Change in Indoor Particle Levels After a Smoking Ban in Minnesota Bars and Restaurants

David L. Bohac, MS, Martha J. Hewett, MS, Kristopher I. Kapphahn, BME, David T. Grimsrud, PhD, Michael G. Apte, PhD, Lara A. Gundel, PhD

Background: Smoking bans in bars and restaurants have been shown to improve worker health and reduce hospital admissions for acute myocardial infarction. Several studies have also reported improved indoor air quality, although these studies generally used single visits before and after a ban for a convenience sample of venues.

Purpose: The primary objective of this study was to provide detailed time-of-day and day-of-week secondhand smoke– exposure data for representative bars and restaurants in Minnesota.

Methods: This study improved on previous approaches by using a statistically representative sample of three venue types (drinking places, limited-service restaurants, and full-service restaurants), conducting repeat visits to the same venue prior to the ban, and matching the day of week and time of day for the before- and after-ban monitoring. The repeat visits included laser photometer fine particulate ($PM_{2.5}$) concentration measurements, lit cigarette counts, and customer counts for 19 drinking places, eight limited-service restaurants, and 35 full-service restaurants in the Minneapolis/St. Paul metropolitan area. The more rigorous design of this study provides improved confidence in the findings and reduces the likelihood of systematic bias.

Results: The median reduction in $PM_{2.5}$ was greater than 95% for all three venue types. Examination of data from repeated visits shows that making only one pre-ban visit to each venue would greatly increase the range of computed percentage reductions and lower the statistical power of pre–post tests. Variations in $PM_{2.5}$ concentrations were found based on time of day and day of week when monitoring occurred.

Conclusions: These comprehensive measurements confirm that smoking bans provide significant reductions in SHS constituents, protecting customers and workers from $PM_{2.5}$ in bars and restaurants.
(Am J Prev Med 2010;39(6S1):S3–S9) © 2010 American Journal of Preventive Medicine

Introduction

Secondhand smoke (SHS) is an important indoor air quality concern.[1] Exposure to SHS has been linked to an increased risk of many adverse health outcomes, including lung cancer, asthma onset and exacerbation, and acute respiratory illness.[2] The U.S. Surgeon General has concluded that no level of exposure to SHS is without some associated risk.[1]

While people spend more time at home than any other location, there are many locations outside the home where people have substantial exposures to secondhand smoke. Klepeis[3] used data from the 1992–1994 U.S. Environmental Protection Agency–sponsored National Human Activity Pattern Survey to evaluate the percentage of people who were exposed at different types of locations. He found that 60% reported being exposed at home, 30% in a vehicle, and 23% in a bar or restaurant.

Bar and restaurant smoking bans reduce the health impact of SHS. An observational study of hospital admissions for acute myocardial infarction showed a decline of about 40% in the 6 months following the implementation of a smoking ban in work places and public places in Helena, Montana.[4] Studies of the effect of Italian smoking regulations have also shown a significant reduction of about 11% in hospital admissions for acute myocardial infarction.[5,6]

Workers in bars and restaurants have greater exposure to and health risks from SHS than customers. Eisner et al.[7] studied respiratory symptoms in over 50 bartenders before and after a smoking ban was implemented in California.[7] Before the ban, 74% of the bartenders reported respiratory symptoms; at follow-up exams after the ban, 59%

From the Center for Energy and Environment (Bohac, Hewett, Kapphahn); Grimsrud & Associates (Grimsrud), Minneapolis, Minnesota; and the Indoor Environment Department (Apte, Gundel), Lawrence Berkeley National Laboratory, Berkeley, California

Address correspondence to: David L. Bohac, MS, Center for Energy and Environment, 212 3rd Avenue North, #560, Minneapolis MN 55401-1459. E-mail: dbohac@mncee.org.
0749-3797/$17.00
doi: 10.1016/j.amepre.2010.09.012

of those bartenders no longer had symptoms. One month after the ban, the bartenders had a 5%–7% improvement in pulmonary function. More recent studies by Goodman et al.[8] and Menzies et al.[9] also found a decrease in respiratory symptoms and improvement in lung function of bar workers after implementation of smoking bans in Ireland and Scotland.

