AIR QUALITY IN MICHIGAN RESTAURANTS & CASINOS

BEFORE AND AFTER
MICHIGAN'S *DR. RON DAVIS* STATE SMOKE-FREE LAW

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1.0 Introduction. Reducing exposure to secondhand smoke is important because it causes heart disease, induces asthma, is a known human carcinogen, and has other serious health effects (SG, 2006; CalEPA, 2005; IARC, 2002; NAS, 2010; NIEHS, 2000; WHO, 2005; USEPA, 1992). This report summarizes the results and conclusions from 13 individual studies of air pollution in restaurants and casinos in 13 Michigan cities concerning the effectiveness of Michigan's Dr. Ron Davis Smoke-free Law in reducing the exposure of Michigan citizens to secondhand smoke. The Michigan Department of Community Health, Tobacco Section, with assistance from local health departments and other community agencies, recruited field investigators to measure the air quality in restaurants. The field investigators measured levels of fine particulate matter ($PM_{2.5}$) from secondhand smoke in hospitality venues before and after the statewide smoke-free air law (MGOV, 2009) was passed to determine whether the law was effective in reducing air pollution from secondhand smoke. The study encompassed 78 restaurants in six major regions of the state: Southeast, West, Upper Peninsula, Northern Lower Peninsula, Thumb, and Central, and the following sites participated in the study: Ann Arbor, Detroit, Flint, Grand Rapids, Kalamazoo, Lansing/E. Lansing, Marquette, Midland, Novi, Saginaw, Sault Ste. Marie, Traverse City, and West Branch. Three casinos in the City of Detroit where pre-law data was collected were also included in the study sample, as well as restaurants. This report analyzes the raw data collected by the field investigators and was prepared by the primary author (Appendix B). Individual result reports were prepared for each study site (MDOCH, 2011).

Of the more than 5000 chemicals in secondhand smoke, the two pre-eminent atmospheric markers for secondhand smoke are $PM_{2.5}$ and nicotine (Repace, 2007). While nicotine is a unique marker for secondhand smoke, it cannot be measured in real time. Although $PM_{2.5}$ is not unique to secondhand smoke, by measuring the levels in the presence and absence of smoking, the contribution of smoking to indoor air pollution can be assessed, and indoor air quality problems unrelated to smoking can be identified. Unlike nicotine, $PM_{2.5}$ can be measured in real-time, and as a regulated outdoor air pollutant, has the distinct advantage of being evaluated by reference to air pollution standards. $PM_{2.5}$ is a harmful combustion source air pollutant that is regulated in the outdoor air, and is widely monitored in all states, including Michigan (Michigan Department of Environmental Quality (MDEQ, 2011a), which maintains an extensive outdoor air quality monitoring network. Exposure to $PM_{2.5}$ affects breathing and the cellular defenses of the lungs, aggravates existing respiratory and cardiovascular ailments, and causes adverse health effects on the respiratory and cardiovascular systems; the entire population is affected, but susceptibility to $PM_{2.5}$ pollution varies with age and health status, and persons with heart or lung disease, the elderly, and children being at highest risk from exposure to $PM_{2.5}$ (MDEQ, 2011b; World Health Organization (WHO), 2005; National Academy of Sciences (NAS), 2010; Pope and Dockery, 2006).

The WHO 24-hour $PM_{2.5}$ air quality guideline is 25 $\mu g/m^3$, and its annual standard is 10 $\mu g/m^3$, while the less stringent US Environmental Protection Agency (USEPA) standards are 35 $\mu g/m^3$ averaged over 24 h, and the annual average is 15 $\mu g/m^3$ (USEPA, 2006). USEPA is currently considering the merits of reducing the annual standard level to 13 $\mu g/m^3$, and revising the 24-hour $PM_{2.5}$ standard level down to 30 $\mu g/m^3$

(USEPA, 2011). USEPA(2006) stated that "Scientific studies have found an association between exposure to particulate matter and significant health problems, including: aggravated asthma; chronic bronchitis; reduced lung function; irregular heartbeat; heart attack; and premature death in people with heart or lung disease." There is little evidence to suggest a threshold below which no adverse health effects are anticipated. Adverse health effects may occur at $PM_{2.5}$ concentrations as low as 3–5 $\mu g/m^3$ and the risk increases as exposure increases (WHO, 2005). WHO (2010) concluded that the air quality guidelines for particulate matter recommended by WHO (2005) are also applicable to indoor spaces.

$PM_{2.5}$ is copiously emitted by cigarettes, pipes, and cigars, contains numerous carcinogens, and is the largest component of secondhand tobacco smoke by mass. Secondhand smoke consists of smoke from the burning end of the tobacco product, plus exhaled smoke from the smoker, both of which contain numerous gaseous carcinogens and toxins (Hoffmann and Hoffmann, 1987; Repace, 2007). The evidence on the mechanisms by which tobacco smoke causes disease indicates that there is no risk-free level of exposure; low levels of exposure, such as those encountered by breathing secondhand smoke, lead to a rapid and sharp increase in endothelial dysfunction and inflammation, which are implicated in acute cardiovascular events and thrombosis (Surgeon General, 2010).

When measured before and after a smoke-free policy has been emplaced, $PM_{2.5}$ is a demonstrated atmospheric marker for the presence of secondhand smoke, and a variety of compact and portable real-time monitors are available for its measurement (Repace, 2004; Repace, et al., 2006; Travers et al., 2004; Repace and Lowrey, 1980). In this series of studies, restaurant venues were monitored for $PM_{2.5}$ from 2005 through 2008, prior to the enactment of Michigan's state smoke-free air law, and again in 2011, subsequent to the enactment of the state smoke-free air law, which was effective on May 1, 2010.

2.0 Methods. This study addressed the following research aims: (1) What are the concentrations of secondhand smoke fine particle air pollution ($PM_{2.5}$) in Michigan hospitality venues before and after Michigan's smoke-free air law? (2) Does secondhand smoke create an air quality hazard for hospitality workers and patrons? The organizing principle underlying the data collection was the mass balance model, which posits that the concentration of secondhand smoke is proportional to the ratio of the average smoker density (active smokers per unit volume) to the effective air exchange rate (due to ventilation, air cleaning, and sorption on surfaces) (Repace, 2007). Of the 3 principal variables determining secondhand smoke levels, measurements were made of smoker density and concentration. Air exchange rates were not measured.

In order to address the research questions, a real-time fine particle monitor was deployed by a team of 2 field investigators who visited a convenience sample of six restaurants in each city, before and after the enactment of the state smoke-free air law. Real-time monitors measure particle mass concentration and time. The SidePak™ AM510 Personal Aerosol Monitors were deployed (Jiang, et al., 2011). The SidePak is a rugged, battery-powered lightweight laser photometer, weighing about 16 oz. It is compact and quiet, minimizing interference with normal activities in the area to be measured, and has been widely used in secondhand smoke studies (Travers et al., 2004; Repace, 2009; Jiang et al., 2010). The built-in sampling pump has a size-selective inlet for area measurements with a $PM_{2.5}$ impactor. SidePak AM 510 (TSI, Inc., MN) flow rates were set to 1.7 L/min, fitted with 2.5 μm impactors, and set for 1-minute log intervals.

The calibration factor was set to 1 during the measurements, based on the factory calibration using Arizona Road Dust. In the data analysis, a custom calibration factor of 300 (Jiang et al., 2010) was used to convert the logged nominal instrument readings from uncorrected milligrams per cubic meter to actual micrograms per cubic meter ($\mu g/m^3$) of $PM_{2.5}$ from secondhand smoke or background using a gravimetric calibration factor derived from controlled experiments. The basic calibration and monitoring protocols are described in detail in Jiang et al. (2010; 2011), Repace (2009) and in Repace (2004). The investigators carried the monitors around as they counted patrons and smokers, so that the measurements represent a composite average of the entire area. The field investigators completed total person and active smoker counts 3 to 5 times per visit. Ventilation rates were not measured. The field investigators measured ceiling heights using a laser ruler, recorded times of arrival and departure from venues in a diary. The detailed study protocol is described in Appendix A. The individual venue $PM_{2.5}$ data are expressed in terms of arithmetic means and medians, and the curve-fits to the $PM_{2.5}$ data are expressed as geometric means.

