Folkhälsomyndigheten

Environmental Tobacco Smoke: a literature review on occurrence and dispersion

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Bindningar och jäv

För Folkhälsomyndighetens egna experter och sakkunniga som medverkat i rapporter bedöms eventuella intressekonflikter och jäv inom ramen för anställningsförhållandet.

När det gäller externa experter och sakkunniga som deltar i Folkhälsomyndighetens arbete med rapporter kräver myndigheten att de lämnar skriftliga jävsdeklarationer för potentiella intressekonflikter eller jäv. Sådana omständigheter kan föreligga om en expert t.ex. fått eller får ekonomisk ersättning från en aktör med intressen i utgången av den fråga som myndigheten behandlar eller om det finns ett tidigare eller pågående ställningstagande eller engagemang i den aktuella frågan på ett sådant sätt att det uppkommer misstanke om att opartiskheten inte kan upprätthållas.

Folkhälsomyndigheten tar därefter ställning till om det finns några omständigheter som skulle försvåra en objektiv värdering av det framtagna materialet och därmed inverka på myndighetens möjligheter att agera sakligt och opartiskt. Bedömningen kan mynna ut i att experten kan anlitas för uppdraget alternativt att myndigheten föreslår vissa åtgärder beträffande expertens engagemang eller att experten inte bedöms kunna delta i det aktuella arbetet.

De externa experter som medverkat i framtagandet av denna rapport har inför arbetet i enlighet med Folkhälsomyndighetens krav lämnat en deklaration av eventuella intressekonflikter och jäv. Folkhälsomyndigheten har därefter bedömt att det inte föreligger några omständigheter som skulle kunna äventyra myndighetens trovärdighet. Jävsdeklarationerna och eventuella kompletterande dokument utgör allmänna handlingar som normalt är offentliga. Handlingarna finns tillgängliga på Folkhälsomyndigheten.

Preface

There are severe negative health effects caused by passive smoke indoors, and there is a clear consensus on the lack of a safe level of exposure to tobacco smoke.

The objective of this review is to investigate the scientific literature on tobacco smoke outdoors to determine if smoking causes elevated particle concentrations outdoors and, if so, at what distances from the source of the smoke. The knowledge of how tobacco smoke spreads outdoors is one key factor in understanding the incentives for increasing the number of smoke-free public places.

We thank Professor Tom Bellander at The Institute of Environmental Medicine (IMM), Karolinska Institutet, for his valuable comments on this report.

Innehåll

Summary

Tobacco smoke contains a mixture of more than 7,000 different chemicals, and the smoke from cigarettes has been shown to cause a wide range of diseases and to lead to premature death. The health risks of environmental tobacco smoke (ETS) have been expounded upon by the World Health Organization (WHO) who also states that there are no safe levels of exposure to second-hand smoke. The link between tobacco smoke and increased pollution of indoor air is well known, and the purpose of this study is to summarize the scientific literature on ETS. The focus of the study is on whether smoking causes elevated particle concentrations outdoors and, if so, at what distances from the smoke source.

The search for scientific literature relevant to our study questions was based on the search strategy in a recently published literature review by Sureda et al. A complementary search was carried out in PubMed to find articles published after the Sureda et al. review. A total of 13 articles from both searches were included in this study. In all the included studies, the presence of tobacco smoke in outdoor environments was detected by measuring the concentration of small particles with a maximum aerodynamic diameter of 2.5 microns ($PM_{2.5}$) in air.

The observed settings included restaurants, pubs, and cafés; walkways and streets; and entrances to public buildings. The $PM_{2.5}$ levels in these settings was as high as 204.7 µg m^{-3}, 68 µg m^{-3}, and 496 µg m^{-3}, respectively. Four experimental studies confirmed a distinct increase in $PM_{2.5}$ concentrations in the air during smoking. At a distance up to 1 m from a single smoke source, the $PM_{2.5}$ concentrations reached levels as high as 633 µg m^{-3}, 202 µg m^{-3}, 164 µg m^{-3} m^{-3}, and 181.8 µg m^{-3} in each study. The concentration of ETS decreases exponentially with distance, and this supports the so-called “proximity effect” of ETS. Elevated $PM_{2.5}$ concentrations were measured up to 9 m from the source, and higher oncentrations were measured downwind compared to upwind.

This review of the literature on ETS found evidence for the occurrence of significantly elevated particle concentrations around a smoke source outdoors and for the risk of involuntary human exposure to tobacco smoke in different outdoor settings. However, the number of studies was small, and further research is necessary to better understand the behavior of smoke particles in the air under different outdoor conditions.

Introduction

Smoking is a major public health issue that is the direct cause of about four percent of the total disease burden worldwide (1) and about nine percent of the total disease burden in Sweden (2). In Sweden, 12 000 persons are estimated to die from a tobacco-related disease and around 100 000 new patients are affected by medical conditions related to smoking each year (3). The harmful substances in the smoke from tobacco also affect nonsmoking people who are exposed to environmental tobacco smoke (ETS). Today there is solid evidence for the health risks connected to ETS, and children and fetuses have been shown to be particularly vulnerable (4). In 2004, ETS was estimated to cause 600 000 deaths (one percent of the total mortality) and 10.9 million disability-adjusted life years globally (5).

Environmental tobacco smoke, secondhand tobacco smoke, and passive smoke are all synonyms used in the literature and are defined as "diluted and dispersed air pollutant emissions generated from the consumption of tobacco products" (6). The emissions can be exhaled by a smoker (mainstream smoke) or can be leaving the burning tip of a cigarette or cigar (sidestream smoke).

The smoke from a cigarette shows different patterns of movement when released in the air. Sharp spikes of airborne particle concentrations, called microplumes, have been found in close proximity to a smoke source and consist of thin concentrated streams of smoke that follow complex trajectories when they are released. The microplumes dissipate into the air over time and at further distances from the source. The dissipation of microplumes negatively affects indoor air quality by causing a prolonged increase in particle concentration that depends mainly on the extent of ventilation. It is less likely that smoking outdoors will affect the air quality for the same length of time as indoor smoking, especially when there are no walls to enclose the smoke.

Exposure to ETS can be measured by biomarkers in the blood, saliva, and urine or by particle concentrations in environmental samples of the air, dust, and surfaces. The most frequently used marker for measuring outdoor passive smoke is particulate matter (PM). PM is defined as particles of solids and/or liquids of such dimensions and morphology as to remain suspended in the atmosphere for a certain time depending on their size, form, specific mass, and air turbulence. Larger particles tend to settle quickly while smaller particles can remain suspended in the air for hours and even days and can be transported very far from the generation point by air movements. The size range of ETS particles is approximately 0.02–2 µm, and such particles fall within the range of so-called fine particulate matter ($PM_{2.5}$), which includes particles less than 2.5 µm in aerodynamic diameter. These particles are small enough to remain suspended in the air for days and can penetrate deeply into the lungs where they can cause health problems (7).

The main disadvantage with using PM for measurements of smoke concentration is that $PM_{2.5}$ is not specific for ETS, and measurements using $PM_{2.5}$ should, therefore, be compared to background concentrations when smoke is not present (8). It can be difficult to distinguish tobacco smoke $PM_{2.5}$ from other sources, especially at low concentrations, but this disadvantage is outweighed by the availability of portable, user-friendly, and affordable instruments capable of real-time PM monitoring (7).

