West Lafayette Air Monitoring Study

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Executive Summary

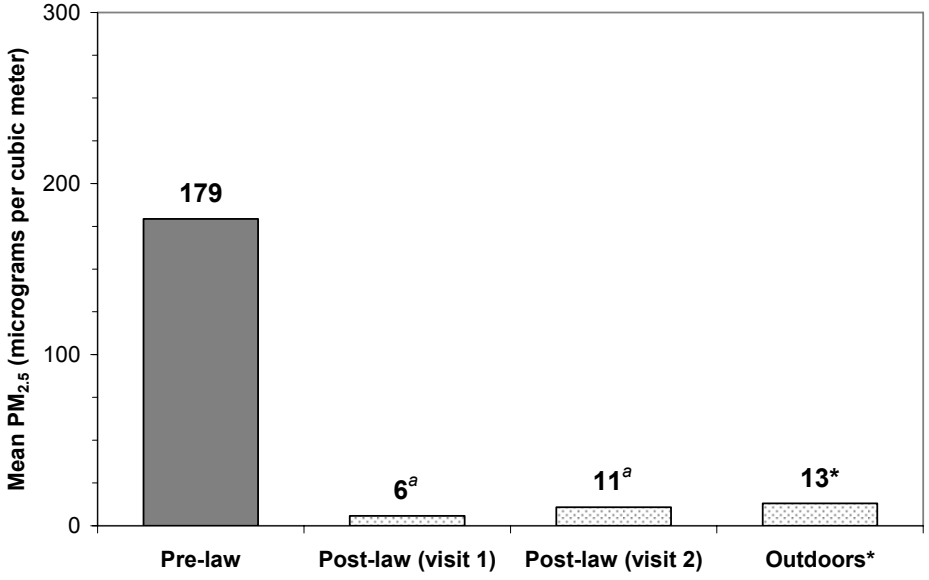
Indoor air quality was assessed in 7 West Lafayette bars and restaurants once before and twice after the implementation of the new West Lafayette smoke-free air law on July 1, 2007. The concentration of fine particle air pollution, $PM_{2.5}$, was measured with a TSI SidePak AM510 Personal Aerosol Monitor. $PM_{2.5}$ is particulate matter in the air smaller than 2.5 microns in diameter. Particles of this size are released in significant amounts from burning cigarettes, are easily inhaled deep into the lungs, and cause a variety of adverse health effects including cardiovascular and respiratory disease and death.

Key findings of the study include:

- The average level of fine particle indoor air pollution declined 94% after the West Lafayette ordinance went into effect in those venues that went smoke-free as a result of the law.
- Compliance with the law during the 14 post-law visits was 93%, as smoking was observed inside during only one post-law visit.
- Before the law, employees in sampled locations were exposed to unhealthy air according to U.S. Environmental Protection Agency (EPA) standards. They now work in environments with safe levels of fine particle air pollution.

Before implementation of the West Lafayette smoke-free air ordinance, locations allowing indoor smoking were significantly more polluted than indoor smoke-free sites and than outdoor air in Lafayette, with levels of pollution in excess of EPA standards. As a result of the West Lafayette ordinance, air quality is dramatically improved for workers and patrons of those hospitality venues where indoor smoking became prohibited.

Figure 1. Indoor Air Pollution Before and After West Lafayette Smoke-free Air Ordinance



[a] p≤0.001 for comparison of pre-law and post-law values (Paired t-test of log-transformed values)

* Used for comparison purposes. Based on the 2007 average $PM_{2.5}$ level at Lafayette, IN EPA monitoring sites. http://www.epa.gov/air/data/

Introduction

Secondhand smoke (SHS) contains at least 250 chemicals that are known to be toxic or carcinogenic, and is itself a known human carcinogen,[1] responsible for an estimated 3,000 lung cancer deaths annually in *never smokers* in the U.S., as well as more than 35,000 deaths annually from coronary heart disease in *never smokers,* and respiratory infections, asthma, Sudden Infant Death Syndrome, and other illnesses in children.[2] Although population-based data show declining SHS exposure in the U.S. overall, SHS exposure remains a major public health concern that is entirely preventable.[3, 4] Because requiring smoke-free environments is the most effective method for reducing SHS exposure in public places,[5] Healthy People 2010 Objective 27-13 encourages all states and the District of Columbia to establish and to enforce smoke-free air laws in public places and worksites.[6]

Currently in the U.S., 22 states, Washington, DC, and Puerto Rico have enacted strong smoke-free laws that include restaurants and bars. The states are Arizona, California, Colorado, Connecticut, Delaware, Hawaii, Illinois, Maine, Maryland, Massachusetts, Minnesota, Montana, New Hampshire, New Jersey, New Mexico, New York, Ohio, Oregon, Rhode Island, Utah, Vermont, and Washington (Montana and Utah laws include bars in 2009; Maryland and Oregon laws go into effect in Feb. 2008 and Jan. 2009 respectively). Well over 50% of the U.S. population is now protected from secondhand smoke in all public places.[7] Florida, Idaho, Louisiana, Nevada, and North Dakota have smoke-free laws that exempt stand-alone bars. Nine Canadian provinces and territories also have comprehensive smoke-free air laws in effect. Hundreds of cities and counties across the U.S. have also taken action, as have whole countries including Ireland, Scotland, Uruguay, Norway, New Zealand, Sweden, Italy, Spain, England and France.

