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Personal Exposure and Indoor Home Particulate Matter: A Review

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Abstract: This review deals with field studies of particles indoors and exposure to particulate concentrations on recent surveys of homes. The results of indoor and personal exposure concentrations are presented. In addition the effect of other related air pollution factors which might have an effect on exposure to particles are discussed. This paper surveys of particle concentrations and sources in homes from 1981 to 2011. Three major studies which in the USA and a large scale study in Europe that carried out to measure personal exposure and indoor home particle concentrations. A number of small personal exposure studies in homes are also briefly summarized. Personal exposure studies in the USA, EXPOLIS cities and Toronto and others similar studies have documented that the personal exposure to $PM_{2.5}$ concentrations was higher than those measured indoors. Most of these studies found a suitable relationship between residential indoor and personal exposure to particulate matter. Personal exposure to respirable particulate matter highly correlated with indoor air. Ambient concentrations obtained from Fixed Site Monitors poorly correlated with total personal exposure to particulate matter concentrations. Some indoor particle source such as smoking, cooking and resuspension of indoor dust may increase subjected to personal exposure and indoor particulate concentrations.

Key words: Air pollution; Personal exposure; Particulate matter; Indoor sources; Respirable particles

INTRODUCTION

Epidemiological studies have found relationship between fine particle concentration in the air and several acute health effects, including mortality, hospital admissions, respiratory symptoms and lung function [1, 2]. These studies mostly discussed about variation in outdoor air pollution measured by fixed site and it's relation with health end points [3-5]. Environmental organizations regulate particles in outdoor air, not indoor or personal exposures. It is still important to consider indoor air and exposure to particles. Major studies about personal exposure to particles have reported good relationships between indoor particulate air concentrations and personal exposure [6, 7]. Some other studies have found that personal exposure were higher than indoor $PM_{2.5}$ concentrations [8, 9]. Since individuals spend the majority of their times indoors, fine particles generated in indoor combustion processes (cooking, smoking, etc.) and by resuspension are important for health effects assessment. The nature and magnitude of indoor particle exposures can change rapidly because of the rapid changes in activities and sources and because of differences in ventilation. This study deals with field studies of particles indoors and exposure to particulate concentrations on recent surveys of homes. The results of indoor and personal exposure concentrations are presented. In addition the effect of other related air pollution factors such as smoking, cooking, vacuum cleaning and other factors which might have an effect on exposure to particles are discussed.

MATERIALS AND METHODS

Exposure is defined as an event that occurs when a person comes in contact with pollutants. This is a definition of an instantaneous contact between a person and a pollutant with a concentration at a particular time.

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There are two methods for measurement of personal exposure [10]. In direct method, levels of exposure are measured on individuals by using a personal sampler or a biological marker. However, in indirect methods, exposure levels are either measured stationary or determined by models [10, 11].

One of the indirect methods of assessing personal exposure is to use a microenvironmental model. Individuals have their own activities and thus are exposed to various levels of pollutants in different locations. The term “microenvironments” is defined as a chunk of air space with homogeneous pollutant [12]. Such microenvironments can either represent outdoor locations (e.g. in front of the home) or indoor locations (bedroom, kitchen, etc). Mage and Buckley defined microenvironment (ME) as a “volume in space, during a specific time interval, which the variance of concentration within the volume is significantly less than the variance between that ME and its surrounding MEs”. Measurements of air pollutants in MEs and the time spent in each microenvironment are used for the estimation of personal exposure levels and then integrated dose or concentration is measured in a unit of air [13].

This paper reviews particle concentrations and sources in homes for the past three decades. A number of smaller personal exposure studies in homes are also briefly summarized. The Harvard six-city study that carried out during 9 years from 1979 to 1988 in 1400 US homes. A large scale study carried out in 433 US homes in two New York state counties in 1986. The EPA particle team studied indoor home air pollution in 178 homes in Riverside, California in 1990. A large scale population-based study in Europe was EXPOLIS study that studied personal exposure and indoor particle concentrations in 6 European cities. Measurements made using standard protocols in Athens (Greece), Basel (Switzerland), Helsinki (Findland), Milan (Italy), Oxford (UK) and Prague (Czech Republic).