The SidePak

3.0 Results. Table 1 shows the results of the pre-law monitoring in 78 restaurants, averaged over both smoking and nonsmoking sections, including 6 venues in each of 13 Michigan cities from pre-law 2005 to post-law 2011. Post-law, one venue, in the city of Novi, could not be measured becaused it had closed down in 2011, yielding 77 venues measured post-law. Table 1 gives the statistics for fine particle air pollution ($PM_{2.5}$): maximum, minimum, and the measures of central tendency (mean with standard deviation, and median). The units of concentration are expressed in micrograms per cubic meter (μg/m^3). The number of active smokers (burning cigarettes), n_s, counted during the duration of the sampling intervals which ranged from about ½ hour to 1 hour in the various venues. These durations also represent the number of 1-minute $PM_{2.5}$ data points for each venue. The active smoker density, D_s, is defined as the average number of burning cigarettes being smoked per unit volume, and is given in units of active smokers per hundred cubic meters of space volume of the smoking area. The average number of patrons present in the venues during the monitoring period is given by *P*, and the volume of the premises is given by *V*, expressed in metric units of cubic meters (m^3), where a cubic meter is equivalent to 35.315 cubic feet.

Table 1. MICHIGAN 13-CITY RESTAURANT $PM_{2.5}$
PRE-LAW vs. POST-LAW SUMMARY STATISTICS

Statistic	Pre-Law	Post-Law
Units	μg/m^3	μg/m^3
Minimum	9.07	1.65
Maximum	601	182
Mean	126	11.8
Median	90.9	6.71
Std. Dev.	(109)	(22.9)
Geometric Mean	115	9.56
Venues Sampled	78	77
Total Persons	2964	4112
Total Active Smokers, N_s	201	0
D_s, Active Smoker Density (n=71)	1.11 range: (0.274-2.69)	0
Median Smoking Prevalence, %	19	0

For individual restaurants, pre-law city means ranged from 9 to 601 μg/m^3, and averaged 126 μg/m^3, (median 90.9 μg/m^3). By contrast, post-law city means ranged from 1.65 to 182 μg/m^3, and averaged 11.8 μg/m^3, (median 6.71 μg/m^3). Geometric means were calculated by plotting all data and fitting it to a lognormal distribution, and represent the measure of central tendency of the curve-fit to the data. The estimated smoking prevalence in each of the 78 Michigan venues was calculated by multiplying the total of the average active smoking count for each of the cities, n_s, by 3, and dividing by the average number of persons. The estimated smoking prevalence in these venues, averaged over the sampled venues in each of 13 cities ranged from 8% to 39.7% using the methods described in Pritsos et al., 2008 and Repace, 2007. The average smoking prevalence was 20.3%, and the median smoking prevalence was 19%.

Exemplifying the nature of the real-time measurements recorded for all venues in the 13 cities, Figure 1 shows a plot of the time-series for the SidePak $PM_{2.5}$ data versus time, over 31-38 minute periods for one Kalamazoo restaurant. Figure 1 compares indoor air pollution levels when smoking was permitted (upper curve) with the $PM_{2.5}$ levels after the Law eliminated smoking (lower curve). The average $PM_{2.5}$ pre-law is 379 $\mu g/m^3$, well into the Hazardous level for $PM_{2.5}$ compared to 9.33 $\mu g/m^3$ post-law, well below the maximum level for Good air quality, as described by Michigan's Air Quality Index. For this restaurant, an estimated 97.5% of the pre-law $PM_{2.5}$ pollution was due to secondhand smoke.

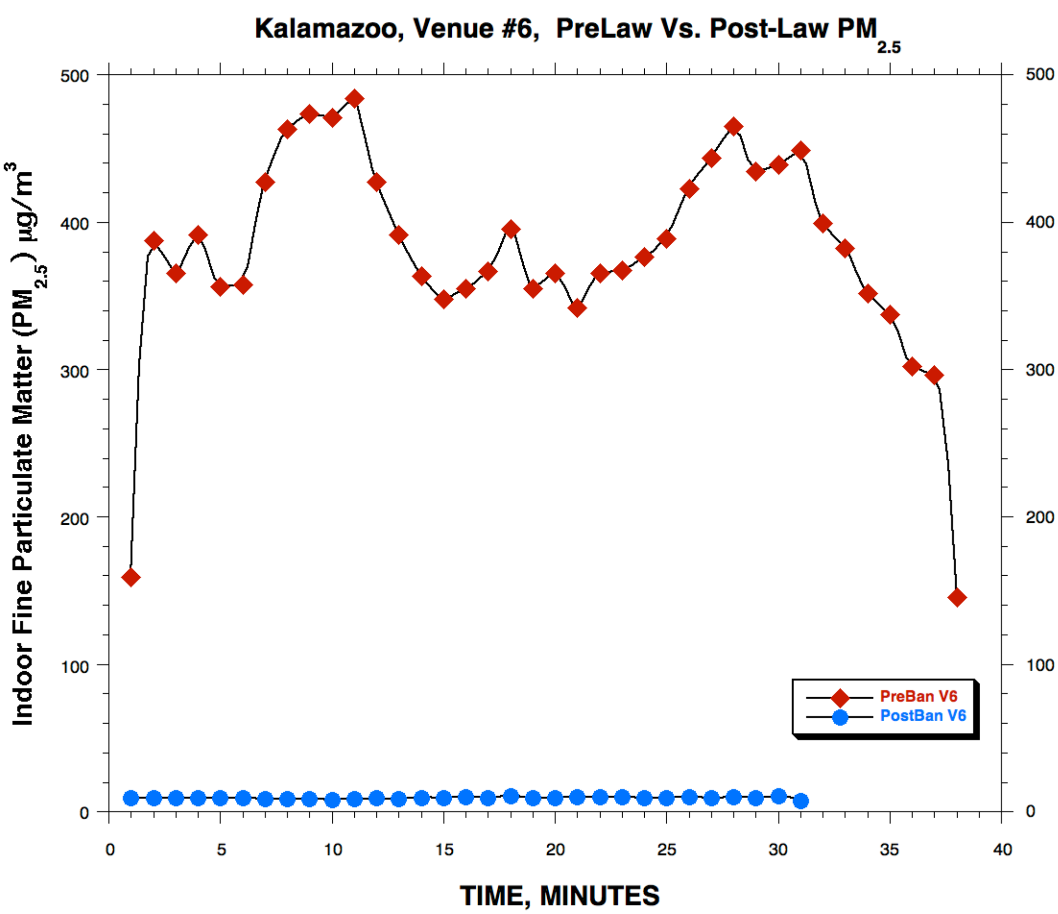

Figure 1. Real-time SidePak measurements in Venue # 6, Pre- and Post-Law. Michigan's state smoke-free air law reduced its indoor air pollution from $PM_{2.5}$ to 2.5% of its pre-law value.

Figures 2a and 2b compare the mean pre-law and post-law results averaged for all venues in each city. In every case, the post-law reductions in $PM_{2.5}$ air pollution are dramatic. The percent reduction in median $PM_{2.5}$ for 77 of the 78 Michigan restaurant venues combined was 93% (means declined by an average of 91%), indicating that the vast majority of indoor air pollution in all venues was due to secondhand smoke, as shown in Figure 3.

4.0. Discussion. The pre- and post-law measurements reported in this study yielded results comparable to those found in previous studies in other states. Repace (2004) performed real-time measurements of respirable particle (RSP) air pollution and particulate polycyclic aromatic hydrocarbons (PPAH), in a casino, six bars, and a pool hall in Wilmington, DE before and after Delaware's smoke-free workplace law. In this study, secondhand smoke contributed 90% to 95% of the $PM_{2.5}$ air pollution during smoking, and 85% to 95% of the carcinogenic particulate polycyclic aromatic hydrocarbons (PPAH), greatly exceeding levels of these contaminants encountered on major truck highways and polluted city streets. Repace, Hyde, and Brugge (2006) found similar results in 6 pubs in Boston, MA before and after Boston's smoke-free law: levels of $PM_{2.5}$ declined by 96%, while PPAH declined by 90%. Similarly, Travers et al. (2004) measured $PM_{2.5}$ in 24 hospitality venues, before and after New York State's clean indoor air law. The average $PM_{2.5}$ concentration was substantially lower after the law went into effect in every venue where smoking or indirect SHS exposure had been observed at baseline, with a grand mean reduction in $PM_{2.5}$ concentration of 84% (324 μg/m^3 to 25 μg/m^3; $p<0.001$). When stratified by the type of venue sampled, the average $PM_{2.5}$ concentration decreased 90% ($p<0.001$) in the 14 bars and restaurants in which smoking was occurring at baseline. Thus, the Michigan results are consistent with the Wilmington, Boston, and Western New York pre- and post-law studies.

