Environmental tobacco smoke in outdoor areas: a rapid review of the research literature.

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Executive Summary

Restrictions on smoking outdoors have been introduced for reasons of public amenity and to promote litter reduction. This review considers the evidence about whether outdoor secondhand smoke (SHS) might also pose health risks to others.

Six published studies have assessed outdoor levels of SHS using metred $PM_{2.5}$ as a marker of exposure. The magnitude of $PM_{2.5}$is dependent on the number of smokers present, proximity of the measurement device to the source of the SHS, the extent to which the outdoor space is physically constrained (e.g., walls, partial roof, umbrellas), and wind. The data show peak outdoor $PM_{2.5}$ levels in semi-enclosed areas with several smokers present can be comparable to those recorded in indoor smoky environments. However, outdoor $PM_{2.5}$ levels are more transient as the smoke plume is less confined and can rapidly dissipate.

SHS can be a major source of $PM_{2.5}$, particularly in indoor environments. The average $PM_{2.5}$ level in bars where smoking occurs is 303 $\mu g/m^3$ and 157 $\mu g/m^3$ in restaurants. Because of repeated and cumulative exposure to SHS in outdoor settings like beer gardens and outdoor eating areas, occupational exposures to $PM_{2.5}$ from SHS are likely to be far higher than those experienced by patrons who are present for far shorter periods. We estimate that occupational exposure to SHS in waitstaff working in outdoor patio areas where smoking is allowed could average 1.6 to 9.8 $\mu g/m^3$ per year. It is thus plausible that occupational exposure to $PM_{2.5}$ in outdoor work settings where smoking is allowed could exceed the Australian National Environment Protection Measure for Ambient Air Quality benchmark *annual* average target of 8$\mu g/m^3$.

An increase of 5$\mu g/m^3$ to 10 $\mu g/m^3$ in average annual $PM_{2.5}$ exposure is associated with a 3-6% increase in all-cause mortality.

Personal monitoring studies have not yet been conducted to corroborate modelled estimates of staff exposure in these settings. Such studies should be conducted to test the modelled exposure estimates we have calculated.

Background

Restrictions on smoking in outdoor settings such as dining and drinking areas of pubs, restaurants and cafes, beaches, playgrounds and in the spectator areas of sporting fields and parks have been justified by reference to litter reduction[1] and preserving public amenity (or preference for air free of tobacco smoke). Recent surveys[2-4] show that large proportions of the community express preference for smokefree alfresco eating.

This review considers the research evidence on whether exposure to SHS might also pose health risks to those exposed in such settings, particularly staff who because of the duration of their exposure across a working day and cumulatively, are likely to inhale more SHS than patrons.

The WHO has declared that there is “no safe level of exposure”[5] to SHS in any setting. However, the research literature on the health consequences of SHS exposure is dominated by studies of those who have been exposed to SHS over many years in domestic and occupational settings. Some studies have shown measurable effects on variables like platelet aggregation arising from short term exposure to SHS. Short-term SHS exposure impairs endothelium-dependent vasodilatation in healthy non-smokers[6], increases the presence of endothelial cell morbidity in the blood[7] and short-term (30-minute) exposure to SHS activates non-smokers' platelets to nearly the extent that they are activated in smokers[7, 8]. Frequent exposure to tobacco smoke is independently associated with arterial changes of preclinical atherosclerosis and increased apolipoprotein B levels among healthy adolescents[9]. These immediate effects on platelets probably act synergistically with the effects on endothelial function.[10]

Questions therefore arise about whether SHS exposures in outdoor settings might cause similar acute effects and whether such cumulative exposure, particularly to occupations required to work in outdoor smoking settings might pose risks to health.

No studies appear to have been published examining either acute nor chronic health effects of outside exposure to SHS.

On 26 June 1998, the National Environment Protection Council (NEPC) incorporated Australia's first national ambient air quality standards as part of the National Environment Protection Measure for Ambient Air Quality (the 'Air NEPM'). The NEPC is a statutory body with law making powers established under the National Environment Protection Council Act 1994. There is corresponding legislation in other state and territory jurisdictions. The standards are legally binding on each level of government.

Air monitoring is routinely undertaken in metropolitan and selected regional cities for ozone, nitrogen dioxide, sulphur dioxide, carbon monoxide, lead and PM_{10} (See http://www.environment.nsw.gov.au/air/nepm/summary.htm). The Air NEPM is mostly used in air quality assessments concerned with urban residential exposure to industrial, traffic, wood fire and bush fire pollutants over days, months and years. Air monitoring of short-term exposure to particles arising from transient outdoor exposures such as SHS are highly likely to produce low 24h or 1 year averaged exposures because of the many hours in a day when such exposure does not occur.

