Delaware County Air Quality Monitoring Study
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Introduction

An estimated 20% of the U.S. adult population are current smokers. The most recent trends in adult tobacco use reveal that smoking prevalence among U.S. adults has stabilized after having fallen across all age groups for several years. Adult smoking prevalence is highest in the Midwest (21.8%) (Centers for Disease Control [CDC], 2011). Although population-based data show declining secondhand smoke [SHS] exposure in the U.S. overall, SHS exposure remains a major public health concern that is entirely preventable.

Clean indoor air [CIA] policies have been adopted by communities across the United States and internationally to protect employees in all workplaces, and others who might venture into work settings, from exposure to environmental tobacco smoke. Because requiring smokefree environments is the most effective method for reducing SHS exposure in public places, Healthy People 2020 Objective TU-13 encourages all states and the District of Columbia to establish and to enforce smokefree air laws in public places and worksites (U.S. Department of Health and Human Services [USDHHS], 2012). Currently, 23 states (Arizona, Delaware, Hawaii, Illinois, Iowa, Kansas, Maine, Maryland, Massachusetts, Michigan, Minnesota, Montana, Nebraska, New Jersey, New York, Ohio, Oregon, Rhode Island, South Dakota, Utah, Vermont, Washington and Wisconsin) and the District of Columbia have adopted comprehensive legislation requiring 100% smokefree workplaces, restaurants, and bars. Together with municipal regulations, these statewide laws protect approximately 47.5% of the population from worksite exposure to SHS (American Cancer Society, 2012).

On June 6, 2011, the Delaware County, Indiana Board of Commissioners unanimously adopted comprehensive smokefree worksite legislation, for the first time prohibiting smoking in all workplaces, including bars. The law went into effect on August 11, 2011. The goal of this study was to compare levels of fine particulate pollution in the indoor air of Delaware County bars and restaurants before and after enactment of countywide comprehensive smokefree worksite legislation. It was hypothesized that there would be a significant reduction in indoor particulate air pollution levels in restaurants and bars after the enactment of the ordinance compared to levels prior to enactment of the ordinance.

Methods

Indoor air quality was assessed in 10 bar/restaurant locations in Delaware County, Indiana. Particulate matter was measured twice in each venue, first in July 2011, before the comprehensive indoor worksite smoking law went into effect, and three months later, in October 2011, after the law took effect.

Venue Selection

A convenience sample of 10 establishments was selected from a list of bars that were exempt from the existing ordinance prior to adoption of the comprehensive smoking ban. These ten venues were selected so as to provide a range of venue characteristics such as: type of venue (i.e. bar, restaurant, restaurant with bar etc…), size of venue, and location. Venues were selected from popular entertainment districts, as well as other locations throughout Delaware County to provide a representative cross section of venues servicing a large and diverse population. The clientele of each establishment varied. Each venue was visited on either a Friday or Saturday evening during both data collection periods.

Measurement Protocol

A minimum of 30 minutes was spent in each venue. The number of people inside the venue and the number of burning cigarettes were recorded every 15 minutes during sampling. These observations were averaged over the time inside the venue to determine the average number of people on the premises and the average number of burning cigarettes. Room dimensions were also determined using a sonic measuring device. Room volumes were calculated from these dimensions, and measured in cubic meters. The active smoker density was calculated by dividing the average number of burning cigarettes by the volume of the room in cubic meters.

A TSI SidePak AM510 Personal Aerosol Monitor (TSI, Inc., St. Paul, MN) was used to sample and record the levels of respirable suspended particles in the air. The SidePak uses a built-in sampling pump to draw air through the device where the particulate matter in the air scatters the light from a laser. This portable light-scattering aerosol monitor was fitted with a 2.5 μm impactor in order to measure the concentration of particulate matter with a mass-median aerodynamic diameter less than or equal to 2.5 μm, or $PM_{2.5}$. Tobacco smoke particles are almost exclusively less than 2.5 μm with a mass-median diameter of 0.2 μm (Klepeis, Apte, Gundel,

Sextro, & Nazaroff, 2003). The Sidepak was used with a calibration factor setting of 0.32, suitable for secondhand smoke (Klepeis, Ott, & Switzer, 2007; Travers, 2008). In addition, the SidePak was zero-calibrated prior to each use by attaching a HEPA filter according to the manufacturer's specifications.