Workplace and community smoking bans have been shown to reduce smoking prevalence and increase cessation. From their review of 21 studies that evaluated the absolute differences in tobacco-use prevalence after the implementation of a ban, Hopkins et al.[10] found a median reduction of 3.4 percentage points. They also reviewed 11 studies that evaluated smoking cessation and found an increase in cessation of 6.4 percentage points.

Smoking bans can also improve indoor air quality. For 11 studies of bars and restaurants where smoking bans were implemented, there was a mean reduction in fine particulate matter ($PM_{2.5}$) of 88% (Table 1). The $PM_{2.5}$ reductions could conceivably be due to a reduction in the number of customers. However, the study of a smoking ban for bars in Austin TX, reported that there was a 90% reduction in $PM_{2.5}$ with no significant change in the number of customers after the ban[14] and there was no significant change in the number of customers at a California pub that had a 90% reduction in respirable particles.[18]

The limitations of these studies are that monitoring generally occurred only once before and once after the ban in each of the venues, that they did not necessarily match the time of day and day of week of the visits before and after the ban to a given venue, and that they used convenience samples of sites. SHS concentrations have been shown to vary greatly on different days at the same venue. In 26 different measurements over a 21-month period, Ott et al.[18] reported a 7:1 variation in the number of patrons and concentration of respirable particles in a tavern where smoking was permitted. About half of the latter variation could be explained by the variation in the number of lit cigarettes. In addition, Travers' measurements[11] in 58 bars and 26 restaurants indicate that there is a 30:1 to 50:1 variation between the highest and lowest $PM_{2.5}$ concentrations for different venues where smoking is permitted. This suggests that an evaluation of smoking ban air quality improvement can be affected by the specific date/time selected for monitoring and the venues included in the sample.

The study discussed here improves on previous approaches by conducting repeat visits to the same venue prior to the ban, matching the day of week and time of day for the before- and after-ban monitoring, and using a statistically representative sample of three different venue types. The rigor of this study addresses concerns of possible bias of past studies that could cloud discussions of the impact of smoking bans.

Methods

Site Selection

A sampling strategy using stratification with disproportionate sampling of venues was designed to maximize the precision of estimates of mean worker and patron population SHS exposures. It was expected that the number of customers for a venue would be strongly related to the number of workers and that optimizing the sample for worker exposure precision would also optimize for customer exposure precision. A Dun & Bradstreet (D&B) database of Minnesota businesses was used to identify 8678 hospitality venues. The primary North American Industry Classification System (NAICS) code was used to place the venues in three categories:

Table 1. Reductions in $PM_{2.5}$ concentrations following implementation of smoking bans

Study	Sites	Type	Location	$PM_{2.5}$ before ban ($\mu g/m^3$)	$PM_{2.5}$ reduction (%)
Travers (2008)[11]	58	Bars	U.S.	28–1375	93
Semple (2007)[12]	41	Pubs	Scotland	8–902	86
Valente (2007)[13]	40	Combination[a]	Rome	119 average	68
Travers (2008)[11]	37	Restaurants with bars	U.S.	8–727	88
Travers (2008)[11]	26	Restaurants	U.S.	20–671	87
Waring (2007)[14]	16	Bars	Texas	63–311	90
Travers (2008)[11]	13	Large recreation[b]	U.S.	35–422	90
Mulcahy (2005)[15]	9	Pubs	Ireland	90–660	75–96
Repace (2004)[16]	8	6 bars, 1 casino, 1 pool hall	Delaware	44–686	90–95
Repace (2006)[17]	6	Bars	Boston	43–338	96
Ott (1996)[18]	1	Pub	California	59.6 average	90

[a]Fourteen bars, 8 restaurants, 6 fast food restaurants, 6 game rooms, and 6 pubs
[b]Bowling centers, pool/dance/bingo halls, and hotel lobby bar
PM, photometer fine particulate

(1) drinking places (NAICS code 722410); (2) limited-service restaurants, cafeterias, and snack and nonalcoholic beverage bars (722211, 722212, and 722213); and (3) full-service restaurants (722110). Comparison of the D&B results with data from the State of Minnesota Quarterly Census of Employment and Wages suggested that the D&B list captured about 99% of full-service restaurants, but only 79% of limited-service restaurants and 74% of drinking places. A total of 3559 venues were removed from the initial database because they were located in an area with an existing ban; 500 because their record did not include the employee count; and 662 because their NAICS code was not one of the five selected.