RESULTS

People spend from 80 to more than 90% of their time at home and other microenvironments [14-18]. Hence, indoor air pollution concentrations and individuals personal exposures can be greater than the outdoor concentration, especially when there are indoor pollution sources.

Studies using personal exposure monitoring have concluded that personal exposures to variety of air pollutants were substantially higher than those concentrations measured by fixed site monitors. Mage and Buckley reviewed 14 personal exposure cases to assess the relationship between personal exposure to particulate matter and simultaneous measurements from fixed site monitoring [14]. These investigations carried out in different seasons or have measured particles over a year and including in a number of different cut sizes. Seven of these cases also included measurements of indoor concentrations sampling. These evaluations reported a much stronger correlation between personal exposure values and indoor particle concentrations than those concentrations measured by fixed site stations. They have concluded that differences in correlations between indoor and outdoor particle concentration with personal exposure included greater time spent indoors and different sources and composition of particulate matter.

The majority of personal exposure studies for particulates have been completed in the USA [7]. This includes large studies such as PTEAM (Particle Total Exposure Assessment Methodology) study and the Harvard Six City Study. Loth and Ashmore suggested that the findings from the US studies have considerable implications on UK, but differences in lifestyle could also significantly modify exposure patterns [19]. The first large-scale study of exposure patterns in Europe was the EXPOLIS study.

EXPOLIS Personal Exposure Study: EXPOLIS was a European study about population exposures to urban air pollution. In EXPOLIS study, population exposures to some important pollutants were measured in six European cities. The pollutants studied in the EXPOLIS were fine particulates ($PM_{2.5}$), carbon monoxide (CO), the most interesting volatile organic compounds (VOCs) with the respect of environmental exposures and public health and nitrogen dioxide (NO_2). The populations in these studies were working age urban populations from large cities. The metropolitan area of Helsinki was the smallest of participating cities (1 million), while the largest was Athens (4 million). The EXPOLIS field measurements were carried out from 1996-97. The general objectives of the EXPOLIS study were a) to measure the distribution of exposures of European adult urban population to major air pollutants; b) to determine the personal, indoor and outdoor environmental and communal parameters that affect these exposures; and c) to develop a probabilistic simulation technique for assessing and predicting the air pollution exposure distributions of different urban subpopulations and consequences of alternative industrial and urban development policies [20].

The EXPOLIS study in Oxford was the first UK study that has measured personal, indoor, outdoor and work exposures to several pollutants simultaneously in an urban adult population sample of 50 subjects [21]. This study showed that geometric mean personal exposure and indoor home $PM_{2.5}$ concentrations were 13.2 µg m $^{-3}$ and 11.4 µg m $^{-3}$, respectively. These values were higher than geometric mean outdoor and work $PM_{2.5}$ concentrations (6.2 and 7.5 µg m $^{-3}$; respectively). Significant correlations were found between the concentrations of $PM_{2.5}$ measured in some microenvironments. The strongest correlation was found between indoor home and personal exposure (weighted average of day and night) to $PM_{2.5}$ concentrations (r=0.54). This is to be expected, as volunteers spent a majority of their time in their homes. There was a significant positive correlation between personal exposure (weighted average of day and night) to $PM_{2.5}$ concentrations and workplace measurements (r=0.35) and no significant correlation was reported between personal exposure (TWA) and outdoor home $PM_{2.5}$ concentrations [22].