The equipment was set to a one-minute log interval, which averages the previous 60 one-second measurements. Sampling was discreet in order not to disturb the occupants' normal behavior. For each venue, the first and last minute of logged data were removed because they are averaged with outdoor and entryway air. The remaining data points were averaged to provide an average $PM_{2.5}$ concentration within the venue. Teams of trained testers from Delaware County did the sampling and researchers from Ball State University analyzed the data.

Statistical Analyses

The primary goal was to assess change in the average levels of $PM_{2.5}$ in venues from before the smokefree air ordinance was enacted to after enactment. Statistical significance was assessed using a paired samples t test on the log-transformed $PM_{2.5}$ concentrations. $PM_{2.5}$ concentrations were log-transformed to achieve normality and homogeneity of variances. The smokefree comparison data were collected using the exact same protocol and these results have been reported elsewhere. (Travers, 2008)

Results

Table 1 displays descriptive statistics for pre-law $PM_{2.5}$ levels by venue. Pre-law $PM_{2.5}$ means ranged from 50.94 $\mu g/m^3$ (venue #6) to 361.84 $\mu g/ m^3$ (venue #3). Mean pre-law $PM_{2.5}$ across venues was 154.14 $\mu g/ m^3$.

Table 1.
Pre-law $PM_{2.5}$ levels by venue

Venue #	Mean (μg/m³)	St. dev.	Max. (μg/m³)	Min. (μg/m³)
1	71.6891	63.28921	218.24	.64
2	203.8503	55.08956	312.64	127.36
3	361.8400	62.22082	435.84	265.28
4	351.6400	54.34956	450.88	224.96
5	133.9200	13.77699	147.52	72.96
6	50.9388	15.98715	83.52	15.68
7	72.8930	12.75240	94.72	28.16
8	105.8720	30.58084	168.64	44.80
9	73.8000	13.10218	97.92	26.24
10	190.6812	54.23704	263.36	14.40

Table 2 displays descriptive statistics for post-law $PM_{2.5}$ levels by venue. Post-law $PM_{2.5}$ means ranged from 3.38 μg/ m^3 (venue #10) to 54.41 μg/ m^3 (venue #1). Mean post-law $PM_{2.5}$ across venues was 13.74 μg/ m^3.

Table 2.
Post-law $PM_{2.5}$ levels by venue

Venue #	Mean (μg/m³)	St. dev.	Max. (μg/m³)	Min. (μg/m³)
1	54.4133	6.32017	66.24	41.92
2	9.8103	3.03077	15.04	4.48
3	4.7587	.30629	5.44	4.16
4	14.7520	2.45056	18.24	8.96
5	8.0772	.74878	10.24	7.04
6	7.3554	1.20672	9.92	3.52
7	7.4240	1.37676	9.92	5.44
8	7.2052	1.79860	10.56	4.48
9	5.0240	8.70865	48.96	2.56
10	3.3813	.57418	4.48	2.56

The degree of change in $PM_{2.5}$, pre-law to post-law, ranged from 24.10% (venue #1) to 98.68% (venue #3).

The mean degree of change in $PM_{2.5}$, pre-law to post-law, was 86.77% (Table 3).

