An Air Quality Survey of Respirable Particles and Particulate Carcinogens in Wilmington Delaware Hospitality Venues Before and After a Smoking Ban

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Abstract

Using state-of-the art monitoring equipment, air quality was assessed in the City of Wilmington, Delaware, in 8 hospitality venues. A casino, 6 bars, and a pool hall were sampled on Friday evening, November 15, 2002, under conditions of unrestricted smoking, and again on Friday evening, January 24, 2003, two months after a smoking ban. Measurements were made of respirable particle air pollution (RSP) and particulate polycyclic aromatic hydrocarbons (PPAH), pollutants known to increase risk of respiratory disease, cancer, heart disease, and stroke. Prior to the smoking ban, all venues were heavily polluted, with indoor RSP levels averaging 20 times outdoor background. For workers, these levels violated the annual National Ambient Air Quality Standard (NAAQS) for fine particles ($PM_{2.5}$) by a factor of 4. Indoor carcinogenic PPAH averaged 5 times higher than outdoor background levels, tripling workers' daily PPAH exposure. By contrast, subsequent to the smoking ban, the indoor air quality levels for both pollutants were, except for RSP in one venue, indistinguishable from outdoors. Secondhand smoke (SHS) contributed 90% to 95% of the RSP air pollution during smoking, and 85% to 95% of the carcinogenic PPAH. Smoking prevalence averaged 15%, much lower than the Delaware average of 23%. Hospitality industry air quality was likely worse in parts of the State where smoking prevalence is higher. Estimated outdoor air exchange rates were very low, apparent casualties of economic pressures in the hospitality industry coupled with the lack of regulation. However, carcinogenic risk apart, increasing ventilation to satisfy the NAAQS during smoking would require an unachievable 80 air changes per hour (133 ft^3 outdoor air/min-person) at a 23% smoking prevalence. This air quality survey demonstrates conclusively that the health of Delaware hospitality workers and patrons has been endangered by secondhand smoke pollution. The Delaware Clean Indoor Air Act's ban on smoking in hospitality workplaces eliminates that hazard, and is well-justified regardless of any real or imagined economic impact.

Introduction: Secondhand smoke (SHS) has been condemned as a health hazard by all U.S. environmental health, occupational health, and public health authorities, including the National Toxicology Program (2000), the National Cancer Institute (1993; 1995), OSHA (1994), the Environmental Protection Agency (1992), the National Institute for Occupational Safety and Health (1990), the Surgeon General (1986), and the National Academy of Sciences(1986). Nevertheless, because of repeated Congressional admonitions that SHS is an issue best handled by States, federal regulatory agencies have been discouraged from undertaking rulemaking or research efforts to protect private-sector workers and the public. However, States have been slow to take action, especially in the hospitality industry sector. Maryland Occupational Safety and Health banned smoking in all workplaces in 1994, but in 1995, the State legislature overrode the rule before it took effect, exempting bars and restaurant bars, apparently in the belief that hospitality industry workers did not warrant the same protection from secondhand smoke as other workers. In 1995, California banned smoking in all restaurants and other workplaces, and in 1998 extended the ban to include all bars. Delaware followed suit in 2002. In 2003, both New York City and Boston will ban smoking in bars.

The California ban on smoking in bars provided immediate respiratory health benefits for bartenders: Eisner et al.(1998) studied the association between SHS exposure and respiratory symptoms in a cohort of 53 bartenders before and after California's prohibition on smoking in all bars and taverns in 1998. 45% of the bartenders were current smokers, who reported no overall change in smoking habits subsequent to the prohibition. 74% of the bartenders initially reported respiratory symptoms; of those symptomatic at baseline, 59% no longer had symptoms at follow-up. 77% initially reported sensory irritation symptoms; at follow-up, 78% of these had symptom resolution. After SHS exposure completely ceased, objective measures of pulmonary function showed a marked 5% to 7% improvement after only one month of smoke-free air. A similar improvement was noted both in nonsmokers *and* smokers. Eisner et al. (1998) concluded that establishment of smoke-free bars and taverns was associated with improvement in workers' respiratory health.

The California regulation also proved to be healthy for its hospitality industry, as Figure 1 shows.

First Quarter Taxable Sales Figures for Restaurants & Bars, State of California '92-'01
Source: California Dept. of Health; California Board of Equalization
<**http://www.boe.ca.gov/news/tsalescont.htm**>

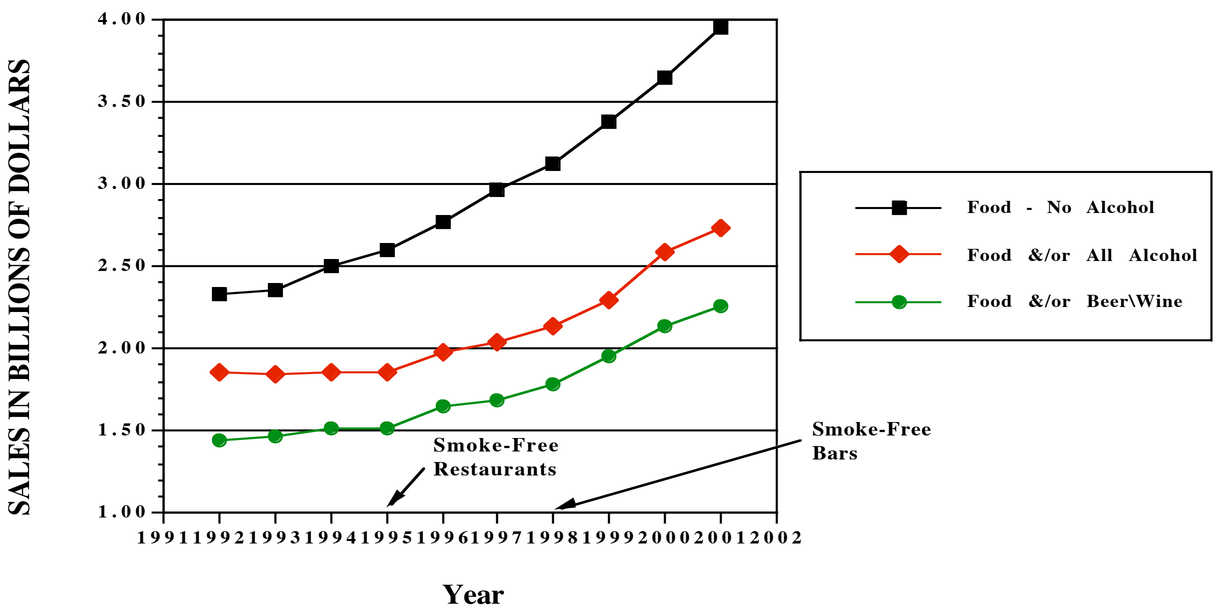

Figure 1. First quarter taxable sales for California restaurants and bars. The sector labeled "Food &/or All Alcohol" includes both stand-alone bars and restaurants with bars. Note that sales were flat in the alcohol sales sector until the smoking ban, and that revenues have increased every year since the ban.

Nonsmoking majority avoids smoky premises: The long-term increase in sales following the California smoking ban may be explained by nonsmokers' aversion to tobacco smoke. In 1995-96, Biener et al. (1999) at the University of Massachusetts (Boston), surveyed a representative sample of 4929 Massachusetts adults to assess who avoids smoky restaurants and bars, and why. The adult population of Massachusetts ($\geq$18 years) is 4.5 million, including 3.7 million non-smokers, and 800,000 smokers. Biener et al.'s survey found that 76% of the nonsmokers were bothered by tobacco smoke, and that 46% of nonsmokers reported that they avoided smoky places due to offensive odors or health worries. Biener et al. estimated that, in 1996, due to secondhand smoke concerns, 515,405 adult nonsmokers avoided patronizing restaurants and 364,400 nonsmokers avoided patronizing bars. This means that 880,000 Massachusetts nonsmokers avoided smoky restaurants and bars, exceeding by 80,000 persons the entire number of smokers in the State. *In other words, secondhand smoke loses trade*.

