Indoor and outdoor particulate matter concentrations on the Mpumalanga highveld – A case study

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Abstract

The household combustion of solid fuels, for the purpose of heating and cooking, is an activity practiced by many people in South Africa. Air pollution caused by the combustion of solid fuels in households has a significant influence on public health. People most affected are those considered to be the poorest, living in low-income settlements, where burning solid fuel is the primary source of energy. Insufficient data has been collected in South Africa to quantify the concentrations of particulate emissions that people are exposed to, especially the respirable fraction, associated with the combustion of solid fuels. The aim of this paper is to gain an understanding of the particulate matter (PM) concentrations a person living in a typical household in a low income settlement in the South African Highveld is exposed to. It also seeks to demonstrate that the use of solid fuels in the household can lead to indoor air pollution concentrations reaching levels very similar to ambient PM concentrations, which could be well in excess of the National Ambient Air Quality Standards, representing a major national public health threat. A mobile monitoring station was used in KwaDela, Mpumalanga to measure both ambient particulate concentrations and meteorological conditions, while a range of dust/particulate monitors were used for indoor and personal particulate concentration measurements. Indoor and personal measurements are limited to the respirable fraction (PM_4) as this fraction contributes significantly to the negative health impacts. The sampling for this case study took place from 7-19 August 2014. Highest particulate matter concentrations were evident during the early mornings and the early evenings, when solid fuel burning activities were at their highest. Indoor and personal daily average PM_4 concentrations did not exceed the 24h National Ambient $PM_{2.5}$ Standard of 65 µg/m^3 nor did they exceed the 24h National Ambient PM_{10} Standard of 75 µg/m^3. The outdoor $PM_{2.5}$ concentrations were found to be below the standards for the duration of the sampling period. The outdoor PM_{10} concentrations exceeded the standards for one day during the sampling period. Results indicate that, although people in KwaDela may be exposed to ambient PM concentrations that can be non-compliant to ambient standards, the exposure to indoor air, where solid fuel is burnt, may be detrimental to their health.

Keywords

particulate matter exposure, indoor air quality, ambient air quality, personal exposure

Introduction

The household combustion of solid fuels (coal, wood, dung, and crop waste), for the purpose of heating and cooking, is an activity practiced by approximately 3 billion people around the world (Chafe et al. 2014). Air pollution caused by the combustion of these solid fuels has a significant influence on public health, attributing to more than 4 million premature deaths globally in 2012 (Bruce et al., 2015). People most affected are those living in low- income settlements in developing countries, where burning solid fuels is the primary source of domestic energy (Xie et al. 2015).

In South Africa, the low level burning of solid fuels such as coal and wood contributes significantly to the high levels of ambient air pollution in the country (Terblanche et al. 1992).Many people in rural communities and in townships utilise solid fuels for cooking and heating. Exposure to the emissions, in particular to the respirable aerosols stemming from these burning practices is known to cause a large number of health problems (Smith 2000). Various literature sources have acknowledged that ambient pollution levels are not necessarily indicative of the concentrations of air pollution that humans are exposed to on an everyday basis, as most people tend to spend most of their time indoors (Lim et al. 2012, Diapouli et al. 2011, Ferro et al. 2004, Smith 2002). The Medical Research Council Burden of Disease Research Unit ranked indoor air pollution at number 15 for South Africa, higher than urban air pollution (MRC 2008, Norman et al. 2007).

This paper aims to evaluate the level of indoor and outdoor particulate matter exposure within a typical household in a low-income settlement in Mpumalanga, South Africa (KwaDela) in the winter period, the time of year in which low level burning practices are particularly prevalent, and to demonstrate that the use of solid fuels in the household level can lead to indoor air pollution concentrations reaching well in excess of the National Ambient Air Quality Standards, representing a major national public health threat.

The following questions were answered (i) what is the outdoor, indoor, and personal exposure of residents; (ii) what is the relationship between outdoor, indoor and personal mass concentration measurements; and (iii) what are the associated diurnal patterns of exposure of residents during the sampling period.

Experimental Method

Sampling Site

KwaDela (26°27'47.53"S; 29°39'51.73"E) is situated in the Gert Sibande Disctrict Municipality of Mpumalanga, South Africa, which lies in the Highveld Priority Area. Located approximately 200 km South-East of Johannesburg. According to census data, Kwadela has a population of about 3777 (Census 2011). In 2014, 79.6% of KwaDela's residents made use of solid fuel burning for daily activities such as heating and cooking.

