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Secondhand Smoke Exposure Levels in Outdoor Hospitality Venues: A Qualitative and Quantitative Review of the Research Literature

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Abstract

Objective—This paper considers the evidence on whether outdoor secondhand smoke (SHS) is present in high enough levels of hospitality venues to potentially pose health risks, particularly among employees of such establishments.

Data Sources—Search strings in PubMed and Web of Science included combinations of environmental tobacco smoke, secondhand smoke, or passive smoke AND outdoor, yielding 217 and 5,199 results, respectively through June, 2012.

Study Selection—Sixteen studies were selected based on abstract review that either entirely or partly measured outdoor SHS exposures (particulate matter (PM) or other SHS indicators).

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COMPETING INTERESTS STATEMENT

The authors have no competing interests to disclose.

CONTRIBUTORSHIP STATEMENT

Simon Chapman and Andrew Hyland compiled much of the initial literature and wrote a Rapid Review of the literature, commissioned by the Sax Institute, NSW Australia. Both also contributed to writing of the current manuscript. From the initial rapid review conducted by Chapman and Hyland, Andrea Licht lead the current manuscript writing and completed the calculations of daily and annual PM_{2.5} exposures presented in table 2. Ms. Licht also updated the initial review of the literature and formatted the paper for all submissions. Mark Travers compiled various grey literature sources and assisted with the updated literature review and writing of the final manuscript. All authors reviewed and accepted the final version(s) of the manuscript.

WHAT THIS PAPER ADDS

This paper is one of the first to review the evidence related to secondhand smoke exposure in outdoor areas of hospitality venues. The findings show that under conditions commonly experienced in these outdoor areas where people are generally close together, secondhand smoke exposures can increase average annual exposure to particulates for both patrons and employees, putting them at increased risk of adverse health effects.

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Data Extraction—The methods used to measure SHS indicators, particularly PM, were assessed for inclusion of extraneous variables that may affect such measurements or the corroboration of ambient levels with known standards.

Data Synthesis—The magnitude of SHS exposure ($PM_{2.5}$) is dependent on the number of smokers present, proximity to the measuring device, outdoor enclosures, and wind. Under specific conditions, peak outdoor $PM_{2.5}$ levels can be comparable to those recorded in indoor smoky environments. Using data from both observational and experimental studies, annual excess $PM_{2.5}$ exposure of full-time waitstaff at outdoor smoking environments could average 4.0 to 12.2 $\mu g/m^3$ under variable smoking conditions.

Conclusions—Although highly transitory, outdoor SHS exposures could occasionally exceed annual ambient air quality exposure guidelines. However, such exposures are likely to be higher for occupationally exposed individuals compared to patrons due to repeated and cumulative outdoor SHS exposures. Personal monitoring studies of waitstaff are warranted to corroborate these modeled estimates.

Keywords

Secondhand Smoke; Outdoor Tobacco Smoke; Particulate Matter

BACKGROUND

Secondhand smoke (SHS) is a rich source of suspended fine particulates and is a significant contributor to total particulate load in indoor environments where smoking occurs.[1] An elevation of 10 $\mu g/m^3$ of long-term exposure to fine particle air pollution ($PM_{2.5}$), including that from tobacco smoke, is associated with 6, 9, and 14 percent increased risk for all cause, cardiopulmonary, and lung cancer mortality respectively.[2]

Indoor smoke-free air laws have had lasting and important health benefits including improved indoor air quality, reductions in SHS exposure and tobacco use, and lower rates of respiratory and cardiovascular events.[3] Less than 11% of the world population is protected by a comprehensive smoke-free air policy covering 100% of all non-hospitality workplaces, bars, and restaurants.[4] Nevertheless, in recent years there has been a normative shift with regard to smoking in public indoor places in which today, 28 countries have country-wide comprehensive smoke-free air laws present.[5] However, as jurisdictions implement indoor smoke-free legislation, the outdoor areas of such locations may become more commonly cited sources of SHS exposure as smoking gets pushed outdoors.[6, 7]

Globally, outdoor smoking restrictions are uncommon,[8] though one of the most widespread outdoor smoking bans occurred in New York City in 2011 when smoking was banned in all parks, beaches, and pedestrian plazas.[9] Given the limited research linking exposures to secondhand smoke from outdoor environments to health effects, many current policies have been justified by citing preservation of public amenity, the potential impacts on social norms surrounding smoking, or litter reduction rather than an overt concern to protect the health of those exposed to SHS.[9-13] Moreover, in communities where indoor smoke-free air laws are already present, surveys have shown that large proportions of respondents would express preference for additional smoke-free policies, such as those in outdoor areas of dining establishments.[14-18]

Assessment of the health consequences of SHS exposure has been dominated by long-term exposure studies conducted in indoor settings where SHS concentrations can remain high long after active smoking has ceased.[19] However, mean outdoor SHS exposures are highly dependent on external factors and must be averaged over several transient peaks occurring

only during active smoking. Thus, the total SHS exposure level received per cigarette will be greater in indoor spaces compared to exposures from cigarettes smoked outdoors.[19]