Aim

The purpose of this study is to summarize the scientific literature on ETS in public outdoor settings.

The two specific study questions are:

1. What levels of tobacco smoke particles have been observed in the outdoor air in different types of public settings?
2. What levels of tobacco smoke particles have been observed in the outdoor air at different distances from one lit or smoked cigarette?

Method

This literature review investigated the scientific literature on ETS with a focus on whether smoking causes elevated particle concentrations outdoors and at what distances from the source of the smoke.

Search strategy

The search for scientific literature relevant to our study questions was based on the search strategy in a recently published literature review by Sureda et al. (9) whose study questions covered those of the present review. In their systematic review, Sureda et al. identified 18 studies with the main objective of measuring secondhand smoke exposure in outdoor settings. The literature search in the article by Sureda et al. covered the period prior to the 1st of September 2012.

In order to identify newly published studies, a complementary search was performed using the following search string, which was the same as in the article by Sureda et al. except for the language criteria: ((“secondhand smoke” OR “environmental tobacco smoke” OR “passive smoking” AND “outdoor”) OR (“tobacco smoke pollution” [Mesh] AND “outdoor”)) AND (PM OR RSP OR $PM_{2.5}$ OR particulate matter OR nicotine OR CO OR cotinine OR marker OR markers OR biomarker OR airborne marker). The PubMed database was searched for papers published from the 1st of January 2012 to the 31st of January 2014.

To identify articles relevant to the study question but not obtained in the search, so-called backward and forward snowballing was performed. Backward snowballing refers to the process of identifying previously unknown articles in the reference list of the articles selected in the study. Forward snowballing refers to the identification of articles in PubMed that have cited the literature review by Sureda et al.

One author screened the citations, abstracts, and full texts of the search results to identify relevant studies and to determine if they met the inclusion criteria. Two authors independently extracted data from the included studies.

Eligibility criteria

The inclusion criteria for papers that were common to both study questions included outdoor smoking, $PM_{2.5}$ as an outcome variable, peer-reviewed articles as a quality standard, no stated conflict of interest with the tobacco industry, and publication in English or Swedish. However, the methodological criteria were specific to each study question. For the study question of “what levels of tobacco smoke particles have been observed in the outdoor air in different types of public settings”, field studies performed in different outdoor settings (bars, cafés, walkways, building entrances, etc.) where a smoke source was present were included. For the study question of ”what levels of tobacco smoke particles have been observed in the outdoor air at different distances from one lit or smoked cigarette”, controlled experimental studies that focus on the exact distances from an identified smoke source were included. (Table 1).

Table 1. Eligibility criteria

	Study question 1	Study question 2
Study question	What levels of tobacco smoke particles have been observed in the outdoor air in different types of public settings?	What levels of tobacco smoke particles have been observed in the outdoor air at different distances from lit or smoked cigarettes?
Outcome variables	$PM_{2.5}$	$PM_{2.5}$
Time period	Prior to 31 January 2014	Prior to 31 January 2014
Language	English and Swedish	English and Swedish
Methodology	Measurements with an active smoke source (at least one cigarette is lit) Observational studies	Identified smoke source and number of smokers/lit cigarettes Controlled experiment Background information (topography, weather, initial levels of $PM_{2.5}$)
Other	No conflict of interest with the tobacco industry Peer-reviewed articles	No conflict of interest with the tobacco industry Peer-reviewed articles

Data extraction

The results of the experiments in each article in this review were extracted in as much detail as possible. Some studies reported data for each specific measurement experiment, while others aggregated the values.

Data analysis and presentation

In order to understand how ETS spreads from a smoke source, the data from four studies with controlled experiments (6, 10-12) were analyzed using a nonlinear mixed model. A nonlinear mixed model takes into account that there is a dependency in the data within the same study, and this was the case for the data in the included studies. An advantage to using nonlinear mixed models is that the measurements, in this case the number of meters from the smoke source, do not need to be the same for all trials, which was the case in the four studies.

A nonlinear fit to the mean $PM_{2.5}$ values from the four studies was performed with an exponential function for each study over the different distances from the smoke source. The exponential function has two parameters that need to be estimated, the value at zero distance and the rate at which the mean $PM_{2.5}$ decreases with distance. The $PM_{2.5}$ value at the source and the rate of the decrease over distance were assumed to vary randomly between studies. The exponential decay function made it possible to extrapolate the $PM_{2.5}$ values beyond the distances from the smoke source that were actually measured in each study. In this analysis, the estimated values for all studies were extrapolated from 0.3 m to 9 m from the smoke source. Because the background concentrations in the studies by Hwang et al. (11) and Ott et al. (12) were not available for each experiment, the minimum and maximum values were adjusted by subtracting an average background concentration.

Results

Search results

The complementary search for the time period from the 1st of January 2012 to the 31st of January 2014 resulted in 20 records (Fig. 1). Thirteen of these studies were duplicates of the 18 articles identified in the literature review by Sureda et al. (9), and five more articles were removed during the title and abstract screening. The full text of the two remaining studies from the PubMed database search and the 18 studies from Sureda et al. were screened, and eleven records met the eligibility criteria presented in Table 1. Backward snowballing on these articles resulted in one more relevant publication, while forward snowballing did not result in further articles. One more article relevant to the study, but not found in the systematic search, came to our attention thanks to an expert in the field and was added to the final search results giving a total of 13 studies.

Nine out of the 13 studies met the inclusion criteria for the first study question concerning the levels of tobacco smoke particles measured in the outdoor air in different settings. These nine were all observational studies and were conducted in Australia, Denmark, the US, and New Zealand. The other four studies met the inclusion criteria for the second study question concerning the level of tobacco smoke particles observed in the outdoor air at different distances from one lit or smoked cigarette, and these were all controlled experiments conducted in the US and Korea. Further details on the 13 studies are provided in the Appendix.

