1.3	1.0
2	457	502	2279	1895	1.0	1.2
3	453	423	2235	1208	1.9	2.2
4	417	480	1017	699	4.8	8.5
5	450	463	1251	1414	5.4	5.2
6	452	436	2256	1854	1.2	0.9
7	457	480	1889	3104	1.7	0.7
8	520	552	2057	1041	0.9	3.5
9		477		1605		13.9
10		478		2005		4.6
11		788		2979		1.7
12	716	446	3356	1821	3.9	7.8
13	736	442	2328	1297	6.5	12.8
14	722	419	5388	3838	0.6	1.3
15	668	437	5294	2647	1.7	2.8
16	767	589	2333	1038	1.6	3.9
17	654	533	1990	1563	0.9	1.2

4 Discussion

Given that neither this study nor two others that were similarly conducted [7,9] found evidence of a decrease in occupancy levels, a ban on smoking in hospitality venues does not appear to cause reductions in patronage. Further, all venues were visited at the same day of the week and time of day during the pre- and post-ban testing in an effort to minimize occupancy variations. Thus, this study found that a smoking ban may not, in fact, be detrimental to local business, as is often the prevailing public belief.

The effects of the ban on reducing the indicators of ETS exposure measured in the air in bars are clear. There was much less smoking after the ban, and four venues had minor issues with occupant non-compliance. Since the $PM_{2.5}$ data were analyzed with the three different sets of correction factors from Jenkins *et al.* [10] to account for instrument overcounting 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 ordinance is effectively reducing the concentrations of indoor fine particles, a common indicator of ETS exposure.

Additionally, the statistically significant decrease in CO concentrations also bolsters the case that the ordinance is effectively reducing public exposure to ETS. However, Venue 17 exhibited an anomalous and inexplicable increase in CO concentration. 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 levels 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 level 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, all indicators of ETS exposure that this study measured decreased considerably in nearly all venues after the ban, and by these air quality standards of $PM_{2.5}$, CO, and VOC concentration reduction, the smoking ban ordinance can be judged a clear success at reducing exposure to ETS. Furthermore, because three separate indicators of ETS exposure decreased after the ban, one can be more certain that the reduction of each individual indicator is due, in fact, to the smoking ban.

Other studies have judged the effectiveness of smoking bans on reducing public exposure to ETS by examining indicators not related to direct indoor air quality monitoring. For example, Sargent *et al.* [15] 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 exposure to ETS. The ban and subsequent study occurred in Helena, Montana, a geographically isolated community with one hospital to serve approximately 68,000 people. During the six 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.

The results of our study and other similar studies show that a smoking ban ordinance is an effective way to reduce indicators of ETS exposure. However, since a sizeable percentage of the public is often opposed to a ban, it is useful to examine the effectiveness of the smoking ban in the context of other ETS control strategies.

Ventilation is a commonly employed strategy used in attempts to control ETS. However, this method is not as effective as a smoking ban, and a clear example of the relative ineffectiveness of ventilation to control ETS concentrations is Venue 5. This particular venue was an enclosed upstairs bar in a local restaurant and will retain its smoking status until 2012 because of its separate ventilation system. Venue 5 had an estimated ventilation rate of just over 5 h^{-1}. It had a pre-ban $PM_{2.5}$ concentration of 72 $\mu g/m^3$, approximately one-half of the pre-ban mean over all venues of 151 $\mu g/m^3$. Furthermore, Venue 5 had a post-ban concentration of 73 $\mu g/m^3$, which is approximately seven times the post-ban mean over all venues of 11 $\mu g/m^3$. Though 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. Furthermore, the 94% average reduction in $PM_{2.5}$ concentrations 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.

Other studies have similarly noted the ineffectiveness of ventilation to control exposure to ETS. In their study of 60 UK pubs, Carrington *et al.* [16] 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. Kolokotroni *et al.* [17] evaluated the effectiveness of ventilation and partitioning to mitigate the effects of passive smoking and determined that ventilation strategies alone, though they do reduce ETS levels somewhat, are generally not sufficient to reduce ETS migration into a non-smoking space.

Since the ban is not viewed favorably by the entire population, the next question to examine is whether the ban provides more protection to the public than is actually necessary. In other words, would ventilation strategies be effective enough? Repace and Lowrey [18] looked at this very question and found that to lower the risk of contracting fatal lung cancer due to ETS exposure in the workplace below acceptable levels (1-in-100,000 chance over a 40 year worker lifetime), impractical amounts of ventilation would be required. They concluded that the only practical controls are complete physical separation or smoking prohibition. Thus, since in most venues complete separation with independent ventilation systems are either not physically or economically feasible, an indoor smoking ban is the only certain way to reduce exposure to ETS and ensure that the health of workers and the public is optimally protected in all hospitality venues.

As an added public health benefit, bans on indoor smoking such as the one in Austin also help encourage people to quit smoking. Hopkins *et al.* [19] surveyed the effectiveness of various interventions to reduce both pubic exposure to ETS and general tobacco use. Based on their survey, the authors "strongly recommend" the use of a smoking ban as an effective tobacco exposure and usage intervention. Of the ten 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. A report by the Surgeon General [20] on reducing tobacco use concluded that an additional benefit to clean indoor air regulations may be a reduction in smoking prevalence both among the workers and the general public. Moreover, the report also states that a smoke-free environment is required for the optimal protection of both nonsmokers and smokers.

In conclusion, this study assessed the effectiveness of an indoor smoking ban in Austin, TX at reducing public exposure to ETS. The study concluded that there was not a statistically significant decrease in occupancy, but that 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 concentrations of VOCs known to be found in cigarettes measured in three venues decreased to below detection levels for all but two common compounds. Moreover, the reduction in ETS exposure due to the smoking ban was examined in the context of other smoking ban studies and ETS control strategies. Due to the reduction in ETS indicators after the smoking ban and the ETS-related health effects described in the literature, Austin's comprehensive ban on indoor smoking can be judged effective at and necessary for reducing public exposure to ETS and improving public health.

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