Regardless, acute health effects have been associated with short term, low level SHS exposure. Even very low concentrations ($4.4 \mu\text{g}/\text{m}^3$) of environmental tobacco smoke (measured in $\text{PM}_{2.5}$) were found to facilitate eye, nasal, and throat irritations among non-smokers.[20] Potentially more serious acute effects on respiratory[21] and cardiovascular health have been observed, such as impaired flow-mediated vasodilation in healthy non-smokers,[22] endothelial cell morbidity,[23] or platelet aggregation in non-smokers.[23, 24] Additionally, frequent SHS exposure is also independently associated with preclinical atherosclerosis.[25, 26]

Emerging research has suggested that under specific conditions, SHS levels can be temporarily comparable to or even temporarily higher than levels observed indoors.[27-33] However, if average SHS levels are high enough to produce ill health effects, they are likely to be more pronounced among employees working in outdoor areas where smoking is allowed due the higher frequency of exposures experienced across working shifts and overtime. The purpose of this review is to describe the factors that can contribute to higher SHS exposure levels, particularly in outdoor hospitality venues, and to estimate the levels of SHS exposure that may be experienced by waitstaff working at typical outdoor hospitality venues.

METHODS

Searches were conducted June, 2012 using the search strings Topic= (“environmental tobacco smoke”) OR Topic= (“secondhand smoke”) OR Topic= (“passive smoking”) AND Topic= (outdoor) in Web of Science and (((environmental tobacco smoke [Title/Abstract]) OR secondhand smoke [Title/Abstract]) OR passive smoking [Title/Abstract]) AND outdoor [Title/Abstract]) in PubMed, yielding 5,199 and 217 results, respectively. Review of the abstracts yielded only sixteen studies that dealt either exclusively or partly with the direct measurement of outdoor SHS levels. Secondary searches were conducted of the references in these papers, but no further peer-reviewed papers were located.

Of these 16 studies found in the peer-reviewed literature, 6 were completed in non-hospitality settings.[7, 31, 34-37] Although evidence from these studies has been considered, the focus of this paper is on SHS exposure levels observed at outdoor areas of hospitality, or hospitality-like settings. Two studies reported on overlapping results,[6, 32] with the latter updating previous results to include more venues and time point assessments. Reviewed studies, dated between 2007 and 2011, were from the USA (n=5), Australia (n=3), New Zealand (n=3), Canada (n=2), Spain (n=2) and Denmark (n=1). A table summarizing all peer-reviewed studies is available as web only material (Appendix A).

Although the primary conclusions in this report are based on the peer-reviewed literature, non-peer reviewed studies (grey literature) consisting of conference proceedings, abstracts, and reports not apparently published in indexed journals were also reviewed. These were obtained via contact with colleagues in the field and searches of personal research collections. The seven studies found in the grey literature are only considered as supplementary evidence.[19, 33, 38, 39-42]

Using the data obtained from the experimental and observational studies in the peer-reviewed literature, estimates of excess $\text{PM}_{2.5}$ exposure were calculated. These estimates are meant to approximate the above-background $\text{PM}_{2.5}$ exposure levels that may be experienced by employees working at typical smoking-allowable outdoor hospitality venues. Appendix B (web only material) provides the calculations used.

RESULTS

Measuring SHS Contamination in Outdoor Settings

Given the complex nature of SHS, direct measurements are difficult to obtain. However, multiple methodologies have been developed to measure representative components of SHS as proxies for overall exposure. One such component, nicotine, has been measured extensively using both the nicotine concentration present in the air[38] as well as the individual biologic dose received, though cotinine, a nicotine metabolite.[43-45] However airborne nicotine concentrations may not necessarily reflect that of other constituents of SHS,[46] and “between-individual” differences in nicotine metabolism have been noted.[44, 45] Other studies have measured specific carcinogenic components of SHS, such as particulate polycyclic aromatic hydrocarbons (PPAH)[47] or the tobacco-specific carcinogen NNAL[48] as proxies for SHS exposure. The resulting exposures levels obtained by the use of biomarkers like cotinine or other carcinogenic compounds are representative of all cumulative exposures over a given time period. This can make it difficult to differentiate exposures of interest, such as exposures from outdoor sources of SHS exposure, from other exposures experienced over the same period of time.

Measurement of airborne particulate matter (PM), yet another component of SHS, is the most common method to assess SHS exposure. Although particles less than 2.5 microns in diameter (PM_{2.5}) are not specific to particles originating from combustion of tobacco products, a substantial amount is released from burning cigarettes, and such measurements have been validated as a method for assessing SHS exposure indoors.[49, 50] Of the sixteen studies found in the peer reviewed literature assessing outdoor SHS levels, 13 elected to measure PM_{2.5} levels (Appendix A). The remainder of this paper focuses on SHS exposures measured by PM_{2.5}.