Personal exposure monitoring of $PM_{2.5}$ and other air pollutants was carried out among 201 randomly selected adult participants (25-55 years old) in the EXPOLIS study in Helsinki, Finland [23]. Koistinen and co-workers [23] reported that personal exposure to $PM_{2.5}$ concentrations was higher than the respective residential outdoor, residential indoor and workplace indoor $PM_{2.5}$ concentrations for both smokers and non-smokers. Geometric mean personal exposure concentrations of active smokers (31.0±31.4 µg m $^{-3}$) were almost doubled those of participants exposed to environmental tobacco smoke (ETS) (16.6±11.8 µg m $^{-3}$) and three times those of participants not exposed to tobacco smoke (9.9±6.2 µg m $^{-3}$). Mean indoor concentrations of $PM_{2.5}$ (20.8±23.9 µg m $^{-3}$) in ETS homes were approximately 2.5 times the concentrations of $PM_{2.5}$ in non-ETS homes (8.2±5.2 µg m $^{-3}$). Indoor home $PM_{2.5}$ concentrations were the best predictors of personal exposure concentrations. Personal exposures to $PM_{2.5}$ of all participants both smoking and non-smoking was strongly correlated with home and workplace indoor concentrations (R^2=0.53 and 0.38, respectively). Residential indoor and workplace $PM_{2.5}$ concentrations and traffic density in the nearest street from the home were the best predictors for personal exposure to $PM_{2.5}$ concentrations of non-ETS participants. Combination of these factors explained 77% of the variance. Multiple regression, not including residential and workplace indoor concentrations as input identified ambient $PM_{2.5}$ concentration and home location as significant predictors of personal exposure, accounting for 47% of the variance. Personal exposure concentrations were significantly higher than for individuals living in the city centre compared with individuals in suburban family homes. Residential outdoor concentrations were strongly correlated with $PM_{2.5}$ concentrations measure by fixed monitoring station (R^2=0.9) and $PM_{2.5}$ personal exposure concentrations were higher in summer than during other seasons.

Budet has described $PM_{2.5}$ personal exposure in the European EXPOLIS study in Grenoble, which included non-smoking adult volunteers. The mean 48-hour personal exposure ranged from 21.9 µg m $^{-3}$in summer to 36.7 µg m $^{-3}$ in winter. Outdoor personal exposures, determined as the difference between the 48-hour and indoor masses, were slightly higher than the 48-hour personal exposures [24].

Oglesby [25] has concluded from the EXPOLIS-EAS study in Basel that personal exposures to $PM_{2.5}$ mass were not significantly correlated to the corresponding home outdoor concentrations (r=0.07). Chemical analysis of the collected particulate was undertaken. However, personal exposures and home outdoor concentrations of sulphur (sulphate) were highly correlated (r=0.85) in homes without indoor sources or relevant activities. In contrast, there was a weaker correlation between personal exposure and home outdoor concentrations for chemical indicators of traffic generated and crustal particles [25]. This study concluded that for regional air pollution, fixed-site fine particle concentrations are valid exposure surrogates. However, for source specific exposures, fixed site data are probably not the optimal measure.

In conclusion, the highest exposure correlations in EXPOLIS studies were found between the personal exposures and the corresponding indoor air concentrations. However, the association between the personal exposures and outdoor/ambient air concentrations were considerably lower in all cities. Personal exposures during leisure time correlated better with outdoor/ambient concentrations than personal exposure during the working day in Helsinki. The correlation between personal and indoor air and ambient concentrations improved when removing the ETS exposed subjects, but this decreased the correlation coefficients between personal exposures and indoor air concentrations and also between the personal exposures during workday and leisure time. In spite of these generalisations, there are considerable differences between the cities.