Secondhand (SHS) smoke is a rich source of suspended fine particulates and is widely acknowledged as a significant contributor to total particulate load in indoor environments where smoking occurs. Table 1 shows ambient air quality standards for total particulates in Australia.

Table 1: Maximum ambient particulate concentration standards in Australia's "Air NEPM"

Pollutant	Averaging period	Maximum (ambient) concentration	Australian Goal
Particles as PM_{10}	1 day	50µg/m^3	Goal within 10 years (maximum allowable exceedences): 5 days a year
Particles as $PM_{2.5}$	1 day 1 year	25µg/m^3 8µg/m^3	Goal is to gather sufficient data nationally to facilitate a review of the standard as part of the review of this Measure scheduled to commence in 2005.

Source: http://www.environment.gov.au/atmosphere/airquality/standards.html#air

NOTE: $PM_{2.5}$ are particles less than 2.5 microns in diameter, which is about 1/100th the width of a human hair

Long-term exposure to fine particle air pollution is associated with 6, 9, and 14 percent increased risk for all cause, cardiopulmonary, and lung cancer mortality respectively, for each elevation of 10µg/m^3.[11]

A large research literature exists concerning the impact of SHS on indoor air quality. Because the primary focus of this study is on SHS in outdoor settings, the literature on indoor exposures has been summarised through reference to the largest and most robust studies, in view of the space constraints. One of the largest studies performed on SHS in indoor settings examined $PM_{2.5}$ in 1,822 bars, restaurants, retail outlets, airports, and other workplaces in 32 geographically dispersed countries between 2003 and 2007. On average, the $PM_{2.5}$ level in places where smoking was observed was 8.9 times greater than in places where smoking was not observed[12]. Many other studies also find that pollution levels are about an order of magnitude higher inside venues where smoking is occurring compared to smokefree venues.

Klepeis et al (2009) note that while a person can be exposed to air pollution such as industrial and transport pollution in public sites, "much exposure, in general, has been attributed to local residential sources, including smoking, cooking, cleaning, and the use of various common household products. Relatively weak sources close to an individual are likely to contribute more to a person's exposure, than stronger, but more distant sources."[13] The phenomenon of the "personal cloud" has been observed in personal monitoring surveys, where highly elevated particle concentrations in a person's breathing zone occur relative to concurrent samples taken away from those immediate zones. This has given rise to studies of the "indoor proximity effect" where persons in close proximity to an indoor pollution source may inhale concentrated emissions. More recently, a corresponding "outdoor proximity effect" has been studied[14] in relation to exposure to tobacco smoke outdoors.

The purpose of this literature review is to estimate SHS exposure levels in outdoor venues where smoking is permitted guided by the following three questions:

1) How do levels of measured SHS in outdoor eating and drinking areas compare with levels recorded in indoor eating and drinking areas where smoking was previously allowed?
2) How do levels of measured SHS contaminants in outdoor eating and drinking areas compare with established benchmarks for air quality?
3) How are levels of exposure to SHS contaminants affected by factors such as where smoking is allowed, and how does the likelihood of harm vary by factors such as the density of smokers, proximity to smokers and the degree of openness of the area?

Search Strategy. Searches were conducted of PubMed, Medline, and Google Scholar in late October 2010. Search strings included: combinations of environmental tobacco smoke OR ETS or secondhand smoke or passive smoking AND outdoor*. We also searched the past ten years of the leading journal *Atmospheric Environment* on-line with the string smoking OR tobacco to locate any papers relevant to outdoor tobacco smoke. The papers thus retrieved included many that concerned analysis of only indoor environments. Six reports dealing either exclusively or partly with the measurement of SHS outdoor were located in the peer-reviewed literature retrieved through these searches. Secondary searches were then conducted of the references in these papers, but no further papers were located. These 6 papers dated from 2007 to 2010 and were from Australia (n=3) and the USA (n=3).

Grey (non-peer reviewed) literature not in indexed journals. We also searched for non-peer reviewed studies from the authors' personal research collections of several conference presentations and reports not apparently published in indexed journals. The website of Repace Associates Inc (http://www.repace.com/reports.html) contained self-published material on outdoor SHS analysis. The conclusions in this report are primarily based on the peer-reviewed literature. However, we also provide a summary of the findings in the non-peer reviewed literature in Appendix 2 to this report.

Review Question 1: How do levels of measured SHS in outdoor eating and drinking areas compare with levels recorded in indoor eating and drinking areas where smoking was previously allowed?

There are multiple ways to measure SHS but a common method is to measure levels of particulate matter ($PM_{2.5}$) in the air. $PM_{2.5}$ are particles that measure less than 2.5 microns in diameter, about 1/100th the width of a human hair. $PM_{2.5}$ comprises many other particles besides those originating from combusted tobacco products. Studies show that $PM_{2.5}$ measurements are a validated method for assessing SHS exposure[15, 16].