Instrumentation

A mobile monitoring station was used to obtain ambient concentrations of particulate matter (PM_{10} and $PM_{2.5}$ were measured using a MetOne BAM 1020, MetOne E-Bam and MetOne E-Samplers) and meteorological data (temperature, humidity, pressure, wind speed and direction, rainfall). The ambient monitoring site was located at the Secondary School close to the centre of KwaDela. Additionally two E-samplers were used to measure ambient PM concentrations ($PM_{2.5}$ and PM_{10}) in separate locations of the settlement.

The household considered in this study was semi-randomly chosen for indoor monitoring. Indoor particulate concentrations (PM_4) were measured using the TSI DustTrak (Models 8520 and 8530) photometric monitors, while the personal exposure of one of the residents in the household (PM_4) was monitored using the TSI SidePak AM510 photometric monitor. Temperature iButtons were placed in strategic locations within the sampling household to help better understand the indoor temperature dynamics. This included measuring temperatures in various rooms of the household (bedroom, kitchen, by the stove, and outside the house).

Sampling was conducted as part of a larger sampling campaign in KwaDela in various seasons (winter 2013 and 2014 and summer 2014 and 2015). This paper focuses on the measurements taken in one household in the winter 2014 campaign. This study was approved by the North-West University Research Ethics Committees (NWU-00066-13-S3).