Each of the three venue-type strata was then broken into three substrata, using employee information from the commercial database such that the establishments in each substratum (within an establishment type) contained approximately the same number of total employees. The approximate number of employees in each substratum exposed to SHS was then estimated based on the fraction of venues that allowed smoking. This was determined from telephone calls to a random sample of establishments in each stratum. Finally, the SE of the population mean concentration was minimized and venue allocation was optimized by weighting in proportion to both the number of employees working at venues where smoking was allowed and the expected SD of the SHS concentration.[19] Limited data from a previous study by the authors in the same geographic area indicated that the SD of particle concentrations in drinking places was roughly twice that in full-service restaurants. The limited-service venues were assumed to have the same SD as full-service venues. The optimized sample distribution included 37 full-service restaurants, nine limited-service restaurants, and 19 drinking places.

For practical reasons, the sampling frame was limited to locations within a 20-mile radius of downtown Minneapolis. Available data suggested only minor differences in smoking levels between urban and rural populations, reducing the potential bias due to this practical constraint (B Schillo, ClearWay Minnesota, personal communication, 2010). A total of 829 establishments remained in the sampling frame within 20 miles of downtown Minneapolis, of which 395 were estimated to permit smoking. Calls to determine smoking status were made in random number order until enough smoking-permitted venues had been identified to fill the stratum quota. Field monitoring of SHS component concentrations was conducted using area sampling at these locations near other customers within the establishment. Previous research suggests that, in these environments, area sampling results correlate well with personal monitoring results and produce similar median exposure estimates for a number of SHS species.[20]

Secondhand Smoke Tracer Selection

SHS is made up of a complex, dynamic mixture of over 4000 gas and condensed phase compounds with both gas phase constituents and particles causing adverse health effects.[21] Successful measurement of SHS exposure in hospitality venues requires a tracer that is reasonably specific to SHS and can be measured cost effectively with acceptable accuracy.[20,22,23] This analysis uses real-time, photometer measurements of $PM_{2.5}$ as the primary indicator of SHS exposure, a measure used in many prior studies (Table 1). The reported post-ban reductions in $PM_{2.5}$ indicate that SHS is most often the dominant source of $PM_{2.5}$ in hospitality venues where smoking is allowed. Gas phase SHS tracers, including nicotine, were monitored for 8% of the pre-ban visits, and the correlations of those concentrations with $PM_{2.5}$ are reported elsewhere.

Monitoring Protocol

The primary objective of this study was to provide detailed time-of-day and day-of-week SHS exposure data for representative bars and restaurants in Minnesota. The implementation of a statewide smoking ban 7 months after the start of the field monitoring provided an opportunity to study the effects of a smokefree policy on the air quality of the 65 bars and restaurants in the study.

Field monitoring was conducted at three different times of day (lunch, dinner, and evening) and on four different day types (Fridays, Saturdays, Sundays, and other weekdays). Monday through Thursday were grouped together in the "other weekday" category since it was expected that the number of customers would be similar for those days, compared to Fridays and the weekend days. All visits were conducted unannounced without the knowledge of the venue staff or customers. This was expected to provide less-biased results since the venue would not make any operational changes for the monitoring period and, since owner approval was not required, it allowed complete freedom in selecting a statistically representative sample of venues. Each short-term visit was conducted by one person carrying the instruments in either a briefcase or backpack.

The monitors were instructed to sit in the smoking section, in the area with the greatest concentration of people and well away from outside doors or doors to the kitchen. In addition to the real-time measurements of $PM_{2.5}$, each monitor used a personal digital assistant with a customized database application developed to record observational data, including the time entering and leaving the venue, the number of customers and lit cigarettes, and the start and end of associated outdoor monitoring periods. Monitors were instructed to remain in the venue for at least 10 minutes and to measure outside conditions for at least 10 minutes for each group of four venues. Eight percent of the data set was generated from visits that lasted for 2 hours and included supplementary SHS tracer measurements that are not presented in this paper.

A TSI Inc. SidePak AM510 Aerosol Monitor was used for continuous, real-time monitoring of $PM_{2.5}$. Specifications about this instrument and similar SHS monitoring devices have been reported elsewhere.[11,24–27] The manufacturer recommends that users determine the calibration factor for the specific monitoring application[25] and previous studies have reported factors from 0.295 to 0.328.[11,26,27] Personal Environmental Monitor gravimetric measurements from 202 visits of 2 hours each were used to establish a SidePak calibration factor of 0.31 for the SidePak measurements for this project.