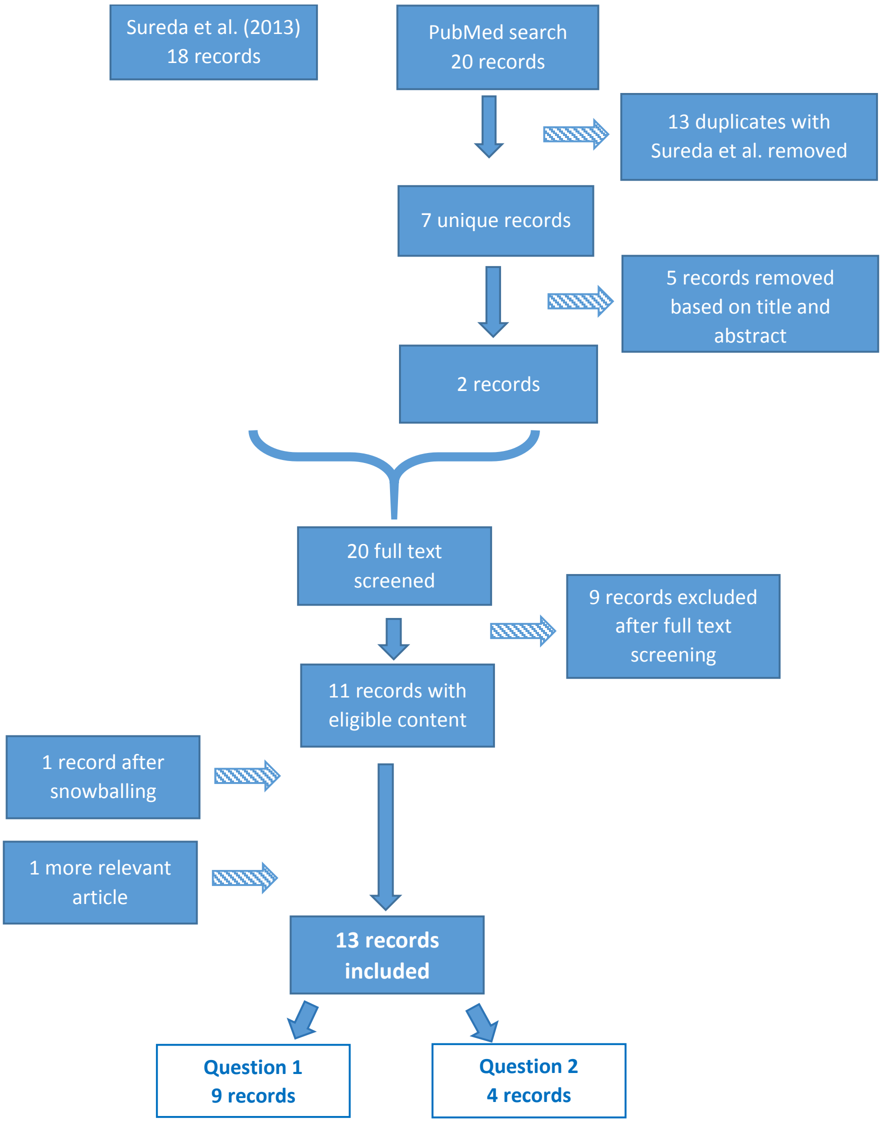

Figure 1. Study selection. Illustration of the process followed in the selection and assessment of the studies.

Results for study question 1: $PM_{2.5}$ concentrations in different types of outdoor settings

Tables 2 to 4 present data that are linked to the research question on the levels of tobacco smoke particles that have been measured in different types of outdoor settings. The studies were all observational studies that reported existing particle levels in real outdoor settings. The values obtained in the studies were all affected by both measurement methods and background variables. Examples of background variables included the number of cigarettes, the weather, and the topography. The main differences in measurement methods were cigarette time versus total time exposure, the length of the measuring period, and the time period used for the average.

Restaurants, pubs, and cafés

Six studies measured ETS in outdoor restaurants, pubs, and cafés (13-18) (Table 2). In total, 117 locations were included in the six studies. The maximum reported $PM_{2.5}$ from each study varied between 73.7 µg• m^{-3} and 271.3 µg• m^{-3}. A variation in $PM_{2.5}$ values was seen within a single site in two studies (13, 18). The greatest variation was found in an experiment by St. Helen et al. (18) (E2, Table 2) where the lowest and the highest values were 16.4 µg• m^{-3} and 271.3 µg• m^{-3}, respectively. The monitoring time in this study was 11.5 h on four different days for a total of 46 h and was by far the longest monitoring period compared to the other studies with an average monitoring time of 30 min.

In two of the six studies, the background levels of $PM_{2.5}$ were subtracted from the results (14, 15). These background values were on average 8.4 µg• m^{-3} in Cameron et al. (15) and 5.3 µg• m^{-3} in Brennan et al. (14). The average $PM_{2.5}$ in the four studies that did not subtract backgrounds levels were all reported to be higher than in Cameron et al. and Brennan et al.

The topographic characteristics seemed to contribute to the variation in the levels of $PM_{2.5}$ concentrations. The settings with greater degrees of enclosure had generally higher concentrations of $PM_{2.5}$ compared to settings that were less enclosed. For example, the highest level reported by Wilson et al. (189 µg• m^{-3}) was from a bar that had four walls and a partial roof (13). The lower levels from the same study were reported from settings far more exposed to the open air. However, the topography was not the only factor that played a role, as seen in the study by St Helen et al. (18). In their study, when measuring in restaurants the one restaurant with three walls and a roof had a higher maximum value (115.7 µg• m^{-3}) compared to the restaurant with no walls or roof (44.7 µg• m^{-3}). But when measuring in bars the highest value was obtained from a bar with neither walls nor a roof (271.3 µg• m^{-3}) and the lowest was from a bar with two walls and a roof (64.8 µg• m^{-3}).

Table 2. $PM_{2.5}$ concentrations in outdoor restaurants, pubs, and cafés ($\mu g \bullet m^{-3}$)

Study, year	Setting	Measure	No Obs.[a]	Average $PM_{2.5}$	Min $PM_{2.5}$	Max $PM_{2.5}$	Results with multiple cigarettes	Walls	Roof
Wilson (2007) (13)	Four outdoor smoking areas of bars (E1-E2)[b] and restaurants (E3-E4) in the Central Business District of Wellington City, New Zealand.	Total time exposure Average levels over 1-min periods Total recording time/experiment: 35 min	35	E1: 19	8	55	At least two cigarettes smoked during the measurement period. On average 4 cigarettes burning during 30 minutes at three observation time points.	E2: four walls E1, E3-E4: more exposed to open air and wind	E2: partial roof E1, E3-E4: more exposed to open air and wind
			35	E2: 75	13	189			
			35	E3: 30	9	103			
			35	E4: 20	7	51			
			140	E1–E4: 36	7	189			
Brennan (2010) (14)	Nineteen pubs and bars with at least one indoor area with an adjacent semi-enclosed outdoor eating/drinking area in Victoria, Australia.	Total time exposure Average levels over 30 s periods Total recording time/experiment: 30 min	1140	18.8[c]	3.7	73.7	An increase of one in the mean number of lit cigarettes related to an increase of 24% in the geometric mean of outdoor $PM_{2.5}$ [d]	Yes	Yes
Cameron (2010) (15)	69 visits to 54 unique outdoor dining areas in Melbourne, Australia.	Total time exposure Average levels over 30 s periods Average recording time/experiment: 25.8 min	3560	17.6[c]	2.7	78	Average exposure levels increased for both total time exposure and cigarette time exposure by 34% for every additional active smoker within 1 meter of the monitor.	50% had walls	71% had overhead cover
		Cigarette time exposure Average levels over 30 s periods Average recording time/experiment: 9.9 min	1366	27.3[c]	2.6	112.7			
Stafford (2010) (16)	Al fresco areas of 12 cafés and 16 pubs in eight local government areas in metropolitan Perth and Mandurah, Australia.	Cigarette time exposure Average levels over 1 min periods Average recording time/experi	545	14.25	n.a.	142.08	There was evidence of a dose response increase with mean concentrations for none, one, and two or more smokers. (No smokers: 3.98 $\mu g \cdot m^{-3}$,	Most venues had no or only overhead cover with only 7% of venues having both overhead and	Most venues had no or only overhead cover with only 7% of venues having both overhead and side cover.