Table 3.
Percent change in $PM_{2.5}$ levels, by venue

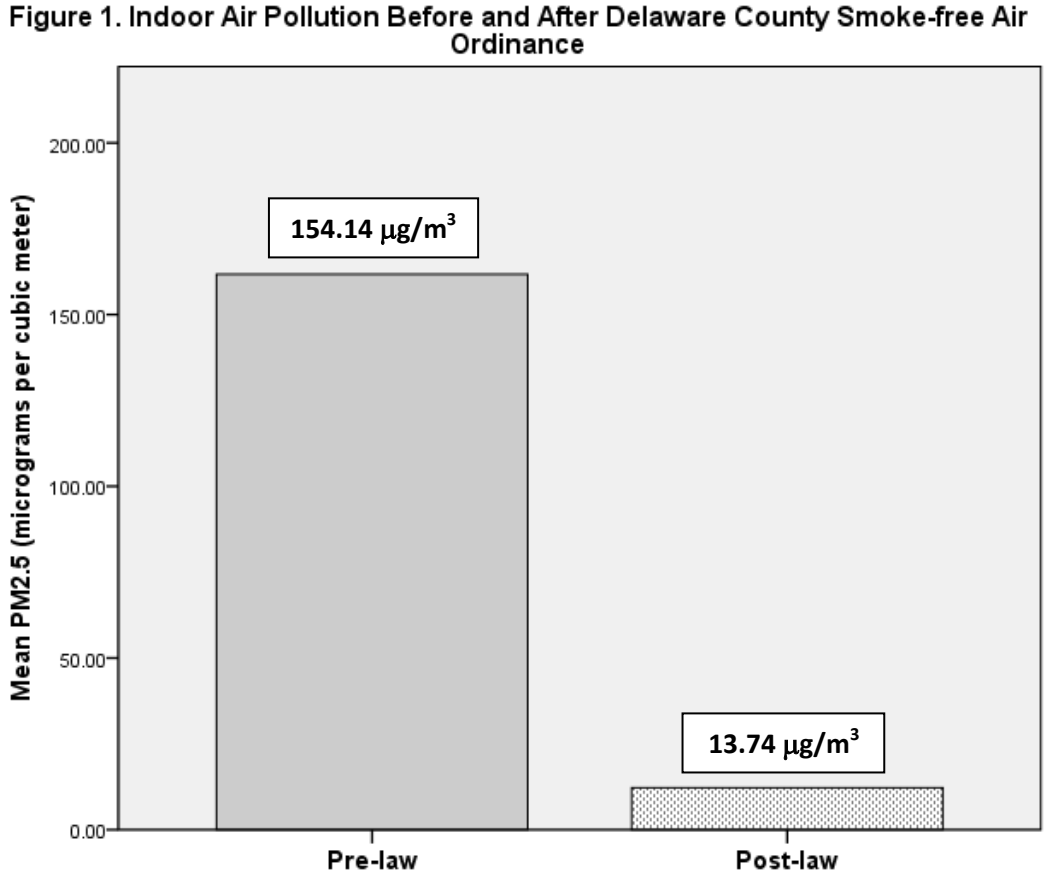
Venue #	Mean Pre-law (μg/m³)	Mean Post-law (μg/m³)	% change
1	71.6891	54.4133	24.10
2	203.8503	9.8103	95.19
3	361.8400	4.7587	98.68
4	351.6400	14.7520	95.81
5	133.9200	8.0772	93.97
6	50.9388	7.3554	85.56
7	72.8930	7.4240	89.82
8	105.8720	7.2052	93.19
9	73.8000	5.0240	93.19
10	190.6812	3.3813	98.23

Paired-samples t test assessed the significance of the change in log-transformed mean $\mu g/m^3$ pre-law to post-law. The change in $PM_{2.5}$ levels between pre-law and post-law was statistically significant ($t = -7.652$, $p<0.001$).

Observed compliance with the smokefree air ordinance was universal, 100%. Smoking was not observed during any of the 10 post-law visits, whereas smoking was observed during all of the pre-law visits. The average number of burning cigarettes decreased from 5.4 cigarettes before the law to 0.0 after the law and the average active smoker density decreased from 1.13 burning cigarettes per 100 m^3 to 0.00 in the locations sampled (Table 4).

Table 4.
Venue volume, mean number cigarettes smoked, and smoker density, by venue

Venue	Area (m^3)	Mean # cig./visit Pre	Mean cig. per 100 m^3 Pre	Mean # cig./visit Post
1	161	3.25	2.02	0
2	251	7.67	3.06	0
3	683	11.33	1.66	0
4	1096	7.33	0.67	0
5	222	3.2	1.44	0
6	888	3.25	0.37	0
7	626	2.25	0.36	0
8	281	4.75	1.70	0
9	269	3.67	1.36	0
10	309	7.33	2.37	0



Discussion

Particulate matter air pollution consists of various solid and liquid droplets, both inorganic and organic, suspended in the air. These pollutants include acids, organic chemicals, metals, soil and dust particles, and allergens (such as pollen and mold spores). Innumerable controlled studies have established the causative link between particulate air pollution and serious acute and chronic health problems, such as heart arrhythmias, myocardial infarction, asthma and bronchitis. Elevated levels of particulate matter pollution have been linked to increased emergency room visits, increased school and work absences, lost productivity, and more days of restricted activity (U.S. Environmental Protection Agency [EPA], 2012). In order to protect the public's health, the EPA set a new limit of 35 $\mu g/m^3$ for $PM_{2.5}$ on December 17,

2006 as the average level of exposure over 24-hours in outdoor environments. There is no EPA standard for indoor air quality. There were over 80 EPA cited epidemiologic studies in creating a particulate air pollution standard in 1997 (EPA, 1997).