Major US Personal Exposure Studies: There have been two large-scale personal exposure studies in the US. The Harvard Six-City and PTEAM studies had somewhat different aims and therefore different study was designed. In the Harvard study homes with school-age child were selected for monitoring and did not employ a probability-based sample. Therefore the results strictly apply only for homes that were monitored and not to a wider population. However, this study was carried out in a very large number of homes, suggesting that the results should be broadly applicable to homes with school-age children in the six cities. The PTEAM study used a fully population-based sample and therefore results from this study can be applied to the whole population of Riverside households who are not smokers. Besides, this study did not include households with smokers in residence. Therefore indoor concentrations are likely to slightly underestimate those for the population as a whole. Different monitors with different cut points were applied in these studies. Then, exact comparisons are not possible. However, there are not significant differences between the $PM_{3.5}$ and $PM_{2.5}$ cut points and therefore results from measurements can be generally readily compared. In PTEAM study, personal exposure and indoor PM_{10} concentrations were also measured, however no PM_{10} measurement was carried out in the Harvard study [7].

The PTEAM study carried out personal exposure monitoring of PM_{10} for non-smoking Riverside, California residences for individuals aged ten and above. The findings showed that the population-weighted daytime personal PM_{10} concentrations averaged about 159 µg m $^{-3}$ and was higher than indoor or outdoor mean concentrations of 95 µg m $^{-3}$. The night-time mean personal PM_{10} exposure concentrations was much lower (77 µg m $^{-3}$) and more similar to the overnight mean indoor (63 µg m $^{-3}$) and mean outdoor (86 µg m $^{-3}$) concentrations. Author concluded that the major reason of increased personal exposure was the personal cloud effect that is produced by individuals' activities and resuspension of particulate matter. Outdoor PM_{10} concentrations explained about 25-30% of the variance in indoor concentrations, but only about 16% of the variance in personal exposures. This is understandable, because of the influence of indoor activities such as smoking, cooking, dusting and vacuuming on exposure to particles. Indoor PM_{10} concentrations explained about 50% of the variance in personal exposures [14]. Neither the indoor concentrations nor the outdoor concentrations alone, nor the time-weighted averages of indoor and outdoor concentrations, however, could explain more than about two-third of observed variance in personal exposures. Combination of outdoor particle concentrations, smoking and cooking were the major sources of indoor home particulate matter concentrations. The 'extra' personal exposure concentrations could potentially be explained by resuspension during individual's activities.

The personal exposure component of the Harvard Six-City study was conducted in Watertown, Massachusetts and Steubenville, Ohio [26]. The indoor $PM_{3.5}$ concentrations were better correlated with personal exposure concentrations than outdoor levels. The indoor sulphate (representing fine particles <1 µm) had the strongest correlation with personal exposure concentrations. Spengler [27] has reported the results of personal exposure to respirable particulate matter and gases for the populations of Kingston and Harriman (Tennessee). Both towns had similar 24-hour outdoor (ambient) RSP concentrations during the period of this study; Harriman averaged RSP concentrations only 1 µg m $^{-3}$higher than Kingston. In both towns, the average of the personal and indoor concentrations of RSP was approximately 25 µg m $^{-3}$higher than the ambient RSP concentrations, suggesting the presence of significant indoor sources [27]. Approximately 75% of the indoor samples and 95% of personal samples were above the mean outdoor concentration of 18 µg m $^{-3}$. No significant correlations were found between ambient concentrations and either personal exposure or indoor concentrations. However, the personal exposure RSP concentrations were strongly correlated with indoor RSP concentrations, mostly at the p=0.0001 level, suggesting a strong effect of indoor RSP concentrations on personal RSP exposures. In the sample as a whole, only 1% of the variance in personal exposures for the whole sample group could be explained by the ambient RSP concentrations whilst 50% of the variance in personal exposure could be explained by the indoor concentrations. In terms of the influence that this has on epidemiological studies, it was suggested that the indoor concentrations should be used to avoid misclassification of exposure.

Other Personal Exposure Studies: Several other large-scale personal exposure studies and a number of smaller studies have been performed in the U.S. The results of these studies are summarised in Table 1.