In the largest study of indoor $PM_{2.5}$ levels in restaurants (n-607) and bars (n-429) undertaken in 32 countries where smoking was permitted in these settings, the average $PM_{2.5}$ levels were 303 $\mu g/m^3$ in bars and 157 $\mu g/m^3$ in restaurants [12].

Four observational studies have examined outdoor levels of $PM_{2.5}$ and one of these studies also examined changes in indoor air quality simultaneously after smokefree legislation was passed.

The Brennan et al study[17] best addresses Review Question 1. Changes in $PM_{2.5}$ before and after a smoking ban in indoor dining areas of restaurants and bars in Melbourne were examined. Measurements were taken both indoors and in outdoor patios of 19 pubs. The mean $PM_{2.5}$ levels observed indoors decreased from 103$\mu g/m^3$ when smoking was allowed to 26$\mu g/m^3$ to when smoking was prohibited. In the outdoor areas of these same pubs, which were not covered by the smokefree legislation, $PM_{2.5}$ levels averaged 19$\mu g/m^3$ and 13$\mu g/m^3$ in each assessment (for a combined average $PM_{2.5}$ level of 16$\mu g/m^3$). Ambient outdoor $PM_{2.5}$ levels averaged 5$\mu g/m^3$ across all assessment periods.

Cameron et al[18] reported on $PM_{2.5}$ data from 69 outdoor dining areas in Melbourne, measured within 1m of an active smoker. $PM_{2.5}$ levels averaged 18$\mu g/m^3$ across all measurement points, and 27$\mu g/m^3$ during periods when active smoking was occurring. The mean number of lit cigarettes observed was just 0.7 during measurements. However, it would often be the case that more than 0.7 smokers were simultaneously smoking in close groups in such settings, so the average levels reported here would be conservative in estimating such exposures. Ambient background levels of $PM_{2.5}$ were 8$\mu g/m^3$. Smoking in these outdoor patios contributed an average excess above ambient levels of nearly 10$\mu g/m^3$ of particulates during the measurement period.

Stafford et al[19] performed a similar study to Cameron et al[18] in 28 alfresco areas of cafes and pubs in Perth and Mandurah. $PM_{2.5}$ levels in periods when no smoking was occurring averaged 4$\mu g/m^3$ (approximately 30% of total measurement time) and increased to 11$\mu g/m^3$ when one smoker was present (approximately 30% of total measurement time), and to 17$\mu g/m^3$ when two or more smokers were present (approximately 40% of total measurement time). The weighted average of these $PM_{2.5}$ levels is 14$\mu g/m^3$, which is a 10$\mu g/m^3$ boost in $PM_{2.5}$ levels from outdoor smoking averaged across the entire measurement period. Importantly, this study did not specify the distance from smokers at which the measuring equipment was placed so its results are less instructive.

Hess et al [20] investigated commuter exposure to particulates inside and outside 7 bus shelters and $PM_{2.5}$ measurements were taken for 840 minutes. Exposure to $PM_{2.5}$ inside shelters averaged 18% higher than exposure outside. Statistical modelling shows that the presence of a smoker inside a bus shelter was associated with a 22.7μg/m^3 increase in $PM_{2.5}$ levels in the shelter, which contributed far more to atmospheric pollution than variables indicating whether buses were fuelled by diesel or hybrid technology and whether the bus stop was near a traffic signal queue. While not a hospitality venue, this paper provides further evidence suggestive of the importance of semi-enclosed micro-environments where smoking occurs contributing to raised levels of $PM_{2.5}$

Experimental work by Klepeis et al (2009) concluded that the proximity to the source of SHS exposure is a critical factor in determining the dose. The authors found that average $PM_{2.5}$ levels of 100μg/m^3 can be found within 0.5m of a single cigarette, with exposure levels approximately halving for each subsequent doubling of the distance from the point source. $PM_{2.5}$ levels from a single cigarette approach background levels beyond approximately 2m, although multiple cigarettes smoked simultaneously can extend this radius.

From these studies there are three key findings: (1) smokefree indoor legislation dramatically reduces indoor $PM_{2.5}$; (2) four observational studies each estimate outdoor smoking adds approximately 10μg/m^3 or more of excess exposure; (3) experimental work shows that the excess exposure can exceed that estimated from the observational studies by an order of magnitude and that proximity is the key factor the drives the level of exposure. Increases in exposure are observed within 2m from a single cigarette.

Review Question 2: How do levels of measured SHS contaminants in outdoor eating and drinking areas compare with established benchmarks for air quality?