4.1 Effect of smoking prevalence and ventilation. Models can be used to estimate concentrations of secondhand smoke (SG, 2006). The mass balance model may be used to understand how the $PM_{2.5}$ levels are affected by smoking and ventilation (Ott, 1999). The Active Smoker Model is one such model (Repace, 2007). This model posits that the secondhand smoke $PM_{2.5}$ concentration is directly proportional to the active smoker density and inversely proportional to the room air exchange rate, which is derived from removal processes including the ventilation rate per occupant and the deposition rate on room surfaces (so-called third-hand smoke). The default ventilation rate is given by ASHRAE Standard 62-2001 (ASHRAE, 2001), the last national ventilation standard to prescribe ventilation rates for restaurants with smoking. Since that time, ASHRAE has recommended ventilation rates only for nonsmoking premises (ASHRAE, 2005). The model's default assumptions posit that all smokers are "habitual smokers" (HS) who smoke identically at a rate of 2 cigarettes per hour, so that the smoker is actively smoking (AS)1/3 of the time; that the maximum occupancy of the restaurant is as defined in ASHRAE 62-2001: a maximum occupancy 70 persons per 1000 ft^2, or per 10,000 ft^3, assuming a 10 ft default ceiling height, that the prevalence of smokers among the customers is the same as the statewide smoking prevalence: 19%, that the ventilation rate of the typical restaurant is 20 ft^3/minute, that the deposition rate on surfaces is a fixed 30% higher than the ventilation rate. Equation 1 gives the mathematical form of this model (Repace, 2007):

$$R = 650\frac{D_S}{C_V}, \text{ Eq. 1,}$$

in units of micrograms per cubic meter (μg/m^3) where D_S is defined as the density of active smokers in the space in units of burning cigarettes per hundred cubic meters, and C_V is the air exchange rate in air changes per hour. $D_{HS} = 3N_S$, where N_S is the number of active smokers (AS) observed during the averaging time. These default values and their predictions for secondhand smoke $PM_{2.5}$ in Michigan restaurants are calculated as follows:

MODELING SECONDHAND SMOKE $PM_{2.5}$ IN MICHIGAN RESTAURANTS

1. The Michigan statewide smoking prevalence was 19% in 2009.
2. At the maximum default occupancy of ASHRAE Standard 62, 70 Persons/10,000 ft3, and a 19% smoking prevalence, the density of active smokers will be 1/3 of the number of habitual smokers, D_{HS}: $D_S = D_{HS}/3$ = (70 Persons/283 m^3)(19 Smokers/100 Persons), yielding D_S = 1.57 AS/100m^3.
3. From Table 1, the observed average number of active smokers is D_S = 1.11 AS/100m^3. This implies an average occupancy of (100)(1.11/1.57) = 70.7% of maximum, which is reasonable considering the measurements were nearly all made on Friday and Saturday nights.
4. The default design air exchange rate from ASHRAE Standard 62-2001 is C_V = (70 Persons/10,000 ft^3)(20 ft^3/Person)(60 minutes/hour) = 8.4 air changes per hour (h^{-1}).
5. Applying the default values to Equation 1 yields an expected average secondhand smoke concentration for a Michigan restaurant at 70.7% occupancy of: R= (650)(D_S/C_V) = (650)(1.11/8.4) = 86 μg/m^3.
6. The default background $PM_{2.5}$ concentration is assumed from the post-ban median $PM_{2.5}$ from Table 1, B = 6.71 μg/m^3.
7. The predicted total $PM_{2.5}$ is then $R+B$ = 86 μg/m^3 + 6.71 μg/m^3 = 92.7 μg/m^3.
8. From Table 1, the observed median concentration averaged over 78 smoking-permitted venues in 13 Michigan cities is 90.8 μg/m^3.
9. The percent difference between the predicted and observed median values is 2.1%.
10. The range in active smoker density from Table 1 is $0.274 \leq D_S \leq 2.69$. Substituting this range in for D_S in step 5 yields a range in R of: 21 μg/m^3 $\leq D_S \leq$ 208 μg/m^3, and with the 6.71 background added, R+B ranges from about 28 μg/m^3 to 216 μg/m^3, which correspond respectively to about the 10^{th} and 80^{th} percentiles of the pre-law distribution shown in Figure 6.
11. Thus, the mass-balance model can explain the median concentration observed, as shown in Figure 3, as well as account for 70% of the concentration variation among the 78 venues. This result is in accord with the work of Repace et al. (2011a), who reported that 60% of the variation in $PM_{2.5}$ concentration in a study of air pollution in 66 US casinos with smoking was explained by smoker density variation, and only 15% by ventilation rate variation.

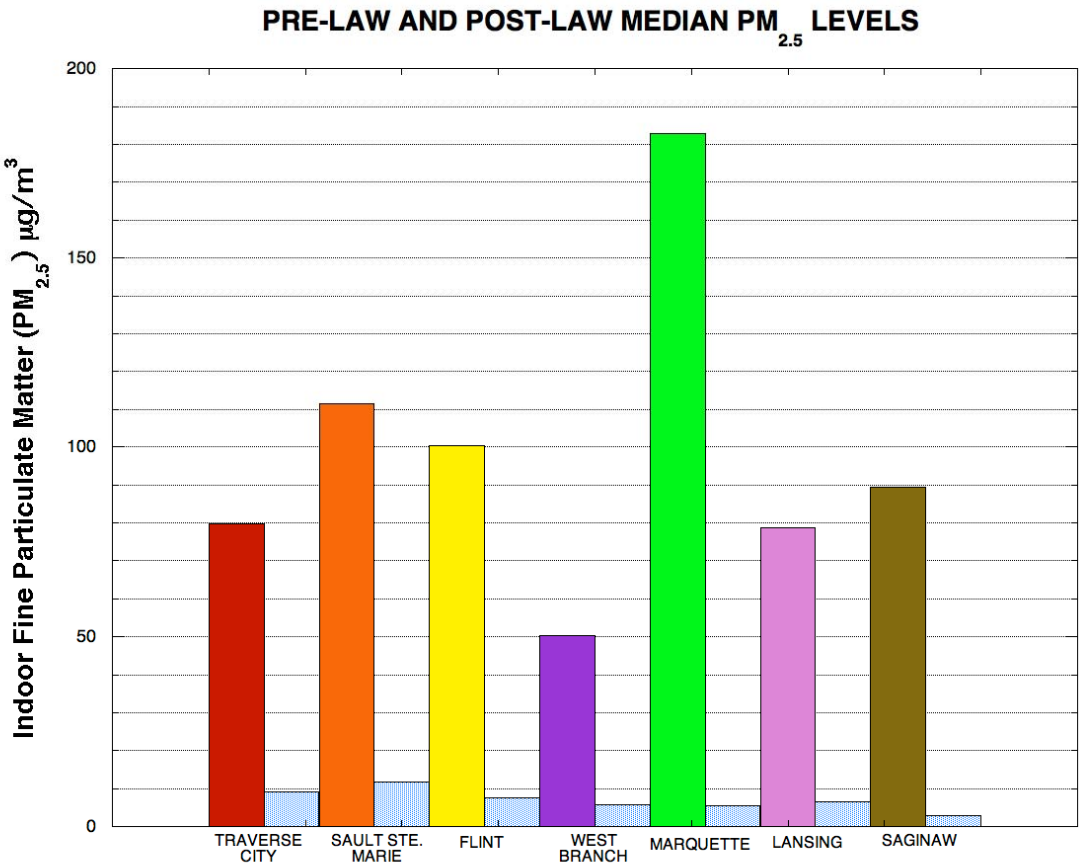

Figure 2a. Mean air pollution levels in the restaurants in 7 of 13 Michigan Cities monitored pre-and-post Michigan's Smoke-free Air Law. The larger colored bars represent the pre-law $PM_{2.5}$, while the much smaller shaded bars to the right of each colored bar are the post-law levels for each city.