Before enactment of the nonsmoking ordinance, the average $PM_{2.5}$ level in the Delaware County venues was 154.14 $\mu g/m^3$, which is 4.4 times higher than the National Ambient Air Quality Standard (NAAQS) for 24 hours ($35\mu g/m^3$). The results of this study were consistent with similar studies involving indoor air quality. A similar study conducted in Indianapolis, Indiana which compared smokefree venues to venues where smoking was allowed found comparable results. The average level of indoor air pollution was 164 $\mu g/m^3$ in smoking venues and $15\mu g/m^3$ in smokefree venues (Travers, 2009). An 89% decrease in $PM_{2.5}$ was also documented in Bloomington, Indiana locations that went smokefree after the city implemented a smokefree air ordinance (Travers, Hyland, & Repace, 2004). Similar results were found in a study conducted in Grant County, Indiana, where the average $PM_{2.5}$ level was 113 $\mu g/m^3$ in eight smoking venues and the average $PM_{2.5}$ level in five smokefree venues was 9 $\mu g/m^3$ (Travers, 2008). A study of a single tavern in California found an average decrease of 82% in respirable suspended particles (RSP) after smoking was prohibited by a city ordinance (Ott, Switzer, & Robinson, 1996). These studies support the assertion that policies which regulate the use of tobacco products in enclosed areas can have an immediate and dramatic impact on indoor air quality.

The health effects of exposure to secondhand smoke are well documented. Since 1964, 30 U.S. Surgeon General's reports have addressed the health risks associated with SHS. SHS is classified as a potential cancer-causing agent by the Occupational Safety and Health Administration (OSHA). Because there is no recognized safe level of secondhand smoke exposure, the National Institute for Occupational Safety and Health (NIOSH) recommends that exposures to SHS be reduced to the lowest levels possible (American Cancer Society, 2011).

Conclusions

This study demonstrated that workers and patrons in Delaware County, Indiana, were exposed to harmful levels of secondhand smoke in hospitality venues prior to enactment of the smokefree air ordinance. On average, workers and patrons in Delaware County were exposed to

indoor air pollution levels over four times the National Ambient Air Quality Standard, and the level of indoor air pollution was comparable to levels of other indoor smoking venues in the state. Partial smokefree laws do not protect workers and patrons from harmful indoor air pollution. However, when smoking is completely prohibited as with Delaware County's comprehensive smokefree air ordinance, air quality is significantly improved.

Table 5.
Fine Particulate Air Pollution in Delaware County, Indiana Venues

		Pre-law					Post-law					
Venue #	**Size (m^3)**	**Date sampled**	**Ave. # people**	**Ave. # burning cigs.**	**Active smoker density***	**Ave. $PM_{2.5}$ level ($\mu g/m^3$)**	**Date sampled**	**Ave. # people**	**Ave. # burning cigs.**	**Active smoker density**	**Ave. $PM_{2.5}$ level ($\mu g/m^3$)**	**% reduction in $PM_{2.5}$**
1	161	7/22/11	41	3.25	2.02	72	10/14/11	31	0	0	54	24.10
2	251	7/22/11	31	7.67	3.06	204	10/14/11	74	0	0	10	95.19
3	683	7/22/11	51	11.33	1.66	362	10/14/11	62	0	0	5	98.68
4	1096	7/22/11	42	7.33	0.67	352	10/14/11	16	0	0	15	95.81
5	222	7/23/11	10	3.20	1.44	134	10/15/11	18	0	0	8	93.97
6	888	7/23/11	17	3.25	0.37	51	10/15/11	52	0	0	7	85.56
7	626	7/23/11	16	2.25	0.36	73	10/15/11	23	0	0	7	89.82
8	281	7/23/11	13	4.75	1.70	106	10/15/11	18	0	0	7	93.19
9	269	7/23/11	9	3.67	1.36	74	10/15/11	19	0	0	5	93.19
10	309	7/23/11	21	7.33	2.37	191	10/15/11	13	0	0	3	98.23
Average	480		25.1	5.40	1.13	154		33	0	0	12	86.77

NOTES: *Average number of burning cigarettes per 100 cubic meters.