Table 1: Summary of particulate personal exposure assessment studies, which included simultaneous indoor home measurements

Authors and location	Sample	Duration of sampling	Indoor mean concentration (μg m^{-3})	Personal exposure mean concentration (μg m^{-3})	Correlations between exposure and other concentrations
Rojas-Brancho 2002 Santiago [33]	8 pilot 20 main Children (10-12 years)	24-h	$PM_{2.5}$=68.5 $PM_{2.5-10}$=35.4	$PM_{2.5}$=69.5 $PM_{2.5-10}$=76.3	Personal exposures were strongly associated with both indoor and outdoor concentrations for $PM_{2.5}$ (r=0.84 and r=0.80 respectively), but weakly associated for $PM_{2.5-10}$ (r= 0.36 and r=0.24 respectively)
Janssen 1997 Netherlands [34]	45 children (10-12 years)	24-h Weekday	Classrooms 8-h PM_{10} = 157 24-h PM_{10} = 74.4	PM_{10} =105	The correlation within subjects between personal exposure and outdoor concentration was r =0.63 in non-ETS homes and 0.59 in ETS homes for children living in Wageningen and Amsterdam.
Janssen 1998 Netherlands [36]	37 non-smoking adults (Ages 50-70)	24-h 10 indoor samples	PM_{10}= 35	PM_{10} =61.7	The correlation coefficient within subjects for personal to outdoor was r = 0.50 overall and excluding exposure to ETS was r=0.71. The estimated cross-sectional correlation coefficients were lower (r=0.34 and 0.50 respectively. The association within subjects for personal-indoor was r=0.72.
Pellizzari 1999 Toronto [29]	1000 participants	3-day	Median PM_{10}=23.1 Median $PM_{2.5}$ =15.4	Median PM_{10}= 48.5 Median $PM_{2.5}$ = 28.4	Correlation coefficient between $PM_{2.5}$ personal exposure and indoor concentrations was high (r=0.79), while correlation between personal and outdoor, fixed site and roof site concentrations were low (r=0.16-0.27).
Heavner 1996 US [36]	104 female	14-hr in home and 7-h at work	ETS homes $PM_{3.5}$ = 88.8 Non-ETS homes $PM_{3.5}$= 27.6	ETS homes $PM_{3.5}$ =67.7 Non-ETS homes $PM_{3.5}$=32.1 ETS work $PM_{3.5}$= 15.96	12.9%-28.7% of the RSP in smoking homes and 9.6%-22.7% of the RSP in smoking workplaces was attributable to ETS.
Authors and location	Sample	Duration of sampling	Indoor mean concentration (μg m^{-3})	Personal exposure mean concentration (μg m^{-3})	Correlations between exposure and other concentrations
Rojas-Bracho 2004 US [28]	18 subjects (patients with COPD)	12-h	Winter $PM_{2.5}$= 17.2 Winter PM_{10} =37.3 Summer $PM_{2.5}$ = 17.7 Summer PM_{10} =28.3	Winter $PM_{2.5}$ =21.6 Winter PM_{10} = 40.7 Summer $PM_{2.5}$ =21.5 Summer PM_{10} =34.7	Time-weighted indoor concentrations were significant predictors of personal PM_{10} and $PM_{2.5}$ exposures. For $PM_{2.5}$ the covariate coefficient was 0.91 during the winter and 1.2 during the summer. Also time-weighted outdoor $PM_{2.5}$ concentrations, underestimated personal $PM_{2.5}$ exposures from outdoor environments (0.69, 95% CI,-0.11-1.49, p<0.10).
Ebelt 2000 Canada [35]	16 COPD patients	24-h	NA	Mean $PM_{2.5}$= 18	The correlation coefficient between the ambient and personal measurements was 0.48.
Wheeler 2000 UK [30]	10 children	12-h	$PM_{2.5}$ =23 PM_{10} =42	$PM_{2.5}$ =15 PM_{10} =35	Correlations between the 3 season mean personal PM_{10} and $PM_{2.5}$ with both garden data and FSM data were weak (range r=0.07-0.39). There was a stronger correlation between the personal PM_{10} and $PM_{2.5}$ concentrations and the corresponding home concentrations (r=0.59 and 0.53 respectively)
Bahadori 1999 US [31]	10 non smoking patient	12-h	Day $PM_{2.5}$ = 16 Day PM_{10} = 22 night $PM_{2.5}$= 12 night PM_{10}= 15	$PM_{2.5}$ = 22 PM_{10} = 33	There was no correlation between indoor and outdoor (r=0.03 day, r=0.01 night) for PM_{10} and (r=0.28 day and r=0.12 night) for $PM_{2.5}$. Personal exposures were correlated with indoor concentrations for both PM_{10} (r=0.69) and $PM_{2.5}$ (r=0.64) The intercept for PM_{10} was 25 whereas for $PM_{2.5}$ it was only 5.
Lioy 1990 US [32]	8 non-smoking homes and 14 personal		24-h	PM_{10} =54 PM_{10}=84	A portion of non-smokers' personal exposure was due directly or indirectly to the outdoor air. Cross-sectional regression on all personal exposure of the PM_{10} concentrations indoors or at the nearest outdoor site produced very low r=0.22. The longitudinal correlation between outdoor and personal exposure was 0.46.
Authors and location	Sample	Duration of sampling	Indoor mean concentration (μg m -^{3})	Personal exposure mean concentration (μg m^{-3})	Correlations between exposure and other concentrations
Brains 2010 Czech Republic [37]	1 subject	24-h	$PM_{2.5}$ =15.1	$PM_{2.5}$ =14.9	Concentrations obtained from FSMs showed reasonably association with total personal exposure to particulate matter.