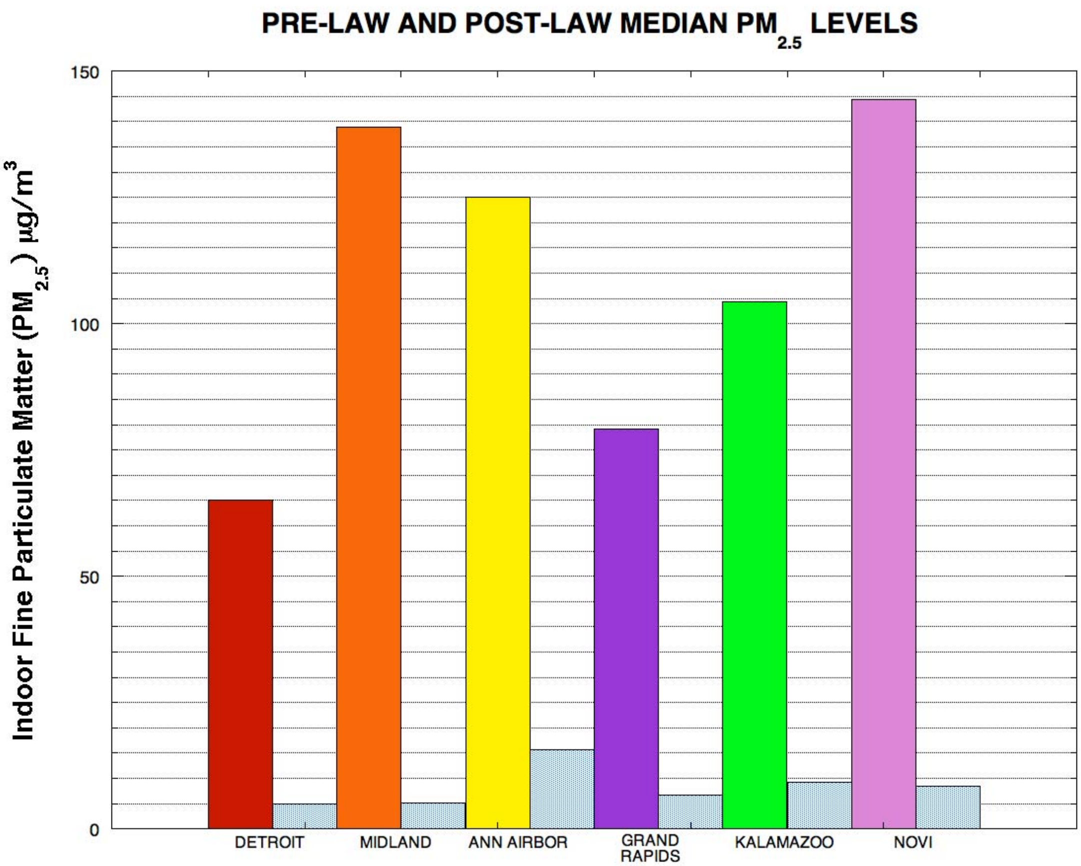

Figure 2b. Figure 2a. Mean air pollution levels in the restaurants in the remaining 6 of 13 Michigan Cities monitored pre-and-post Michigan's Smoke-free Air Law. The larger colored bars represent the pre-law $PM_{2.5}$, while the much smaller shaded bars to the right of each colored bar are the post-law levels for each city.

The reported estimated adult smoking prevalence for Michigan in 2009 was 19.6% compared to 17.9% for the US (CDC-BRFSS, 2009). However, in 2005-2006, when these data were collected, it was 22.1% for Michigan and 20.6% for the US. As shown in Table 1, the estimated overall median smoking prevalence for the patrons of these 78 venues derived from the data on occupancy and active smoking counts, was 19%, approximately equal to the Michigan adult smoking prevalence in 2009, and 14% lower than the State average in 2005.

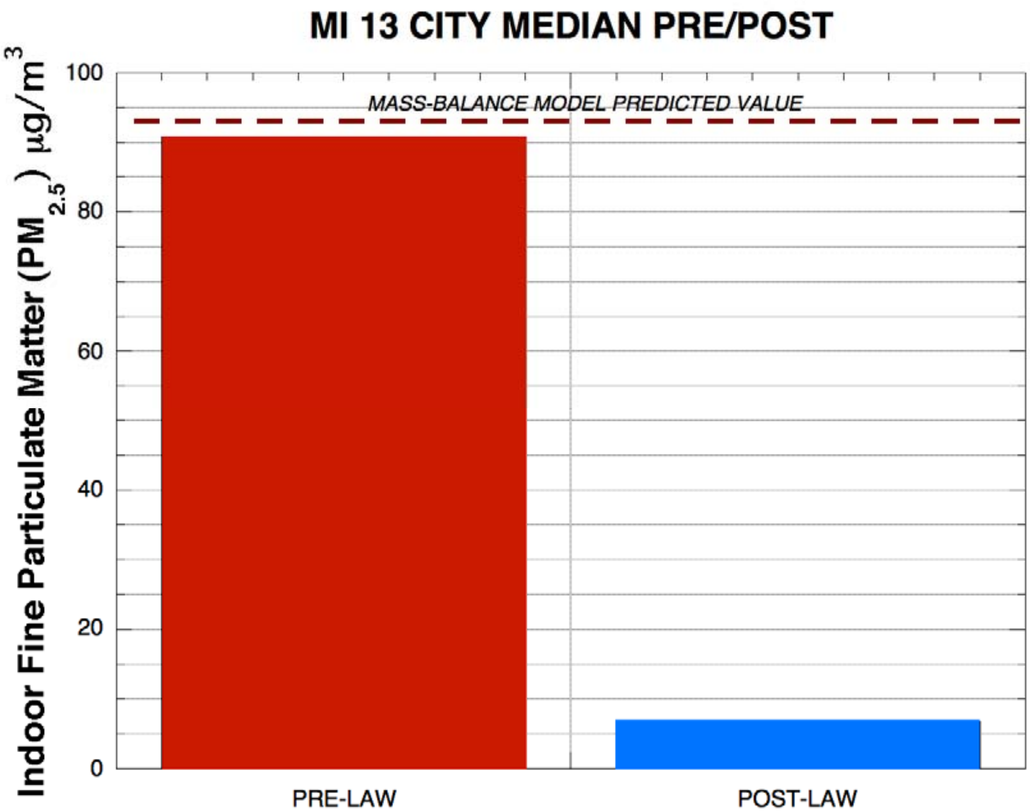

Figure 3. Combined median $PM_{2.5}$ level for all 13 Michigan Cities drop by 93% due to Michigan's Dr. Ron Davis Indoor Air Law. The prediction of the active smoker model used to guide the sampling strategy is shown by the dotted line for the pre-law condition.

5.0. Secondhand Smoke in Detroit Casinos

As with the 78 restaurants, SidePak real-time fine particle monitors were deployed by 2 teams of field investigators who visited the same 3 Detroit casinos, before and after the enactment of the state smoke-free air law. The 3 casinos' $PM_{2.5}$ was measured on Saturday evenings, pre-law on April 18, 2009, and post-law on May 14, 2011. Unlike the restaurants, however, the Detroit casinos were exempted from the Dr. Ron Davis smoke-free law by the State legislature. Table 2 summarizes the results, averaged over all 3 casinos. Due to the large volumes and large numbers of persons and smokers, counts of persons, smokers, and measurements of space volumes were not made. $PM_{2.5}$ pollution levels were 95 $\mu g/m^3$ pre-law, compared to 86 $\mu g/m^3$ post-law, less than 10% different, with occupancy not controlled for. Figure 4 compares the mean pre-law smoking and post-law results for each Detroit casino and to the 3 smoke-free casinos in California, Delaware, and Nevada (Repace et al., 2011). The Detroit casinos, exempt from the Dr. Ron Davis smoke-free law, had unhealthy levels both pre-law and post-law, in marked contradistinction to Detroit's restaurants, whose pollution levels declined from unhealthy levels pre-law by 93% to healthy levels post-law (Figure 5). In contrast, 3 smoke-free casinos studied in California, Delaware, and Nevada had very low levels of $PM_{2.5}$ pollution, averaging 3.1 μg/m^3.

Table 2. 3 DETROIT CASINO $PM_{2.5}$ PRE-LAW vs. POST-LAW SUMMARY STATISTICS

Statistic	Pre-Law	Post-Law
Units	μg/m^3	μg/m^3
Minimum	6.6	23.1
Maximum	193	281
Mean	94.9	85.7
Median	94.2	85.7
Std. Dev.	(25.8)	(6.19)
Geometric Mean	92.6	85.6