The effect of the smoking ban was evaluated by monitoring at each venue after the October 1, 2007, implementation of the statewide smokefree policy. The monitoring protocol was the same as that used for the first portion of the study when smoking was allowed. The monitors were required to stay in the venue for at least 10 minutes. During that time they recorded the number of customers present and the number of lit cigarettes, and they used a SidePak for $PM_{2.5}$ measurements. The percentage reduction in $PM_{2.5}$ was computed for each venue by comparing the concentration for the visit conducted after the ban to the average concentration for all of the visits conducted before the ban at that venue for the same type of day and time of day.

Results

Table 2. Indoor $PM_{2.5}$ concentrations before and after implementation of a smoking ban in Minnesota

Venue type	Venue # (*n*)	Before ban ($\mu g/m^3$) Avg	Before ban ($\mu g/m^3$) Med	After ban ($\mu g/m^3$) Avg	After ban ($\mu g/m^3$) Med	Reduction[a] (%) Avg	Reduction[a] (%) Med	95% CI for median[b] Lower (%)	95% CI for median[b] Upper (%)
Drinking place	19	113.0	70.6	2.7	1.0	94.5	**98.6**	94.7	99.3
Limited service	8	84.7	109.5	3.3	1.4	75.5	**98.5**	40.3	99.3
Full-service	35	55.8	37.4	2.9	2.2	86.3	**95.6**	92.3	97.6
All	**62**	**77.1**	**52.1**	**2.9**	**1.9**	**87.4**	**97.4**	**95.0**	**98.3**

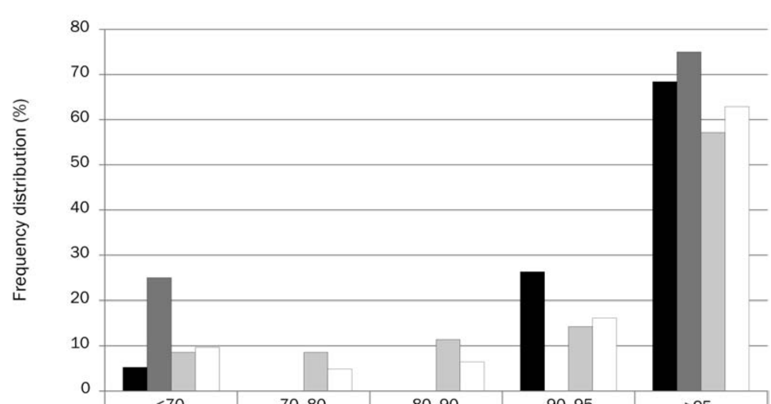
[a]The average and median percentage reduction for the venues within each venue type and all venues. This is different from the percentage reduction in the group average and median values before and after the ban, which can be computed directly from the tabulated values.
[b]Sign CI for the median calculated using Minitab 15. CIs are computed using the nonlinear interpolation procedure of Hettmansperger and Sheather.[28]
Avg, average; Med, median; PM, photometer fine particulate

Successful monitoring after the ban was completed for 62 of the 65 venues. Two thirds of these visits were conducted on Fridays and Saturdays, with 24% conducted Sundays and 8% conducted midweek (i.e., Monday through Thursday). A total of 88% of the visits were conducted during the dinner or evening period, and 12% were conducted at lunchtime. Visits to 50 venues were completed within 2 months after the ban was implemented, and visits to the remaining 12 venues were completed approximately 18 months after the ban was implemented. At least 10 minutes of $PM_{2.5}$ monitoring were conducted in each venue after implementation of the statewide smoking ban, and the average monitoring duration was 26 minutes.

No smoking was observed in any of the venues after the ban went into effect, and fine particle concentrations were significantly reduced (Table 2; Figure 1). The median reduction in $PM_{2.5}$ was greater than 95% for all three venue types. Wilcoxon signed rank sum tests were used to test lower bounds for the median reduction in $PM_{2.5}$ concentration (Table 2). If this study were repeated, there would be only a 5% likelihood that the median reduction for a sample of 62 venues would be less than 93%.