		ment: 19.46 min					One smoker: 10.59 µg·m^{-3}, One or more smokers: 14.25 µg·m^{-3}, Two or more smokers: 17 µg·m^{-3})	side cover.	
Edwards (2011) (17)	Semi-enclosed outdoor areas in seven pubs in the Central Business District in Wellington City, New Zealand.	Total time exposure Average levels over 30 s periods Total recording time/experiment: 30 min	418,420	April/ June 74 Aug/Jan 91	April/ June 32 Aug/ Jan 34	April/ June 109 Aug/J an 161	At least one person smoking at the start of the measurement period	On three or more sides	Yes
St Helen (2011) (18)	Outdoor waiting areas and patios of restaurants and bars in five locations in downtown Athens, Georgia, US. Three bars (E1-E3) and two family restaurants (E4-E5).	Total time exposure Average levels over 15 min with 30 s recording intervals Total recording time/experiment: 11 hours and 30 min per day for 1–4 days	184	E1: 63.9 E2: 51 E3: 30.1 E4:39.7 E5: 16.6	E1: 16.2 E2: 16.4 E3: 16.9 E4: 15.2 E5: 7.96	E1: 20 4.7 E2: 271.3 E3: 64.8 E4: 115.7 E5: 44.7	Bars 4.5 smokers on average Restaurants 2 smokers on average	E1 two E2 none E3 two E4 three E5 none	E1 no E2 no E3 yes E4 yes E5 no

a) The number of observations was calculated from the number of measurements and the total measurement time for each experiment.
b) Single experiments within a study (E).
c) Background concentrations were subtracted from the source period average.
d) Geometric mean indicates the central tendency or typical value of a set of numbers by using the product of their values (as opposed to the arithmetic mean that uses their sum).

Walkways and streets

One of the selected studies measured ETS in walkways and streets on the Golden Mile route in Wellington City, New Zealand (19). In this study, the average $PM_{2.5}$ levels when smoking was observed were significantly higher than when it was not observed (9.3 µg• m^{-3} vs. 6.3 µg• m^{-3}). The maximum level of PM2.5 recorded was relatively low (68 µg m^{-3}), and this might be expected given the open-air setting and the fact that the observer recorded the $PM_{2.5}$ concentrations while walking along the walkways and streets.

Table 3. $PM_{2.5}$ concentrations in outdoor walkways and streets (µg•m^{-3})

Study, year	Setting	Measure	No Obs [a]	Average $PM_{2.5}$	Min $PM_{2.5}$	Max $PM_{2.5}$	Results with multiple cigarettes
Parry (2011) (19)	Four samples as two observers walked along the Golden Mile route in Wellington, New Zealand.	Total time exposure Average levels over 30 s periods Total recording time: 21 hours per observer	151,200	14.2	1	68	Multiple smokers, mean 23.7

a) The number of observation was calculated from the number of measurements and the total measurement time for each experiment.

Entrances to public buildings

Two studies measured ETS outside entrances to public buildings. One study investigated the area in front of a conference center in Copenhagen (20), and the other investigated the entrances to 28 commercial and corporate office buildings in Toronto (21). The main difference between the two studies was that Boffi et al. (20) reported average levels over two minutes while Kaufman et al. (21) reported average levels over 10 seconds. Averages over a shorter time period are more likely to capture the high concentrations of particles in microplumes, and this could be an explanation for the higher maximum level reported in Kaufman et al. (496 µg• m^{-3}) compared to the maximum level in Boffi et al. (98.9 µg• m^{-3}) (Table 4).

Table 4. $PM_{2.5}$ concentrations outside entrances to public buildings (µg•m^{-3})

Study, year	Setting	Measure	No Obs [a]	Average $PM_{2.5}$	Min $PM_{2.5}$	Max $PM_{2.5}$	Results with multiple cigarettes
Boffi (2006) (20)	In front of the Bella Center in Copenhagen, Denmark, with smokers under a roof	Total time exposure Average levels over 2 min periods Total recording time: 35 min	18	17.8	10.3	98.9	18 smokers during a measuring time of 35 min
Kaufman (2011) (21)	28 commercial and corporate office buildings in Toronto, Canada	Raw data (10 sec average) Total recording time/experiment: 30 min (in total 754 min while 1–4 cigarettes were smoked and 112 min while 5+ cigarettes were smoked).	5040	Mean 1–4 cigarettes 15.2 Mean 5+ cigarettes 22.8	0	496	Mean 1–4 cigarettes 15.2 Mean 5+ cigarettes 22.8

a) The number of observations was calculated from the number of measurements and the total measurement time for each experiment.

Figure 2 shows the minimum and maximum average levels of $PM_{2.5}$ concentrations in different outdoor settings. As mentioned above, a direct comparison between the results is not possible due to differences in measurement methods and background variables. However, there is evidence of increased levels of $PM_{2.5}$ due to tobacco smoke in all of the three settings studied.

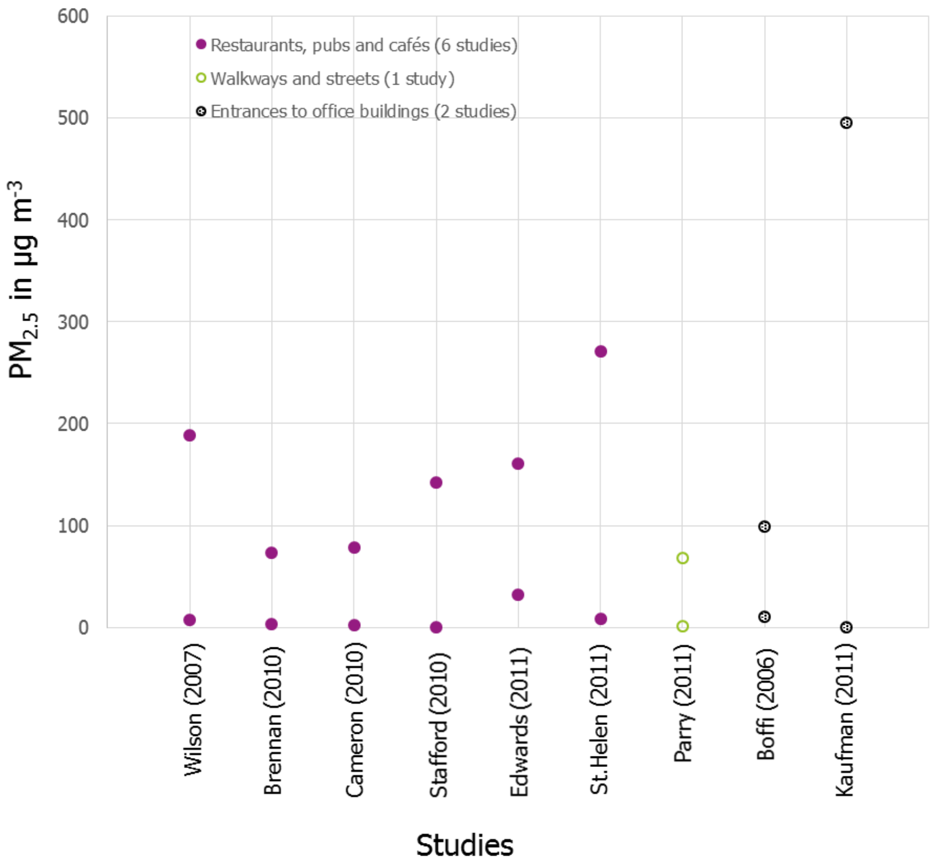

Figure 2. $PM_{2.5}$ in different public outdoor settings (max-min).

Multiple cigarettes smoked simultaneously

Some of the studies reported higher levels of $PM_{2.5}$ when multiple cigarettes were smoked simultaneously, and this was seen regardless of setting. Stafford et al. (16) suggested a dose-response relationship between $PM_{2.5}$ concentrations and the number of cigarettes smoked simultaneously. Parry et al. (19) stated that the level of $PM_{2.5}$ was 3.1 times higher when multiple cigarettes were observed compared to a single smoked cigarette (23.7 µg• m^{-3} vs. 7.7 µg• m^{-3}, respectively). Kaufman et al. (21) stated that the average outdoor level of $PM_{2.5}$ increased from 15.2 µg• m^{-3} when 1–4 cigarettes were burning to 22.8 µg• m^{-3} when 5+ lit cigarettes were observed (Fig. 3).