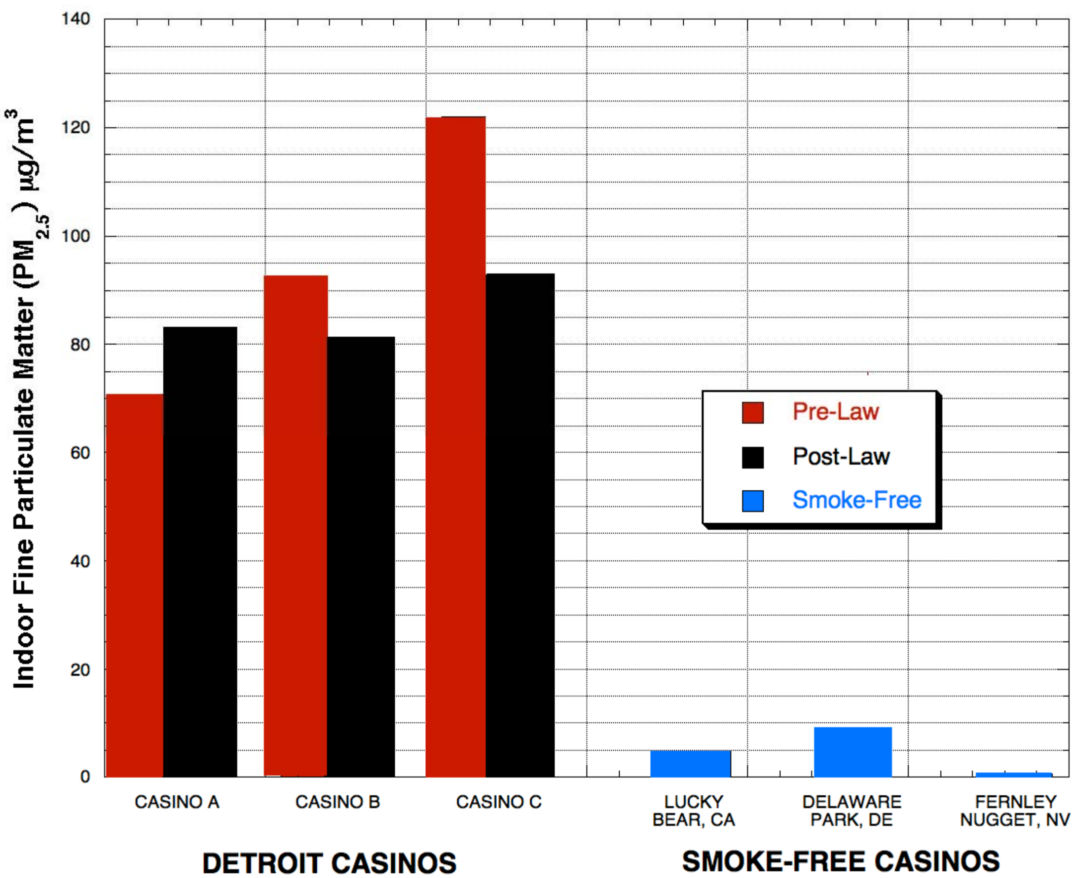

Figure 4. Mean air pollution levels in 3 smoky Detroit casinos exempted from Michigan's Dr. Ron Davis Smoke-free Air Law, versus 3 smoke-free casinos in California, Delaware, and Nevada.

In sum, the air in all 3 Detroit casinos, exempted from Michigan's Dr. Ron Davis Smoke-free Air Law, was in the Unhealthy Range of Michigan's AQI, both prior to and subsequent to the law's enactment. Air quality in the Detroit casinos was about 30 times as polluted with $PM_{2.5}$ as 3 smoke-free casinos studied in California, Nevada, and Delaware (Repace et al., 2011a). When compared to the air quality measured in 91 other smoking US casinos, the Detroit casinos were more polluted than 73% of the 91 smoking casinos studied (Repace et al., 2011b).

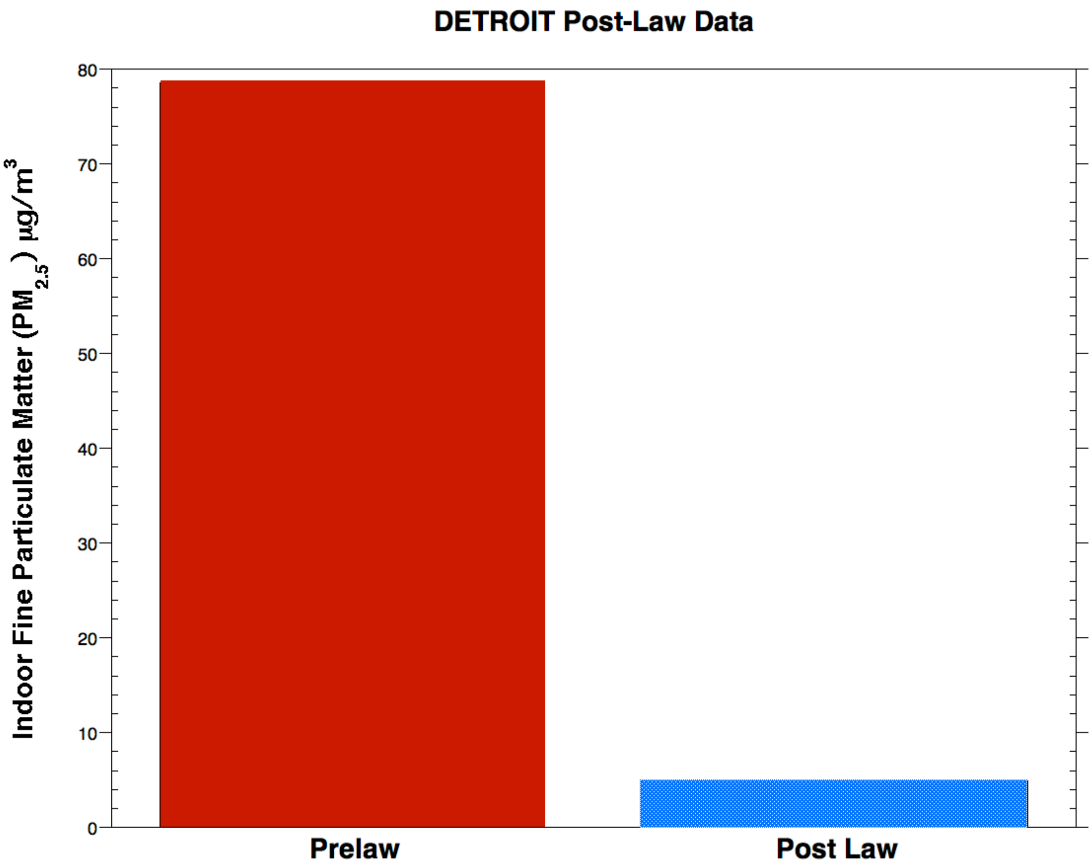

Figure 5. Combined median $PM_{2.5}$ level for 6 Detroit restaurants drops an average of 93% due to Michigan's Dr. Ron Davis Indoor Air Law, in marked contrast to Detroit casinos, which were exempt from the law.

6.0. Health Implications. Many jurisdictions around the US have acted to reduce public secondhand smoke exposure in the hospitality industry. Smoke-free laws now cover almost 74% of US restaurants and 63% of US bars (ANR, 2010). These laws afford significant protection from the adverse health effects due to secondhand smoke. For example, Moraros et al. (2010) reported that Delaware's 2003 comprehensive non-smoking ordinance, which extended its 1994 workplace smoking ban to restaurants, bars, and casinos, was associated with statistically significant decreases in both acute myocardial infarction and asthma incidence in Delaware residents when compared with non-Delaware residents. The National Toxicology Program has identified secondhand smoke as a known human carcinogen (NIEHS, 2000). Secondhand smoke has been identified as a cause of cancer of the lung, breast, and nasal sinus (Johnson et al., 2011; CalEPA, 2006). Unsurprisingly, secondhand smoke particulate matter measured in numerous hospitality venues, including bars, restaurants, and casinos, has been found to contain a substantial fraction of carcinogenic polycyclic aromatic hydrocarbons (Repace, et al., 2011). Secondhand smoke is a prolific source of $PM_{2.5}$ in indoor air, with each cigarette emitting about 14 milligrams of $PM_{2.5}$, and cigars emitting 3 to 5 times as much (Repace, et al., 1998).

Appendix C describes the Air Quality Index used by Michigan's Department of Environmental Quality, *"developed and federally mandated to quickly communicate short-term, current air information to the public. Simply put, the AQI is a health indicator for people who want to know whether the air they are breathing 'right now' is healthy. … It is calculated in near real-time using hourly data [primarily ozone and $PM_{2.5}$] from continuous air monitors. The AQI identifies air pollutant concentrations as one of six color-code category levels ranging from good to hazardous. This simple tool allows people to make health decisions about daily activities… "* (MDEQ, 2011b).

Figure C-1 shows the frequency distributions for outdoor air in Michigan from 2007 to 2010. The annual geometric mean is 13.25 mg/m3, corresponding to Good Air Quality (range 10 to 18 $\mu g/m^3$), a range into which 95% of the 77 venues fall post-law. Thus, for nearly all restaurants, the post-law $PM_{2.5}$ concentrations are comparable to the low average levels found in the outdoor air. Figures 1-4 demonstrate clearly that the pre-law ventilation and air cleaning practices followed by these venues failed to control $PM_{2.5}$ air pollution, while the state clean indoor air law easily attained this goal for all but 5% of the venues by reducing smoker density to zero.