The average $PM_{2.5}$ concentration reduction over all 62 venues was 87.4% (95% CI=86.5%, 88.4%). The average $PM_{2.5}$ reduction was less than the median because of the left-skewed distribution of the reductions (Figure 1), which in turn reflects a trend of lower percentage reduction in $PM_{2.5}$ for venues with lower concentration of $PM_{2.5}$ before the ban. The six venues that had a $PM_{2.5}$ reduction of less than 70% had a median $PM_{2.5}$ concentration of 13.1 $\mu g/m^3$ before the ban—much lower than the pre-ban median of 52.1 $\mu g/m^3$ for all 62 venues.

The pre-ban $PM_{2.5}$ concentrations are averages from typically three visits to each venue on the same day of the week and time of day. The concentrations measured on different visits often varied considerably (Figure 2). For example, for venue FL-2, the pre-ban concentration ranged from 2.4 to 78.0 $\mu g/m^3$, which



	<70	70–80	80–90	90–95	>95
Drinking places	5.3	0.0	0.0	26.3	68.4
Limited service	25.0	0.0	0.0	0.0	75.0
Full service	8.6	8.6	11.4	14.3	57.1
All	9.7	4.8	6.5	16.1	62.9

$PM_{2.5}$ reduction (%)

Figure 1. Frequency distribution of percentage $PM_{2.5}$ reduction by venue type
PM, photometer fine particulate

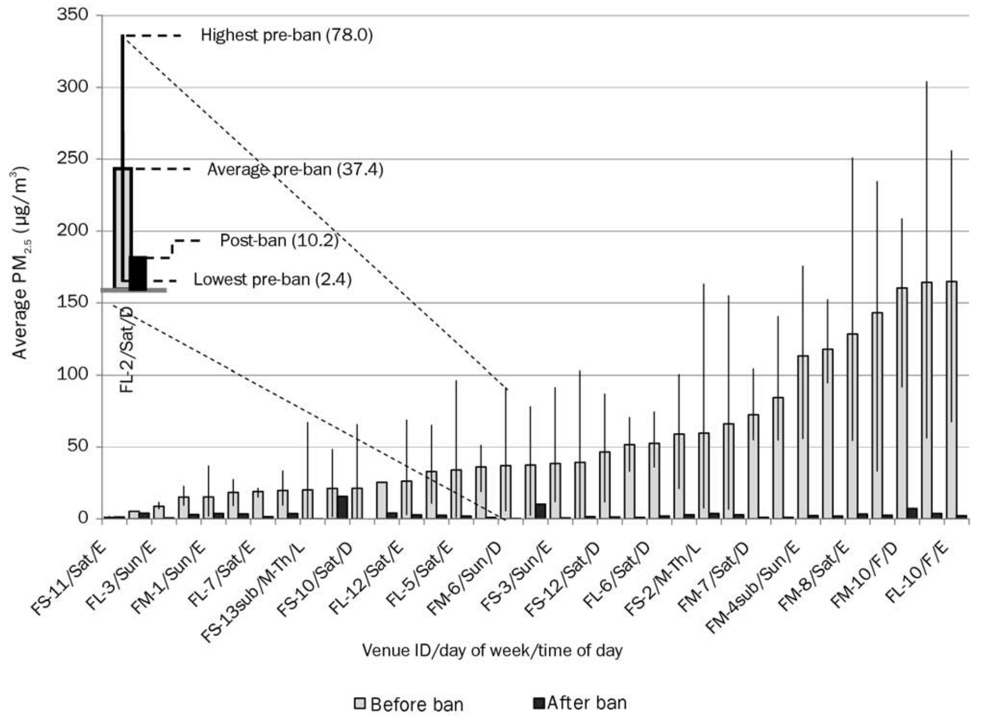


Figure 2. $PM_{2.5}$ concentration before and after ban in full-service restaurants. The vertical lines for the pre-ban concentration bars indicate the minimum and maximum concentrations measured. The labels indicate the venue, day of week, and time of day.
D, dinner; E, evening; L, lunch; PM, photometer fine particulate

would have resulted in changes in PM2.5 ranging from a 320% increase to an 87% decrease. The repeated measurements provide a more representative pre-ban concentration of 37.4 μg/m^3 and reduction of 72.8%.

Before implementation of the smoking ban, the average $PM_{2.5}$ concentration for the three types of venues varied greatly by day of week and time of day (Figure 3).