The Delaware Situation: In 2002, the *Delaware Clean Indoor Air Act* was amended to ban smoking, effective November 27, in restaurants, bars, and casinos, hospitality venues which had been excluded in the original act passed by the General Assembly in 1994. This measure was intended to give hospitality workers the same occupational health protection that workers in other sectors already enjoyed. The law is administered by the State Health Department, which has received requests from businesses for exemptions to the rules based on putative economic or libertarian grounds. Opponents asserted they would attempt to repeal this amended Act when the legislature re-convened in 2003 (Miller & Talorico, 2002). Therefore, in an effort to assess the impact of secondhand smoke on the Delaware hospitality industry, The American Lung Association of Delaware commissioned a 2-phase study to assess the air quality in 8 selected hospitality venues in the City of Wilmington: a casino, 6 bars, and a pool hall, as described in Table 1. Wilmington, located in New Castle County, is the largest city in Delaware, with a population of 73,000, and is a hub for the chemical and shipping industries. The first phase was conducted on Friday evening, November 15, 2002, before the smoking ban, and the second was conducted two months later, on Friday evening, January 24, 2003, after smoking ban compliance had been demonstrated. This report describes the Wilmington air quality survey and its results.

Principal Investigator: This study was designed and conducted by James Repace, MSc., of Repace Associates, Inc. He is a health physicist and an international secondhand smoke consultant who has published 60 scientific papers on the hazard, exposure, dose, risk, and control of secondhand smoke. He has received numerous national honors, including the Robert Wood Johnson

Foundation Innovator Award, the Flight Attendant Medical Research Institute Distinguished Professor Award, and the Surgeon General's Medallion. He holds an appointment as a Visiting Assistant Clinical Professor at the Tufts University School of Medicine. He is a former senior policy analyst and scientist with the U.S. Environmental Protection Agency, serving on both the Air Policy and Indoor Air Staffs, Office of Air and Radiation, and in the Exposure Analysis Division, Office of Research and Development. He served as a consultant to OSHA on its proposed rule to regulate secondhand smoke and indoor air quality, and as a research physicist at the Naval Research Laboratory in the Ocean Sciences and Electronics Divisions. His curriculum vitae may be viewed at www.repace.com.

Methods: Two fractions of the particulate phase of secondhand smoke were chosen for measurement: respirable particles (RSP), consisting of airborne particulate matter in the combustion size range below 3.5 microns in diameter ($PM_{3.5}$), and particulate polycyclic aromatic hydrocarbons (PPAH). Cigarettes, pipes, and cigars are major emitters of RSP and PPAH (Repace and Lowrey, 1980; 1982; Repace et al., 1998). RSP was chosen in part because there are relevant recently-promulgated federal health-based outdoor air quality standards for a very similar fraction of RSP called $PM_{2.5}$ (Wallace, 1996; USEPA, 1997). EPA's outdoor air standards are widely accepted as a basis for judging the quality of indoor air (e.g., see ASHRAE Standard 62- 1981, 1989, 1999). $PM_{3.5}$ was also selected in part to compare directly to previously-published $PM_{3.5}$ measurements of tobacco smoke pollution by this and other investigators (Repace, 1987). Many epidemiological studies have shown that increases in daily average RSP levels are associated with increased morbidity and mortality. Moreover, there is new evidence that even shorter-term exposures can have cardio-pulmonary health effects (Pope and Dockery, 1999; Lanki, et al., 2002), SHS included (Repace, 2002). While daily average concentrations can readily be assessed by pump-and-filter gravimetric sampling, these are not real-time capable. Short-term exposures can be assessed only by real-time monitors, such as photometers. Lightweight, battery-powered photometers, such as the data logging MIE personalDataRAM (pDR-1200), have been developed, calibrated against standard pump-and-filter gravimetric methods, and deployed in environmental epidemiology studies (Lanki et al., 2002). Lanki et al.(2000) reported a good correlation ($R^2 = 0.86$) between the pDR-1200 and gravimetric sampling in field studies of personal exposures to respirable particles in the EXPOLIS air pollution study conducted in Europe.

PPAH was chosen in part because it consists of a mixture of well-known carcinogens present in tobacco smoke, as well as diesel exhaust, and wood smoke (Hoffmann & Hoffmann, 1987). PPAH have been implicated in heart disease and stroke mechanisms as well (Glantz & Parmley, 1991). Total PAH include both gaseous and particulate phase compounds. The classic PPAH compound is benzo(a)pyrene, which is a known human lung carcinogen (Danissenko, et al., 1996). There are more than 100 PAH molecules; measurement of PPAH will underestimate the total number of PAH in the air. Portable real-time PAH monitors have been developed, calibrated against standard gas-chromatography /mass spectrometry methods, and deployed in environmental epidemiology studies (Chuang et al., 1999; McBride et al., 1999; Repace et al., 1998). Recently a new, lightweight, battery-powered PPAH monitor, the data logging EcoChem PAS2000, has been developed, and is deployed in these experiments.

Part I: Measurements Prior to the Delaware Smoking Ban

Repace and Lowrey (1980) pioneered the use of real-time measurements to study air pollution from secondhand smoke in the hospitality industry; the present survey was conducted according to protocols they developed (Repace, 1987a,b), but using current state-of-the-art equipment. Accordingly, an air quality monitoring instrument package was assembled and first deployed on Friday, November 15, 2002 in the selected Wilmington-area hospitality venues. The weather on that evening (6 PM to Midnight) was fair and relatively mild, with barometric pressure between 30.01 inches of mercury and 30.06 inches of mercury. The outdoor temperature was 51.8 ºF at 6 PM, decreasing to 44.6 ºF by midnight. Winds were 7 mph at 6 PM, and lowered to 3.5 mph by midnight. Relative humidity ranged from 38% to 61% during the same hours [www.wunderground.com].

Each venue was visited for an average of about ~ 1/2 hr (range, 15 to 45 min). RSP ($PM_{3.5}$) was recorded using a pump-driven ThermoMIE personalDataRAM model pDR-1200 real-time aerosol monitor (ThermoAndersen, Inc., Smyrna, GA), and PPAH were sampled using a pump-driven EcoChem PAS2000CE real-time particle-bound polycyclic aromatic hydrocarbon monitor (EcoChem Analytics, Inc., League City, TX). The pDR1200 was used with a factory calibration of 1.00; the instrument was HEPA-zeroed and the calibration rechecked prior to each day's sampling. The PAS2000CE was also used as factory calibrated. Both devices incorporate data loggers and can output mass concentration and time to a computer; both were synchronized and set for 1-minute averaging times. Outdoor and in-transit locations were sampled before and after each venue, as well as a nonsmoking hotel room before and after the hospitality survey. The miniaturized monitors were concealed, and sampling was discreet in order not to disturb occupants' normal behavior. All venues were well-patronized during the measurements. The monitoring package was generally unobtrusively located along an outside wall 2 ft to 4 ft from the floor, for the bars and the pool hall areas; in the casino, which had more open space, the package was moved about the 1000-foot perimeter of the main salon during the measuring period.

Each room's dimensions were measured using a Calculated Industries Dimension Master ultrasonic digital ruler (range 2 ft – 50 ft, resolution ± 1%), by a Bushnell Yardage Pro Sport Compact infrared laser Rangefinder (range 10 yd to 700 yd, resolution ± 1 yd), or in one instance, by pacing. Except for the casino, where only a representative sample was taken, the total number of persons present was counted at the beginning and end of the sampling period, and the number of burning cigarettes being smoked was counted at the beginning, middle, and end of that period. The clock time upon entering an establishment was recorded so that each venue could be identified in the data. Personnel from American Lung Association of Delaware designated the venues to be sampled, provided transportation, and assisted the principal investigator with person-counts.

Generalizing Measured Values: Data were collected so that values for area and volume, smoker density, air exchange rate, average concentration of the measured pollutant, and the estimated SHS contribution could be calculated. It is important to note that SHS concentrations can be both predicted and generalized by published mathematical models, by comparing measured values with those calculated using statewide smoking prevalence, default occupancy and ventilation rates specified for bars, game rooms, and casinos by the American Society of Heating, Refrigeration, and Ventilation Engineers (ASHRAE). ASHRAE Standard 62-1989, *Ventilation for Acceptable Indoor Air Quality*, specified ventilation rates for odor control "to accommodate a moderate amount of smoking" for premises in which smoking was allowed. [*N.B.*: A subsequent edition of ASHRAE Standard 62, issued in 1999, repealed the former recommendation for ventilation rates in smoking buildings, stating that "since 1989, numerous cognizant authorities have determined that environmental tobacco smoke is harmful to human health. These authorities include among others, the United States Environmental Protection Agency, World Health Organization, American Medical Association, American Lung Association, National Institute of Occupational Safety and Health, National Academy of Sciences, Occupational Safety and Health Administration, and the Office of the U.S. Surgeon General."]