The Australian "Air NEPM" standard for $PM_{2.5}$ is 25μg/m^3 averaged across 24 hours and 8μg/m^3 when averaged across a year. None of the studies reviewed measured or estimated 24 hour nor annual $PM_{2.5}$ averages in outdoor settings where smoking occurred.

Peak measures recorded in the reviewed studies ranged from 142 [19], 162[17] to 484 [18]. *Mean* $PM_{2.5}$ concentrations measured for periods in outdoor patios where smoking was permitted ranged from 11 to 19 μg/m^3 averaged across the entire sampling period and varied depending on number of smokers present, distance of measurement from the source, presence of semi-enclosure and wind. Ambient background $PM_{2.5}$ levels ranged from 4 to 8 μg/m^3 in these studies.

The fundamental question is whether SHS levels of exposure as measured from both observational and experimental studies are sufficient to justify a requirement that outdoor areas should be smokefree. Klepeis et al estimate that occupational exposure to waitstaff working in a patio where smoking is allowed is 23.7μg/m^3 over the course of a typical shift.[13] Klepeis et al assumed the scenario of a food and drink waitstaff working a 6-h dinner shift at an outdoor cafe or pub where smoking is allowed at each table, the worker taking 40 or 50 orders during the shift and that 10 of these tables each have 1 smoker present when the worker attends to them. The worker is assumed to be exposed to outdoor tobacco smoke for 100 minutes, and because the worker stands above the patrons, the rising plume can enter the worker's breathing zone at close range – 0.25m is assumed. Drawing on the modelled concentrations in Table 3 of their paper, and using a cigarette fine particle emission rate of 1.4 mg min^{-1} (Klepeis et al., 1996), the 24hour particle exposure from serving tables is predicted as 1.4 x 244 μg/m^3 X 100 min/1440 min = 23.7μg/m^3. This averages to 5.9 μg/m^3 of excess occupational exposure over a 24-hour period. For an employee working full-time, this occupational exposure to SHS will increase the average *annual* exposure by approximately 5.2μg/m^3.

There are a number of assumptions made in this projection. Some factors that make this conservative are that (1) it only considers exposure from patrons at tables the waitstaff is serving when these patrons are being served and it does not include exposure from other patrons at other tables which would often be close in such settings; (2) it assumes only one cigarette is smoked at each table, whereas in reality tables may have multiple smokers;(3) it only assumes close exposure for 100 minutes during a work shift. However, the projection assumes that the SHS exposure will occur in very close proximity (0.25m), which may not replicate a real-world setting (staff would seem unlikely to be less than a quarter of a metre from patrons for sustained periods).

An alternative projection is as follows. Assume that a waitstaff works an 8 hour shift with 4 hours spent waiting tables outdoors and 4 hours spent inside getting drinks and food. Assume also that there is an average of 0.7 smokers present at all times[1]. The waitstaff will be exposed to SHS at varying distances and angles throughout the course of their shift while they are working outdoors and presumably not at all while they are inside. Table 3 in Klepeis et al provides experimental data on particulate concentrations at varying distances and wind speed and directions. If we assume light wind speed and average the $PM_{2.5}$ concentrations across all distances assessed to reflect the varying nature of exposure throughout the course of a shift, the occupational attributable exposure is 42.8μg/m^3 extra from an 8 hour shift or an excess 14.3μg/m^3 of added $PM_{2.5}$ over 24 hours. Averaged over the entire year assuming 250 work days, this is an extra 9.8 μg/m^3 per year attributable to outdoor occupational exposure, above and beyond the background (all source) $PM_{2.5}$ exposures.

[1] The two observational studies had an average of 0.7 active smokers present during observation times. The data reported in Table 3 of Klepeis et al is modelling a point source emitting a standard 1 mg of particles per second but the average emissions per cigarette are 1.4 mg. Therefore, the exposures in Table 3 are multiplied both by the number of active smokers and the average emissions per cigarette (0.7 * 1.4 mg), which is approximately 1.

From the *observational* studies in outdoor areas of bars and restaurants[17-19], it was estimated that $PM_{2.5}$ levels are elevated by approximately 10 $\mu g/m^3$ when active smoking is occurring, which was 70% of the time in these studies for an added 7ug/m3 of occupational exposure. An employee who works a full 8 hour shift (1/3rd of a day) under these conditions will have elevated their 24-hour $PM_{2.5}$ exposure by 2.3 $\mu g/m^3$ under these assumptions. The annual occupational exposure is 1.6 $\mu g/m^3$.

The average $PM_{2.5}$ exposure from these three observational studies is likely an underestimate of the true exposure because by their design measurements were not taken in very close proximity to the point source, and this is precisely the circumstance when exposures are largest. Therefore, we put more weight on the estimated exposures from the experimental studies.