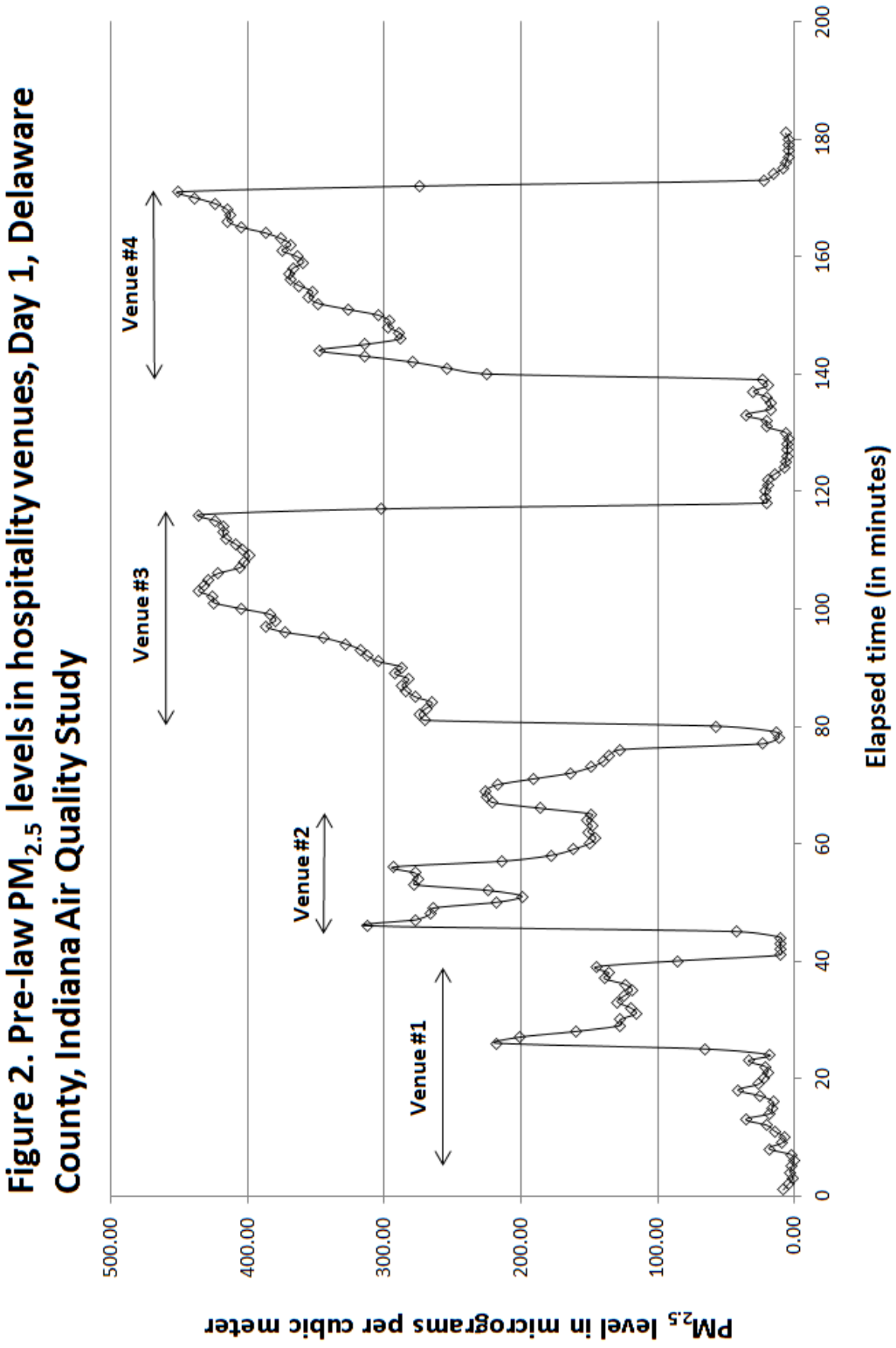


Figure 2. Pre-law $PM_{2.5}$ levels in hospitality venues, Day 1, Delaware County, Indiana Air Quality Study