These three studies were performed in different types of settings and with different measurement methods, and a direct comparison of the results could be misleading. Stafford et al. measured $PM_{2.5}$ in the outdoor areas of 28 pubs and cafés with a minimum of 15 minutes of $PM_{2.5}$ measurements, and data were collected on the maximum and average number of cigarettes and the maximum and average number of people smoking. In Parry et al., sampling occurred along the Golden Mile in Wellington, New Zealand, with a manual record of the number of people who were observed smoking every second hour, but the maximum number of smoked cigarettes observed simultaneously was not reported in the article. Finally, Kaufman et al. measured $PM_{2.5}$ outside 28 entrances to office buildings. Air quality measurements were taken in 30 min sessions and observational data about the number of lit cigarettes within 9 m of the entrances were recorded at 5 min intervals.

Two more articles supported the evidence of increased levels of $PM_{2.5}$ in the presence of multiple cigarettes smoked simultaneously (14, 15). In Brennan et al. (14), an increase of one in the mean number of lit cigarettes was associated with a 24 percent increase in the geometric mean[1] outdoor $PM_{2.5}$. Similarly, Cameron et al. (15) reported that average exposure levels increased by around 34 percent for every additional smoked cigarette within 1 m of the monitor.

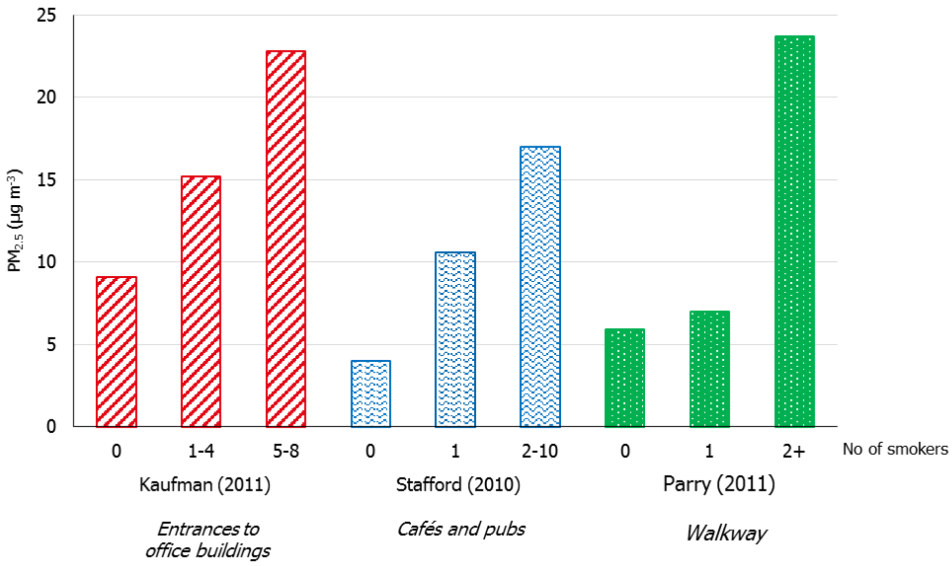

Figure 3. Average $PM_{2.5}$ in the presence of multiple smokers as reported in three different studies.

[1] Geometric mean indicates the central tendency or typical value of a set of numbers by using the n^{th} root of the product of their values (as opposed to the arithmetic mean that uses their sum divided by the number).

Results for study question 2. $PM_{2.5}$ concentrations at different distances from one lit or smoked cigarette in outdoor air

Outdoor $PM_{2.5}$ concentrations from tobacco smoke

The levels of $PM_{2.5}$ particles increased in the presence of outdoor smoking in all four of the controlled studies included in this review (6, 10-12) (Table 5). Three of the studies were performed in California by the same research group (6, 10, 12) and two of them applied the same measurement method (10, 12). One study was conducted in Korea by a different research group (11) (Table 5).

In the four studies, the $PM_{2.5}$ concentrations were measured during the burning of one cigarette either smolder-smoked (passive in an ashtray) or smoked by a person. However, the experimental design differed between the studies and this likely affected the results. For example, the time intervals for the measurements and the parameters that were included in the calculation of the average differed between the studies.

In the report by Ott el al. (12) the $PM_{2.5}$ concentration was measured every second for the active smoking period of one cigarette. The maximum average level obtained from the seven experiments was 202 µg• m^{-3} measured at a distance of 0.5 m from the smoke source (E1, Table 5). Acevedo-Bolton et al. (10) also measured the $PM_{2.5}$ values during the active smoking period of one cigarette, but the time interval of the measurements was every ten seconds. The maximum average level reported from their 13 experiments was 164 µg• m^{-3} measured at a distance of 0.5 m (E3, Table 5). Hwang et al. (11) measured $PM_{2.5}$ concentration continuously for 5 min under nonsmoking conditions, then for 3 min while one cigarette was smoked by a smoking doll, and then for an additional 5 min after cessation of the cigarette smoking, for a total of 13 minutes in 1 s intervals. The maximum average level obtained during the smoking period was 181.8 µg• m^{-3} measured at a distance of 1 m from the smoke source. Klepeis et al. (6) measured the average levels of $PM_{2.5}$ over 1 min periods during active smoking. At a distance of 0.3 m from a smoked cigarette, the maximum level was as high as 633 µg• m^{-3} (E1–7, Table 2). It is important to note that three of the seven experiments in this study were performed on-site in an outdoor café where the number of lit cigarettes and the exact distances from the smoke source could not be controlled for.

The background $PM_{2.5}$ concentrations in the three studies performed in California varied between 0.4 μg• m^{-3} and 8.9 μg• m^{-3}. In the studies by Acevedo-Bolton et al. and Klepeis et al., the background concentrations were subtracted from the reported values. In Ott et al., the background levels[2] were not subtracted from the results, and these varied between 0.5 μg• m^{-3} and 2.7 μg• m^{-3}. The background levels in Hwang et al. during the pre-smoking and post-smoking period were significantly higher than in the studies from California and ranged from 15.4 μg• m^{-3} to 61.7 μg• m^{-3}. However, the results reported in Table 5 for Hwang et al. were taken only from the 3 min active smoking period and the background levels were not subtracted.

The wind speed was generally low in all of the experiments in the four studies, and the average wind speed ranged from 0.2 m/s to 1.8 m/s. In the study by Klepeis et al., the smoke particles were shown to blow in the wind direction even at low wind speeds of 0.5 m/s. In one experiment, the upwind levels were practically zero while the downwind $PM_{2.5}$ concentrations during smoking were on average 582 μg• m^{-3} at 0.3 m (6). Ott et al. performed seven experiments at bus stops. In one of the experiments (E1, Table 5), the $PM_{2.5}$ concentration was 1.8 μg• m^{-3} at a distance of 0.5 m upwind from the smoke source and 202 μg• m^{-3} at 0.5 m downwind from the smoke source. Hwang et al. reported that wind direction and wind speed were significantly associated with $PM_{2.5}$ concentrations, and downwind concentrations were greater than upwind concentrations (11).