Table 1: Continued

Authors and location	Sample	Duration of sampling	Indoor mean concentration (μg m $^{-3}$)	Personal exposure mean concentration (μg m $^{-3}$)	Correlations between exposure and other concentrations
Mohammadyan 2005 UK [17]	40 Non-smoking	48-h	Day $PM_{2.5}$ = 27.3 night $PM_{2.5}$= 19.0	$PM_{2.5}$= 30.3	The correlation coefficient between the ambient and personal measurements was 0.48. The correlation coefficient between the indoor home and personal exposure was 0.61.
Sørensen 2003 Denmark [38]	50 students	48-h	NA	Median $PM_{2.5}$=16.1	Moderate exposure to concentrations of PM can induce oxidative DNA damage and that personal $PM_{2.5}$ exposure is more important in this aspect than is ambient $PM_{2.5}$ background concentration.
Nikasinovic 2006 France [39]	44 healthy and 41 asthmatic children	48-h	PM_{10}= 24 PM_{10}= 21.9	$PM_{2.5}$= 42.4 $PM_{2.5}$=30.4	$PM_{2.5}$ concentrations were significantly associated with the percentage of eosinophils, with the determination coefficients of the model being 44%.
Edwards 2009 EXPOLIS study [40]	90 office worker	48-h	NA	$PM_{2.5}$=33.7	Participants exposed personal microenvironments are a greater fraction of the lower end of the $PM_{2.5}$ exposure distribution.
Kim 2006 Toronto [41]	28 COPD patients	24-h	NA	$PM_{2.5}$ =22	central fixed-site measurements of $PM_{2.5}$ may be treated as surrogates for personal exposures to $PM_{2.5}$ in epidemiological studies
Turpin 2007 US [42]	219 exposure and indoor home	48-h	Median $PM_{2.5}$ = 14.4	Median $PM_{2.5}$= 31.4	In epidemiologic studies that rely on central-site monitoring data, such transformations may result in measurement error and this possibility warrants further investigation.
Mohammadyan 2010 UK [43]	1 home	6-h	Mean $PM_{2.5}$ = 18.4		Cooking, penetration of outdoor particles and resuspension of particles can affect indoor particle levels