Log-probability plots of the frequency distributions for the pre- and post-law data are plotted in Figure 6 are interpreted as follows: any point on the line gives the percentage of the restaurants below a particular concentration on the horizontal axis. The solid lines for the curve-fits in Figure 6 can be generalized or modeled to estimate the range in air quality that might be expected for the remainder of unsampled Michigan restaurants before and after the protection of the Dr. Ron Davis Law. For example, to find the estimated percentage of venues with indoor concentrations above the level of WHO's 25 $\mu g/m^3$ 24-h guideline, we find "25" on the vertical axis in $\mu g/m^3$, and then we estimate the corresponding horizontal axis value, <10%. If the venues selected were to be considered as representative of the distribution to be found for all Michigan restaurants pre-law, this suggests that 100% - <10% = >90% of the venues would be at or above 25 $\mu g/m^3$. Similarly, about 15% of the venues would be below 35 $\mu g/m^3$, so 85% would be at or above 35 $\mu g/m^3$, the numerical value of EPA's 24-h standard. In this way, the estimated frequency distribution of Michigan restaurants can be displayed, and the percent of the venues at or above any concentration can be read directly from the graph by simple subtraction.

The straight lines show that for the most part, the data are lognormally distributed, as expected for atmospheric pollution. However, at the 92nd percentile in Figure 6 for the post-law data, the curve shows a "hockey-stick" shape, indicating that 5 of the post-law restaurants (6.4%), although smoke-free, have other indoor air quality problems, consistent with the findings of Repace et al. (2006) in Boston and Repace and Johnson (2006) in Ottawa restaurants relating to use of oil candles, or introduction of broiling smoke into restaurant dining rooms due to defective ventilation systems.

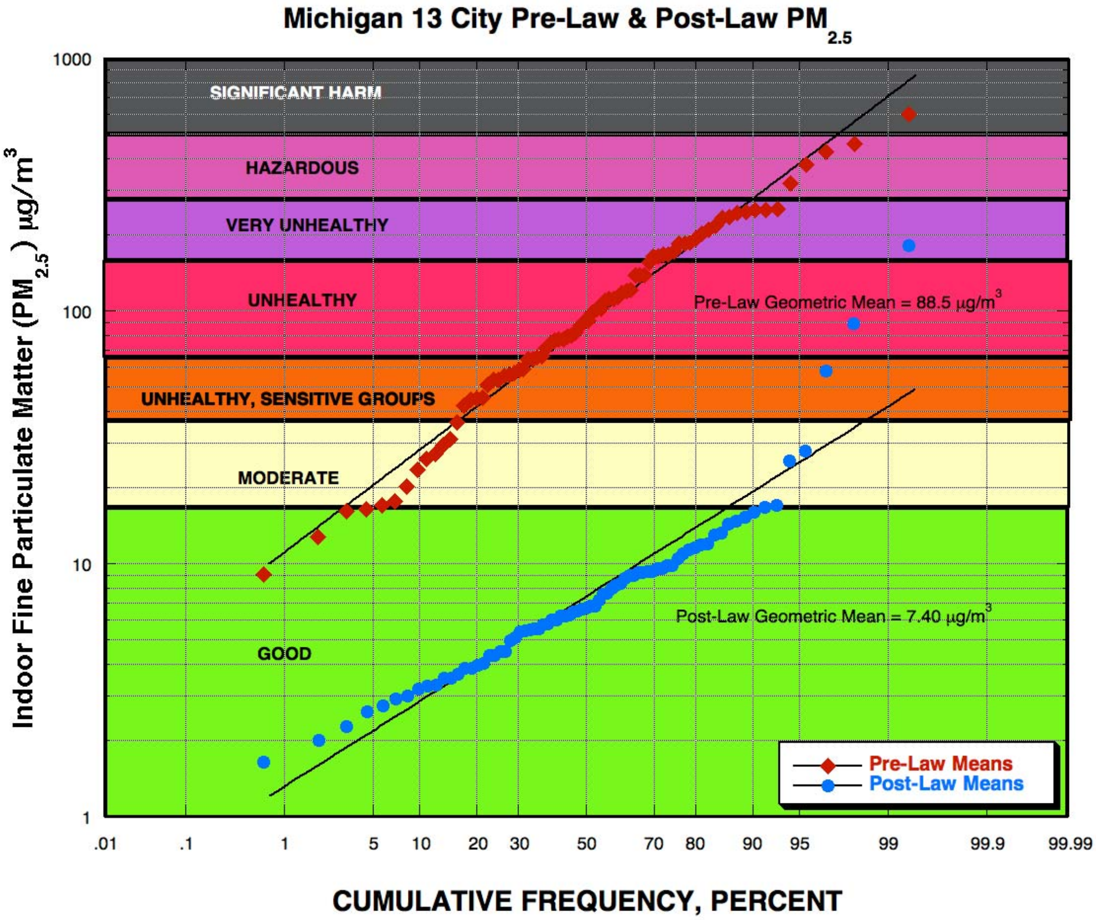

Figure 6. $PM_{2.5}$ frequency distributions for 78 Michigan restaurants pre-Smokefree-law and 77 post-Smokefree-law, vs. the Michigan AQI descriptors, Good to Hazardous. Pre-law, 85% of the venues have moderately polluted to dangerous air quality. Post-law, about 94% of those venues have good to very good air quality; the remaining 6% have other indoor air problems.

The AQI refers only to $PM_{2.5}$ as a criteria air pollutant, and as such, suggests that $PM_{2.5}$ in the outdoor air and $PM_{2.5}$ from secondhand smoke appear to have similar toxicity Pope et al. (2009). However, secondhand smoke contains numerous toxic substances, many of them not normally present in outdoor air, and some tobacco-specific. Secondhand smoke contains at least 172 toxic substances in both its gas and particulate phases, of which 33 are classified as hazardous air pollutants, 47 as hazardous wastes, 3 as criteria air pollutants, and 67 as known carcinogens (Repace, 2007). Of the latter, 20 are involved in lung carcinogenesis, and of these, PPAH (10 compounds) are among the most significant (Hecht, 1999).

This study demonstrates that secondhand smoke has caused major indoor air quality problems in Michigan restaurants, but that indoor air quality improves dramatically after Michigan's Dr. Ron Davis Smoke-free law was enforced.

6. Conclusions.

1. Seventy-eight restaurants in 13 Michigan cities were monitored for fine particulate air pollution before and after Michigan's Dr. Ron Davis Smoke-free Air Law, using real-time air quality monitors for fine particulate air pollution ($PM_{2.5}$).
2. The Dr. Ron Davis Law succeeded in reducing geometric mean levels of harmful secondhand smoke fine particle air pollution ($PM_{2.5}$) by 92% for a 78-restaurant sample of Michigan Hospitality establishments.
3. 85% of the Michigan restaurants studied had poor to dangerous air quality, on average Unhealthy, prior to the smoke-free law's enactment, caused by secondhand smoke pollution.
4. 93% of these restaurants had good to very good $PM_{2.5}$ air quality subsequent to the smoke-free law's enactment.
5. For Michigan, Michigan's Dr. Ron Davis Clean Indoor Air Law, by eliminating secondhand smoke, was effective in reducing $PM_{2.5}$ air pollution from secondhand smoke to the low levels found outdoors.
6. Detroit's casinos, exempted from Michigan's Dr. Ron Davis Law, had Unhealthy air quality both before and after the Law's enactment, in marked contrast to Detroit's restaurants, whose pollution levels declined from Unhealthy pre-law to Healthy post-law.
7. The Dr. Ron Davis Smoke-free Air Law was highly effective in improving air quality in its restaurants and reducing the risk of the diseases of secondhand smoke exposure.

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APPENDIX A. **Study Protocol for Evaluating Changes in Air Quality Before and After the Implementation of a Smoke-free Air Worksite Law**
[MDCH, Tobacco Control, 2010]

Title
Michigan Smoke-free Air Law Air Monitoring Study

Introduction:
The MDCH, Tobacco Section, with assistance from the local health departments and other community agencies, will be recruiting adult volunteers to measure the air quality in restaurants before (conducted between 2005 and 2008) and after the statewide smoke-free air law is passed.

Purpose:
To measure changes in the level of particulate matter from secondhand smoke in restaurants before and after the statewide smoke-free air law has passed to determine whether the statewide smoke-free air law is effective in reducing air pollution from secondhand smoke.