West Lafayette, Indiana is located in Tippecanoe County. It is home to Purdue University and 28,778 permanent residents. On July 1, 2007, West Lafayette implemented a city-wide ordinance banning smoking in all indoor workplaces and public gathering areas. Now all indoor city workplaces are 100% smoke free, including restaurants and bars. Exceptions of the law include: outdoor places of employment, private homes (except when used as a licensed child care, adult day care or health care facility), up to 25 percent of rooms in hotels, and all membership clubs, retail tobacco stores, and tobacco bars. Smoking is allowed outdoors, except where prohibited by other applicable laws.

The goal of this study was to evaluate the effect of the new July 1, 2007 ordinance on the level of indoor air pollution in West Lafayette worksites that went smoke-free. It was hypothesized that indoor air would be less polluted in these places after the implementation of the ordinance.

Methods

Overview

A total of 7 bars and restaurants visited both before and after the July 1, 2007 implementation of the West Lafayette ordinance prohibiting smoking in indoor public places. Locations were visited once before the law and twice after the law. The pre-law visits were made on April 12, 2007, while the post-law visits were made on July 12 and September 27, 2007. Post-law visits occurred on the same day of the week (Thursday) and at the same time of day as the pre-law visits. Some sites were individually-owned establishments and some were part of local or national chain entities.

Measurement Protocol

Researchers spent a minimum of 30 minutes 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. The IntelliMeasure Distance Estimator (Stanley Tools, New Briton, CT) was used to measure room dimensions and hence the volume of each of the venues. The active smoker density was calculated by dividing the average number of burning cigarettes by the volume of the room in 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.[8] The Sidepak was used with a calibration factor setting of 0.32, suitable for secondhand smoke. This calibration factor was determined in an experiment with the SidePak collocated with another light-scattering instrument that had been previously calibrated against standard pump-and-filter gravimetric methods and used in SHS exposure studies.[9] Klepeis et al. found a similar SHS calibration factor for the Sidepak when compared to a Piezobalance (Kanomax, Inc.) which provides direct measurements of RSP mass concentrations.[10] This calibration factor has also been confirmed by another researcher who compared Sidepak measurements of SHS to gravimetric measurements using a Personal Environmental Monitor (PEM for PM2.5, MSP Corporation, Shoreview, MN).[11] In addition, the SidePak was zero-calibrated prior to each use by attaching a HEPA filter according to the manufacturer's specifications.

TSI SidePak AM510 Personal Aerosol Monitor

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 outdoors and entryway air. The remaining data points were averaged to provide an average $PM_{2.5}$ concentration within the venue.

> ***$PM_{2.5}$ is the concentration of particulate matter in the air smaller than 2.5 microns in diameter. Particles of this size are released in significant amounts from burning cigarettes, are easily inhaled deep into the lungs, and are associated with respiratory and cardiovascular disease and death.***

Roswell Park Cancer Institute staff trained the Indiana testers and analyzed the data.

Statistical Analyses

The primary goal was to assess the difference in the average level of $PM_{2.5}$ in worksites and public places after the implementation of a smoke-free air law. Since $PM_{2.5}$ levels are generally log-normally distributed, all statistical testing was performed using log-transformed $PM_{2.5}$ values. Pre- and post-law $PM_{2.5}$ values were compared using a paired-samples *t* test. Descriptive statistics including the venue volume, number of patrons, and average smoker density (i.e., number of burning cigarettes per 100 m^3) are reported for each venue and averaged for each time period as well.