Observed levels of SHS contaminants in outdoor areas

Experimental studies can provide valid means to quantify outdoor tobacco smoke (OTS) levels under controlled scenarios. Two studies by Klepeis and colleagues quantified exposures and addressed the effects of proximity to the source and varying wind speeds and directions on OTS concentrations.[27, 51]

Controlled experiments conducted at a private residence by Klepeis and colleagues used clusters of various monitors (Photoelectric aerosol sensors [PAS], laser counters [GRIMM], and Nephelometers [NEPH]). Measurements were converted from each respective monitor’s native unit to measure respirable suspended particle (RSP) mass concentrations in $\mu\text{g}/\text{m}^3$ which is a close approximation of PM_{2.5}. [27] Monitor clusters were placed on opposite sides of smolder-smoked cigarettes at distances between 0.25 and 4 meters away. “Smoking” sessions used 3-5 cigarettes burned successively. During periods of active “smoking” the overall average OTS particle levels ranged from 10-22 $\mu\text{g}/\text{m}^3$ (NEPH) to 38-61 $\mu\text{g}/\text{m}^3$ (PAS) across all distances over 10 minute experimental periods. These results were likely influenced by a “microplume effect”, in which highly transitory peaks, some exceeding 1,000 $\mu\text{g}/\text{m}^3$, were observed in close proximity to active smoking sources.

Follow-up experiments by Klepeis and colleagues used carbon monoxide (CO) as a tracer gas to better understand human exposures to air pollutants occurring within short distances from a point source in ground-level outdoor environments.[51] CO was released from a central point at known emission rates while surrounding sensors measured CO concentrations in a 3-dimensional array at various heights and distances away. Precise wind speeds and directions were continuously monitored and recorded. Based on these experiments, statistical modeling approaches were developed to estimate air concentrations for other pollutants and source emission rates, such as those arising from OTS particle

exposures. The average RSP particle concentration due to OTS was estimated to be 70-110 $\mu\text{g}/\text{m}^3$, calculated using the reported average fine particulate emission rate of cigarettes (1.4 mg/minute), the normalized average single direction concentration of 50-80 $\mu\text{g}/\text{m}^3$ per mg/minute (from CO experiments), and a range of horizontal distances of 0.25-0.5m.

Although these experimental studies provide evidence of emissions from single point sources under controlled scenarios, they may not be fully applicable to real world hospitality-like settings. Observational studies may provide additional empirical evidence about factors that may temporarily influence SHS ($\text{PM}_{2.5}$) exposures in outdoor hospitality venues. In particular, four observational studies in the peer reviewed literature provided the most detailed information on such factors.[28-30, 52] Three of these studies collected $\text{PM}_{2.5}$ data using the TSI SidePak AM510 monitor, applying a calibration factor of 0.32 (unit-less) to the raw data to correct for properties related to SHS.[28-30] A fourth study measured real-time $\text{PM}_{2.5}$ levels using the DustTrak (TSI, Inc.) monitor, also applying a calibration factor of 0.32 to the raw data.[52]

Cameron et al. collected data within 1m of active smokers at a convenience sample of 69 outdoor dining areas in Melbourne, Australia.[29] Mean ambient levels were 8 $\mu\text{g}/\text{m}^3$. $\text{PM}_{2.5}$ levels averaged 18 $\mu\text{g}/\text{m}^3$ across the total observation time period (average of 25.8 minutes/venue) and 27 $\mu\text{g}/\text{m}^3$ when active smoking was present (averaged over 10 minutes). After accounting for ambient concentrations, smoking in these outdoor patios contributed an average excess above ambient levels of nearly 10 $\mu\text{g}/\text{m}^3$ of particulates over the entire measurement period.

Stafford et al. measured $\text{PM}_{2.5}$ levels in 28 alfresco cafes and pubs in Perth and Mandurah, Australia.[30] Mean $\text{PM}_{2.5}$ levels for none, one, and two or more smokers were 3.98, 10.59, and 17.00 $\mu\text{g}/\text{m}^3$, respectively, with the weighted average $\text{PM}_{2.5}$ concentration over “smoking present” periods being 14 $\mu\text{g}/\text{m}^3$ (total of 388 smoking minutes logged). After adjusting for background levels (3.98 $\mu\text{g}/\text{m}^3$), active smoking outdoors contributed a 10 $\mu\text{g}/\text{m}^3$ boost in $\text{PM}_{2.5}$ levels across the entire measurement period. A limitation of this study is that data on distance or position of the smokers relative to the monitor was not collected. Although this study did include an indicator of wind conditions, it was unclear how wind speeds were assessed, and direction was not reported.