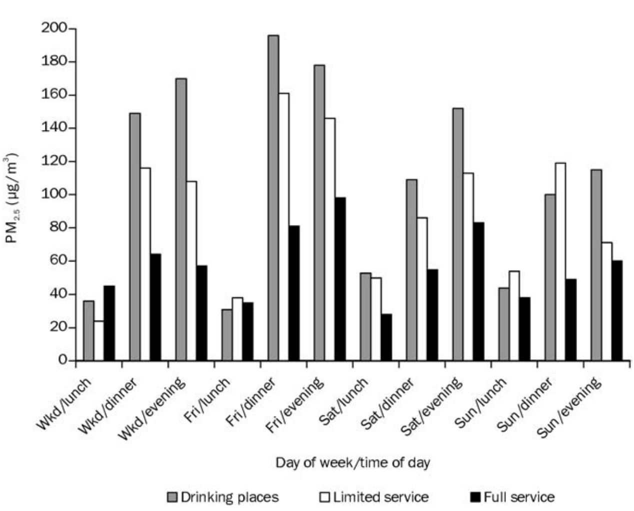


Figure 3. Average $PM_{2.5}$ by day of week, time of day, and venue type
PM, photometer fine particulate

The average concentration was highest during the Friday dinner period for drinking places and limited-service restaurants, and during the Friday evening period for full-service restaurants.

A second source of indoor $PM_{2.5}$ is the outdoor air that enters the establishment through its ventilation system and through infiltration of the building's envelope. Table 3 presents the ratio of outdoor-to-indoor fine particle concentrations measured before and after the ban. Before the ban, the ratio of the average outdoor $PM_{2.5}$ concentration to the average indoor concentration was 0.05, indicating that indoor sources dominated the measured indoor concentrations. After the ban the ratio of the averages was 0.68, suggesting that much of the indoor particulate matter had its origin outdoors.

The indoor $PM_{2.5}$ concentrations for the 62 averaged pre-ban points and 62 post-ban points were regressed on potential explanatory variables. Using stepwise regression (p(F) to enter=0.0; to remove=0.1), only four variables entered the regression (change in R^2 for each variable added shown in parentheses).

$$PM_{2.5,inside} = -7.30 + 17.68 * LitCigs + 2.83 * PM_{2.5,outside} + 23.08 * Pre + 22.63 * Fri$$

Step change in R^2 for each variable respectively: (0.575)(0.043)(0.020)(0.012)

"Pre" and "Fri" are dummy variables for pre- or post-ban (1 or 0, respectively) measurements and for measurements on Friday (1) or other days (0). Variables which did not enter included number of customers, number of workers, days since the ban went into effect (0 for pre-ban data), and dummy variables for type of establishment, day of week (other than Friday), and time of day.

Discussion

Indoor air measurements in a probability sample of 62 venues in the Minneapolis–St. Paul metropolitan area before and after implementation of a statewide smoking ban show a median reduction in fine particle concentrations of 97.4%. The median reduction in $PM_{2.5}$ was greater than 95% for all three categories of venues: drinking places, limited-service restaurants, and full- service restaurants. The overall average reduction of 87.4% is similar to the venue-weighted average of 86% for results from 11 previous studies of 255 venues reported in the literature.[11–18] The $PM_{2.5}$ reductions are also similar to the 83% median reduction in urinary cotinine and 85% reduction in 4-(methylnitrosamino)-1-(3-pyridyl)-1-butanol (NNAL) for 24 bar and restaurant workers who were evaluated before and after the Minnesota smoking ban went into effect.[29]

Table 3. Average outside to average inside particle concentrations before and after implementation of smoking ban in Minnesota

Venue type	# Venues	Before ban Inside ($\mu g/m^3$)	Before ban Outside ($\mu g/m^3$)	Before ban Out/in	After ban Inside ($\mu g/m^3$)	After ban Outside ($\mu g/m^3$)	After ban Out/in
Drinking place	19	113.0	3.6	0.03	2.7	1.1	0.40
Limited-service	8	84.7	4.7	0.06	3.3	1.5	0.47
Full-service	35	55.8	4.3	0.08	2.9	2.1	0.73
All	**62**	**77.1**	**3.9**	**0.05**	**2.9**	**1.9**	**0.68**

The most important predictor of indoor $PM_{2.5}$ concentrations was the number of lit cigarettes ($R^2=0.575$). Pre- and post-ban status accounted for only 2% of the variation in indoor $PM_{2.5}$, presumably because the impact of the ban was captured by the "lit cigarettes" variable. Unmeasured factors that likely account for some of the remaining variability include the ventilation level, proximity of the monitoring team to the lit cigarettes, number of cigarettes smoked recently (within minutes to hours), and errors in cigarette counts, especially in busy or crowded venues.