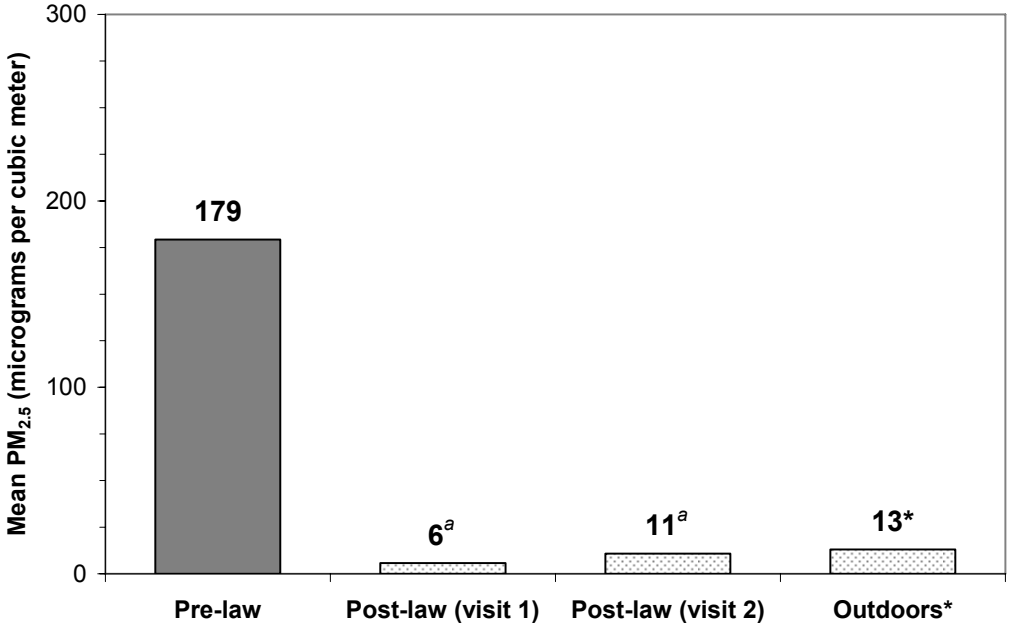
Results

The average $PM_{2.5}$ level in the 7 locations that went smoke-free as a result of the West Lafayette ordinance was 179 $\mu g/m^3$ before the law, 6 $\mu g/m^3$ after the law during visit 1, and 11 $\mu g/m^3$ after the law during visit 2. The mean of the two post-law visits were not significantly different and were averaged for simplicity. Comparing the pre-law visits to the average of the two post-law we see there was an average 94% reduction in fine particle indoor air pollution. These aggregate results are shown in Figure 1. The difference between pre-law and post-law $PM_{2.5}$ levels is large and statistically significant ($t(6)=23.2$, $p<0.001$, $r=0.96$).

Compliance with the smoke-free air ordinance was high at 93%. Smoking was observed during only one of the 14 post-law visits, whereas smoking was observed during all of the pre-law visits. The average number of burning cigarettes decreased from 2.1 cigarettes before the law to 0.0 after the law and the average active smoker density decreased from 0.49 burning cigarettes per 100 m^3 to 0.00 in the locations sampled. $PM_{2.5}$ level was significantly correlated with the active smoker density, $r_s=0.77$, $p<0.01$.

There is an outdoor air monitoring site in Lafayette, IN that uses the EPA's Federal Reference Method for measuring $PM_{2.5}$ in outdoor air. The average $PM_{2.5}$ level for 2007 from this site was found at http://www.epa.gov/air/data/ and was used to determine the average outdoor $PM_{2.5}$ level as a comparison for this study. This average outdoor $PM_{2.5}$ level is 12.6 $\mu g/m^3$ (shown in Figure 1).

Figure 1. Indoor Air Pollution Before and After West Lafayette Smoke-free Air Ordinance



[a] p≤0.001 for comparison of pre-law and post-law values (Paired t-test of log-transformed values)

* Used for comparison purposes. Based on the 2007 average $PM_{2.5}$ level at Lafayette, IN EPA monitoring sites. http://www.epa.gov/air/data/

Table 1. Fine Particle Air Pollution in West Lafayette Hospitality Venues

		Pre-Law					Post-Law (visit 1)					Post-Law (visit 2)					
Venue Number	Size (m^3)	Date Sampled	Average # people	Average # burning cigs	Active smoker density*	Average $PM_{2.5}$ level ($\mu g/m^3$)	Date Sampled	Average # people	Average # burning cigs	Active smoker density*	Average $PM_{2.5}$ level ($\mu g/m^3$)	Date Sampled	Average # people	Average # burning cigs	Active smoker density*	Average $PM_{2.5}$ level ($\mu g/m^3$)	% reduction† in $PM_{2.5}$
1	556	4/12/07	35	4.0	0.72	666	7/12/07	25	0.0	0.00	10	9/27/07	36	0.0	0.00	43	96.0%
2	151	4/12/07	22	1.3	0.88	64	7/12/07	5	0.0	0.00	4	9/27/07	36	0.0	0.00	4	93.8%
3	779	4/12/07	57	2.3	0.30	67	7/12/07	44	0.0	0.00	4	9/27/07	72	0.0	0.00	4	94.0%
4	652	4/12/07	44	2.0	0.31	70	7/12/07	16	0.0	0.00	4	9/27/07	61	0.0	0.00	5	93.6%
5	878	4/12/07	51	2.0	0.23	128	7/12/07	4	0.0	0.00	2	9/27/07	8	0.0	0.00	7	96.5%
6	1,445	4/12/07	35	2.0	0.14	223	7/12/07	15	0.0	0.00	13	9/27/07	10	0.3	0.02	10	94.8%
7	116	4/12/07	28	1.0	0.86	37	7/12/07	12	0.0	0.00	4	9/27/07	24	0.0	0.00	3	90.5%
Average	654		39	2.1	0.49	179		17	0.0	0.00	6		35	0.0	0.00	11	94.2%

NOTES: * Average number of burning cigarettes per 100 cubic meters.
† based on the average of the 2 post-law visits

Table 1 shows the results for each location visited.