Brennan et al. examined changes in outdoor and indoor air quality levels after implementation of an indoor smoking ban in Melbourne, AU.[28] Outdoor hospitality venues visited were semi-enclosed with direct access to indoor areas (n=19). Concurrent outdoor and indoor monitoring occurred for 30 minutes at each venue within 5 meters of the indoor-outdoor access point. Contrary to predictions, geometric mean (GM) outdoor $\text{PM}_{2.5}$ levels decreased 38% after implementation of the smoking ban (from 19.0 $\mu\text{g}/\text{m}^3$ to 13.1 $\mu\text{g}/\text{m}^3$), while adjusting for ambient $\text{PM}_{2.5}$ levels (5 $\mu\text{g}/\text{m}^3$). The observed mean smoking prevalence outdoors increased from pre- (6.2%) to post-ban (7.3%) (p=0.401). However, the smoking prevalence indoors at the pre-ban assessment (4.7%) was already lower than the prevalence outdoors (6.2%), suggesting that smoking behaviors may have already shifted outdoors prior to the ban. This may explain why the smoking prevalence outdoors did not significantly increase at the post-ban assessment.

A study by St. Helen and colleagues from the U.S. observed outdoor $\text{PM}_{2.5}$ levels at five hospitality venues measured on up to four separate occasions. Mean $\text{PM}_{2.5}$ levels at three locations (Bar 1: 63.9 $\mu\text{g}/\text{m}^3$, Bar 2: 51.0 $\mu\text{g}/\text{m}^3$, and Restaurant 1: 39.7 $\mu\text{g}/\text{m}^3$) were found to be significantly elevated above ambient levels (20.4 $\mu\text{g}/\text{m}^3$, p<0.0001). After adjusting for vehicular traffic near venues, the number of smokers present remained the only statistically significant predictor of Log($\text{PM}_{2.5}$) levels, indicating that SHS exposures are the likely

source of PM_{2.5} levels observed at outdoor areas of hospitality venues. However, this study did not adjust for other factors that are known to influence PM_{2.5} levels such as the presence of partial enclosures or the proximity of smokers to the monitors, and may also be limited by the inclusion of a small number of venues.[52]

Other observational studies have come to similar conclusions, but the findings should be interpreted cautiously. Compared to other studies,[28-30, 52] outdoor PM_{2.5} levels were observed to be much higher in studies by Wilson and colleagues.[6, 32] In four randomly selected outdoor smoking areas of hospitality venues, an average of four lit cigarette present produced mean PM_{2.5} levels of 36 µg/m³ (range 19-75) while ambient concentrations averaged 14 µg/m³. In two purposefully selected outdoor areas with a higher degree of enclosure, mean PM_{2.5} levels were 65 and 182. Data concerning many external factors that could affect these levels, such as monitoring proximity, were not provided, and the inclusion of only four study sites limits the use of this data. However, this study does highlight that increasing the degree of enclosure of an “outdoor” space can dramatically increase PM_{2.5} levels.

There is also evidence to suggest that OTS can drift indoors, compromising indoor smoke-free environments.[6, 7, 28, 32-35, 39] In addition, once tobacco smoke has drifted indoors, it does not dissipate as quickly as it would in outdoor environments.[39] However, most of these studies did not specify the distance from entrances to monitors or other factors such as traffic between areas and the presence of open or closed doors, compromising the ability to make valid assessments of this data.

In summary, several key findings are obtained from these studies: (1) observational studies estimate that exposure to SHS outdoors adds approximately 10µg/m³ or more of excess PM_{2.5} exposure; (2) although exposures are almost always highly transitory, experimental studies find that excess exposure levels can exceed estimated levels obtained from observational studies by an order of magnitude; (3) it may be possible for outdoor to indoor SHS drift leading to contamination of indoor smoke-free environment; and (4) outdoor PM_{2.5} concentration can be similar to levels observed in indoor smoking allowable areas, but these levels are highly influenced by external factors.

Influence of external factors on levels of exposure to SHS contaminants

Number of lit cigarettes—Results from Zhang, et al. showed that increasing numbers of lit cigarettes per 1000 ft² of patio area (0, 1.0-4.3, 4.4-8.7, 8.8-16.7, and 16.8-41.7 lit cigarettes) increased the geometric mean PPAH levels from 4.7µg/m³ (no cigarettes) to 9.1, 16.9, 19.1, and 27.0 µg/m³, respectively.[47] Although regression models by Stafford et al. only predicted about 40% of the overall variance in PM_{2.5}, the number of active smokers present was found to be the greatest contributor to the variance.[30] Other multivariate modeling by Brennan found that an increase of one in the number of mean lit cigarettes was associated with a 25% increase in GM outdoor PM_{2.5}. [28] After adjusting for pedestrian and vehicle traffic, St. Helen and colleagues found that lit cigarettes at or passing by outdoor study sites significantly increased log (PM_{2.5}) levels.[52]

Distance from monitor to point source—Most studies assessing the distance between active smoking and a monitoring device have demonstrated a proximity effect. Experimental work has found that RSP levels were approximately halved for each doubling of distance from the point source,[27, 51] but approached ambient levels at distances >2m.[51] Based on regression modeling by Cameron, cigarettes smoked at distances >1m from a monitor did not significantly predict overall PM_{2.5} levels (p=0.261).[29] Outdoor SHS levels have been found to be roughly equal to or greater than indoor SHS levels at very close distances (<0.5m).[27] Although waitstaff are often in close proximity to customers, such distances

may not be applicable to real world exposures between smoking and non-smoking individuals at typical smoking-allowable outdoor areas of hospitality venues.