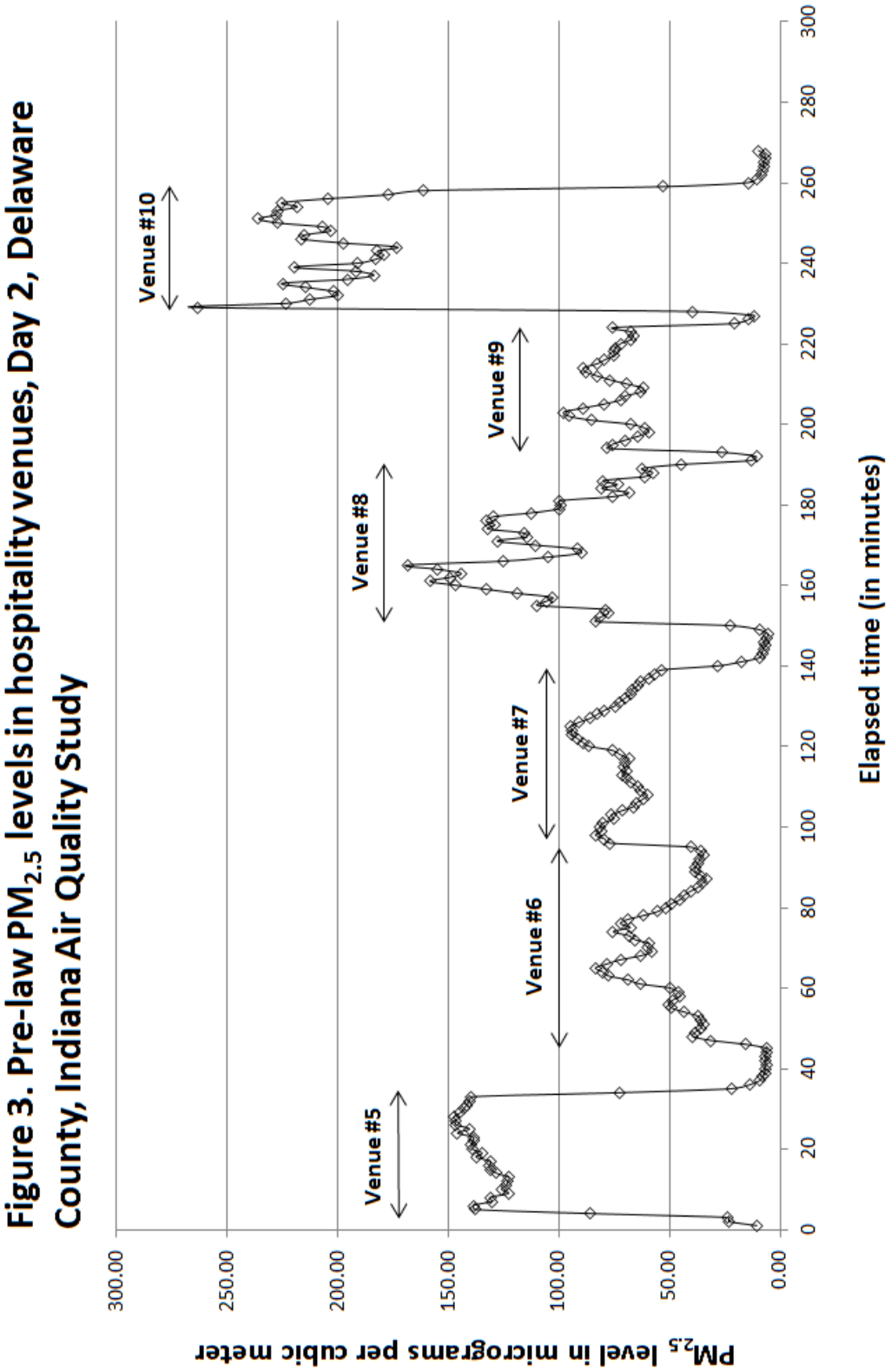


Figure 3. Pre-law PM2.5 levels in hospitality venues, Day 2, Delaware County, Indiana Air Quality Study
PM2.5 level in micrograms per cubic meter
300.00
250.00
200.00
150.00
100.00
50.00
0.00
Elapsed time (in minutes)
0
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
Venue #5
Venue #6
Venue #7
Venue #8
Venue #9
Venue #10