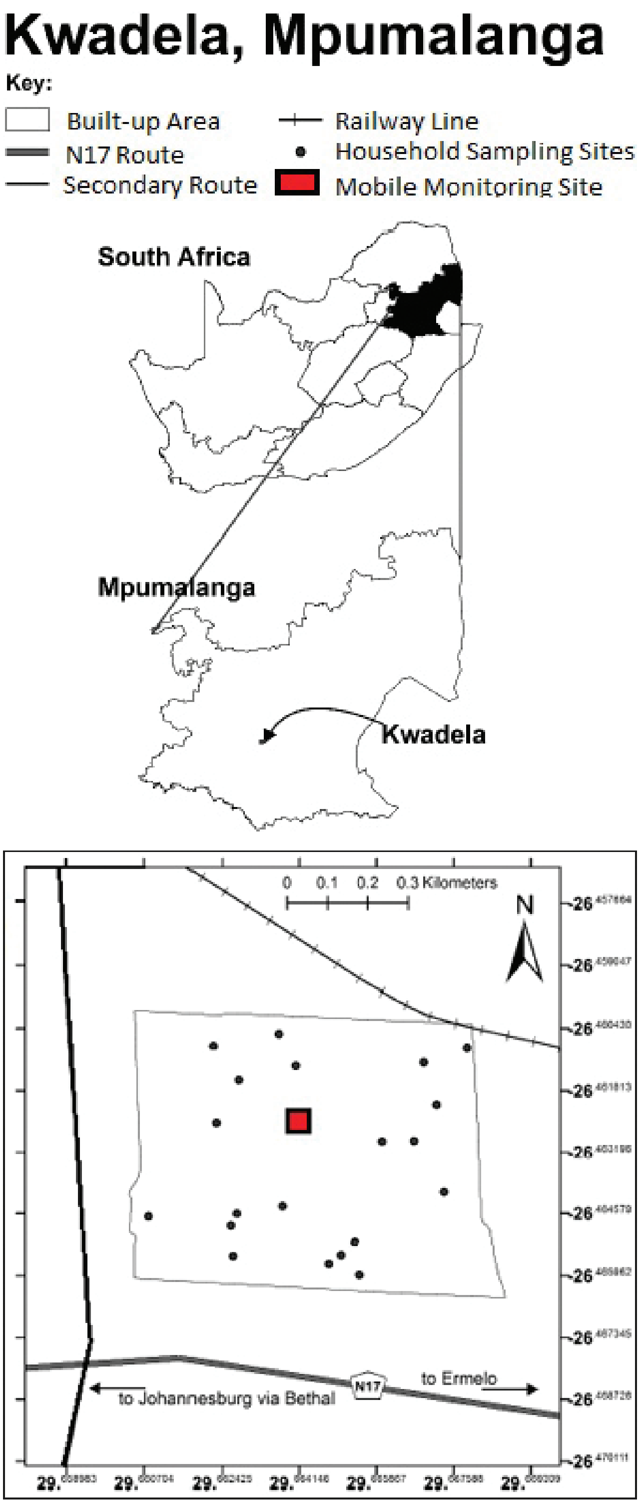

***Figure 1**: Map of Kwadela showing the distribution of household and mobile monitoring sites.*

Data Processing and Analysis

The data collected by the various instruments was merged into one overarching data set by synchronising the sampling intervals of the various instruments into an hourly data set. The instruments within the mobile monitoring station were checked once a week during the sampling. The indoor instruments were zero calibrated and flow checked as per manufacturer's instructions. The personal monitoring instruments were flow checked once a week and zero calibrated each day before sampling.

Simple time series were plotted to identify the average diurnal PM patterns of the specific household. Furthermore, correlations between the indoor and outdoor and indoor and personal particulate concentration levels were found. Lastly, frequency distributions illustrated the 99th percentile of indoor and outdoor particulate concentrations.

The indoor and personal PM_4 measurements have been corrected according to the specific photometric calibration factors obtained for the DustTrak and SidePak instruments. It is noted that, as a possible limitation of this study, PM_4 and $PM_{2.5}$ are included as smaller fractions/ subsets of PM_{10}.

Results and Discussion

Exposure of residents to particulate matter

Mean outdoor $PM_{2.5}$ and PM_{10}, indoor PM_4 and personal PM_4 concentrations were 27±18 and 21±122 and 17±23 and 16±7 µg/m³ respectively (Table 1). The variability of the particulate matter was highest for outdoor PM concentrations. 99th percentile values for outdoor $PM_{2.5}$, outdoor PM_{10}, indoor PM_4 and personal PM_4 concentrations were 81, 303, 126 and 30 µg/m³ respectively. Frequency distributions indicate that the majority of all PM concentrations measured fall between 0 and 50 µg/m³ (Figures 2-5).

***Table 1**: Descriptive Statistics of Outdoor, Indoor and Personal PM Measurements in (ug/m³).*

	N	M	SD	Min	Max
O PM_{10} (ug/m³)	178	48	122	1	1518
O $PM_{2.5}$ (ug/m³)	274	27	18	2	196
I PM_4 (ug/m³)	291	17	23	1	154
P PM_4 (ug/m³)	7	16	7	10	112

N - Sample size M – Mean SD – Standard deviation
Min – Minimum value Max – Maximum value
O – Outdoor I – Indoor - P – Personal

Relationship between indoor, outdoor and personal PM concentrations

The value of R^2 in the regression analyses in Figures 6 and 7 indicate a weak correlation between indoor and outdoor $PM_{2.5}$ concentrations (R^2 =0.087) and between indoor and outdoor PM_{10} concentrations (R^2=0.11). However, the correlation between personal and indoor PM is stronger at R^2=0.93 (Figure 8). This result limited by the fact that merely 7 measurements were available for this particular case. Regression analyses between the personal PM_4 and outdoor (PM_{10} and $PM_{2.5}$) measurements are not displayed here as there are too few data points for personal PM_4 to be representative of the true relationship.