$PM_{2.5}$ concentrations decreased after the law in all seven of the places visited. Post-law levels were very low (<15 $\mu g/m^3$) during all visits except the second visit to venue 1 where levels were elevated (43 $\mu g/m^3$). It is not clear why levels were elevated during this visit but it could be from tobacco smoke drift from outside, unobserved smoking inside the venue, or another source of particles such as cooking.

The real-time plots showing the $PM_{2.5}$ level in each venue minute-by-minute during sampling are presented in the Appendix, Figures 2 through 5, starting on page 11. The real-time plots throughout sampling reveal the following results: 1) low background levels are observed outdoors; 2) much higher levels of fine particle air pollution are measured in venues before the law, when smoking was permitted; 3) peak exposure levels when smoking was permitted can far exceed the average recorded levels in a given venue; 4) indoor fine particle pollution levels are much lower following implementation of the smoke-free air ordinance.

Figure 2 shows the plot for the pre-law monitoring done on April 12. Figures 3 and 4 show the plots in the same 7 locations but during the post-law monitoring performed on July 12 and September 27 respectively. Figure 5 shows the pre- and post-law (visit 1) data together on the same graph for comparison purposes. The large reduction in indoor fine particle air pollution after the law is apparent in this figure where the pre-law and post-law data is presented using the same y-axis scale.

Discussion

The EPA cited over 80 epidemiologic studies in creating a particulate air pollution standard in 1997.[12] The EPA has recently updated this standard and, in order to protect the public health, the EPA has set limits of 15 $\mu g/m^3$ as the average annual level of $PM_{2.5}$ exposure and 35 $\mu g/m^3$ for 24-hour exposure.[12, 13] In order to compare the findings in this study with the annual EPA $PM_{2.5}$ exposure standard, it was assumed that a full-time employee in the locations sampled that allow smoking works 8 hours, 250 days a year, is exposed to 179 $\mu g/m^3$ (the average level in all sites before the ordinance) on the job, and is exposed only to background particle levels of 12.6 $\mu g/m^3$ during non-work times. For a full-time employee their average annual $PM_{2.5}$ exposure was 51 $\mu g/m^3$. The EPA average annual $PM_{2.5}$ limit is exceeded by 3.4 times due to their occupational exposure. After the smoke-free air law, these same workers are now exposed to an average particle concentration of 9 $\mu g/m^3$ on the job and, for a full-time employee in these West Lafayette venues, the overall average annual exposure is 12 $\mu g/m^3$, a safe level according to the EPA. Based on the latest scientific evidence, the EPA staff currently proposes even lower $PM_{2.5}$ standards to adequately protect the public health,[14] making the high $PM_{2.5}$ exposures of people in smoking environments even more alarming.

Previous studies have evaluated air quality by measuring the change in levels of respirable suspended particles (RSP) between smoke-free venues and those that permit smoking. In Indiana, an 89% decrease in $PM_{2.5}$ was documented in Bloomington locations that went smoke-free after that town implemented a smoke-free air ordinance.[15] A similar 85% reduction in $PM_{2.5}$ levels was seen in Indianapolis locations that went smoke-free, however levels were unchanged in the locations that were exempt from the Indianapolis ordinance.[16] Ott et al. did a study of a single tavern in California and showed an 82% average decrease in RSP levels after smoking was prohibited by a city ordinance.[17] Repace studied 8 hospitality venues, including one casino, in Delaware before and after a statewide prohibition of smoking in these types of venues and found that about 90% of the fine particle pollution could be attributed to tobacco smoke.[9] Similarly, in a study of 22 hospitality venues in Western New York, Travers et al. found a 90% reduction in RSP levels in bars and restaurants, an 84% reduction in large recreation venues such as bingo halls and bowling alleys, and a 58% reduction even in locations where only SHS from an adjacent room was observed at baseline.[18] A cross-sectional study of 53 hospitality venues in 7 major cities across the U.S. showed 82% less indoor air pollution in the locations subject to smoke-free air laws, even though compliance with the laws was less than 100%.[19]

Other studies have directly assessed the effects SHS exposure has on human health. One study found that respiratory health improved rapidly in a sample of bartenders after a state smoke-free workplace law was implemented in California[20], and another study reported a 40% reduction in acute myocardial infarctions in patients admitted to a regional hospital during the 6 months that a local smoke-free ordinance was in effect.[21] Smoke-free legislation in Scotland was associated with significant early improvements in symptoms, lung function, and systemic inflammation of all bar workers, while asthmatic bar workers also showed reduced airway inflammation and improved quality of life.[22]

Farrelly et al. also showed a significant decrease in both salivary cotinine concentrations and sensory symptoms in hospitality workers after New York State's smoke-free law prohibited smoking in their worksites.[23]