[2]Three background time periods: more than 5 min of measurements before smoking, after the first cigarette (circa 5 min), and more than 5 min after the last cigarette.

Table 5. $PM_{2.5}$ concentrations measured at various distances from a smoke source (one cigarette) in outdoor environments (µg•m^{-3})

Study, Year	Study design	Measure	Average $PM_{2.5}$ at various distances from a smoking source in µg·m^{-3} (number of observations; min–max $PM_{2.5}$)															Upwind (–) Downwind (+)	Wind speed (m/s)
			0–0.5 m	0.5 m	0.6 m	0.5-1 m	0.9 m	1 m	1.1 m	1.3 m	1.4 m	1.5 m	1.8 m	[2-4] m	3m	6m	9m		
Klepeis (2007) (6)	Four controlled experiments in a backyard patio (E1–E4)[a] Three on-site experiments in a sidewalk café (E5–E7)	Cigarette time exposure Average levels over 1-min periods [b]	E1–E7: 177 (104; 0–633)[c]			E1–E7: 128 (51; 0–380)[c]						E1–E7: 32 (32; 0–92)[c,d]		E1–E7: 11 (33; 0–25)[c]				+/–	0.41
Acevedo-Bolton (2013) (10)	Four controlled experiments on a park bench (E1–E4) Five controlled experiments around a round table in a backyard patio (E5–E9) Two controlled experiments around a square table on the front law (E10–E11) Two controlled experiments around a rectangular picnic table in a park (E12–E13)	Cigarette time exposure[b,e] Average levels over active smoking period, measurement every 10 s		E1: 48 (1)				E1: 26 (1)				E1: 23 (1)						+	1.8
				E2: 36 (1)				E2: 0 (1)				E2: 0 (1)						+	1.8
				E3: 91 (2; 17–164)				E3: 6.7 (1)										+	0.7
				E4: 57 (2; 17–96)				E4: 9.3 (1)										+	0.7
											E5: 12,5 (2; 11–14)		E5: 20 (1)						0.34
											E6: 30,8 (2; 1.7–60)		E6: 31 (1)						0.34
											E7: 33 (2; 33–33)		E7: 4.3 (1)						0.34
											E8: 26 (2; 0–52)		E8: 9.2 (1)						0.34
							E9: 5,8 (2;5.1–6.5)				E9: 4.1 (1)	E9: 2.5 (1)							0.34
								E10: 36 (1)		E10: 16 (2; 7-25)									0.32
								E11: 73 (1)		E11: 20.5 (2; 20–21)									0.32
					E12: 32 (1)				E12: 27 (1)										0.49

					E13: 29 (1)				E13: 32 (1)										0.49
Hwang et al. (2014)(11)	98 controlled experiments at the same site on a rooftop performed over 5 days.	Average levels over active smoking period (3 min), measurement every 1 s.						107.3 (98: 32.8–181.8)							48.6 (98: 26.9–70.3)	42.5 (98: 22.5–62.5)	42.2 (98: 22.0–62.4)		0.8±0.6
Ott (2014) (12)	Seven controlled experiments at six bus stops (E1–E7)	Cigarette time exposure[e] Average levels over active smoking period, measurement every 1 s		E1: 102 (2; 1,8–202)[g]				E1: 1.9 (1)										+/–	0.74
				E2: 64,7 (3; 17–153)				E2: 67.3 (3; 12–173)				E2: 36,7 (3; 11–83)						–	0.74
				E3: 58,5 (2; 15–51)				E3: 17 (2; 5–29)				E3: 8 (2; 3–13)						–	1.26
				E4: 52,5 (2; 46–59)				E4: 26 (2; 24–28)				E4: 30 (2; 28–32)						–	0.6
				E5: 104 (2; 70–138)[g]				E5: 46.5 (2; 44–49)[h]				E5: 28,5 (2; 24–33)[h]						–	1.13
				E6: 66,5 (2; 37–96)				E6: 58.5 (2; 39–78)				E6: 34,5 (2; 21–48)							
				E7: 59 (1)				E7: 16 (1)										–	0.44

Notes:

[a)] Single experiments within a study (E).

[b)] Background concentrations were subtracted from the source period average to give *incremental exposure* due to proximity to the source.

[c)] The min-max values in Klepeis et al. were calculated by adding and subtracting twice the standard deviation from the mean reported in Table 6 (page 531).

[d)] Klepeis et al. grouped the distance from the source in the outdoor experiments. We compared the range 1–2 m with the results obtained at 1.5 m in the other two studies. In experiments E5 to E7, the distances were visually estimated.

[e)] Cigarette time exposure: measurements only during active smoking.

[f)] Background concentrations were not subtracted from the source period average.

[g)] In experiment E1, the smoker had two persons sitting 0.5 m on each side of him. The lower value was measured in the upwind position and the higher one in the downwind position.

[h)] In experiment E5, the smoker was placed at the opposite end of the bench compared to the other experiments in the same study. This means that the different air movement due to traffic could have affected the $PM_{2.5}$ values.

$PM_{2.5}$ concentrations at various distances from a smoke source

The $PM_{2.5}$ concentrations were measured at several distances from the smoke source in all of the four controlled studies included in this overview (6, 10-12). The $PM_{2.5}$ concentrations were measured at increasing distances from 0.3 m up to 9 m from the smoke source, but the distances varied both within and between the studies (Table 5).

The $PM_{2.5}$ concentration decreased with increasing distance from the smoke source. In two experiments on a park bench in the study by Acevedo-Bolton et al. (10), the most significant decreases in average $PM_{2.5}$ concentrations were seen between 0.5 m and 1 m from the smoke source (E1-E2, Table 5). The $PM_{2.5}$ concentrations were 48 μg• m^{-3} and 36 μg• m^{-3} at 0.5 m from the smoke source in experiments E1 and E2, respectively, 26 μg• m^{-3} and 0 μg• m^{-3} at 1 m, and 23 μg• m^{-3} and 0 μg• m^{-3} at 1.5 m. The same pattern of decreasing concentrations with increasing distance from the smoke source was observed in the experiments at bus stops by Ott et al. (12). For example, in five of the seven experiments (E1, E3, E4, E5, and E7, Table 5) the most significant decrease in $PM_{2.5}$ concentrations was seen between 0.5 m and 1 m. In the other two experiments, the drop in $PM_{2.5}$ concentrations was seen primarily between 1 m and 1.5 m (E2 and E6, Table 5).

In Hwang et al. (11) the average $PM_{2.5}$ concentrations during active smoking decreased from 107.3 μg• m^{-3} at 1 m from a lit cigarette to 42.2 μg• m^{-3} at 9 m from the cigarette, but as mentioned above the background levels were not subtracted (at 1 m the pre-smoking average background level was 34.4 μg• m^{-3} and at 9 m it was 39.6 μg• m^{-3}).

A decrease in concentrations with increasing distances from the smoke source was also presented in Klepeis et al. (6). However, the distances in the experiments were estimated visually and the measurements were aggregated regardless of wind direction (6).

Figure 4a presents the minimum and maximum values at different distances from the smoke source for each study. Minimum and maximum values for Hwang et al. and Ott et al. were adjusted by subtracting an average background concentration given that the background concentration for each experiment was not available. A trendline for the values obtained in each study shows the average $PM_{2.5}$ concentrations in relation to distance from the smoke source and how the levels drop off with increasing distance. The rate at which the concentration decreases is greater closer to the smoke source and decreases with increased distance. Figure 4b presents a comparison of the trendlines in the four studies. The trendlines are extrapolated beyond the distances actually available in each study.