Predicted SHS-RSP and PPAH Concentrations for a model Pub, Casino, and Pool-Hall/Bar occupied and ventilated according to ASHRAE Standard 62 Default Conditions:

1. ASHRAE Standard 62-1989 Default design ventilation rate and building occupancy: Bars: outdoor ventilation rate, 30 cubic feet per minute per occupant (cfm/occ or ft^3/min-occ); maximum (default) occupancy, 100 persons per 1000 ft^2 of floor area. Casinos: 30 cfm/occ for outdoor ventilation air, for a maximum occupancy of 120 persons per 1000 ft^2. For a pool hall which contains a bar (as does the pool hall in this study), I assume that the default is assumed to be the same as for a bar; game rooms are specified to be ventilated at 25 cfm/occ, for a maximum occupancy of 70 persons per 1000 ft^2.

2. Predicted Design Air Exchange Rates: Assuming a 10-foot ceiling, the default design air exchange rate for a pub is: C_v = (30 ft^3/min-occ)(100 occ/10,000 ft^3)(60 min/hr) = 18 air changes per hour (h^{-1}). This is a very high air exchange rate, and because design ventilation rates are operationally unenforced, it is likely that few pubs are ventilated according to design (or building code). For Casino "A", which has a ceiling height of 14 ft, the default air exchange rate is estimated as C_v = (30 ft^3/min-occ)(120 occ/14,000 ft^3)(60 min/hr) = 15 h^{-1}.

3. Predicted Active Smoking Prevalence: The current Delaware average adult habitual smoking prevalence is 23% (MMWR, 2001). Thus in a group of adult Delawareans consisting of mixed smokers and nonsmokers according to the Statewide smoking prevalence, 23% of the entire group would be expected to be habitual smokers. Of those, 1/3, or ~8% would be expected to be observed actively smoking at any one time (Repace & Lowrey, 1980; Repace, 1987). In other words, the physical observable in a field survey is not the number of habitual smokers, but rather the number of burning cigarettes averaged over the measurement period. Thus in a field survey in Delaware the number of burning cigarettes would be expected to be n_s = 8% if the smoking prevalence is representative of the prevalence in the larger Delaware population. As Table 1 shows, this is very close to the 8.5% active smoking prevalence actually observed in a representative sample of all 176 persons found playing slot machines along the periphery of the central salon in Casino "A".

4. Predicted Active Smoker Density: Also, if a bar has a percentage of smokers equal to the current Delaware prevalence rate, it would have a default smoker density of (0.23 smokers/occ)(100 occ/10,000 ft^3) = 23 smokers per 10,000 ft^3, or in metric units, 23 smokers per 283 cubic meters (m^3), of whom 1/3 would be expected to be actively smoking at any one time (Repace & Lowrey, 1980), which yields an active smoker density of D_s = (1/3)(23)/2.83 = 2.7 active smokers (i.e.,

burning cigarettes (BC) per 100 m^3. At the default smoking prevalence of 23%, Casino "A" would be expected to have a default smoker density of (0.23 smokers/occ)(120 occ/14,000 ft^3) = 19.7 smokers per 10,000 ft^3, or in metric units, 19.7 smokers per 283 m^3, of whom 1/3 would be expected to be actively smoking at any one time (Repace & Lowrey, 1980), corresponding to a predicted active smoker density of D_s = (1/3)(19.7)/2.83 = 2.3 active smokers, i.e., burning cigarettes (BC), per 100 m^3.

5. <u>The SHS-RSP Modeling Equation</u>: Repace and Lowrey (1980) and Repace (1987) derived an equation for the calculation of uniformly-mixed SHS-RSP levels in a building as a function of the active smoker density D_s, in units of burning cigarettes per hundred cubic meters (BC/100m^3) in the building and the building's air exchange rate C_v, in units of air changes per hour (h^{-1}):

$$RSP_{ETS} = 650\frac{D_s}{C_v} \qquad \textbf{(Eq. 1),}$$

where a 20% decay rate is incorporated to account for particle removal by surfaces. This model is in good agreement with the time-series model of Ott et al. (Ott, 1999). It is important to note that because Eq. 1 represents a uniform dilution model, it may underestimate the exposure concentration for persons, such as bartenders and casino dealers, who must work in close proximity to sources of secondhand smoke.

Using Eq. 1, the predicted respirable smoke particulate (RSP) concentration ($PM_{3.5}$) for a Delaware pub under the default assumptions is calculated as:

$$\text{SHS-RSP}_{pub} = 650(2.7)/(18) = 98\ \mu g/m^3.$$

Assuming a background RSP concentration of 10 $\mu g/m^3$ from outdoor non-SHS sources, a field study of fine particle pollution from smoking under default conditions (full occupancy, average smoking prevalence, and ASHRAE Standard ventilation rate) would be expected to show a concentration of the order of about 110 $\mu g/m^3$. For the casino, again under default assumption, the predicted level above background is calculated to be:

$$\text{SHS-RSP}_{casino} = 650(2.3)/(15) = 100\ \mu g/m^3.$$

These predictions will serve as ball-park numbers to expect in a field study, and as a basis for generalizing the results of the field study to similar venues that may have different smoker densities or air exchange rates. If the smoker density in a particular venue is lower -- or the air exchange rate higher -- than the default calculation, the measured concentration will be lower; if the smoker density is higher or the air exchange rate lower, the measured concentration will be higher. For example, as Table 2 shows, Casino "A"s observed 205 $\mu g/m^3$ RSP concentration is about double the predicted ball-park value, suggesting that the ventilation rate was about half as much as ASHRAE Standard 62 prescribes, since the casino appeared nearly fully occupied, and the smoking prevalence appeared about average.

The U.S. Annual National Ambient Air Quality Standard (NAAQS) for RSP. To place the predicted and observed levels of RSP into perspective, The NAAQS for particulate matter 2.5 microns in diameter or less ($PM_{2.5}$), which encompasses combustion-related particulate by-products such as tobacco smoke, chimney smoke, and diesel exhaust. In 1997, the EPA promulgated a 24-hour NAAQS for $PM_{2.5}$, of 65 $\mu g/m^3$, not to be exceeded more than once per year, and an annual NAAQS for $PM_{2.5}$ of 15 $\mu g/m^3$, based on protecting human health (Fed. Reg., 1997; Ware, 2000). The NAAQS for $PM_{2.5}$ is designed to protect against such respirable particle health effects as premature death, increased hospital admissions, and emergency room visits (primarily the elderly and individuals with cardiopulmonary disease); increased respiratory symptoms and disease (children and individuals with cardiopulmonary disease); decreased lung function (particularly in children and individuals with asthma); and against alterations in lung tissue and structure and in respiratory tract defense mechanisms in all persons. (Fed. Reg., 1997). $PM_{2.5}$ and $PM_{3.5}$ are closely related (Wallace, 1996). New Castle County, DE, which includes Wilmington, slightly exceeded the NAAQS for $PM_{2.5}$, with an average of 16.6 $\mu g/m^3$ over the 3 year period, 1999-2001 [List 1: Counties Exceeding the $PM_{2.5}$ NAAQS. M. Schmidt, US EPA www.epa.gov/s97is.vts].

Comparison of observed and predicted levels with federal air quality standards. Since the NAAQS incorporates an averaging time, a worker will be assumed to be exposed to RSP from both SHS on the job 1/3 of the day for about 250 days per year and to background RSP only for all 365 days per year, since RSP from outdoors penetrates readily into buildings. Thus, assuming ASHRAE default values, a worker would be exposed to an on-the-job SHS-RSP exposure of ~100 $\mu g/m^3$ for 250 days per year, and to a 24-hr background level of 16.6 $\mu g/m^3$ for all 365 days per year. The worker's weighted average total RSP exposure is calculated as: [(1/3)(100 μg/m^3)(250d/y)+(16.6 μg/m^3)(365d/y)]/365 d/y = (8,333/365 + 16.6)= 39 μg/m^3. This violates the NAAQS by a factor of (39/15) = 2.6. Thus, at average smoking prevalence and full occupancy, plus ASHRAE Standard 62 ventilation rates, a hospitality worker would breathe what is arguably *de facto* unclean air, violating the NAAQS by a factor of ~2-1/2. With this understanding in mind, we can more readily interpret the results of the Wilmington Air Quality Study.