The effects of passive smoking on the cardiovascular system in terms of increased platelet aggregability, endothelial dysfunction, increased arterial stiffness, increased atherosclerosis, increased oxidative stress and decreased antioxidant defense, inflammation, decreased energy production in the heart muscle, and a decrease in the parasympathetic output to the heart, are often nearly as large (averaging 80% to 90%) as chronic active smoking. Even brief exposures to SHS, of minutes to hours, are associated with many of these cardiovascular effects. The effects of secondhand smoke are substantial and rapid, explaining the relatively large health risks associated with secondhand smoke exposure that have been reported in epidemiological studies.[24]

The hazardous health effects of exposure to second-hand smoke are now well-documented and established in various independent research studies and numerous international reports. The body of scientific evidence is overwhelming: there is no doubt within the international scientific community that second-hand smoke causes heart disease, lung cancer, nasal sinus cancer, sudden infant death syndrome (SIDS), asthma and middle ear infections in children and various other respiratory illnesses. There is also evidence suggesting second-hand smoke exposure is also causally associated with stroke, low birthweight, spontaneous abortion, negative effects on the development of cognition and behavior, exacerbation of cystic fibrosis, cervical cancer, and breast cancer in pre-menopausal women. The health effects of secondhand smoke exposure are detailed in recent reports by the California Environmental Protection Agency[25] and the U.S. Surgeon General[26].

Conclusions

This study documented the substantial improvement in indoor air quality that occurred after the implementation of West Lafayette's smoke-free air ordinance. Fine particle air pollution dropped a dramatic 94% in places where smoking was occurring before the law.

Before implementation of the West Lafayette ordinance, locations allowing indoor smoking were significantly more polluted than indoor smoke-free sites and than outdoor air in Lafayette, with levels of pollution in excess of EPA standards. As a result of the West Lafayette ordinance, air quality is dramatically improved for workers and patrons of these hospitality venues. This reduction in exposure to toxic secondhand smoke will result in improved quality of life and health outcomes for West Lafayette workers and residents.

Acknowledgments

Support for this study was provided by Indiana Tobacco Prevention and Cessation and the Flight Attendant Medical Research Institute.

Appendix

U.S. Environmental Protection Agency Air Quality Index		
Air Quality Index Levels of Health Concern	**$PM_{2.5}$ ($\mu g/m^3$)**	**Meaning**
Good	**≤15**	**Air quality is considered satisfactory, and air pollution poses little or no risk.**
Moderate	**16-40**	**Air quality is acceptable; however, for some pollutants there may be a moderate health concern for a very small number of people who are unusually sensitive to air pollution.**
Unhealthy for Sensitive Groups	**41-65**	**Members of sensitive groups may experience health effects. The general public is not likely to be affected.**
Unhealthy	**66-150**	**Everyone may begin to experience health effects; members of sensitive groups may experience more serious health effects.**
Very Unhealthy	**151-250**	**Health alert: everyone may experience more serious health effects.**
Hazardous	**≥251**	**Health warnings of emergency conditions. The entire population is more likely to be affected.**

Real-time plots of $PM_{2.5}$ levels in this study start on the following page.