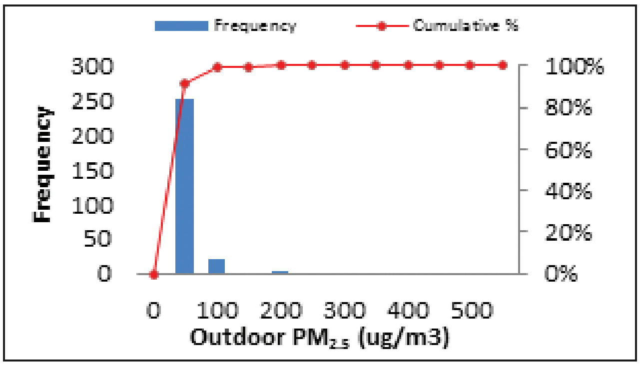

***Figure 2**: Distribution of mean 1-hourly outdoor $PM_{2.5}$ mass concentrations in µg/m³.*

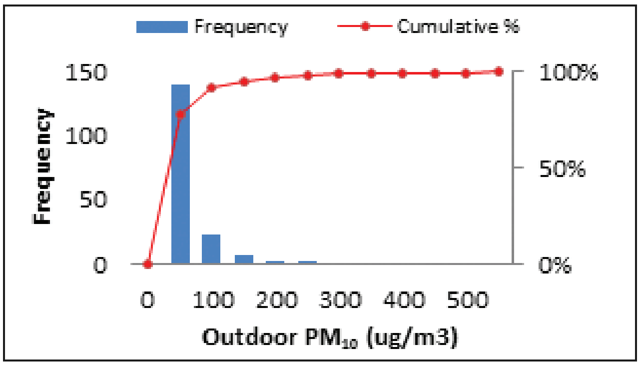

***Figure 3**: Distribution of mean 1-hourly outdoor PM_{10} mass concentrations in µg/m³.*

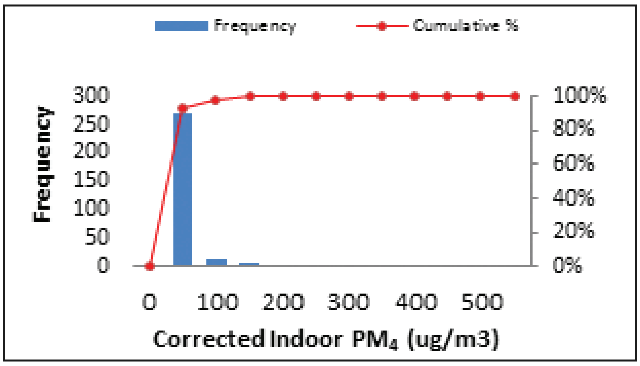

***Figure 4**: Distribution of mean 1-hourly indoor PM_4 mass concentrations in µg/m³.*

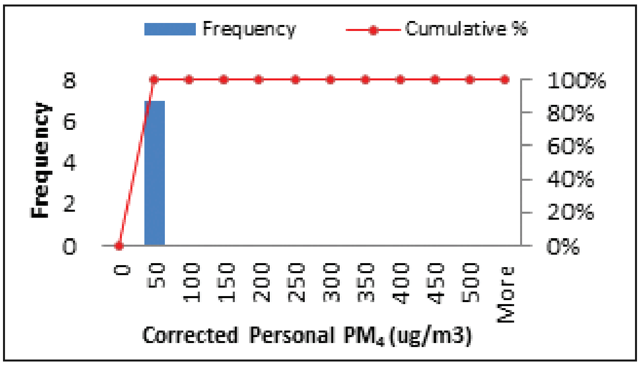

***Figure 5**: Distribution of mean 1-hourly personal PM_4 mass concentrations in µg/m³.*

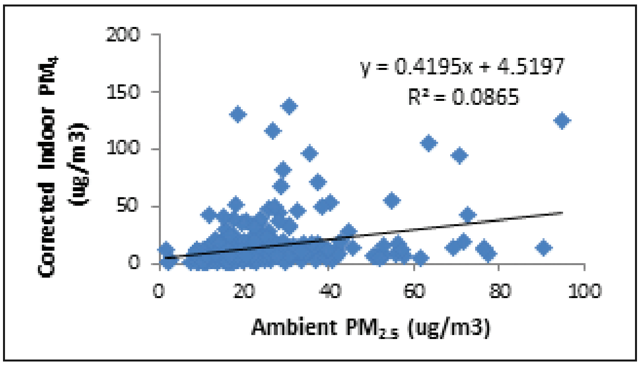

***Figure 6**: Regression analysis of indoor (PM_4) and outdoor ($PM_{2.5}$) concentrations in µg/m³.*

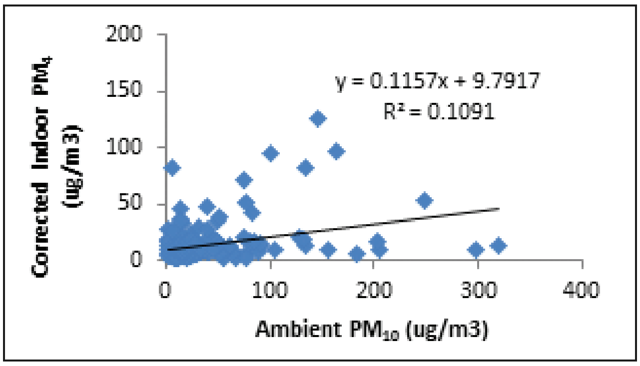

***Figure 7**: Regression analysis of indoor (PM_4) and outdoor (PM_{10}) concentrations in µg/m³.*

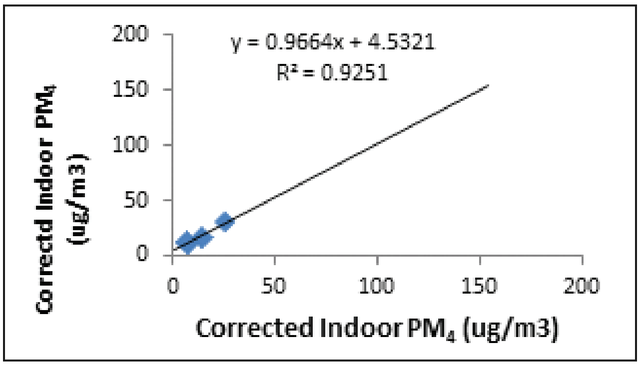

***Figure 8**: Regression analysis of personal and indoor PM_4 concentrations in µg/m³.*

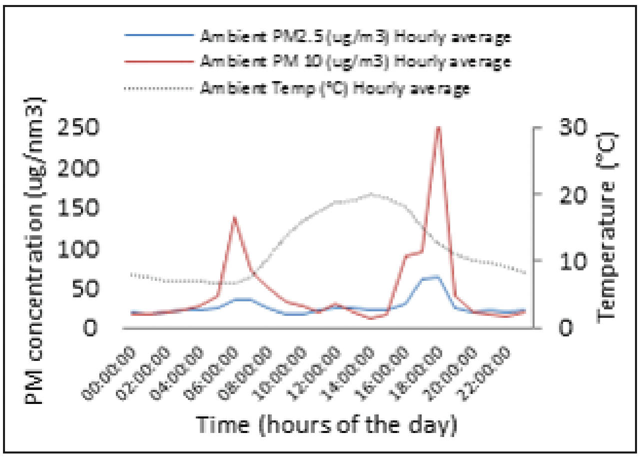

***Figure 9**: Hourly concentrations of outdoor particulate matter averaged during the winter period 7-19 August 2014.*

Diurnal patterns of exposure

Lower ambient temperatures and morning and evening time periods correspond with outdoor PM peaks (Figure 9). Higher stove temperatures link to cooking and heating activities in the early morning and afternoon hours as well as the evening hours with elevated indoor PM concentrations (Figure 10). Morning and evening peaks are also likely to be caused by vehicle emissions.

Indoor and outdoor PM concentrations follow a similar diurnal trend throughout the day, however, the mean PM_{10} hourly average concentrations lie above the mean outdoor $PM_{2.5}$ and indoor PM_4 concentrations. The visible diurnal trend is a signature trend for low level burning practices, indicating that all measured PM levels are directly influenced by solid fuel burning in the household and most likely by surrounding households. The differences in outdoor $PM_{2.5}$ and outdoor PM_{10} concentrations can most likely be attributed to the fact that the two monitoring instruments were located in different areas of KwaDela, being exposed to different ambient PM concentrations entirely.