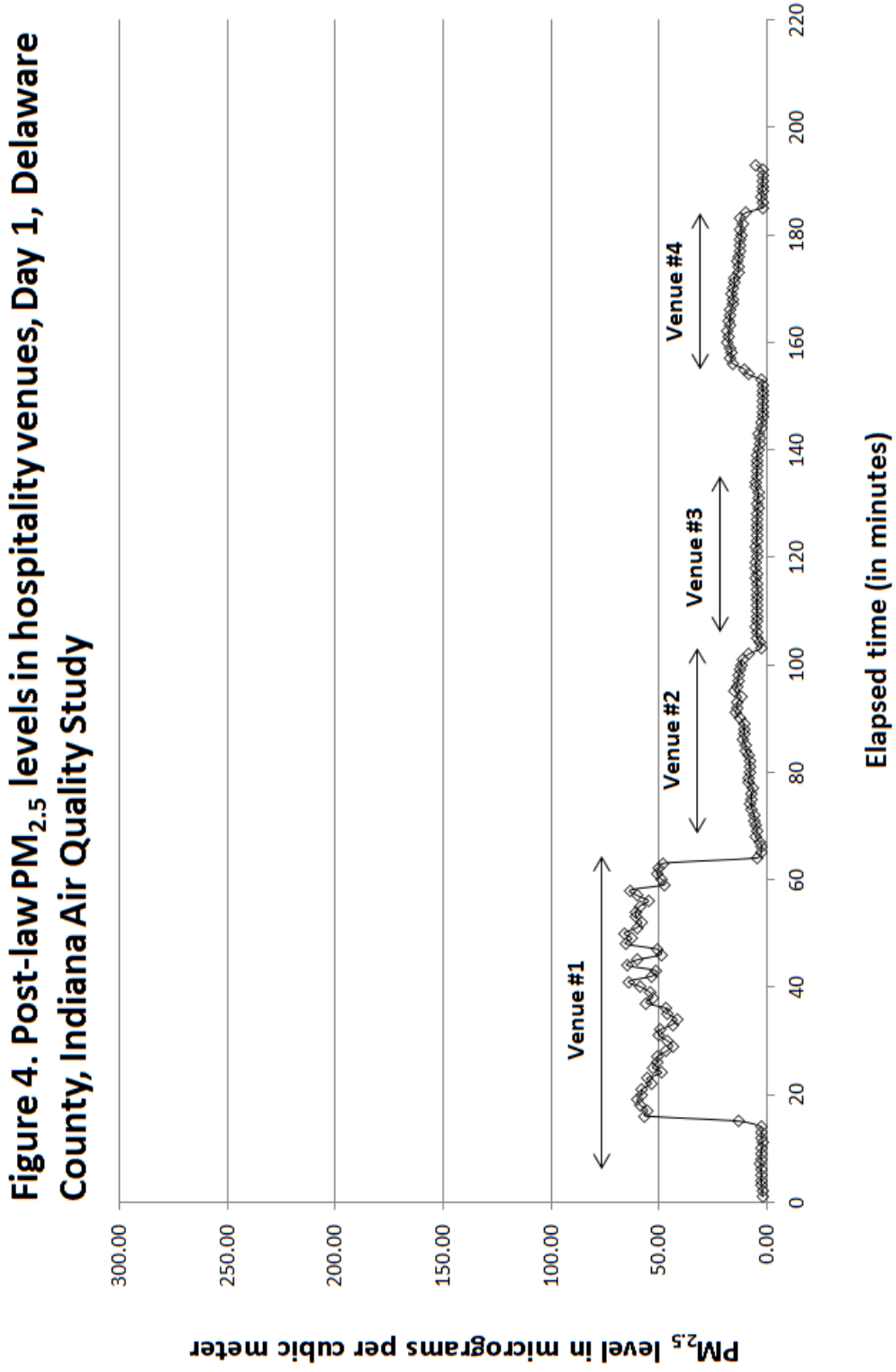


Figure 4. Post-law $PM_{2.5}$ levels in hospitality venues, Day 1, Delaware County, Indiana Air Quality Study
$PM_{2.5}$ level in micrograms per cubic meter
300.00
250.00
200.00
150.00
100.00
50.00
0.00
Elapsed time (in minutes)
0
20
40
60
80
100
120
140
160
180
200
220
Venue #1
Venue #2
Venue #3
Venue #4