Under the two different sets of assumptions set out above, a full time outdoor waitstaff would receive 1.6$\mu g/m^3$ (estimated from three observation studies[17-19]) to 9.8$\mu g/m^3$ (estimated from modelling predictions from experimental work[13]) of occupational SHS exposure averaged over an entire year and between 2.3 $\mu g/m^3$ (estimated from three observation studies[17-19] to 14.3 $\mu g/m^3$ (estimated from modelling predictions from experimental work[13] when averaged over the course of a 24 hour period during work days. The Australian target for average annual $PM_{2.5}$ exposure is 8 $\mu g/m^3$; therefore, it is plausible that occupational exposure alone in outdoor work settings where smoking is allowed would exceed this threshold. An increase of 5 $\mu g/m^3$ to 10 $\mu g/m^3$ in average annual $PM_{2.5}$ exposure is associated with a 3-6% increase in all-cause mortality[21].

Review Question 3: How are levels of exposure to SHS contaminants affected by study factors such as where smoking is allowed and how does the likelihood of harm vary by factors such as the density of smokers, proximity to smokers and the degree of openness of the area?

As stated above, the number of cigarettes being smoked, the proximity of the measuring device to the source of the smoke, variations in enclosure (umbrellas, awnings etc) and wind are all consistently associated with variations in $PM_{2.5}$ exposure. The highest exposures are found where there are most smokers, nearest to a $PM_{2.5}$ measurement device, under sheltered, windless conditions. Such scenarios can be commonly found in outdoor dining and drinking settings such as crowded beer gardens, hotel or restaurant patios, and sidewalk al fresco dining arrangements where tables are side-by-side, often under awnings or umbrellas.

Empirical data suggest that each added smoker increases the concentration of $PM_{2.5}$ by $10\mu g/m^3$ [18, 19]. Klepeis et al's experimental work shows that $PM_{2.5}$ concentrations are approximately halved for each doubling of distance from the point source from 0.5m[14]. Klepeis et al also shows that tripling the wind speed from 0.1m/s to 0.3m/s decreased $PM_{2.5}$ levels by about one-third[13]. Cameron et al. estimate that overhead coverage increases $PM_{2.5}$ levels by 50%[18].

In summary, these studies together suggest that typical outdoor dining areas of cafes and restaurants, and outdoor drinking areas (patios, beer gardens) of pubs which often see tables close together –well within 2m – and which often have umbrellas, shade cloth or semi-enclosed awnings, will often see patrons and staff exposed to greater concentrations of tobacco generated $PM_{2.5}$ than in the study conditions described above.

Tobacco-originating $PM_{2.5}$ exposure drops sharply after 2m from a single point smoking source, but outdoor areas often have more than one smoker contributing smoke to such areaa. A "2 metre rule" policy which specified (for example) a "no-smoking within 2 metres of other persons" is therefore likely to be inadequate in limiting exposure. In addition, such a rule would be constantly violated as smokers moved about.

Finally, we note that personal monitoring studies of waitstaff have not yet been conducted to corroborate modelled estimates of staff exposure in these settings. Such studies should be conducted to test the modelled exposure estimates we have calculated.

Appendix 1: Table summary of all peer reviewed studies of outdoor secondhand smoke.

Lead Author and location	Date	Exposure Examined	Study Design	Sample Size	Summary of Methods	Findings
Brennan[17] (Melbourne)	2010	$PM_{2.5}$	Observational	19 pubs measured >1 hour pre/post ban both indoors and outdoors	$PM_{2.5}$ levels were measured pre- and post indoor smoking restrictions simultaneously in each of the indoor and outdoor areas.	Indoor $PM_{2.5}$ levels reduced 66% post ban. Outdoor levels were reduced from 19µg/m^3 to 13µg/m^3 postban, though policy does not apply outdoors. No evidence of outdoor $PM_{2.5}$ levels increasing indoor $PM_{2.5}$ levels.
Cameron[18] (Melbourne)	2010	$PM_{2.5}$	Observational	69 outdoor dining areas	$PM_{2.5}$ measurements taken when sitting within 1 metre of a smoker in an outdoor dining area.	Background levels were 8.4µg/m^3 and 27.3µg/m^3 during periods of active smoking. Maximum peak concentration was 484µg/m^3 (30 second interval). Each added cigarette increased $PM_{2.5}$ levels by 30%, overhead coverage increased $PM_{2.5}$ levels by 50%.
Stafford[19] Perth & Mandurah	2010	$PM_{2.5}$	Observational	28 outdoor areas of cafes and pubs	$PM_{2.5}$ measurements taken from location in outdoor area for >15 minutes	Background levels were 4 µg/m^3 and 14.3 µg/m^3 during periods of active smoking. (10.6 µg/m^3 with only 1 smoker and 17.0 with 2+ smokers). Maximum peak concentration was approximately 75 µg/m^3 averaged over the duration of the assessment (15+ minutes)
Hess [20] (New York)	2010	PM2.5	Observational	840 minutes of measurements inside and outside 7 outdoor bus shelters	PM2.5 measurements taken simultaneously inside and outside bus shelters and impact of cigarette smoking and other factors on levels were assessed	The presence of a smoker inside a bus shelter was associated with a 22.7 ug/m3 increase in PM2.5 levels in the shelter, which by far contributed more to atmospheric pollution than variables indicating whether buses were fuelled by diesel or hybrid technology and whether the bus stop was near a traffic signal queue.
Klepeis[14] (California)	2007	$PM_{2.5}$	Observational and Experimental	8000 minutes of monitoring	5 different exposure assessment methods to perform a series of randomized and field studies	$PM_{2.5}$ experiments when individual cigarettes were smoldered and measurements were taken at various distances revealed a mean particle concentration of 177µg/m^3 within 0.25 - 0.5m of the point source, 128µg/m^3 within 0.5 - 1m, 32µg/m^3 within 1 - 2m, and 11µg/m^3 between 2 - 4m.