Method & Sample:
The State of Michigan will be represented by the following six major regions of the state: Southeast, West, Upper Peninsula, Northern Lower Peninsula, Thumb, and Central, and the following 14 sites will participate in the study: Ann Arbor, Detroit, Flint, Grand Rapids, Kalamazoo, Lansing/E. Lansing, Marquette, Midland, Novi, Saginaw, Sault Ste. Marie, Traverse City, and West Branch. Casinos in the City of Detroit where pre-law data was collected will also be included in the study sample, as well as restaurants. Data using the TSI SidePak AM 510 Personal Aerosol Air Monitor was collected in a convenience sample of restaurants, between 2005 and 2008, for the pre-law data collection. Six of the same restaurants where pre-law data was collected will be re-visited for the post-law data collection. In the case where six of the same restaurants cannot be re-visited, additional smoke-free restaurants will be added to obtain the difference in the average measurement of particulate matter before and after the law was passed. Local agency coordinators from each of the 14 sites will be asked to recruit at least two volunteers to visit these restaurants using the air monitor. Two air monitors will be used in succession in the 14 cities.

In addition to particulate matter data that is collected by the air monitor, the date, entry and exit time, number of people in the venue, and dimensions of the venue (i.e., length, width, and height), will be collected via a measurement laser and noted by the volunteers on a data sheet provided by MDCH, Tobacco Section. Local coordinators and volunteers will be trained by MDCH Tobacco Sections staff on how to use the air monitor and collect other data approximately 2 weeks before their scheduled data collection. MDCH Tobacco Section staff will develop a training schedule with local coordinators for their particular site.

Risk/incentive:
No risk is expected to volunteers in collecting the data or to anyone in the restaurants during data collection via the air monitor. The name of the restaurant will be documented for reference to compare the pre- and post-law data; however, the name of the restaurant will not be used for any other purposes and the data that is shared with local coordinators via report form will not include restaurant names, as the data will be de-identified and reported in a summary format. Each volunteer will be provided a total stipend of $30 per evening to cover the cost of food and drinks while they are collecting data at the restaurants. The volunteers will need to purchase drinks or food while they visiting the restaurants so that they can be customers while they are collecting air quality data via the air monitor.

Period of the study:
Data collection will occur over a six-month period, between October 1, 2010 and April 30, 2011, and data analysis and a study report will be completed by July 2011.

Data Management:
Data will be stored in the air monitor and then transferred into a secured, electronic file in the air monitoring software, TrakPro, and transferred into a secure file in SPSS 15 for data analysis. Local raw data for each site will be provided up on request. A study report with aggregated statewide and local level results will be provided to all local contractors.

Study Team:
The study team will provide the technical assistance throughout the duration of the study to all participating agencies, collect the air monitoring data from each local site, conduct the data analysis, and provide a study report to all local contractors. The study team will involve staff members from the MDCH, Tobacco Section.

APPENDIX B. **Qualifications of the Primary Author:**

James Repace, MSc., is a biophysicist and an international secondhand smoke consultant who has published 86 scientific papers, 79 of which concern the hazard, exposure, dose, risk, and control of secondhand smoke. His work was cited 19 times in the 2006 Surgeon General's Report.* He has received numerous national honors for his pioneering work on secondhand smoke exposure, dose, risk, and control, including the Flight Attendant Medical Research Institute Distinguished Professor Award, the Robert Wood Johnson Foundation Innovator Award, the Surgeon General's Medallion, and a Lifetime Achievement Award from the American Public Health Association. He holds an appointment as a Visiting Assistant Clinical Professor at the Tufts University School of Medicine, Dept. of Public Health. Website: www.repace.com.

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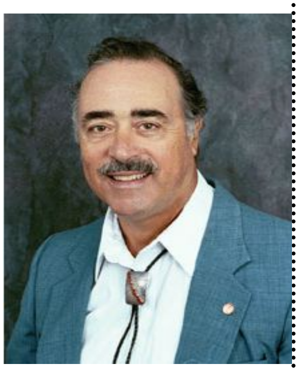

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APPENDIX C. MICHIGAN AIR QUALITY INDEX (MDEQ, 2011b), pp 34-35.

AIR QUALITY INDEX:

Air Quality Index

The Air Quality Index (AQI) was developed and federally mandated to quickly communicate short-term, current air information to the public. Simply put, the AQI is a health indicator for people who want to know whether the air they are breathing 'right now' is healthy. **MIair** AQI values are displayed in a forecast table and shown as color-coded dots plotted on a Michigan map. It is calculated in near real-time using hourly data [primarily ozone and $PM_{2.5}$] from continuous air monitors. The AQI identifies air pollutant concentrations as one of six, color-coded category levels ranging from good to hazardous.[13] This simple tool allows people to make health decisions about daily activities, such as whether to adjust physical exertion levels. Staff meteorologists include a Forecast Discussion to provide upcoming conditions.

A relative scale of 0 to 500 (shown below in **Table 4-1**) is used to display AQI values; the higher the AQI number, the greater the pollution concentration and potential for short-term health concerns. The index is not intended to provide an indication of long-term chronic air pollution exposure (months or years), nor does it reflect additive or synergistic health effects that may result from exposure to multiple air pollutants. Note that during 2008, the AQI values for $PM_{2.5}$ and O_3 concentrations were adjusted to align closely with National Ambient Air Quality Standard changes.

Table 4.1: BREAKPOINTS FOR AQI POLLUTANT CONCENTRATIONS

AQI VALUE	$PM_{2.5}$ (24 hr) μg/m^3	PM_{10} (24 hr) μg/m^3	SO_2 (24 hr) ppm	O_3 (8 hr) ppm	O_3 (1 hr) ppm	CO (8 hr) ppm	NO_2 (1 hr) ppm
301-500 Hazardous	250.5 – 500.4	425 – 604	0.605 – 1.004	→	0.405 – 0.604	30.5 – 50.4	1.25 – 2.04
201-300 Very Unhealthy	150.5 – 250.4	355 – 424	0.305 – 0.604	0.116 – 0.374	0.205 – 0.404	15.5 – 30.4	0.65 – 1.24
151-200 Unhealthy	65.5 – 150.4	255 – 354	0.225 – 0.304	0.096 – 0.115	0.165 – 0.204	12.5 – 15.4	-
101-150 USG	35-5 – 65.4	155 – 254	0.145 – 0.224	0.076 – 0.095	0.125 – 0.164	9.5 – 12.4	-
51-100 Moderate	15.5 – 35.4	55 – 154	0.035 – 0.144	0.060 – 0.075	-	4.5 – 9..4	-
0-50 Good	0.0 – 15.4	0 – 54	0.00 – 0.03	0.000 – 0.059	-	0.0 – 4.4	-

[13] The AQI must not be confused with NAAQS, which determine an area's compliance with provisions set forth in the federal CAA.

Air quality in Michigan generally falls in the good or moderate range. An area will occasionally fall into the "unhealthy for sensitive groups" range, but rarely reaches unhealthy levels.

Table 4.2 identifies the AQI colors and the associated health statements by individual air pollutant.

Table 4.2: The AQI Colors and Health Statements

AQI COLOR, CATEGORY & VALUE	PARTICULATE MATTER ($\mu g/m^3$) 24-Hour	OZONE (ppm) 8-Hour / 1-Hour	CARBON MONOXIDE (ppm) 8-hour	SULFUR DIOXIDE (ppm) 24-hour	NITROGEN DIOXIDE (ppm) 1-hour
GREEN: Good 1-50	**None**	**None**	**None**	**None**	**None**
YELLOW: Moderate 51-100	Unusually sensitive people should consider reducing prolonged or heavy exertion.	Unusually sensitive people should consider reducing prolonged or heavy exertion.	***None***	**None**	**None**
ORANGE: Unhealthy for Sensitive Groups 101-150	People with heart or lung disease, older adults, and children should reduce prolonged or heavy exertion.	Active children and adults, and people with lung disease such as asthma, should reduce prolonged or heavy outdoor exertion.	People with cardiovascular disease, such as angina, should limit heavy exertion and avoid sources of CO, such as heavy traffic.	People with asthma should consider limiting outdoor exertion.	**None**
RED: Unhealthy 151-200	People with heart or lung disease, older adults, and children should avoid prolonged or heavy exertion. Everyone else should limit prolonged exertion.	Active children and adults, and people with lung disease such as asthma, should avoid pro-longed or heavy exertion. Everyone else, especially children, should reduce prolonged outdoor exertion.	People with cardiovascular disease, such as angina, should limit moderate exertion and avoid sources of CO, such as heavy traffic.	Children, asthmatics, and people with heart or lung disease should limit outdoor exertion.	**None**
PURPLE: Very Unhealthy 201-300	People with heart or lung disease, older adults, and children should avoid all physical activity outdoors. Everyone else should avoid prolonged or heavy exertion.	Active children and adults, and people with respiratory disease such as asthma, should avoid all outdoor exertion. Everyone else, especially children should limit outdoor exertion.	People with cardiovascular disease, such as angina, should avoid exertion and sources of CO, such as heavy traffic.	Children, asthmatics, and people with heart or lung disease should avoid outdoor exertion. Everyone else should limit outdoor exertion.	Children and people with respiratory disease, such as asthma, should limit heavy outdoor exertion.
MAROON: Hazardous 301-500	Everyone should avoid any outdoor exertion; people with heart or lung disease, older adults, and children should remain indoors.	Everyone should avoid all outdoor exertion.	People with cardiovascular disease, such as angina, should avoid exertion and sources of CO, such as heavy traffic. Everyone else should limit heavy exertion.	Children, asthmatics, and people with heart or lung disease should remain indoors. Every-one else should avoid outdoor exertion.	Children and people with respiratory disease, such as asthma, should limit moderate or heavy outdoor exertion.