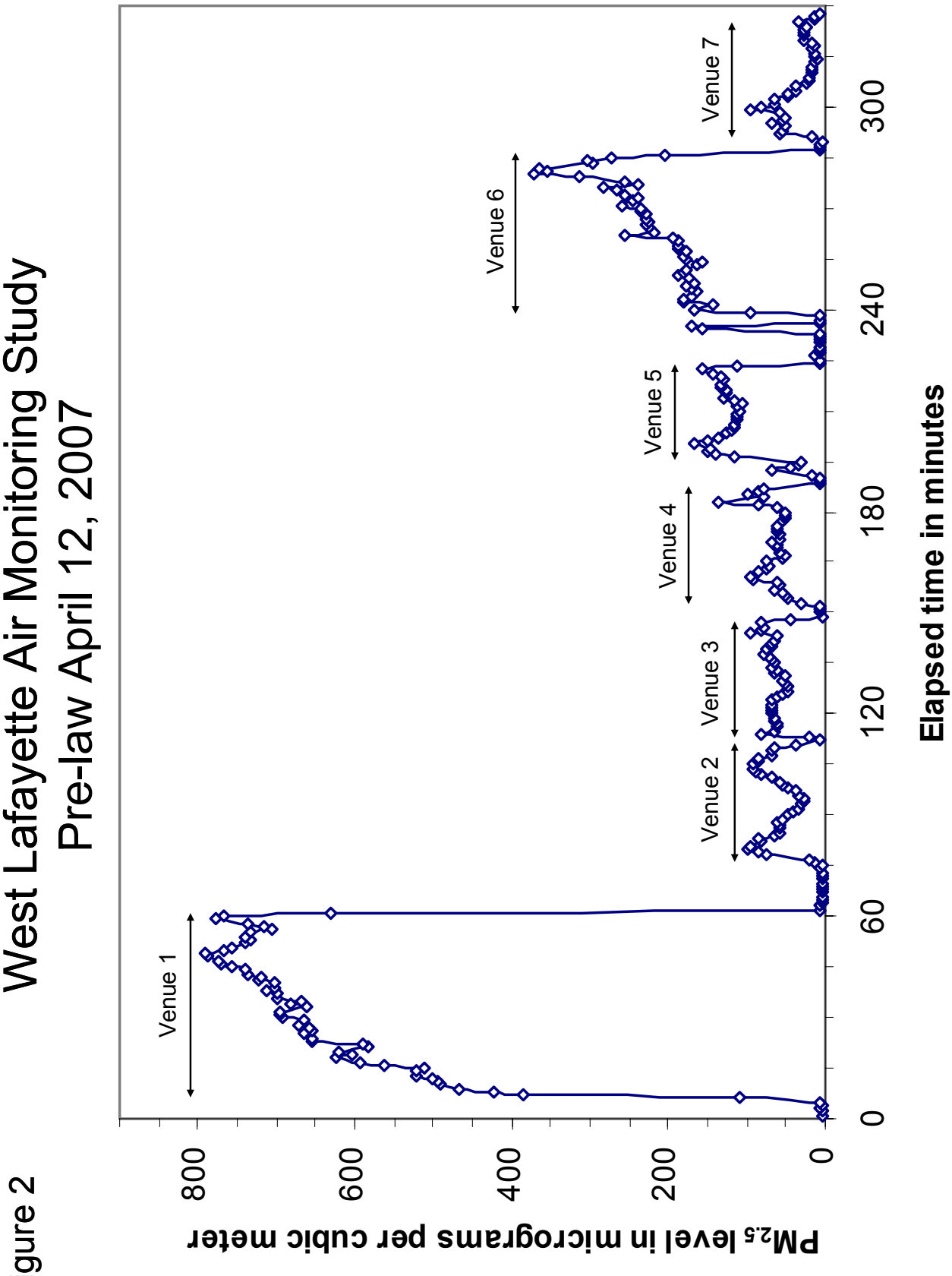

West Lafayette Air Monitoring Study
Pre-law April 12, 2007
PM2.5 level in micrograms per cubic meter
0
200
400
600
800
Elapsed time in minutes
0
60
120
180
240
300
Venue 1
Venue 2
Venue 3
Venue 4
Venue 5
Venue 6
Venue 7