How much ventilation would be required to meet the NAAQS? To satisfy the NAAQS, a worker's weighted annual average exposure would have to be ≤ 15 μg/m^3. Assume that the annual average outdoor RSP level in Wilmington is as low as the 10 μg/m^3 that our measurements showed on the 15th of November. Then, if we let X be the maximum concentration of SHS-RSP which would satisfy the 15 μg/m^3 NAAQS requirement, then [(1/3)(X μg/m^3)(250d/y)+(10 μg/m^3)(365d/y)]/365 d/y = (0.228 X + 10 μg/m^3) = 15 μg/m^3. Thus, X = 650 D_s/C_v ≤ 22 μg/m^3. For a bar with a Delaware average smoking prevalence, D_s = 2.7. Solving for C_v ≥ (650)(2.7)/22 ≥ 80 air changes per hour. This is equivalent to (80/18)(30 cfm/occ) = 133 cfm/occ, and would still not guarantee that the air was safe from a carcinogenic or toxic standpoint, since SHS is a known human carcinogen (NTP, 2000; NCI, 1993; USEPA, 1992).

<u>The Wilmington Air Quality Study Pre-Smoking Ban Results</u>. On Friday evening, November 15, 2002, before the Delaware hospitality industry smoking ban, from 6 PM to 12 AM, continuous measurements of respirable particles (RSP), in the particle size range less than 3.5 microns in diameter ($PM_{3.5}$) and carcinogenic particulate polycyclic aromatic hydrocarbons (PPAH), were made in 8 hospitality venues in which smoking was occurring, including a casino, 6 bars, and a pool hall/bar combo. Control measurements were conducted outdoors, in transit, and in a tenth-floor non-smoking hotel room at a downtown Wilmington Hotel. Table 2 organizes the study results. Figure 2 shows a "time series" plot of the data: the RSP and PPAH concentrations as a function of time. The heavy pollution in the hospitality venues relative to outdoors is evident. Figure 3 displays the RSP and PPAH concentrations as a function of smoker density and air exchange rate. It is readily seen that concentrations increase with increasing smoker density. Figure 4 shows that a strong correlation exists between the RSP and PPAH (correlation coefficient, r = 0.86) [the maximum value for r is 1.00, a perfect correlation]. Figure 4 suggests that the average SHS-RSP/SHS-PPAH ratio is about 2000:1.

Pre-ban Air Quality Survey Summary Results:

Average Venue Concentration: The RSP levels in 7 of 8 venues met or exceeded predicted levels based on default assumptions. It appears that smoking indoors generally raised the short-term levels of fine particle air pollution and airborne particulate PAH carcinogens massively compared to the controls. The combined average of the outdoor measurements and the hotel room for RSP was about 10 micrograms per cubic meter ($\mu g/m^3$), and for PPAH was about 20 ng/m^3. By comparison, the averages for the indoor hospitality venues were RSP, 230 $\mu g/m^3$, ten times background and PPAH, 134 ng/m^3 nearly 7 times background.

Average Venue smoking prevalence: The average prevalence of active smoking (burning cigarettes) for all venues was 5% of observed patrons, corresponding to an estimated habitual smoker prevalence of 15%. This is 2/3 of the 23% current prevalence of habitual smoking in the adult population in Delaware.

Average Venue air exchange rate: The average calculated air change rate (excluding the casino) was 1.4 air changes per hour, much lower than the 15 - 18 air changes per hour derived from the default assumptions of ASHRAE Standard 62, the operable engineering design criterion. All venues either significantly or massively failed to meet the recommended ventilation rates of ASHRAE Standard 62, which are generally incorporated into local building codes. Although the casino ventilation rate could not be assessed based on the data collected, comparison of the measured concentration with the predicted indicates that the ventilation rate was no more than half that recommended by Standard 62, since the smoking prevalence was the same as predicted, the occupancy was fairly full, but the concentration was twice that predicted. Table 2 also shows that for the 7 venues for which air exchange rates could be calculated from the measured data, none had ventilation rates more than 1/6 as high as ASHRAE recommends. Because supplying fresh conditioned air imposes costs at an average of approximately $1 per square foot per year at ASHRAE-recommended rates, there is an economic incentive for building owners to under-ventilate buildings, and buildings ventilated to code are rare. Failure to enforce operational building code-specified ventilation rates – common throughout North America -- leads to widespread non-compliance. Although ASHRAE design ventilation rates are incorporated into many regional and international building codes, once the air-handling system is installed and inspected, compliance with these recommended ventilation rates is not enforced, in part because it is very difficult and costly to measure ventilation rates as well as to train and deploy personnel to enforce them in thousands of buildings.

Average Venue Compliance with the NAAQS: All 8 venues violated the NAAQS for respirable particulate air pollution. Overall, the average RSP level for all venues violated the NAAQS by a factor of greater than 4 {[(1/3)(220 $\mu g/m^3$)(250 d/y)/365 d + (16.6 $\mu g/m^3$)(365d/y)/365 d]/15 $\mu g/m^3$ = [50+ 16.6]/15 = 4.4}. This is a significant increase in the risk of respiratory disease for hospitality workers.

Average Venue PPAH levels: Although no standards have been set for PPAH, on a 24-hr average basis for the 8 venues sampled, PPAH exceeded background levels by a factor of [(113/3) + 21)]/21 = 2.8, significantly increasing exposure of workers to substances known to be implicated in the causation of cancer, heart disease, and stroke.

Average Percent of Pollution due to SHS: Relative to background levels, it appears that secondhand smoke contributed an average of 96% of the RSP pollution and 85% of the PPAH pollution average for the 8 Venues. Figure 2 shows the RSP and PPAH concentrations as a function of time for each of the venues, separated by outdoor and in-transit measurements. The 15 $\mu g/m^3$ level of the NAAQS is down in the noise. Measuring $PM_{2.5}$ and $PM_{3.5}$ will yield similar results with respect to tobacco smoke, a sub-micron aerosol (Wallace, 1996).

Average Venue Smoking Prevalence: Most venues had average to very low smoking prevalence. Only 2 of the 8 venues had an estimated smoking prevalence as high or higher than the Delaware average of 23%, – the Casino, and Bar C – however, the bar area in the latter was only a small fraction of the total area, which had a well-attended restaurant and a large arcade game area populated with uncounted nonsmoking persons. The remainder of the venues had smoking prevalences of from 1/2 to as low as 1/8 of the average state prevalence. This suggests that other areas of Delaware where the smoking prevalence may be higher than in the city may have much higher levels of secondhand smoke.

Part II: The Wilmington Air Quality Study Post-Smoking Ban Results.

All hospitality venues were re-measured after the smoking ban took effect, and it was judged by Lung Association personnel that their compliance with the ban was satisfactory. On Friday evening, Friday, January 24th, 2003, ~2 months after the Delaware hospitality industry smoking ban, continuous measurements of respirable particles (RSP), in the particle size range less than 3.5 microns in diameter ($PM_{3.5}$) and carcinogenic particulate polycyclic aromatic hydrocarbons (PPAH), were made from 6 PM to 12 AM, in the same 8 hospitality venues (the casino, 6 bars, and pool hall) as prior to the ban, in the same order and about the same time of night. The Wilmington, DE airport weather (6 PM to Midnight) was fair and cold, with barometric pressure between 30.27 inches of mercury to 30.33 inches of mercury. The outdoor temperature ranged from 26.6 °F at 6 PM, decreasing to 21.2 °F by midnight. Winds were 20 mph at 6 PM, and lowered to 8.1 mph by midnight. Relative humidity ranged from 31% to 54% during the same period [www.wunderground.com].

As in the pre-ban field study, control measurements were performed outdoors, in transit, and in the same tenth-floor non-smoking hotel room at a downtown Wilmington Hotel. Table 3 organizes the study results. The number of persons present in the 8 premises are of the same order as before the ban, with some premises showing more persons, and some less. Real-time miniaturized data logging environmental monitoring equipment for temperature, relative humidity, carbon monoxide, and carbon dioxide, unavailable at the time of the pre-ban field study, was deployed. Carbon dioxide measurements are useful for estimating the ventilation rate per occupant, for comparison with ASHRAE Standard 62.