Health Advisories associated with regulated outdoor air pollutants in Michigan (MDEQ, 2011b). Although the pollutants are not regulated in the indoor environment, the health effects associated with a given pollutant at a given level of air quality are apt descriptors.

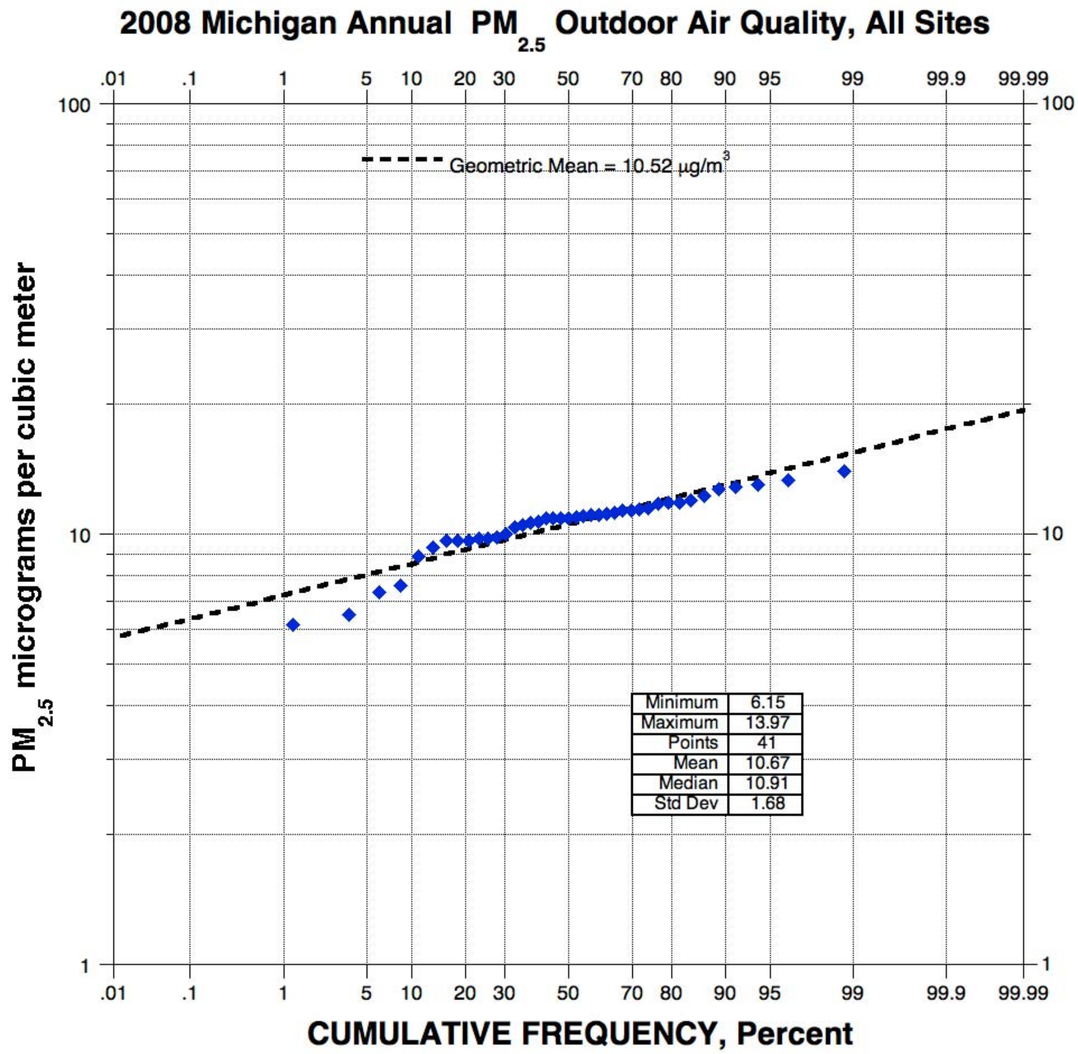

Figure C-1. A log-probability plot of outdoor $PM_{2.5}$ for all 41 sites in the State of Michigan in 2008 (MDEQ, 2011a).

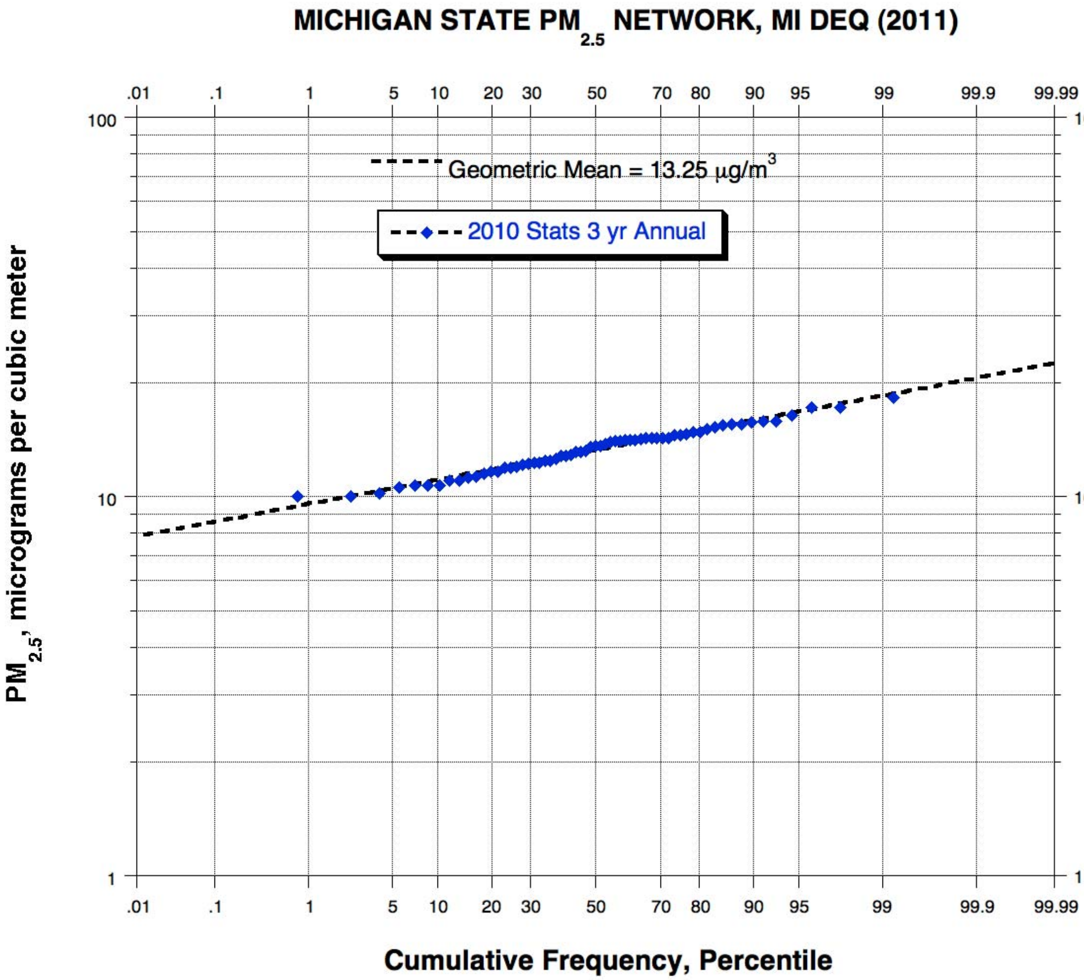

Figure C-2. A log-probability plot of 3-year average outdoor $PM_{2.5}$ for 63 sites in the State of Michigan, 2007-2010 (MDEQ, 2011a).

Statistic	**µg/m³**
Minimum	10
Maximum	18.2
Points = 63	
Data Mean	13.37
Data Median	13.60
Model Geometic Mean (curve-fit)	13.25