Wind Conditions—Only two observational studies reported on wind conditions, but they were based solely on observations made by data collectors and thus should not be used in making conclusions.[30, 40] Controlled experiments completed indoors utilizing a fan to blow smoke plumes at a constant speed of 0.4m/s found that RSP levels were approximately three times higher downwind relative to upwind levels.[27] Outdoors, wind observed to blow the smoke plume from smolder-smoked cigarettes in a single direction at approximately 0.5m/s lead to mean downwind PM_{2.5} levels of 130 µg/m³ measured at 0.6 m away. Mean RSP levels were still elevated above background levels by 13-41 µg/m³ at further downwind distances away (1.7-2.7m), while RSP levels measured at 0.6 m upwind to smolder-smoked cigarettes were nearly zero (2µg/m³).[27]

Normalized average CO concentrations were observed to fall by one-third to one-half as average wind speeds increased from <0.2m/s to 0.2-0.5m/s.[51] While CO concentrations approached ambient levels at horizontal distances of about 2 m, this distance may be somewhat extended under low wind conditions (<0.2m/s), possibly resulting in 30%-50% higher concentrations downwind nearby active smoking.[51]

Partial enclosures—Enclosures such as walls, fences, garden umbrellas and roofs can substantially influence exposures to SHS in outdoor areas. These conditions may lead to “street canyon” effects which are characteristic of unobstructed air movement along building boundaries resulting in windier conditions and higher levels of ventilation. Conversely, partially enclosed areas may contain SHS to a greater degree.[27] The purposeful monitoring of two highly enclosed “outdoor” smoking areas in New Zealand demonstrated the influence of SHS exposures under these conditions; mean levels were found to be 124 µg/m³ compared to only 36 µg/m³ from open air smoking areas.[32] Although Brennan and colleagues found no association between outdoor air quality and the level of enclosure,[28] two studies estimate that outdoor overhead coverage can increase SHS levels by about 50%-70%.[27, 29]

From unpublished literature, mean PM_{2.5} levels in outdoor hospitality venues in Vancouver, BC ranged from 6 to 430 µg/m³, although many of these venues had complete roof coverings and nearly complete wall coverings.[41] High, yet transitory peak 10-second PM_{2.5} level were also found in a fairly enclosed outdoor courtyard (716 µg/m³)[40] and levels were also elevated under patio and table umbrellas.[39, 40, 42]

Measured outdoor SHS contaminants compared with established air quality benchmarks

The World Health Organization (WHO) provides guidelines for short (24-hour) and long term (annual) PM exposures.[53] Guidelines for ambient air quality, including PM and other harmful components are also provided by factions within individual countries, such as the U.S. Environmental Protection Agency (EPA) and Australia’s National Environment Protection Council (NEPC).[54, 55] Table 1 presents the ambient air quality standards for total particulates for the WHO, the United States, and Australia.

Air monitoring of short-term exposures to PM arising from transient outdoor exposures such as SHS are likely to produce low 24-hour or annually averaged exposures due to intermittent and typically short exposure periods. No guidelines or standards are presently available for such intermittent exposure to PM_{2.5}, but some studies have attempted to estimate 24-hour or annual PM_{2.5} exposure from outdoor SHS using the aforementioned guidelines[6, 27, 32, 51] or the U.S. Air Quality Index (AQI).[30, 41, 56] These standards were devised for total ambient air pollution which has a different composition than tobacco-specific pollution.[27]

However, the fundamental issue is whether such transient outdoor SHS exposures are sufficient to exceed such guidelines, thus making a stronger case to warrant the need for outdoor smoke-free legislation. Although studies using personal-level air monitoring may better describe individual SHS exposures in outdoor smoking-allowable areas, such data is currently unavailable. In the interim, short term exposure levels can be estimated using data reported in observational and experimental studies, as summarized below.

Observational Studies—Three observational studies of outdoor bar and restaurant areas suggest that PM_{2.5} levels are elevated by approximately 10 µg/m³ during times when active smoking occurs.[28-30] Such studies may not accurately account for meteorological or proximity factors, but it is unlikely that the aforementioned 24-hour or annual guidelines for PM_{2.5} exposure would be exceeded based on these estimates.

Experimental Studies—Experimental studies may provide more precise measurements of external factors. However, modeled assumptions may under- or over-estimate the true occupational exposures from secondhand smoke as they may not reflect real-world exposures. Nevertheless, work by Klepeis (2007) estimated that the EPA 24-hour standard for fine particulates could be exceeded if an individual experienced as few as 9 cigarette events, each lasting approximately 10 minutes at a downwind distance of 0.3 meters.[27] However, this estimate was based on levels obtained from one very short measurement period (10-minute), at a close distance to a smoker, limiting the generalizability of this estimate.