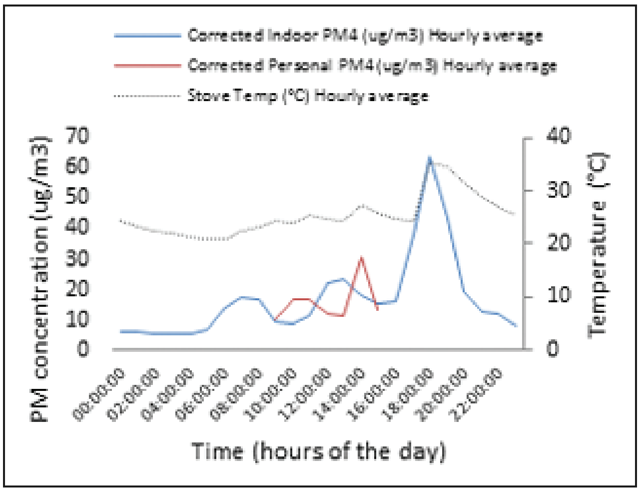

***Figure 10**: Hourly concentrations of indoor PM_4 averaged during the winter period 7-19 August 2014.*

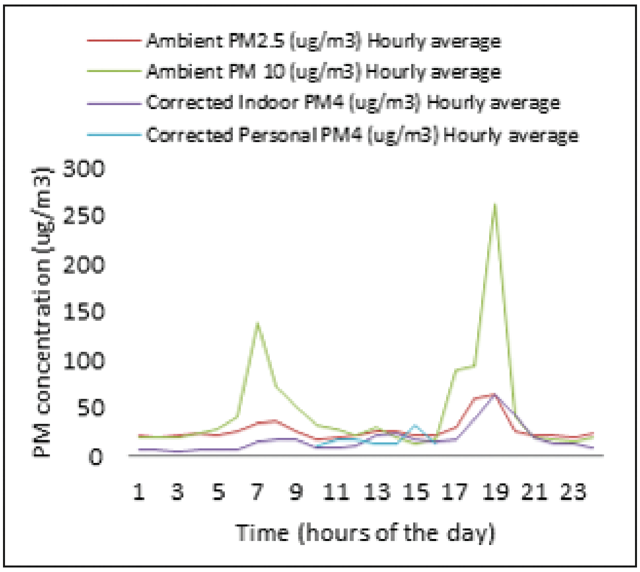

***Figure 11**: Hourly concentrations of indoor and outdoor PM concentrations averaged during the winter period 7-19 August 2014.*

Indoor and personal daily average PM_4 concentrations did not exceed the 24h National Ambient $PM_{2.5}$ Standard of 65 µg/m^3 nor did they exceed the 24h National Ambient PM_{10} Standard of 75 µg/m^3. The outdoor $PM_{2.5}$ concentrations were found to be below the standards for the duration of the sampling period. The outdoor PM_{10} concentrations exceeded the standards for one day during the sampling period (Figure 12).

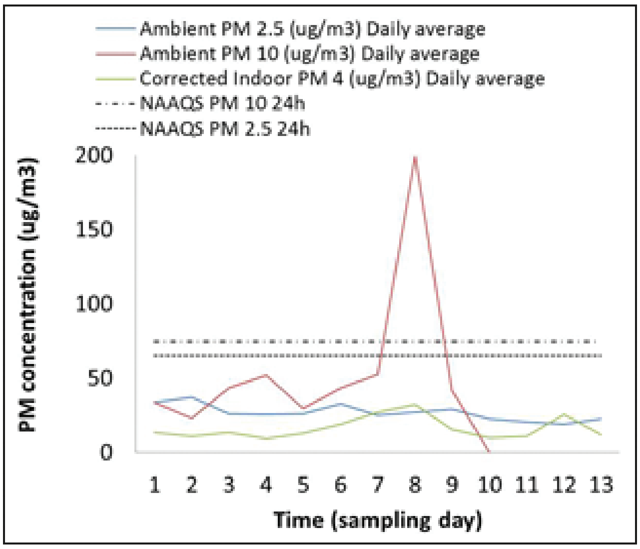

***Figure 12**: Daily average for PM concentrations measured against the NAAQS for PM_{10} and $PM_{2.5}$ over the sampling period.*

Conclusion

This study indicates that, in this household and during this sampling campaign, PM concentrations experienced outdoors were on average higher than those experienced indoors. Outdoor mean concentrations were 48 µg/m^3 and 27 µg/m^3 for PM_{10} and $PM_{2.5}$ and indoor mean concentrations were 17 µg/m^3 and 16 µg/m^3 for indoor and personal measurements respectively. Extreme events were evident in outdoor PM_{10} measurements where a maximum hourly value of 1518 µg/m^3 was measured. Maximum hourly values for outdoor $PM_{2.5}$, indoor PM_4 and personal PM_4 were found to be 196 µg/m^3, 15µg/m^3 and 122 µg/m^3 respectively.

Even though this study outlines the PM concentrations experienced at only one household, it gives an indication of the average indoor PM_4 concentrations an average person experiences in the Highveld, Mpumalanga, where the combustion of solid fuels is a daily practice occurring in the majority of households. This study indicates that people living in KwaDela are exposed to high PM concentrations which may exceed ambient PM standards outdoors, but that they are exposed to high PM concentrations even indoors, which may be detrimental to their health.

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