Measurement of Carbon Dioxide (CO_2) levels as a surrogate for air exchange rate. Appendix C of ASHRAE Standard 62 (ASHRAE, 1999) specifies the following equation for C_s, the equilibrium CO_2 levels in parts per million (ppm) in a space:

$$C_s = \frac{N}{V_o} + C_o \qquad \textbf{(Eq. 2),}$$

where N is the CO_2 generation rate per person (N = 0.30 L/min, corresponding to office work), V_o is the outdoor air flow rate per person, and C_o is the CO_2 concentration (ppm) in the outdoor air; $C_o \sim 400$ ppm, and N = 5000 L/s-occupant. Equation 2 is typically used to estimate the flow rate adequacy based upon an indoor CO_2 measurement. Note that the flow rate of $V_o = 30$ CFM/person (15 L/s-p) specified by ASHRAE 62-1989 for gambling casinos or bars corresponds to a CO_2 level of $C_s = (5000/15) + 400 = 733$ ppm.

Estimation of air exchange rates from CO_2 levels. As discussed above, at full occupancy, a CO_2 level of 733 ppm indicates an air exchange rate of 18 air changes per hour (h^{-1}). However, if equilibrium is not achieved or the occupancy is less than full, 733 ppm will represent less than 18 h^{-1}. For example, Venue *C* has a CO_2 level of 784 ppm. This calculates out to 13 liters per second per person (L/s-P) in comparison with a specified 15 L/s-P from the ASHRAE Standard. But Venue *C* also has a very low occupancy of 13 persons per 1000 ft^2, coupled with a very high 33 ft ceiling. The corresponding air exchange rate calculates out to be just 1/27th of 18 air changes per hour [(218 P/15,573 m^3)(13.0 L/s-P)(3.6 m^3-s/L-h) = 0.66 h^{-1}]. This is close to the air exchange rate of 0.36 h^{-1} calculated from the SHS RSP concentration using Eq. 1. The right-most column of Table 3 shows the air changes per hour calculated from the CO_2 levels. While the ventilation rate per occupant is second best of the 8 venues, and is 87% of the design CO_2 level, the actual rate of air exchange -- which determines the rate of pollutant removal -- is totally inadequate. Table 2 shows that Venue *C* had only 3 burning cigarettes on Nov. 15th. Table 3 shows for Venue *C*, that this was sufficient to increase the carcinogenic PPAH concentration in this massive 550,000 cubic foot facility by (1/7.8%) = 13-fold. Even huge dilution volumes cannot overcome the high emission rates of toxic and carcinogenic pollutants generated during cigarette smoking.

While two of the 7 venues for which air exchange rates could be calculated (Venues *F* and *G*) appear to be much higher than the rest, this appears to be an artifact of having located the monitoring package too close to the front doors through which persons were constantly coming and going, on a night when there was a substantial indoor/outdoor temperature difference, leading to considerable influx of cold air from outdoors, and localized dilution of the CO_2 levels.

Figure 5 shows the RSP and PPAH concentrations as a function of time; the dramatic improvement in air quality in all hospitality venues relative to prior to the ban is evident by contrasting Figure 5 with Figure 2. Except for the pool hall, most venues are indistinguishable from background concentrations. Even the very poorly ventilated pool hall (CO_2 level 2000 ppm, compared to 733 ppm expected) has only 17% of pre-ban RSP (possibly caused by chalk dust) and just 1.2% of pre-ban PPAH. The RSP air quality in most of these 8 venues is now little different from outdoors. PPAH is very close to or below outdoor background levels in all venues.

Comparison of pre-ban and post-ban RSP and PPAH in Table 3 shows that the levels of each in the absence of indoor smoking are small fractions of those measured during smoking, demonstrating conclusively that it is tobacco smoke – not confounders from cooking or other sources – that produced the massive fine particle and carcinogen pollution observed in Figure 2. Levels of RSP ranged from 2.5 to 25% of pre-ban values and averaged 9.4%, while PPAH concentrations ranged from 0.5% to 11% of pre-ban levels, and averaged 4.7%. Thus, the post-ban measurements suggest that about 90% of the fine particle pollution and 95% of the particle-bound PAH carcinogens can be attributed to tobacco smoke. This may be contrasted with the pre-ban results using the outdoor background as a reference point, suggesting that, during smoking, for the 8 hospitality venues overall, an estimated average of 96% of the RSP concentration and 84% of the PPAH concentration was due to secondhand smoke. Expressing these as a range, it can be stated with confidence that 90% to 95% the RSP pollution, and 85% to 95% of the PPAH pollution measured in the pre-ban visit was due to smoking. The smoking ban has generally reduced the exposure of workers and patrons to these harmful pollutants to outdoor background levels, except for RSP in the pool hall, which still has been reduced to 17% of its pre-ban concentration .

Discussion: Figures 3, 4, and 5 taken together demonstrate conclusively that secondhand smoke causes the massive RSP and PPAH pollution elevations shown in the 8 hospitality venues of Figure 2. Smoking in these Wilmington hospitality venues caused levels of respirable particles and particle-bound PAH carcinogens exposure to increase by ten- to twenty-fold. The models developed from Equation 1 generalize the results to other Delaware hospitality venues. What are the likely health consequences of such pollution? According to the Agency for Toxic Substances and Disease Registry (ATSDR, 2003), "animal studies have shown that PAH exposure increased the rate of birth defects in test animals, and reduced their ability to fight disease, even after short-term exposure. It is not known whether these effects occur in people. However, people exposed to PAHs for prolonged periods have developed cancer. Animal studies have demonstrated that some PAHs have caused lung cancer, stomach cancer, and skin cancer." Ten carcinogenic particulate-phase PAHs have been identified in tobacco smoke as listed in Table 4; this is one-sixth of known tobacco smoke carcinogens (Hoffmann and Hoffmann, 1998).

A body of evidence connecting exposure to SHS to premature death has accumulated during the past two decades, and has been summarized in several authoritative reports compiled by panels of scientific and medical experts. The U.S. National Toxicology Program has included SHS on its list of *known human carcinogens* (NTP, 2000), a list which includes asbestos, coal tar dyes, and mustard gas, reaffirming the landmark judgment of the U.S. Environmental Protection Agency in 1992 (USEPA, 1992).

Thus, the reduction in carcinogenic PAHs caused by the Delaware smoking ban as shown by this study, has *demonstrably* reduced the risk of cancer for thousands of Delaware hospitality workers, managers, and patrons.

Concerning RSP pollution, Samet et al. (2000) concluded that there is consistent evidence that the levels of fine particulate matter in the air are quantitatively associated with the risk of death from all causes and from cardiovascular and respiratory illnesses. Other indicators of impaired respiratory health, such as upper and lower respiratory symptoms, and decrements in lung function also occur with increasing particulate air pollution. Secondhand smoke has been linked to both cardiovascular and respiratory disease mortality (NCI, 1997). Long-term repeated exposure to particulate air pollution, like that experienced by workers in the hospitality industry, is known to increase the risk of chronic respiratory disease and the risk of cardiorespiratory mortality. Short-term exposures to particulate air pollution, like that experienced by hospitality industry patrons, can aggravate existing cardiovascular and pulmonary disease and increase the number of persons in a population who become symptomatic require medical attention, or die (Pope and Dockery, 1999). Thus it may be confidently stated that the smoking ban in the Delaware hospitality industry has decreased the risk of these diseases in both workers and patrons, as the levels of fine particle air pollution in these venues has decreased by ten to twenty fold.

Hospitality industry smoking bans are now becoming widespread. Both New York City and Boston will implement these in the next few months. Even in Ireland, which has a very strong pub culture and a 30% smoking prevalence, will ban smoking in pubs, clubs, and restaurants; more than 50 bar staff are suing their employers, claiming they developed cancer and emphysema as a result of passive smoking (Sheahan, 2003).

Finally, as the World Health Organization has stated: “Commercial interests often have delayed the implementation of indoor air pollution controls in spite of scientific evidence of harmful health impacts. Everyone has the right to breathe healthy indoor air. No agent at a concentration that exposes an occupant to an unnecessary health risk should be introduced into indoor air” (Molhave and Kryzanowski, 2003). It is clear from the data developed here, that secondhand smoke has imposed a clear and present danger to the health the workers and patrons of the hospitality industry, which has been removed by the smoking ban. Its rollback would benefit only the tobacco industry.