Later work by Klepeis estimated an occupational 24-hour particle exposure to waitstaff working in smoking-allowable outdoor patios to be 23.7µg/m³. [51] This estimate assumed approximately 100 minutes of total OTS exposure, very close proximity to the smoking patron (0.25 m), and exposures contributed by the presence of only one smoking patron at tables directly served by the worker. From these estimates, however, the 24-hour standards for PM_{2.5} exposures would likely be exceeded only if extra-occupational PM_{2.5} exposures are assumed.[51]

Estimated projections combining observational and experimental research—

Due to the inherent limitations of both the observational and experimental studies, combining data from each study type may provide the most valid and reliable estimates of daily and annual occupational outdoor SHS exposures. From observational studies, a typical outdoor hospitality worker in a smoking-allowable area may be exposed to active smoking between 40% [29] and 70% [30] of their total working time, or about the SHS equivalent of 0.4 to 0.7 lit cigarettes at any given time from varying distances and angles.

Particulate concentrations at varying directions and wind speeds can be obtained from experimental data (Klepeis et al., table 3, page 3165).[51] Assuming light winds (0.1m/s), the average air pollution concentration from an arbitrary source averaged over all distances and angles was 42.8 µg/m³ (see appendix B).[51] This figure can be manipulated to resemble OTS pollution using exposure data on the presence of active smoking from observational studies [29, 30] and the fine particle emission rate for a cigarette (1.4 mg/min). [57] From this data, the excess PM_{2.5} exposures from outdoor tobacco smoke incurred over typical working shifts can be estimated and compared to 24-hour and annual exposure guidelines.

Table 2 estimates the 24-hour and annual PM_{2.5} exposures from occupational outdoor tobacco smoke exposures using sensitivity analyses for lower (0.4 lit cigarettes present at all times), moderate (0.7 lit cigarettes present at all times), and higher (1.0 lit cigarette present at all times) SHS exposure conditions. After accounting for ambient PM_{2.5} levels averaged

from observational studies ($6.5 \mu\text{g}/\text{m}^3$), the excess occupational outdoor tobacco smoke attributable $\text{PM}_{2.5}$ exposure for an 8-hour shift was calculated to be $17.5 \mu\text{g}/\text{m}^3$ under the lower smoking exposure condition, $35.4 \mu\text{g}/\text{m}^3$ under the moderate smoking exposure condition, and $53.4 \mu\text{g}/\text{m}^3$ under the higher smoking exposure condition (see appendix B).

The 24-hour and annual estimates are presented for occupational exposures with varying time spent working outdoors (4-hour vs. 8-hour shifts). Depending on the smoking exposure conditions present, part-time employees working 4-hour shifts outdoors may experience between $2.9 \mu\text{g}/\text{m}^3$ (lower exposure) and $8.9 \mu\text{g}/\text{m}^3$ (higher exposure) of excess 24-hour $\text{PM}_{2.5}$ exposure attributable to outdoor occupational SHS. Among full time workers (8-hour shifts), this would equate to between $5.8 \mu\text{g}/\text{m}^3$ and $17.8 \mu\text{g}/\text{m}^3$ added over a 24-hour period. At the highest exposure condition assessed, this equates to an estimated annual excess of $6.1 \mu\text{g}/\text{m}^3$ (part time) to $12.2 \mu\text{g}/\text{m}^3$ (full time) of added $\text{PM}_{2.5}$ exposure attributable to outdoor occupational tobacco smoke exposures, above and beyond ambient levels.

These calculated estimates suggest that it is unlikely for outdoor occupational SHS exposure alone to exceed any of the aforementioned guidelines for 24-hour $\text{PM}_{2.5}$ exposure. Although it may be plausible that such exposures could occasionally exceed the annual $\text{PM}_{2.5}$ exposure guidelines, this was only under the highest modeled exposures.

Of note, the average outdoor air pollutant concentrations calculated from the Klepeis (2009) data are averaged across a large distance from the emission source (0.25-4m) to reflect the varying nature of exposure due to movement of waitstaff.[51] However, all distances were weighted equally in creating this measure, possibly resulting in an underestimate of the true exposure as studies have shown that concentrations decrease as a function of distance to the point source.

CONCLUSIONS

Together, these studies suggest that typical outdoor dining or drinking areas of bars and restaurants can lead to elevated levels of SHS exposure for both patrons and workers. Although outdoor tobacco smoke is far more transient than indoor tobacco smoke, patrons and staff can be briefly exposed to high concentrations of tobacco-generated $\text{PM}_{2.5}$ under certain conditions. Evidence from the studies presented here suggests that these levels may occasionally be equivalent to or higher than levels observed in indoor setting when smoking is permitted at close proximity.