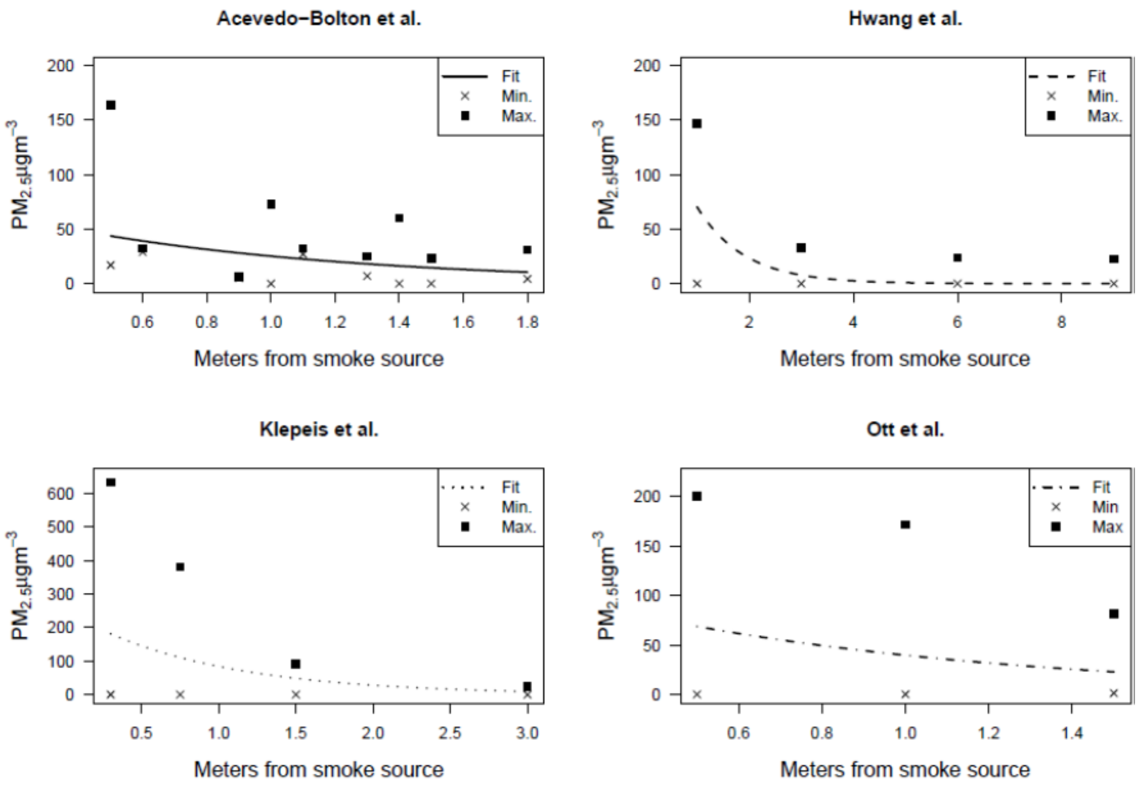

Figure 4a. PM 2.5 concentrations at various distances from a smoke source in four different studies. For each study, the minimum and maximum $PM_{2.5}$ concentrations at each available distance from the smoke source are plotted. The trendline is an estimate of the mean. In the study by Klepeis et al.(6), the values were measured in a distance interval but in the figure the values are plotted at the mean distance of each interval.

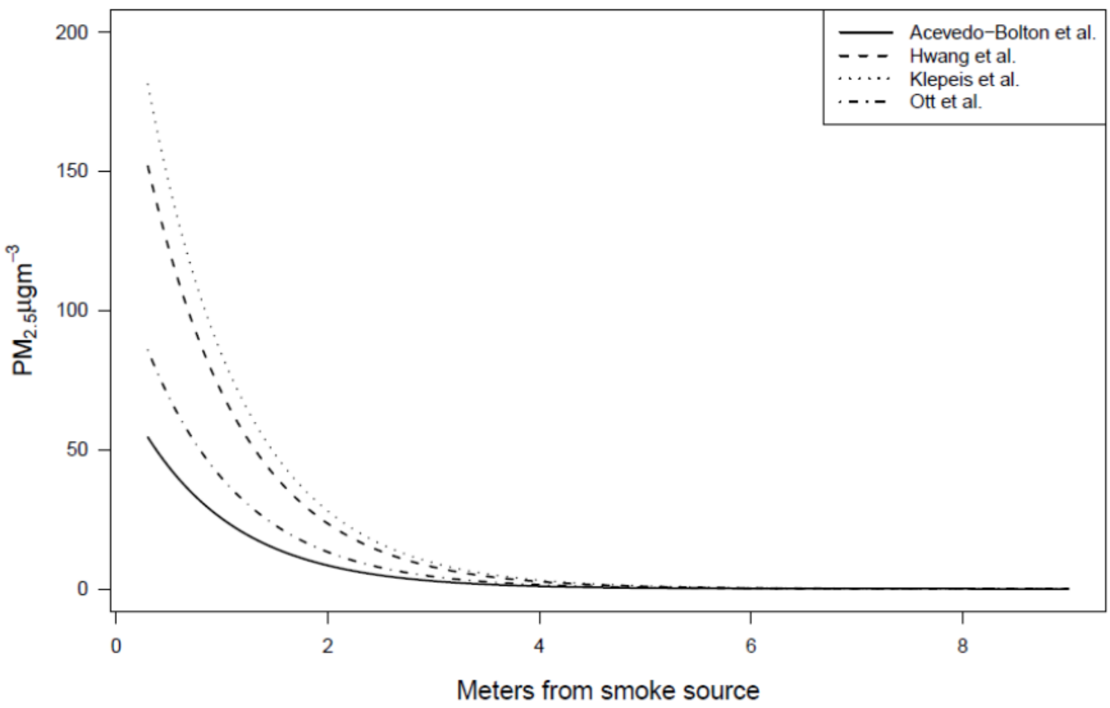

Figure 4b. PM 2.5 concentrations at various distances from a smoke source
Trendlines showing the mean rate at which the concentrations decrease with increasing distance for the four studies. The curves have been extrapolated out to 9 m from the smoke source.

Discussion

The link between tobacco smoke and increased indoor air pollution is well known, and this literature review presents data showing that elevated levels of tobacco smoke also occur in outdoor public settings in connection to smoking. As expected, the levels of environmental tobacco smoke (ETS) are higher in the proximity of the smoke source, decrease with increasing distance from the smoke source, and increase with the number of active smoke sources. The number of studies was small, this prevents this relationship from being quantified and makes it difficult to draw general conclusions.

This review concerns both the levels of ETS particles that have been observed in outdoor air in different types of public settings where smoking is allowed and the levels of ETS particles that have been observed in outdoor air at different distances from a lit or smoked cigarette. In total, 13 studies fulfilled the inclusion criteria, including nine observational studies (13-21) and four controlled studies (6, 10-12). All included studies used $PM_{2.5}$ as a marker to measure the concentration of ETS in the outdoor air, but this is not a specific marker for tobacco smoke. Particles are emitted from other sources, and outdoor levels are affected by things like vehicle emissions. However, when background levels are taken into account $PM_{2.5}$ is a well-established marker of the direct changes in air quality due to tobacco smoke.