<u>Conclusions</u>:

1. **Air quality was assessed in 8 hospitality industry venues in Wilmington, DE, before a smoking ban, using state-of-the-art real-time respirable particulate air pollution and particulate carcinogen monitors.**

2. **Despite the low smoking prevalence, averaging about 2/3 of the Delaware State smoking prevalence of 23%, all venues were heavily polluted with fine particle air pollution (RSP), violating the U.S. annual National Ambient Air Quality Standard (NAAQS) for respirable particulate air pollution for hospitality workers by an average of 4 to 1, with short-term exposures increasing on average, by a factor of 20:1, raising occupants' risk of cardiopulmonary disease.**

3. **The 24-hr average levels of particulate polycyclic aromatic hydrocarbons (PPAH) were increased over background levels in the 8 venues by an average of nearly 3:1, and the short-term levels by 5:1, raising occupants' risk of cancer, heart disease, and stroke.**

4. **During smoking, for the 8 hospitality venues overall, an estimated average of 96% of the indoor RSP pollution and 84% of the indoor PPAH carcinogens were due to secondhand smoke, using measured outdoor levels as a referent.**

5. **Prior to the smoking ban, all venues appeared to be under-ventilated by factors ranging from 1/2 to 1/50 (average 1/13, corresponding to 1.4 air changes per hour). ASHRAE Standard 62, the North American engineering standard for ventilation, requires 30 cfm/occ, equivalent to 18 air changes per hour, for the venues visited. After the smoking ban, on a ventilation rate per actual occupant basis, no venue met the ASHRAE standard.**

6. **To bring a bar with Delaware average smoking prevalence into compliance with the NAAQS for $PM_{2.5}$ would require more than 80 air changes per hour (133 cfm/occ). However, this increase would still not ensure that the air was safe from a carcinogenic or toxic standpoint.**

7. **Hospitality industry air quality in rural parts of Delaware where smoking prevalence is higher than Wilmington was likely to be worse.**

8. **Air pollution measurements made subsequent to the smoking ban suggest that, compared to pre-ban levels, 90% of the RSP and 95% of the PPAH carcinogens can be attributed to tobacco smoke, using pre-ban indoor concentrations as a referent.**

9. **The Delaware smoking ban has significantly reduced the risk of cancer, heart disease, stroke, and respiratory disease among workers and patrons in the hospitality industry.**

10. **Based on the California and Massachusetts experience, there should be a long-term positive economic impact for the Delaware hospitality industry as a result of the smoking ban. Whether this occurs or not, public policy has a higher obligation to protect the health of workers and citizens by ensuring clean indoor air.**

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Table 1. 8 Wilmington, Delaware Hospitality Venues in which Air Quality Measurements Were Made; Areas Described as "Smoking" Were Smoking on Nov. 15, 2002, and Nonsmoking on Jan. 24, 2003 after the Ban. Alphabet letters before Venue descriptions are keyed to figures 2 and 5. All restaurant areas were nonsmoking on both dates unless otherwise specified.

Venue	Description
A. Casino	Large volume slot machine-only casino with restaurant/bar areas, all smoking; 1 relatively small nonsmoking area prior to the ban. Monitors circulated around periphery of central salon during smoking tour; during nonsmoking tour, monitors located in outer portion of coat-check room open to surrounding air thru large window.
B. Bar/Restaurant	Standup/sit-down smoking bar area with adjacent dining table area; located in a mid-size shopping mall with an outdoor entrance. Monitors on both smoking and nonsmoking tours located in same location at end of bar area.
C. Bar/Restaurant/Games	Large volume nonsmoking restaurant/video game arcade; caters to families, but with a fenced-off bar-oasis (the only smoking area prior to the ban). Monitors located inside bar area at periphery at same location on both visits.
D. Bar/Restaurant	Sit-down smoking bar; open passage to dining area; genteel sports-bar-like atmosphere. Monitors located at same spot ~6 ft from vestibule at one end of bar area on both visits.
E. Bar/Nightclub	Large sit-down smoking bar surrounded by smoking dining tables with adjacent dance floor; has bouncer but no cover charge; serves singles, couples, and parties. Monitors located between barstools in proximate locations on each visit.
F. Bar/Restaurant	Sit-down smoking bar with large adjacent nonsmoking restaurant area for dining. Monitors located on opposite sides of one end of bar area on each visit.
G. Bar/Nightclub	Stand-up smoking bar with adjacent dance floor catering to college-age singles; very crowded, has aggressive bouncer and cover charge. Monitors located ~6 ft from front door and on opposite sides for each visit. Door was frequently opened as persons entered or left premises. Several patrons smoked outside the door during the nonsmoking tour.
H. Pool Hall	Standup/sit-down smoking bar contiguous to adjacent smoking pool hall; adults only. Monitors located on periphery of pool table area during smoking tour; at a nearby pool table during the nonsmoking tour.

Table 2. Nov. 15, 2002 Wilmington, Delaware Indoor/Outdoor Air Quality Survey Results

Venue	Area (ft^2)	Ceiling Ht. (ft)	Volume (m^3)	Ave. # Persons Present[+]	Ave. # Persons per 1000 ft^2	Ave. # Burning Cigarettes[+]	% of Persons Actively Smoking[+]	Estimated Smoker Prevalence % of all Persons in Venue	Ave.[+] RSP, μg/m^3	Ave.[+] PAH, ng/m^3	D_s, Active Smoker Density[◊]	C_v, Est.[c] Air exchange rate, air changes per hour (h^{-1})
A. Casino	32,499[β]	14	12,884[β]	176**	-	15**	8.5%	25.5%**	205	163	-	-
B. Bar	1,800	10	510	104	58	7.33	7.0%	21%	337	241	1.44	2.9
C. Restaurant /bar/video games	16,740	33	15,573	24.3[†]	-	3	12.3%[†]	37%[†]	34	44	0.02	0.36
D. Bar/ Nightclub	5,175	30	4396	75.5	15	2.33	3.1%	9.3%	96	46	0.05	0.38
E. Bar/ Restaurant	2,592	10	710	135	52	2	1.5%	4.5%	127	89	0.28	1.6
F. Bar/ Restaurant	2,228	8	518	102	46	1	1.0%	3.0%	103	53	0.19	1.34
G. Bar/ Nightclub	864	12	294[†]	170[†]	197	2.5	1.5%	4.5%	252	183	0.85	2.3[d]
H. Pool Hall	3,780	10	1,070	191	51	9.7	5.1%	15.3%	686	249	0.90	0.87
Mean (SD) All Venues					**70** **(SD 64)**		**5.0%** **(SD 4.0)**	**15.0%** **(SD 12.0)**	**230** **(SD 208)**	**134** **(SD 86.5)**		**1.4** **(SD 0.95)**
Nonsmoking Hotel Rm1004	~150	8	34	1	-	0	0	0%	**8.0*** **(SD 1.0)**	**15*** **(SD 7.4)**	0	-
Outdoors/In Transit[¶]	-	-	-	0	-	0	0	0%	**11[¶]** **(SD 3.2)**	**27[¶]** **(SD 28)**	0	-

[◊]*(D_s in units of burning cigarettes per 100 m^3); *[66 minute weighted average (45 min before and 21 min after all Venue sampling)];* [β]*(central salon only);* [c]*(Using Eq. 1);* [+]*(29 min (SD 8 min) ave.);* [¶](5 to 25 min samples); [†]*(bar area only); **(persons at peripheral slots in central salon only);* [d]*(outer door open).*