Due to outdoor weather conditions and dispersion effects, tobacco-originating $\text{PM}_{2.5}$ exposure levels have been shown to drop sharply under most conditions at distances greater than 2m from a single point source. However, outdoor areas of bars or restaurants often have more than one smoker present, potentially contributing to higher SHS concentrations. As a result, this 2m radius may be substantially extended due to dense table placement, a greater number of active smokers, single directional and light wind speeds, and other factors such as partial wall or roof coverings. Although partial smoke-free policies may be practical and enforceable in some outdoor settings where movement by both patrons and waitstaff is at a minimum, they may be particularly inadequate in limiting SHS exposures for both patrons and workers in settings where patrons are mobile, such as beer gardens or outside areas of bars.

Pope and colleagues estimate that an increase of $5\text{-}10 \mu\text{g}/\text{m}^3$ in average annual $\text{PM}_{2.5}$ exposure is associated with a 3-6% increased risk in all-cause mortality.[2] Similarly, increases in annual $\text{PM}_{2.5}$ exposures are also associated with increased risk of cardiopulmonary and lung cancer mortality.[58] As our calculated annual estimates of excess $\text{PM}_{2.5}$ exposures attributable to outdoor tobacco smoke ranged from $2.0\text{--}12.2 \mu\text{g}/\text{m}^3$

under varying exposure conditions, it may be plausible for staff working in smoking-allowable outdoor areas to present with ill health effects from such occupational exposures. However, personal monitoring studies are necessary to corroborate these calculated estimates.

The studies presented here have reported that patrons and staff have highly variable secondhand smoke exposure levels in outdoor drinking or dining areas of bars, restaurants, or pubs. Moreover, not only did exposure vary by location, but SHS levels could be highly variable within the confines of a single venue. Because these studies used stationary monitors, it not feasible to assess the variation in SHS exposure experienced by waitstaff during the course of a typical work day. However, to date, no personal monitoring studies of waitstaff in outdoor settings have been conducted to corroborate the modeled estimates of staff exposures in these worksite settings. Such studies may be inherently challenging due to higher costs, difficulty in recruitment of individual waitstaff, securing agreement for participation from businesses, or the potential for changes in behaviors of both waitstaff and patrons due to monitoring activities.

Additional studies were found that assessed PM_{2.5} exposures in non-hospitality settings such as outside of buildings, walking on city streets or in semi-enclosed bus shelters.[7, 31, 34-37] However, the estimates presented in this paper are based on observational studies of hospitality settings and experimental studies simulating hospitality-like settings. Therefore, it may not be appropriate to generalize these estimates to other outdoor settings where exposures are likely to be different. Similar studies assessing outdoor SHS exposures in parks, beaches, or other outdoor settings are warranted to support exposure-based legislation aimed at restricting smoking in these locations.

Limitations of the paper, particularly the calculation presented in table 2, do exist, the first of which is the extrapolation of the experimental studies to the real-world scenarios used in our calculations. Smolder-smoked cigarettes, used in experimental studies, generate SHS that is comprised only of sidestream smoke, while SHS from free-range smoked cigarettes contains a mixture of sidestream and exhaled mainstream smoke. At least initially, the median particle size of sidestream smoke is smaller than that of the particles of mainstream smoke.[59] Therefore, it is plausible that PM_{2.5} exposure levels generated from experimental studies using smolder-smoked cigarettes may overestimate exposure levels generated if free-range smoked cigarettes were used. However, given that sidestream smoke is estimated to contribute higher particle yields in SHS,[59, 60] the degree of difference is not expected to be very large. Additionally, the results obtained from the experimental studies[27, 51] provide the most comprehensive information on the factors that are most likely to influence SHS levels outdoors. Another limitation is that these findings are based on measurements that have been obtained from a wide range of “outdoor” areas of hospitality settings, from fully open-air to highly enclosed, potentially limiting the consistency between individual studies. Although several assumptions were made to estimate the excess exposures to PM_{2.5}, these estimates may be used as a guide for potential excess exposure levels at typical outdoor hospitality settings.

Of note, this is not a systematic review. However, given the limited available research on SHS exposure measurements in outdoor settings, to the best of our knowledge, this review does report on all available literature at the time of our initial search. Furthermore, widening our search to include the MeSH term for secondhand tobacco smoke, “Tobacco Smoke Pollution” did not result in the identification of additional studies of interest. Thus, the search criteria used was likely sufficient to identify all relevant literature for this review.

Future research is needed to fully understand the potential health effects from intermittent SHS exposures in outdoor areas. Additionally, studies that incorporate both environmental SHS exposure measurements and biomarkers may be warranted to link the contribution of these intermittent SHS exposures to actual internal dose and potential health effects. The estimates obtained here suggest that it is unlikely for PM_{2.5} exposures from SHS alone in outdoor smoking-allowable hospitality settings to exceed the aforementioned PM_{2.5} guidelines. Although these estimates do not incorporate non-tobacco PM_{2.5} sources due to limitations of the available data, SHS related PM_{2.5} exposures from these outdoor hospitality settings may be significant contributors to overall 24-hour or annual PM_{2.5} exposure.