Klepeis[13] California	2009	CO as tracer gas	Experimental	100+ controlled outdoor experiments	CO was emitted from a point source and measured every 15 seconds in up to 36 points around the point source at varying distances.	Average CO levels were approximately proportional to the distance from the point source. Statistical modeling indicates a single cigarette could yield particle concentrations near 100 $\mu g/m^3$ within 0.5 m of the point source but diminishing to background levels after 2m. Models indicate a halving of exposure as the distance from the point source increases.

Appendix 2: Annotated summaries of relevant studies

Brennan et al (2010), Melbourne[17]: $PM_{2.5}$ levels were measured pre- and post indoor smoking restrictions simultaneously in both indoor and outdoor areas of 19 Melbourne pubs. Measurements were taken for at least 30 minutes in each venue. Indoor and outdoor monitors were positioned within 5 metres of each other on either side of the entryway, and field staff noted the distance between observed instances of smoking and the $PM_{2.5}$ monitors. In the indoor areas, which were required to become smokefree between the pre- and post measurements, $PM_{2.5}$ concentrations decreased by 66% from multivariate analysis (geometric mean of 61 $\mu g/m^3$ pre-law to geometric mean of 17.4$\mu g/m^3$ post law). Outdoor areas, which were not regulated by the law also experience decreased $PM_{2.5}$ levels by an average 39% from multivariate analysis (geometric mean of 19$\mu g/m^3$ pre-law to 13$\mu g/m^3$ post law). In post-law assessments, higher levels of outdoor $PM_{2.5}$ were correlated with higher levels of indoor $PM_{2.5}$, suggesting that $PM_{2.5}$ drifts from outdoor to indoor areas; a 100% increase in outdoor $PM_{2.5}$ was associated with an average 36% increase in indoor $PM_{2.5}$ levels.

Cameron et al (2010), Melbourne[18]: $PM_{2.5}$ levels were measured in 69 outdoor dining areas in Melbourne, Australia in 2007 within 1 metre of an active smoker. The average data collection time was 26 minutes per venue. Visual inspection of the number and location of lit cigarettes and overhead coverings was noted. Background levels averages 8.4$\mu g/m^3$, which increased to an average of 17.6$\mu g/m^3$ during the outdoor dining area observational period. When data were restricted to only those time points when a cigarette was actually lit, the average $PM_{2.5}$ level increased to 27.3$\mu g/m^3$. The peak 30-second averaged $PM_{2.5}$ level observed was 484$\mu g/m^3$. In multivariate analysis, each active smoker within 1 metre was associated with a 30% increase in $PM_{2.5}$ levels, and the presence of overhead cover on the outdoor dining area was associated with a 50% increase in $PM_{2.5}$ levels.
Comment: This monitoring study of real-world conditions is an excellent study on this issue and it complements the experimental work by Klepeis[14].

Stafford et al (2010), Perth, WA[19]**:** Measured particulates in outdoor eating and drinking areas of 29 cafes and pubs. 157 non-smoking minutes and 388 smoking minutes were logged. An average of 19.46 minutes of data were collected from each venue (range = 14-28 minutes). Mean $PM_{2.5}$ concentrations for no smokers, one only, one, two or more smokers were 3.98, 10.59, and 17.00$\mu g/m^3$ respectively. The maximum level of $PM_{2.5}$ recorded was 142.08$\mu g/m^3$.
Comment: The $PM_{2.5}$ measurements in this study were somewhat lower than in other studies. However the paper contains no details of the distance from smokers at which the measuring equipment was placed. As we have seen, distance is a critical variable in measurement.