Figure 2

Figure 3

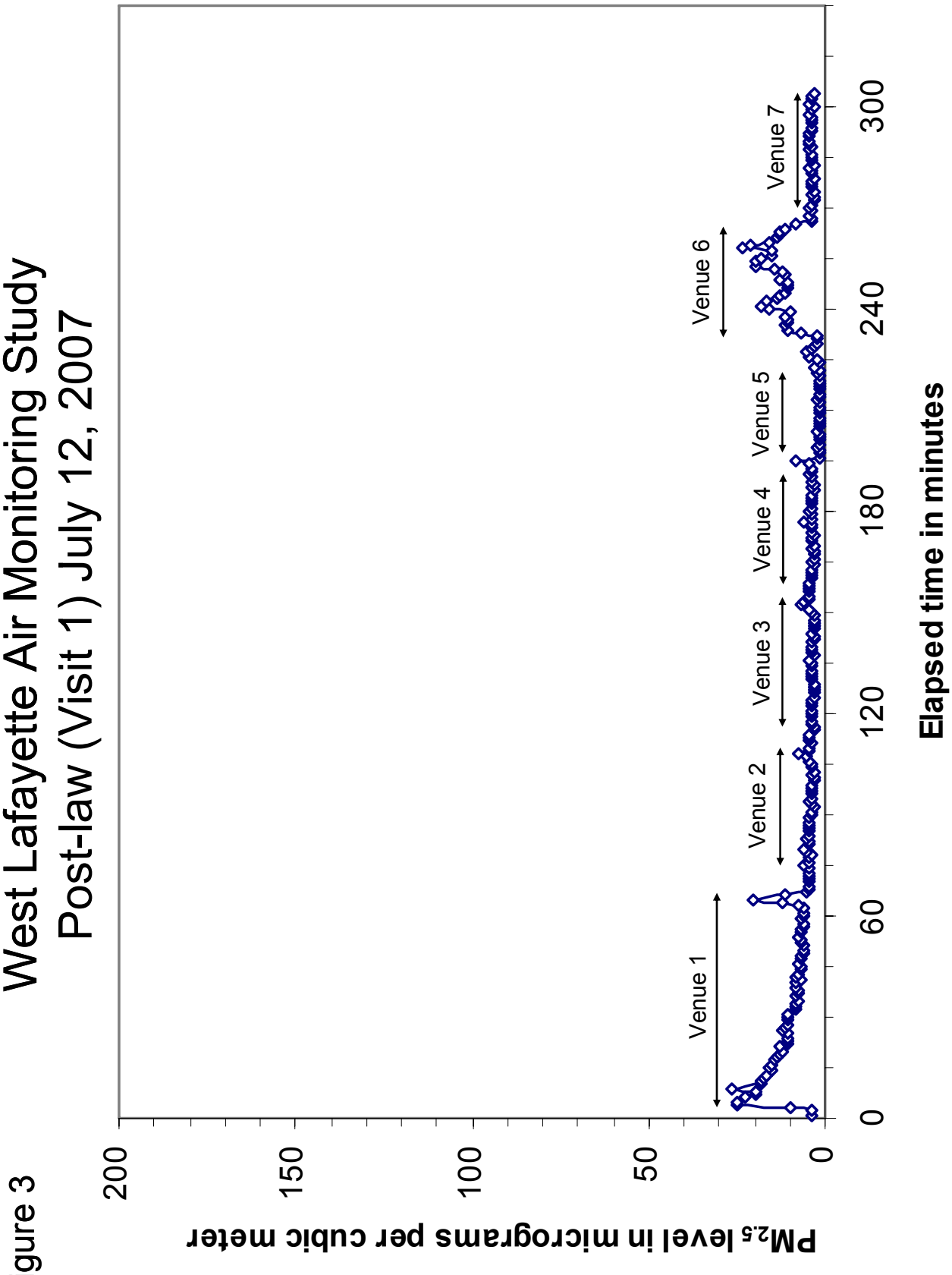

West Lafayette Air Monitoring Study
Post-law (Visit 1) July 12, 2007
PM2.5 level in micrograms per cubic meter
200
150
100
50
0
0
60
120
180
240
300
Elapsed time in minutes
Venue 1
Venue 2
Venue 3
Venue 4
Venue 5
Venue 6
Venue 7