Policy-driven smoke-free policies have typically been grounded in the prevention of adverse health effects to non-users of tobacco products.[5] However, current evidence of potential adverse health effects due to intermittent tobacco smoke exposures at outdoor hospitality venues is weak. To obtain a better evidence base for policy determination in these locations, additional studies, including those employing personal monitoring methods to ascertain more accurate SHS exposures levels, are needed. Moreover, outdoor SHS exposure data in non-hospitality settings is also warranted to support the implementation of smoking restrictions in other outdoor areas. Important secondary, collateral benefits of smoke-free policies may include the denormalization of smoking, lower smoking initiation rates among youth, and reduced tobacco consumption among adults.[12, 13] Therefore, based on the limited data presented in this paper, it seems plausible to suggest that smoking restrictions could be implemented in outdoor areas of bars and restaurants where SHS exposures are fairly high and consistent, as potential adverse health effects would likely be most pronounced in such situations.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Table 1
**Maximum ambient particulate concentration standards from Australia (“Air NEPM”),
the United States (NAAQS), and the World Health Organization**

Pollutant	Averaging period	World Health Organization	United States	Australia
PM ₁₀ Particles	24-hours	50 µg/m ³	150 µg/m ³	50 µg/m ³
PM _{2.5} Particles	24-hours 1 year	25 µg/m ³ 10 µg/m ³	35 µg/m ³ 15 µg/m ³	25 µg/m ³ 8 µg/m ³

Source (AU): <http://www.environment.gov.au/atmosphere/airquality/standards.html#air>

Source (US): <http://www.epa.gov/pm/standards.html>

Source (WHO): http://whqlibdoc.who.int/hq/2006/WHO_SDE_PHE_OEH_06.02_eng.pdf

Table 2
Estimates of 24-hour and Annual PM_{2.5} exposures (in µg/m³) attributed to occupational outdoor tobacco smoke (OTS) under lower, moderate, and higher exposures

	Lower Exposure		Moderate Exposure		Higher Exposure	
WIND CONDITION	0.1m/s		0.1m/s		0.1m/s	
Length of Shift Worked Outdoors	4 hours	8 hours	4 hours	8 hours	4 hours	8 hours
Number of lit cigarettes present at all times ^a	0.4 lit cigarettes	0.4 lit cigarettes	0.7 lit cigarettes	0.7 lit cigarettes	1.0 lit cigarette	1.0 lit cigarette
Cigarette Emission Factor [CEF] (constant) ^b	1.4 mg/minute	1.4 mg/minute	1.4 mg/minute	1.4 mg/Minute	1.4 mg/minute	1.4 mg/minute
Total Cigarette Emissions (# lit cigarettes * CEF)	0.56 mg/cigarette	0.56 mg/cigarette	0.98 mg/cigarette	0.98 mg/Cigarette	1.4 mg/cigarette	1.4 mg/cigarette
Average Air Pollution Concentration across all distances and angles ^c	42.8 µg/m ³	42.8 µg/m ³	42.8 µg/m ³	42.8 µg/m ³	42.8 µg/m ³	42.8 µg/m ³
Average Exposure for 8-hr Shift [*]	24.0 µg/m ³	24.0 µg/m ³	41.9 µg/m ³	41.9 µg/m ³	59.9 µg/m ³	59.9 µg/m ³
Assumed Ambient Air Concentration (constant) ^d	6.5 µg/m ³	6.5 µg/m ³	6.5 µg/m ³	6.5 µg/m ³	6.5 µg/m ³	6.5 µg/m ³
Excess Exposure above Ambient Air Concentration [*]	17.5 µg/m ³	17.5 µg/m ³	35.4 µg/m ³	35.4 µg/m ³	53.4 µg/m ³	53.4 µg/m ³
24-hour excess PM _{2.5} Exposure from occupational OTS [*]	2.9 µg/m ³	5.8 µg/m ³	5.9 µg/m ³	11.8 µg/m ³	8.9 µg/m ³	17.8 µg/m ³
Annual Excess PM _{2.5} Exposure from occupational OTS [*]	2.0 µg/m ³	4.0 µg/m ³	4.0 µg/m ³	8.1 µg/m ³	6.1 µg/m ³	12.2 µg/m ³

^aFrom Cameron et al (2010): active smoking was present 38.4% of the total observation time; From Stafford et al (2010), active smoking was present 71.2% of the total observation time. The higher exposure category is an estimate of when one cigarette is present at all times over the entire 8 hour shift.

^bKlepeis et al (1996) first reported the average fine particulate emission rate for cigarettes of 1.4 mg/minute.

^cKlepeis et al (2009) – This figure (42.8 µg/m³) was calculated from table 3 using light wind (0.1 m/s) speeds

^dAmbient levels averaged 6.5 µg/m³ across observational studies, which were usually measured at off-site locations where no smoking was observed to occur. Brennan: 5 µg/m³, Cameron: 8 µg/m³, Perry: 6 µg/m³, Stafford: 4 µg/m³, Wilson (2007): 14 µg/m³, and Wilson (2011): 2 µg/m³

^{*} See Appendix B, uploaded as “Web Only” material, for an explanation of all calculations.