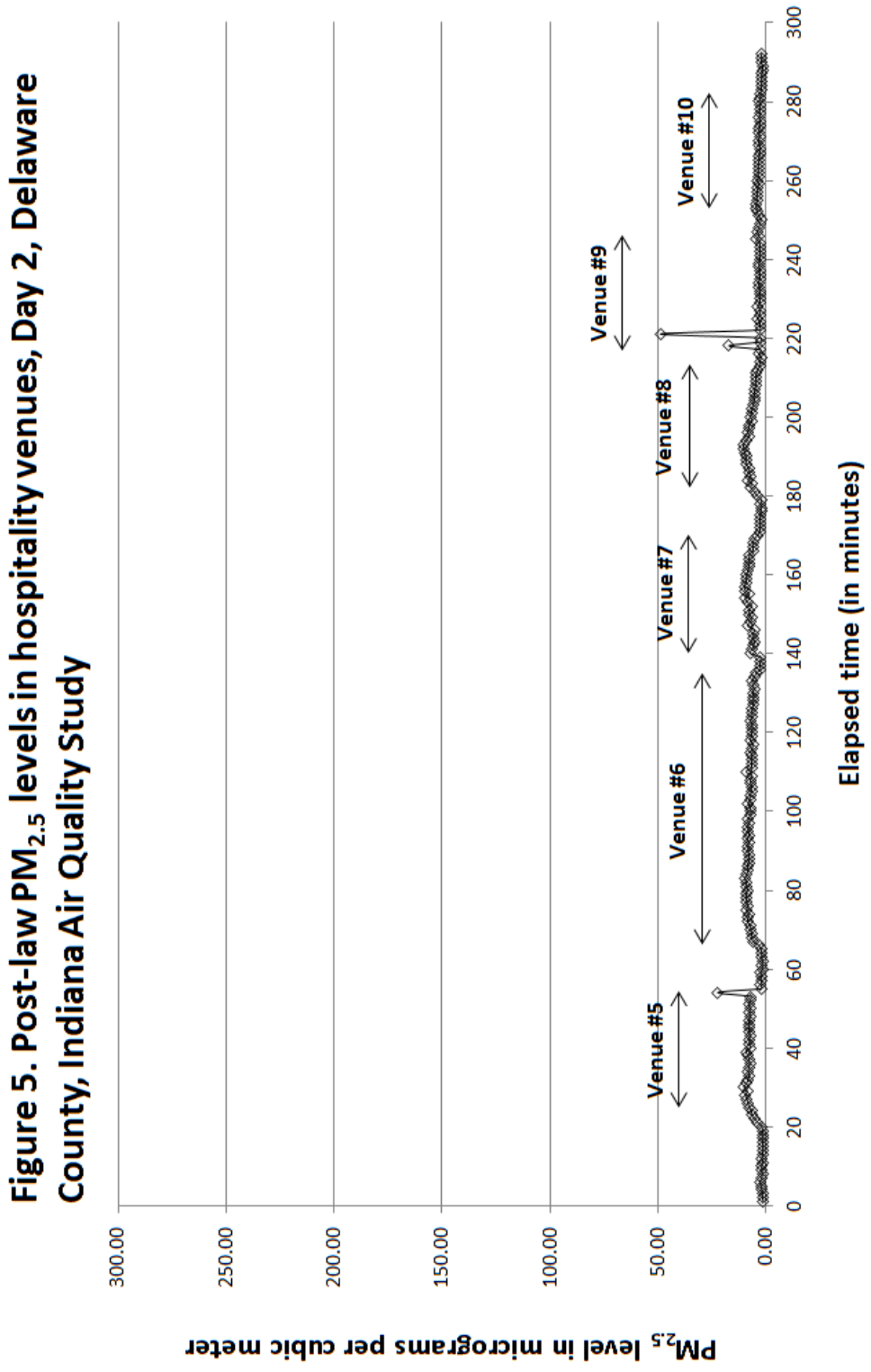


Figure 5. Post-law PM2.5 levels in hospitality venues, Day 2, Delaware County, Indiana Air Quality Study
PM2.5 level in micrograms per cubic meter
300.00
250.00
200.00
150.00
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Elapsed time (in minutes)
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240
260
280
300
Venue #5
Venue #6
Venue #7
Venue #8
Venue #9
Venue #10

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