DISCUSSION

According to the time activity diaries, more than 90% of the monitored subjects in all studies were spent indoor home, in the office and in commuting [8, 17, 37, 41, 42, 44, 48]. Personal exposure studies in EXPOLIS cities and Toronto and others similar studies have documented that the personal exposure to $PM_{2.5}$ concentrations was higher than those measured indoors and outdoors [14, 17, 20, 21, 23, 27-29, 31-34, 36, 39, 42, 51]. This phenomenon has become known as the “personal cloud” effect [7]. The incremental increase of measured personal exposure, compare to time-weighted estimates based on micro-environmental concentrations, has been attributed to several factors, including resuspension of house dust while walking, collection of body dander and clothing fibres (“body cloud”), closer proximity to point sources and elevation of indoor concentrations in non-residential microenvironments (including commuting). Rodes *et al.* [49] noted that these effects are particle size-dependent, with PM_{10} expected to have personal cloud levels six to seven times higher than that for $PM_{2.5}$. In a study carried out by Mohammadyan and co-workers, personal clouds, defined as the difference between the personal exposure and the indoor concentrations were estimated to be 4.6 and 8.2 μg m $^{-3}$ for non-work and daytime exposure respectively [17]. The lower value for non-work may reflect the fact that while the subject was sleeping, the PEM was used as a static monitor. These values are significantly higher than those estimated in EXPOLIS studies in Basel (1.9 and 0.2 μg m $^{-3}$), Helsinki (0.4 and 3.2 μg m $^{-3}$) and Oxford (3.6 and 0.5μg m $^{-3}$) respectively, which may reflect the measurement being made in the breathing zone. The nature of personal cloud has not been determined in U.S. studies. However, Wallace concluded that it may contribute up to 50% of personal exposure during the day, when personal activities are at their highest [7]. Most of the personal cloud is coarse particles that can be more easily resuspended than fine particles, one may conclude that the personal cloud consist largely of coarse particles resuspended by personal activity (walking on carpet, sitting on upholstered surfaces, etc.). However, another hypothesis that the personal cloud is a result of a person's proximity to particle-generating sources such as smoking, cooking, making toast, vacuuming and dusting. However, a few studies showed higher indoor particulate concentrations than personal exposure [30, 37].

In contrast to EXPOLIS studies that showed lower differences between personal exposures and indoor home $PM_{2.5}$ concentrations, the US PTEAM pilot study and the Toronto study concluded that there was a higher difference between the time-weighted average of day and night personal exposure and mean indoor home $PM_{2.5}$ concentration (33.7 and 9.4 µg m^{-3}, respectively). However, the difference between personal exposure (TWA) and indoor home $PM_{2.5}$ concentrations was the lowest (1 µg m^{-3}) in the Indianapolis study that was conducted by Pellizzari and co-workers [50]. Some studies showed similar results to major studies and concluded that personal exposure to particulate matter is not strongly related to outdoor particulate matter concentrations [17, 22, 25-32]. Most of these studies found a better relationship between residential indoor and personal exposure to particulate matter. However, a few studies of patients or children showed a good relationship also between personal particulate exposure and outdoor particle concentrations [33-35, 37]. A major finding in most studies was the increased personal exposure compared to either indoor or outdoor concentrations of all particle fractions.

CONCLUSION

Personal exposure to respirable particulate matter highly correlated with indoor air. Ambient (outdoor) concentrations obtained from Fixed Site Monitors poorly correlated with total personal exposure to particulate matter concentrations. Generally personal exposure to fine particle concentrations was higher than indoor and outdoor levels because of the subjects' personal cloud. Resuspension of indoor dusts while walking, sweeping, vacuum cleaning and dusting, setting upholstered surfaces and individual proximity to particle generating sources like smoking and cooking may increase subjects personal exposure and indoor particulate concentrations.

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