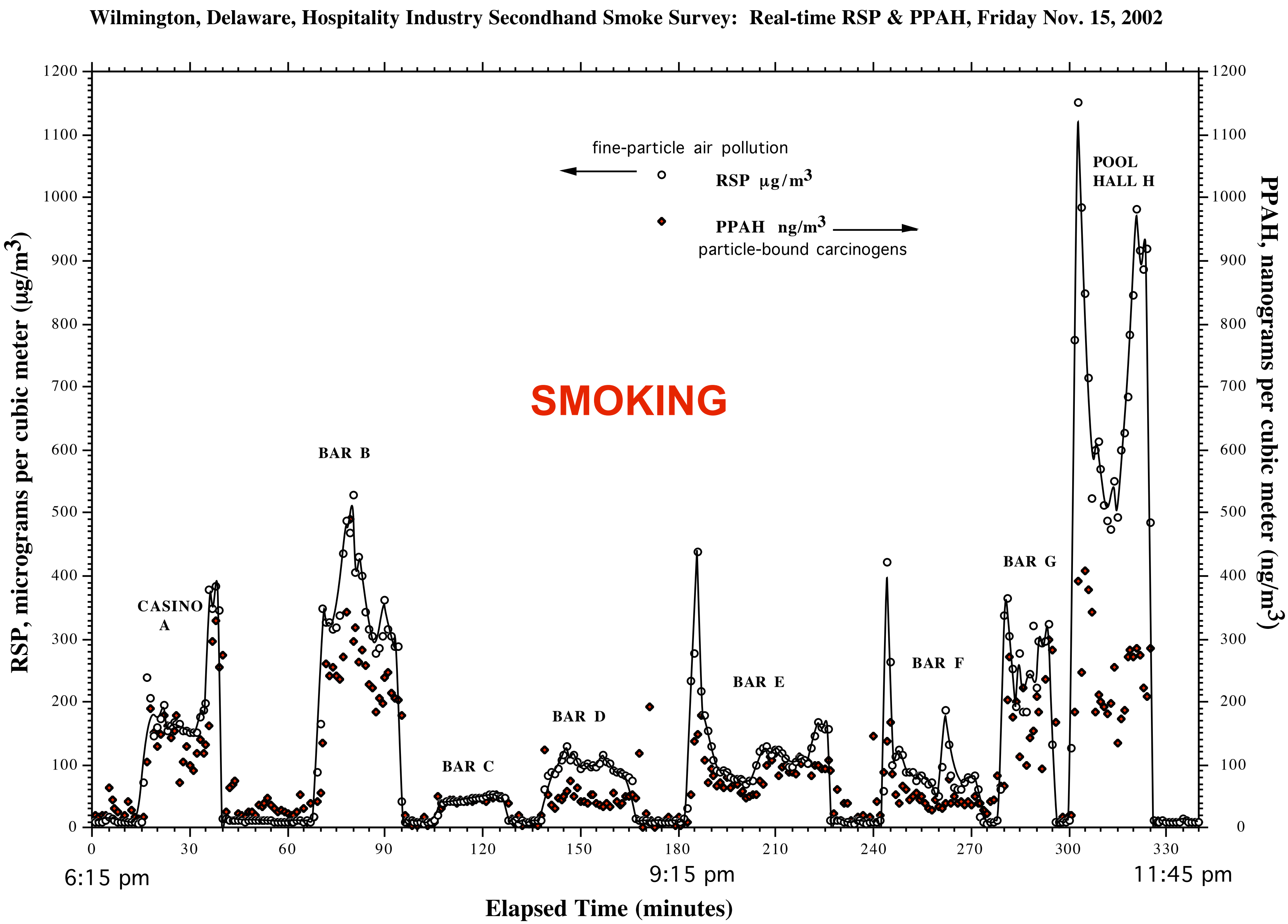

Figure 2. Real-time fine-particle air pollution (RSP) and airborne carcinogens (PPAH) before a smoking ban. Data recorded on Friday Evening, November 15, 2002. Outdoor & in-transit location measurements precede & follow each Venue sampled. For comparison, the National Ambient Air Quality Standard for fine-particle air pollution ($PM_{2.5}$) is 15 µg/m^3, annual average. All venues were crowded, with persons observed to be smoking throughout the sampling periods.

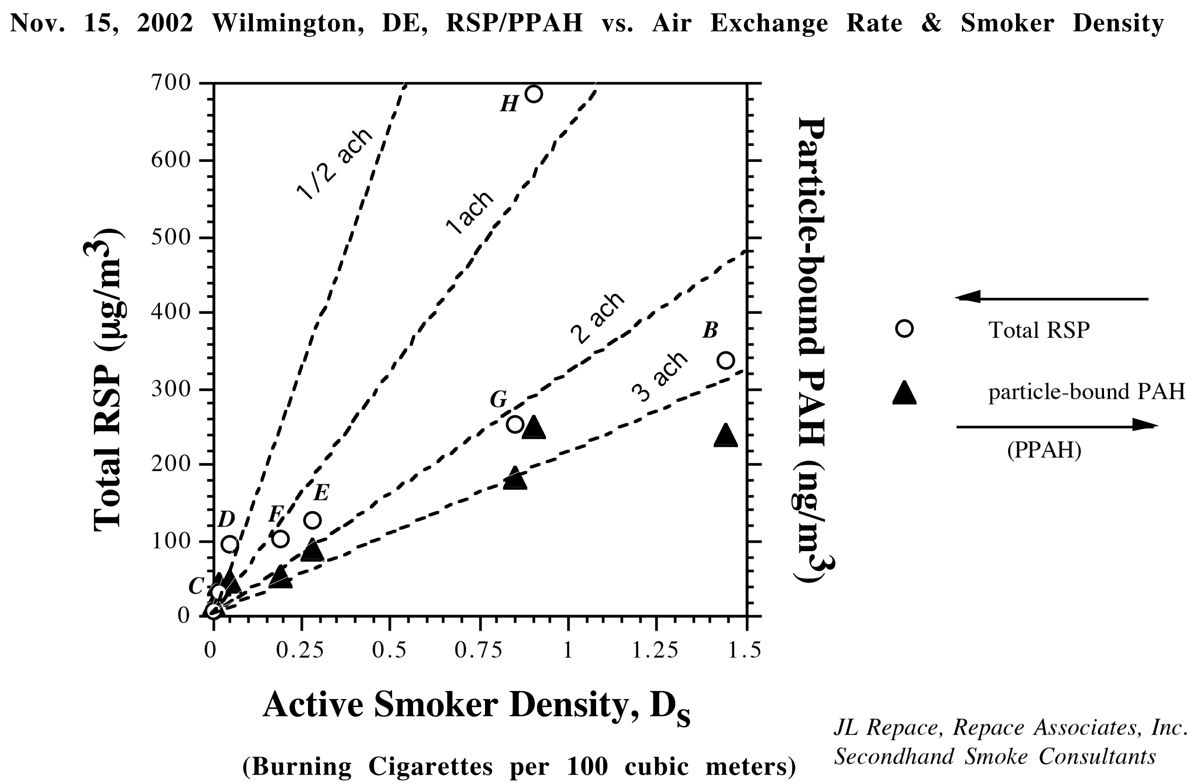

Figure 3. Air pollution in 7 of 8 hospitality venues (casino A not shown) in which smoking occurred, and a nonsmoking hotel room in Downtown Wilmington, Delaware on Friday evening Nov. 15, 2002. Measured RSP and particulate PAH values are displayed as a function of measured active smoker density and air exchange rate estimated using Eq. 1. Both RSP and PPAH increase with increasing smoker density. Air exchange rates for the 7 venues range from ~0.4 to 3 air changes per hour (ach).

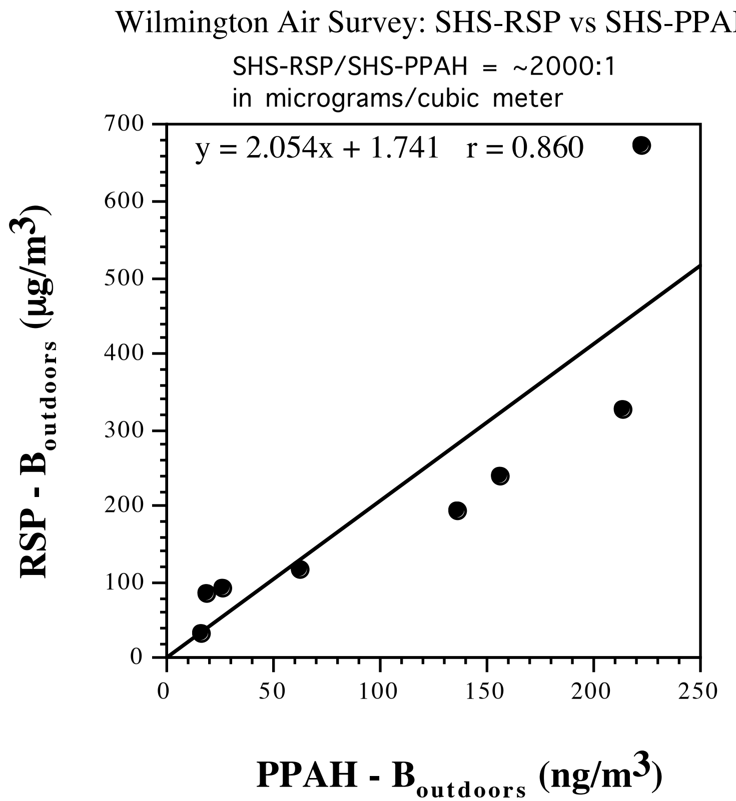

Figure 4. A plot of total indoor RSP less average outdoor/hotel RSP background (estimated SHS-RSP) versus total indoor PPAH less average outdoor/hotel PPAH background (estimated SHS-PPAH) for the 8 hospitality venues. A strong linear correlation between SHS-RSP and SHS-PPAH is seen ($r = 0.86$), with a RSP/PPAH ratio of ~2000:1 .