This study improved on previous approaches by using a statistically representative sample of venues, conducting repeat visits to the same venue prior to the ban, and matching the day of week and time of day for the before- and after-ban monitoring. It also provides results for three different venue types: drinking places, limited-service restaurants, and full-service restaurants. The more rigorous design of this study provides improved confidence in the findings and reduces the likelihood of systematic bias.

Examination of data from repeated visits shows that making only one pre-ban visit to each venue would greatly increase the range of computed percentage reductions and lower the statistical power of pre–post tests. This could be particularly important in any future studies of venue types with lower pre-ban concentrations.

Particle concentrations were significantly higher for dinner and evening periods compared to lunchtime. The variation confirms that the day of the week and time of day can affect monitoring results before bans are in place and estimates of ban impacts. For example, for drinking places, the average pre-ban $PM_{2.5}$ concentration for the Saturday dinner period was 45% less than the average for the Friday dinner period. Similarly, for the eight venues monitored during lunch, the median percentage reduction was 92.9% compared to 97.3% and 98.0% for the venues monitored during the dinner and evening periods respectively. Since the percentage reduction in $PM_{2.5}$ after a ban is affected by the pre-ban concentration, it appears that the selection of the time of day for the monitoring had an impact on the percentage reduction in $PM_{2.5}$ concentrations. This is a new finding that should be considered for the design of future studies.

Conclusion

The measurements indicate that a smoking ban reduces exposure the $PM_{2.5}$ by typically 95%. In bars and restaurants, $PM_{2.5}$ is generally considered to be a valid tracer for SHS exposure. Exposure to SHS has been linked to an increased risk of many adverse health outcomes, including lung cancer, asthma onset and exacerbation, and acute respiratory illness.[2] Studies have confirmed reduced hospital admissions for acute myocardial infarction and improved lung function of bar workers after implementation of smoking bans.[7–9] The ban is a health benefit for customers of the venues and is a major health benefit for employees. Comprehensive smoking bans are a notable success story in public health policy.

Public dissemination of information relating to the grant was made possible by Grant Number RC-206-0050 from ClearWay Minnesota. The contents of this report are solely the responsibility of the authors and do not necessarily represent the official views of ClearWay Minnesota.

No financial disclosures were reported by the authors of this paper.

This paper was supported by ClearWay Minnesota^{SM} as part of a supplement entitled ClearWay Minnesota^{SM}: Advancing Tobacco Control Through Applied Research (Am J Prev Med 2010;39[6S1]).