Figure 4

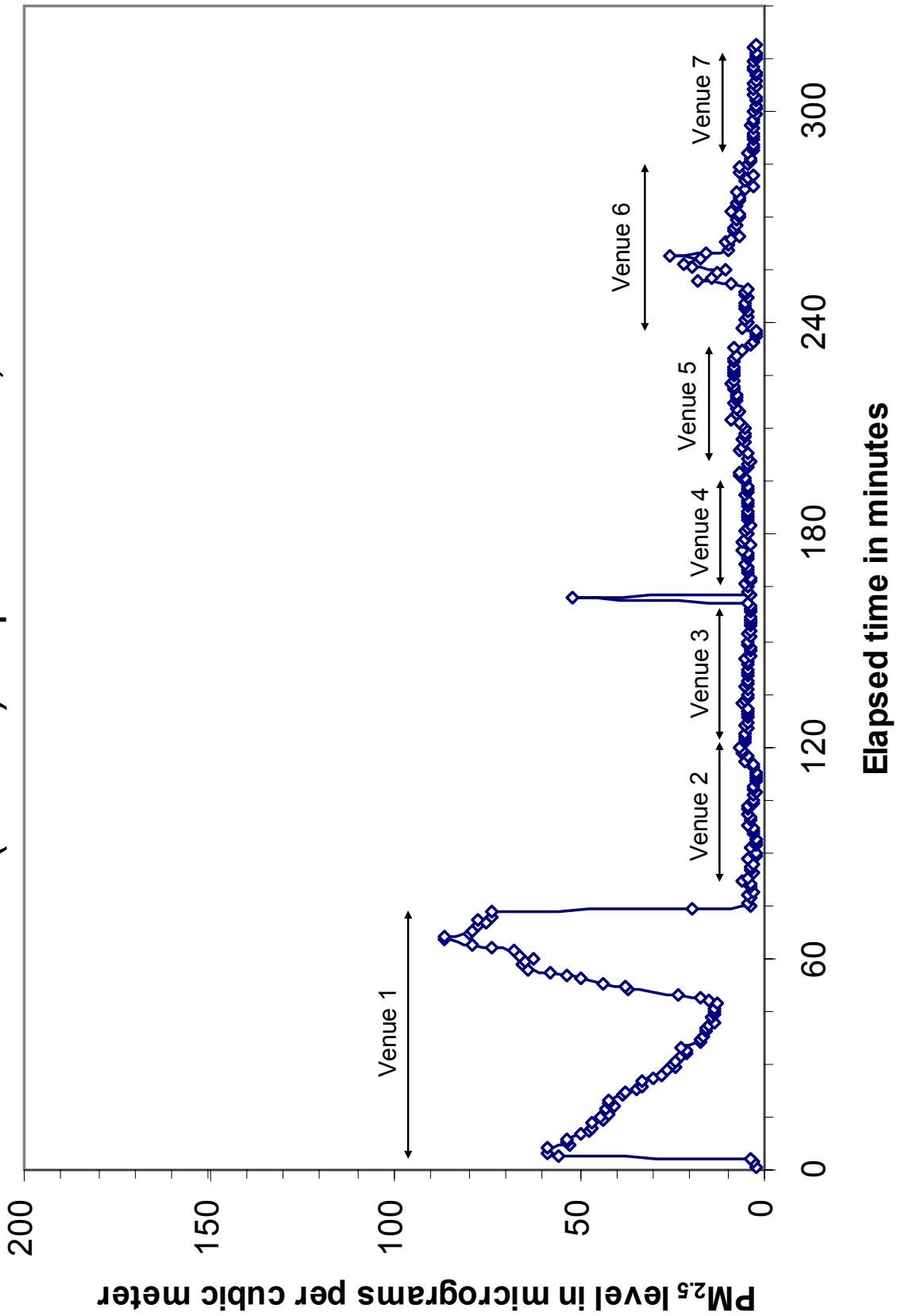
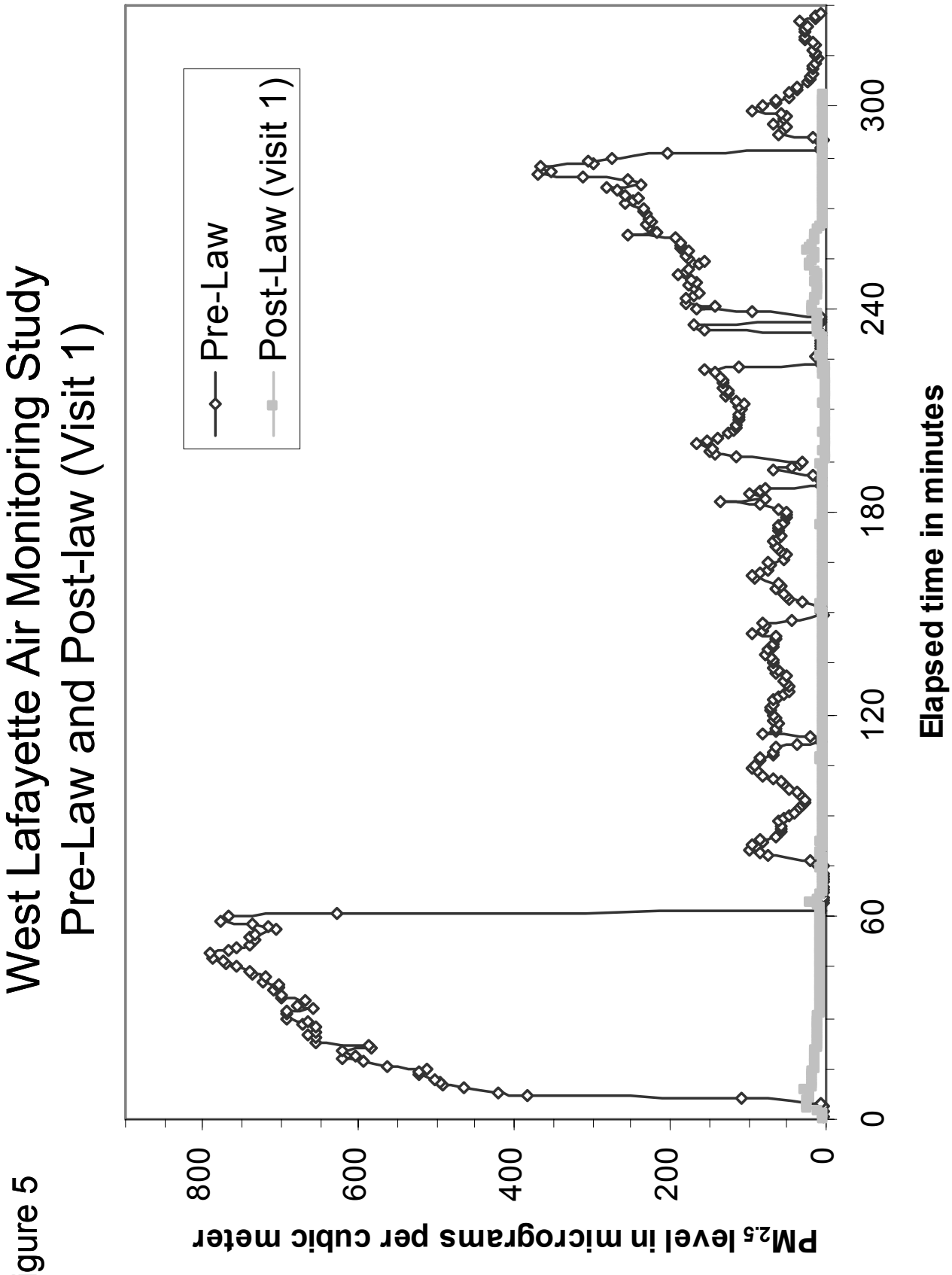

West Lafayette Air Monitoring Study
Post-law (Visit 2) September 27, 2007
PM2.5 level in micrograms per cubic meter
200
150
100
50
0
0
60
120
180
240
300
Elapsed time in minutes
Venue 1
Venue 2
Venue 3
Venue 4
Venue 5
Venue 6
Venue 7

Figure 5


West Lafayette Air Monitoring Study
Pre-Law and Post-law (Visit 1)
Pre-Law
Post-Law (visit 1)
PM2.5 level in micrograms per cubic meter
0
200
400
600
800
0
60
120
180
240
300
Elapsed time in minutes

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