Klepeis et al (2009), California: From over 100 controlled outdoor monitoring experiments of release of CO (as a tracer gas) under different conditions in a

backyard patio, the authors modelled that a cigarette smoker "would cause average fine particle levels of approximately 70-110µg/m^3 at horizontal distances of 0.25-0.5m". They observed that "beyond approximately 2m, average CO levels were near background values" such that the $PM_{2.5}$ levels are reduced in half for every doubling of the distance from 0.5m of the point source per single cigarette. "For some pollutants, this distance might be considered a 'safe distance', depending on toxicity, the authors note. As source emission rates increase (ie: where there is more than one smoker) "we expect the pollutant concentrations to approach measureable levels at distances greater than 2m". The authors estimate a cafe worker's 24 hour average exposure to outdoor tobacco smoke particles. An edited extract of this estimate is at Appendix 2.
Comment: This is a very well designed controlled experiment. It complements the three previous 'real world' studies. These data provide a spatial metric for which elevated SHS levels are expected (i.e., within 2 meters). Importantly, this estimation is a modelled, not recorded estimate. It would be possible to validate such modelling by fitting hospitality workers with personal monitors. The data in Table 3 of this paper serve as the basis for two estimates of occupational exposure presented in the body of the text.

Klepeis et al (2007), California: This study used 5 different exposure assessment methods to perform a series of randomized and field studies to better understand levels of secondhand smoke exposure in outdoor settings. $PM_{2.5}$ experiments when individual cigarettes were smouldered and measurements taken at various distances revealed a mean particle concentration of 177µg/m^3 within 0.25-0.5m of the point source, 128µg/m^3 within 0.5-1m, 32µg/m^3 within 1-2m, and 11µg/m^3 between 2-4m.

The main conclusions from the paper are: (1) outdoor particle concentrations measured near a point source can be comparable to levels observed indoors and reach levels in the hundreds of µg/m^3; (2) the duration of exposure in outdoor settings is more transient than indoors and is highly dependent on wind direction; (3) particle concentrations can drop by half or more as the distance from the point source to point of measurement doubles from 0.5m to 1-2m; no increase in particle concentrations were observed from a single cigarette beyond 4m; (4) in an outdoor patio scenario, the authors estimate that between 8-20 cigarettes could cause an increase in 24 hour particle exposure greater than 35µg/m^3 (the US EPA standard for 24 hour exposure).
Comment: This is the first experimental study of outdoor tobacco smoke. The authors conclude "it is possible for outdoor tobacco smoke to present a nuisance or hazard under certain conditions of wind and smoker proximity."

Kennedy et al (2010), Ottawa, Canada[22]: Examined $PM_{2.5}$ levels in a convenience sample of 12 patio areas in Ottawa, Canada, including 10 patio areas where smoking was allowed and 2 smokefree patio areas. In addition, measurements were made in a park away from busy streets and smokers, and on a busy street during peak hour. Most venues were sampled for at least 30 minutes and visual observations were made noting the time patrons were smoking and the distance from lit cigarettes to the $PM_{2.5}$ monitor. Background levels of $PM_{2.5}$ ranged from 2-8µg/m^3 during the

study period and the 2 smokefree patios had $PM_{2.5}$ levels within this range (5 and 7 μg/m^3). Six patio areas had active smoking during the monitoring period and had increased $PM_{2.5}$ relative to background levels. Average $PM_{2.5}$ levels in the 5 patio areas where smoking was allowed and observed ranged from 10-26 μg/m^3 and a sixth patio area that was a non-smoking section had an average $PM_{2.5}$ level of 23μg/m^3. Peak 10sec averaged $PM_{2.5}$ levels ranged from 44-716μg/m^3 (median 158μg/m^3). In contrast, measurements taken on a busy street during peak hour resulted in an average $PM_{2.5}$ level of 3μg/m^3.
Comment: This study does not provide details such as how many smokers were present and their proximity to the monitor.

Hall et al (2009), Athens, Georgia USA[23]: Non-smokers participated during 6-hr periods in outdoor standing or seating areas of bars and restaurants where indoor smoking was banned, as well as a control outdoor location with no smokers over six weekends during summer and early autumn. Pre- and post-exposure saliva samples (N=25 person-days at the bar site, N=28 person-days at the restaurant site, and N = 11 person days at the control) were analyzed for cotinine. The mean change in the response, (ln(post) - ln(pre)) salivary cotinine levels, was significantly impacted by the type of site (bar, restaurant, control) (F = 5.09; d.f. = 2, 6.7; p = 0.0455). The median percent increase in salivary cotinine from pre-test to post-test was estimated to be 162%, 102%, and 16% at the bar, restaurant, and control sites, respectively, values that were significant increases at bars (t = 4.63; d.f. = 9.24; p = 0.0011) and restaurants (t = 4.33; d.f. = 4.47; p = 0.0097) but not at the control sites. On average, these pre-test to post-test increases in salivary cotinine were significantly higher at bar sites than control sites (t = 3.05; d.f. = 9.85; p = 0.0176) and at restaurant sites compared with control sites (t= 2.35; d.f.=5.09; p=0.0461). They conclude that non-smokers outside restaurants and bars have significantly elevated salivary cotinine levels indicative of SHS exposure.
Comment: This study confirms that the elevated PM2.5 levels observed in the observational and experimental studies translates in to increased exposure to SHS as measured by a biomarker specific to that exposure.