References

1. USDHHS. The health consequences of involuntary exposure to tobacco smoke: a report of the Surgeon General. Atlanta GA: USDHHS, CDC, Coordinating Center for Health Promotion, National Center for Chronic Disease Prevention and Health Promotion, Office on Smoking and Health, 2006.
2. National Cancer Institute. Health effects of exposure to environmental tobacco smoke: the report of the California Environmental Protection Agency. Smoking and Tobacco Control Monograph No. 10. NIH Pub. No. 99-4645. Bethesda MD: USDHHS, NIH, 1999.
3. Klepeis NE. An introduction to the indirect exposure assessment approach: modeling human exposure using microenvironmental measurements and the recent National Human Activity Pattern Survey. Environ Health Perspect 1999;107(2S):S365–S374.
4. Sargent RP, Shepard RM, Glantz SA. Reduced incidence of admissions for myocardial infarction associated with public smoking ban: before and after study. Br Med J 2004;328:977–80.
5. Barone-Adesi F, Vizzini L, Merletti F, Richiardi L. Short-term effects of Italian smoking regulation on rates of hospital admission for acute myocardial infarction. Eur Heart J 2006;27:2468–72.
6. Cesaroni G, Forastiere F, Agabiti N, Valente P, Zuccaro P, Perucci CA. Effect of the Italian smoking ban on population rates of acute coronary events. Circulation 2008;117:1183–8.
7. Eisner MD, Smith AK, Blanc PD. Bartenders' respiratory health after establishment of smoke-free bars and taverns. JAMA 1998;280:1909–14.
8. Goodman P, Agnew M, McCaffrey M, Gillian P, Clancy L. Effects of the Irish smoking ban on respiratory health of bar workers and air quality in Dublin pubs. Am J Respir Crit Care Med 2007;175:840–5.
9. Menzies D, Nair A, Williamson PA, et al. Respiratory symptoms, pulmonary function, and markers of inflammation among bar workers before and after a legislative ban on smoking in public places. JAMA 2006;296(14):1742–8.
10. Hopkins DP, Razi S, Leeks KD, Kalra GP, Chattopadhyay SK, Soler RE. Smokefree policies to reduce tobacco use. Am J Prev Med 2010; 38(2S):S275–S289.
11. Travers MJ. Smoke-free air policy: changing what's in the air and in the body [dissertation]. Buffalo NY: State University of New York at Buffalo, 2008.
12. Semple S, Creely KS, Naji A, Miller BC, Ayres JG. Secondhand smoke levels in Scottish pubs: the effect of smoke-free legislation. Tob Control 2007;16(2):127–32.
13. Valente P, Forastiere F, Bacosi A, et al. Exposure to fine and ultrafine particles from secondhand smoke in public places before and after the smoking ban, Italy 2005. Tob Control 2007;16(5):312–7.
14. Waring MS, Siegel JA. An evaluation of the indoor air quality in bars before and after a smoking ban in Austin, Texas. J Expo Sci Environ Epidemiol 2007;1–9.
15. Mulcahy M, Byrne MA, Ruprecht A. How does the Irish smoking ban measure up? A before and after study of particle concentrations in Irish pubs. Proceedings of Indoor Air 2005, II(1), 1659-62, Beijing, China.
16. Repace J. Respirable particles and carcinogens in the air of Delaware hospitality venues before and after a smoking ban. J Occup Environ Med 2004;46(9):887–905.
17. Repace J, Hyde JN, Brugge D. Air pollution in Boston bars before and after a smoking ban. BMC Public Health 2006;6:266–71.
18. Ott W, Switzer P, Robinson J. Particle concentrations inside a tavern before and after prohibition of smoking: evaluating the performance of an indoor air quality model. J Air Waste Manag Assoc 1996; 46:1120–34.
19. Kish L. Survey sampling. New York: Wiley, 1995.
20. Jenkins RA, Counts RW. Occupational exposure to environmental tobacco smoke: results of two personal exposure studies. Environ Health Perspect 1999;107(2S):S341–S348.
21. Witschi H, Espiritu I, Maronpot RR, Pinkerton KE, Jones AD. The carcinogenic potential of the gas phase of environmental tobacco smoke. Carcinogenesis 1997;18:2035–42.
22. National Research Council. Environmental tobacco smoke: measuring exposures and assessing health effects. Washington DC: National Academy Press, 1986.
23. Daisey J. Tracers for assessing exposure to environmental tobacco smoke: what are they tracing? Environ Health Perspect 1999; 107(2S):S319–S327.
24. Apte MG, Gundel LA, Dod RL, et al. Indoor measurements of environmental tobacco smoke: final report to the Tobacco Related Disease Research Program. LBNL – 49148. Berkeley CA: Lawrence Berkeley National Laboratory, 2004.
25. TSI, Inc. Determining custom calibration factors for photometers: application note ITI-099. www.tsi.com/uploadedFiles/Product_Information/Literature/Application_Notes/DeterminingCustomCalibrationFactorsForPhotometers-ITI-099.pdf.
26. Klepeis NE, Ott WR, Switzer P. Real-time measurement of outdoor tobacco smoke particles. J Air Waste Manag Assoc 2007;57:522–34.
27. Jenkins RA, Ilgner RH, Tomkins BA, Peters DW. Development and application of protocols for the determination of response of real-time particle monitors to common indoor aerosols. J Air Waste Manag Assoc 2004;54(2):229–41.
28. Hettmansperger TP, Sheather SJ. Confidence intervals based on interpolated order statistics. Stat Probab Lett 1986;4:75–9.
29. Jensen JA, Schillo BA, Moilanen MM, et al. Tobacco smoke exposure in nonsmoking hospitality workers before and after a state smoking ban. Cancer Epidemiol Biomarkers Prev 2010;19(4):1016–21.