Table 3. Jan. 24, 2003 Wilmington, Delaware Indoor/Outdoor Air Quality Survey Results Post-Smoking Ban

Venue	Ave. # Persons Present, Post-ban[A]	Ave. Carbon Dioxide (CO_2) ppm	~Temp. °F	Relative Humidity Range %	Persons per 1000 ft^2	Ave.[+] RSP, µg/m^3	Percent Of Pre-ban RSP Value	Ave.[+] PPAH, ng/m^3	Percent Of Pre-ban PPAH Value	Estimated[b] Ventilation rate L/s-P from CO_2	Estimated[b] Air Exchange rate, h^{-1} from CO_2
A. Casino	825[b]	820	68	6-14	-	9.4	4.6	3.7	2.3	11.9	-
B. Bar	188	1716	63	10-23	104	24	7.0	1.3	0.5	3.8	5.0
C. Restaurant /bar/video games	218[c]	784	63	12-20	13	8.4	25	3.4	7.8	13.0	0.66
D. Bar/ Nightclub	137	861	61	12-27	26	4.6	4.8	2.6	5.6	10.8	1.2
E. Bar/ Restaurant	88	1302	59	14-22	34	7.4	5.8	9.8[e]	11	5.5	2.5
F. Bar/ Restaurant	113	775	59	16-25	51	2.5	2.5	1.7	3.2	13.3	10.7[d]
G. Bar/ Nightclub	188	940	59	17-21	217	21	8.3	11[e]	6.0	9.3	21[d]
H. Pool Hall	117	2000	57	17-34	31	119	17	3.0	1.2	3.1	1.2
Mean (SD) All Venues	**-**	**-**	**-**	-	**-**	-	**9.4**	**-**	**4.7**	**-**	**-**
Nonsmoking Hotel Rm1004	1					2.0 (SD 1.9)	-	3* (SD 1.9)	**-**		-
Outdoors/In Transit[¶]						7.4 (SD 8.9)		7.9 (SD 11.5)			-
Carbon monoxide level, ppm: A-2.0; B-2.5; C-2.5; D-2.2; E-2.8; F-2.2; G-2.3; H-3.0											

[A]*(entire premises)*; [b]*(persons around peripheral slots = 196)*; [c]*(33 persons in bar area)*; **[51 minute average (28 min before and 23 min after all Venue sampling)]*;[b]*(Using Eq. 2)*; [+]*(30 min (SD 11 min) averages)*; [¶](7 to 35 min samples); [d]*(~6' from front door)* [e]*(smokers outside door).*

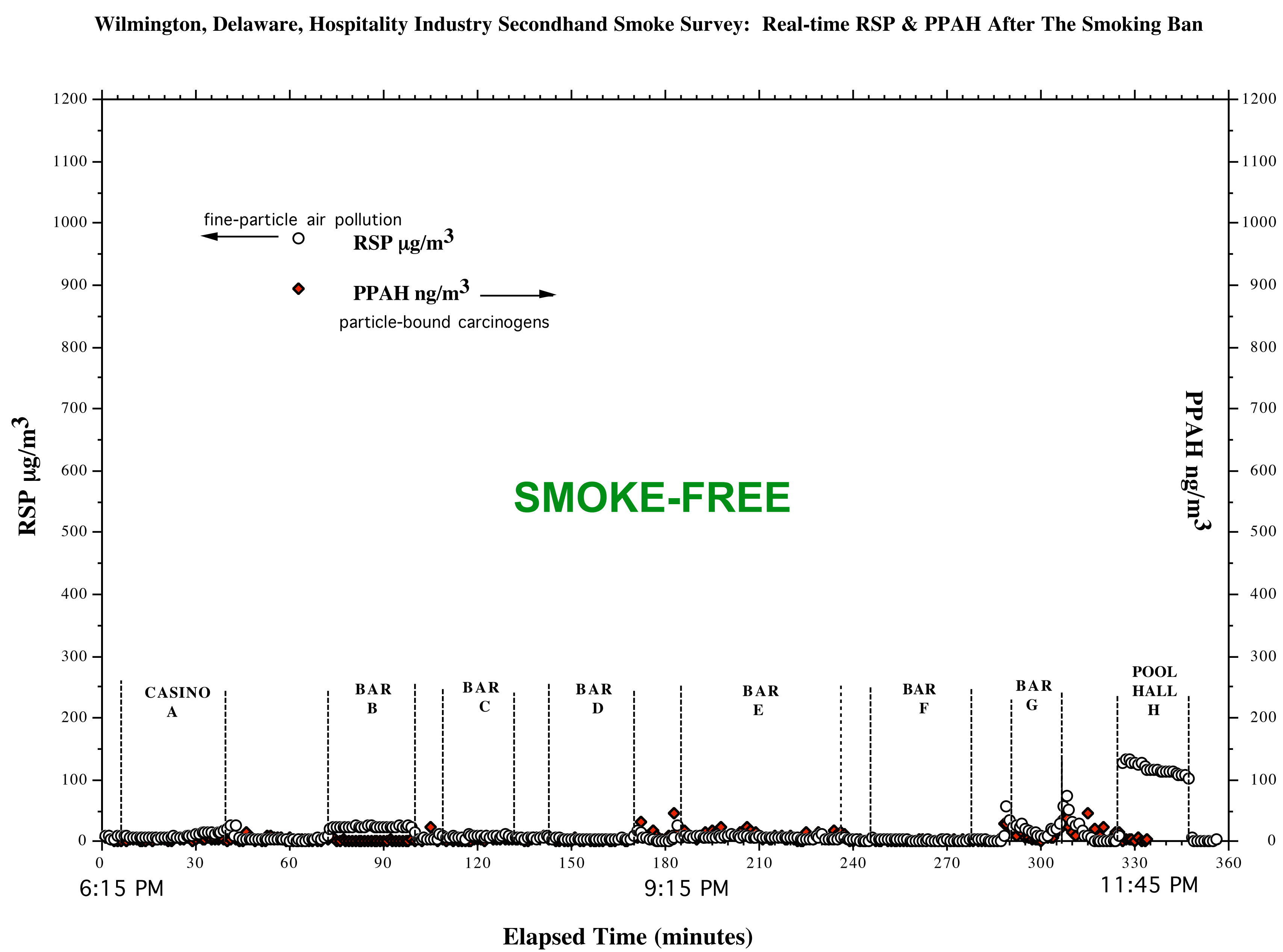

Figure 5. Real-time fine-particle air pollution (RSP) and airborne carcinogens (PPAH) after the smoking ban. Data recorded on Friday Evening, January 24, 2003. Outdoor & in-transit location measurements precede & follow each Venue sampled. All venues were crowded, and all appeared to be in compliance with the Delaware smoking ban. Compare with Figure 2.

Table 4. Carcinogenic PPAH, IARC Status, Amount in Cigarette Smoke

Particulate Phase PAH (PPAH)	IARC Carcinogen In Laboratory Animals	IARC Carcinogen In Humans	Amount Measured In Cigarette Smoke (ng/cig)*	Reference
Benz(a)anthracene	Sufficient		412	A,B
Benzo(b)fluoranthene	Sufficient		132	A,B
Benzo(j)fluoranthene	Sufficient		32	A,B
Benzo(k)fluoranthene	Sufficient			A
Benzo(a)pyrene	Sufficient	Sufficient	74	A,B
Dibenzo(a,i)pyrene	Sufficient			A
Dibenz(a,h)anthracene	Sufficient			A
Dibenzo(a,l)pyrene	Sufficient			A
Indeno(1,2,3-cd)pyrene	Sufficient			A
5-methylchrysene	Sufficient			A
All PPAH			1,067	B
All PAH			13,500	C

References: A. Hoffmann & Hoffmann (1998); B. Gundel et al. (1995); C. Rogge et al. (1994); *ng/cig = nanograms per cigarette. Blank cells indicate no data available; IARC = International Agency for Research on Cancer.