Kennedy et al. (2006). Presentation at Ontario Tobacco Control Conference, 2006 – Tobacco Smoke Pollution in Outdoor Hospitality Settings).[24] $PM_{2.5}$ measurements taken in 12 patio settings in Ontario Canada. Average $PM_{2.5}$ levels were comparable to background levels in 7 of the 12 patios. In the 5 other patios, the average $PM_{2.5}$ level in the patio area was 86μg/m^3 compared to an average of 12μg/m^3 for background levels. Data are not reported on the number of smokers present during these field assessments. The authors conclude that 'it is possible for average outdoor readings on $PM_{2.5}$ to reach levels similar to average indoor readings where smoking is permitted…'.
Comment: The study appears to be unpublished.

Kennedy R, Fong GT. 2009[25]**.** $PM_{2.5}$ measurements were taken at multiple distances from doorway entrances and intensities of point source emissions from machine smoked cigarettes according to the Health Canada test regime.

Experimental parameters were the distance from the doorway (1, 3, 6, 9, or 10 m), a covered or uncovered area, doors continually open or doors opening and closing, and 1 or 4 cigarettes smoked. The peak $PM_{2.5}$ levels observed were for the scenario with 4 cigarettes smoked within 1m of a doorway located under a roof (203$\mu g/m^3$). When just 1 cigarette was burned in open air (not under a roof), $PM_{2.5}$ levels outside the doorway peaked at 15 $\mu g/m^3$, 1m from the point source compared to 5$\mu g/m^3$ background levels. Generally clear increases in $PM_{2.5}$ were detectable within 3m of the point source emissions, and levels increased with increasing numbers of cigarettes smoked and when measurements were taken under a roof.
Comment: While unpublished, these data reinforce previous studies that show that close proximity, physical barriers, and increased numbers of cigarettes contribute to increases in $PM_{2.5}$ exposure.

Kennedy et al. 2008[26]**.** Different provincial laws require different configurations of roof enclosures and umbrellas to be compliant with various policies. Kennedy et al engineered mock outdoor patios and conducted controlled cigarette burn experiments to determine how the presence of patio umbrellas and awnings impacted $PM_{2.5}$ outdoor measurements. In each scenario, 8 cigarettes were machine smoked following the Health Canada testing regime. In 12 trials with an open air configuration, average $PM_{2.5}$ levels exceeded background levels by 41$\mu g/m^3$. In four trials with table umbrellas either touching or not touching each other resulted in approximately a 10-fold increase in $PM_{2.5}$ levels compared to background (average 73$\mu g/m^3$ during burns compared to average 8$\mu g/m^3$ background reading). Similar results were obtained with an awning present (average $PM_{2.5}$ level = 67$\mu g/m^3$).
Comment: While unpublished, these data reinforce previous studies that show that physical barriers contribute to increases in $PM_{2.5}$ exposure.

Repace (2005). Baltimore, Maryland, USA. Measurements of Outdoor Air Pollution From SHS at UMBC (2005). Report Repace website. $PM_{3.5}$ and particulate polycylic aromatic hydrocarbons (PPAH) were measured in the vicinity of building entrances with 2 controlled experiments. In one, 5 cigarettes were smouldered for ~17 minutes each outside of a doorway to a building with the monitoring equipment located 6 feet (<2m) away. In the other 8 smokers were situated in a ring around the monitoring equipment; ring radius was 1.5, 2, 3, and 5m in different scenario trials. Based on these measurements, smoke levels approach background levels only after 7m distance to the point source.
Comment: This study shows that carcinogens are detectable at varying distances from burning cigarettes.

Hess et al (2010), Buffalo, USA[20]: Investigated commuter exposure to particulates inside and outside 7 bus shelters. 840 minutes were recorded. Exposure to $PM_{2.5}$ inside shelters averaged 18% higher than exposure outside “perhaps due in part to the presence of cigarette smoking.” The presence of a smoker inside the shelter boosted $PM_{2.5}$ levels by 22.7$\mu g/m^3$
Comment: While not a hospitality venue, this paper provides further evidence suggestive of the importance of semi-enclosed micro-environments where smoking occurs contributing to raised levels of $PM_{2.5}$

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