The observed settings in the nine observational studies were restaurants, pubs, and cafés (13-18); walkways and streets (19); and entrances to public buildings (20, 21). The highest $PM_{2.5}$ concentrations in these settings were 205 $\mu g \cdot m^{-3}$, 68 $\mu g \cdot m^{-3}$, and 496 $\mu g \cdot m^{-3}$, respectively. All of these outdoor settings are places where smoking typically occurs and where non-smokers could involuntarily be exposed to ETS. The four experimental studies confirmed a distinct increase in $PM_{2.5}$ concentrations in the air during smoking. At a distance up to 1 m from a single smoke source, the $PM_{2.5}$ concentrations reached levels as high as 633 $\mu g \cdot m^{-3}$, 202 $\mu g \cdot m^{-3}$, 164 $\mu g \cdot m^{-3}$, and 182 $\mu g \cdot m^{-3}$ in each of the studies. The concentration of ETS decreased exponentially with distance from the source, and this supports the so-called “proximity effect” of ETS (Fig. 4a and 4b). Elevated $PM_{2.5}$ concentrations were measured up to 9 m away, and higher concentrations were measured downwind than upwind from the source (Table 5).

The values of $PM_{2.5}$ concentrations obtained in these studies were affected both by measurement methods and by background variables. The levels of particles were reported as a mean of several immediate measurements during a smoking period, and the averages were in general higher when a shorter time interval (1 s) was used for the measurement. This could be explained by fluctuations in smoke particle concentrations during a smoking period with peaks of high levels due to microplumes. For example, Klepeis et al. (6) reported peak concentrations during a smoking period that exceeded 1 000–15 000 $\mu g \cdot m^{-3}$. It is clear that the time interval for the measurement affects the sensitivity of the results. Moreover, the length of the monitoring period in a given setting affected the possibility to capture the variation of the real-time $PM_{2.5}$ concentrations over the course of the day.

Background variables such as the level of enclosure of the outdoor site, the wind speed and direction, and the number of cigarettes smoked simultaneously also seem to affect the $PM_{2.5}$ concentrations. The unexpected and divergent results in the study by St. Helen et al. (18) – in which the highest concentrations were obtained in the most open setting – imply that the background factors are complementary and that each one of them can have a significant effect on the $PM_{2.5}$ concentration. Hwang et al. (11) measured ETS concentrations in an open setting and showed that after the smoking period the $PM_{2.5}$ concentrations decreased quickly to the starting values. It is, therefore, important to pay careful attention to all of the possible influencing factors when measuring the levels of ETS in outdoor settings.

The WHO Air Quality Guidelines (22) recommend a daily mean upper limit of outdoor exposure to $PM_{2.5}$ of 25 $\mu g \bullet m^{-3}$ based on an extensive body of scientific evidence relating to air pollution and its health consequences. Most of the revised studies in this review present values higher than the recommended upper limit, even though they are instantaneous measures or means over short periods. However, $PM_{2.5}$ is not the only dangerous substance contained in ETS, tobacco smoke contains a mixture of more than 7,000 different chemicals. The health risks of ETS are well described by the WHO that also states that there are no safe levels of exposure to ETS (22). The potential negative effects of ETS are numerous, and there are both short-term health effects such as triggering of asthma attacks and long-term health effects such as lung cancer and coronary heart diseases. The results in this review indicate that ETS outdoors can reach high levels and be hazardous under certain conditions, such as spending a significant portion of time within a few meters of active smoking.

As mentioned above, the number of studies was quite small and the measurement and reporting methods were not consistent between the studies. The comparison of the results could only be done at a very general level, and this did not allow specific quantification. However, both experimental studies and observational studies conducted by different researchers in different countries all came to the conclusion that $PM_{2.5}$ concentrations increase during smoking outdoors.

In this review, the search strategy was based on an existing literature review that covered the topic of interest. The search for available peer reviewed literature was extended to the 1st of January 2014 by searching in PubMed. The fact that one relevant publication was not found using this search strategy (11) shows that using only one database in the complementary search is a limitation in this review. The search and full text screening was performed by only one author – which can be a limitation – but the data extraction from the included articles was conducted by two authors. As always, there is also a risk of publication bias, but in this case this is perhaps less likely than in epidemiological studies.

The retrieved studies were few in number and had varying experimental designs. Thus it was not meaningful to summarize their findings in quantitative measures. Further studies are needed in order to form a basis for predicting the exposure to ETS in different outdoor situations.

Conclusion

This review shows that there is evidence that people can be exposed to hazardous levels of ETS outdoors in different types of public settings where smoking occurs. The observational data were supported by experimental data showing that a smoke source causes high concentrations of small particles ($PM_{2.5}$) in its immediate vicinity and that elevated levels of tobacco smoke can be detectable up to 9 m or more from the source. However, further research is necessary to gain specific knowledge of concentrations of ETS under different outdoor conditions.

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Appendix

Table 6. Characteristics of the included studies. Study question 1.

Author, year	Country	Study design	Setting	Search source
Boffi et al., 2006	Copenhagen, Denmark	Field study	Car park, street, and entrance to office building	Sureda et al. (2013)
Brennan et al., 2010	Australia	Field study	Pubs and bars	Sureda et al. (2013)
Cameron et al., 2010	Australia	Field study	Bars and restaurants	Sureda et al. (2013)
Edward et al., 2011	New Zealand	Field study	Pubs and bars	Sureda et al. (2013)
Kaufman et al., 2011	Toronto, Canada	Field study	Entrances to office buildings	Sureda et al. (2013)
Parry et al., 2011	Wellington City, New Zealand	Field study	Roadside and walkways	Sureda et al. (2013)
St. Helen et al., 2011	Georgia, USA	Field study	Bars and restaurants	Sureda et al. (2013)
Stafford et al., 2010	Australia	Field study	Pubs and bars	Sureda et al. (2013)
Wilson et al., 2007	New Zealand	Field study	Bars, restaurants, walkways, and parks	Sureda et al. (2013)

Table 7. Characteristics of the included studies. Study question 2.

Author, year	Country	Study design	Setting	Search source
Acevedo-Bolton et al., 2013	California, USA	Controlled experiments	Outdoor patios	PubMed
Hwang et al., 2014	Seoul, Korea	Controlled experiments	Rooftop of the Graduate School of Public Health	Additional source
Klepeis et al., 2007	California, USA	Controlled and on-site experiments	Backyard and sidewalk patios	Sureda et al. (2013)
Ott et al., 2014	California, USA	Controlled experiments	Bus stops	Snowballing

Table 8. Characteristics of the studies excluded for design reasons

Author, year	Country	Study design	Rational for exclusion
Collins et al., 2014	Alberta, USA	Field study	Cooking smoke and environmental tobacco smoke
Hall et al., 2009	Georgia, USA	Field study	No measurement of $PM_{2.5}$
Hess et al., 2010	New York, USA	Field study	No tobacco smoke specifically
Lopez et al., 2012	Austria, France, Ireland, Italy, Poland, Portugal, Slovak Republic, and Spain	Field study	No active smoking source
Repace, 2005	Maryland, USA	Field study	No measurement of $PM_{2.5}$
St. Helen et al., 2012	Georgia, USA	Field study	No measurement of $PM_{2.5}$
Travers et al., 2007	New York, USA	Field study	Not peer reviewed
Wilson et al., 2011	New Zealand	Field study	No information about background levels

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