AIRBORNE PARTICULATE MATTER WITHIN 100 RANDOMLY SELECTED OFFICE BUILDINGS IN THE UNITED STATES (BASE)

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ABSTRACT

The United States Environmental Protection Agency (EPA) has collected extensive indoor air quality data in 100 randomly selected office buildings following a standardized protocol developed for the Building Assessment Survey and Evaluation (BASE) study. These data were collected to provide normative data in typical office buildings for various uses including: a) basis for making policy and guidance development; b) hypothesis development and testing; c) input into risk assessments and environmental models; and, d) comparison of complaint buildings to "typical" building stock. Airborne particulate matter (PM) of respirable (less than or equal to 2.5 microns (µm)) and inhalable (less than or equal to 10µm) size were collected by inertial impaction at a specified flowrate onto pre-weighed filters over an eight-hour period at up to three randomly selected locations within the study area and near the outdoor air intake of the ventilation system. This paper presents the concentration distributions and comparisons of $PM_{2.5}$ and PM_{10} in the BASE buildings and outdoor air near the building.

KEYWORDS: air quality, office building, PM_{10}, $PM_{2.5}$, particulate matter, indoor/outdoor ratio

INTRODUCTION

The U.S. Environmental Protection Agency (U.S. EPA) recently completed the collection phase of a major cross-sectional study, the Building Assessment Survey and Evaluation study (BASE). The goal of the BASE study is to characterize key characteristics of IAQ and occupant perceptions and symptoms in public and commercial office buildings. This paper presents a summary of the concentration data for particulate matter (PM) of respirable (less than or equal to 2.5 microns (µm)) and inhalable (less than or equal to 10µm) size in 100 randomly selected office buildings across the USA, including indoor to outdoor concentration comparisons. Several studies have found associations between PM and various health effects including decreased lung function, alterations in lung tissue and structure, aggravation of respiratory diseases such as asthma, premature death and increased hospitalization admissions and emergency room visits for the elderly and individuals with cardiopulmonary disease. Based on these potential adverse health effects and as part of its efforts to protect the public health, EPA's National Ambient Air Quality Standard for Particulate Matter sets standards for PM in ambient air [1]. In addition, since ambient PM may penetrate into the indoor environment and there are additional sources of PM found indoors, EPA is interested in the concentration of PM indoors and how this exposure may impact the total personal exposure and health and well-being of the public. PM was measured as part of the BASE study to help address this issue for office buildings.

METHOD

Between 1994 and 1998, data and samples were collected in each of 100 office buildings using a standardized protocol over a one-week period during either the summer or winter season [2]. These buildings were randomly selected without regard to indoor air quality concerns, except that buildings with highly publicized indoor air quality problems were excluded. A test space was randomly selected within each building with a target population of no less than 50 occupants served by no more than two air handling units. Data and samples collected at co-located sites include VOCs including aldehydes; PM; radon; microbiological contaminants; carbon monoxide; carbon dioxide; temperature and relative humidity; building characteristics; and occupant symptoms and perceptions of IAQ. Data were also collected regarding characteristics, operation and maintenance of the heating, ventilation and air-conditioning systems. Additional information on building and test space selection and parameters measured can be found in a previous paper [3]. PM_{10} samples were collected in 100 buildings at three randomly selected indoor locations and at one outdoor location. $PM_{2.5}$ samples were collected at one indoor site (co-located with a PM_{10} sampler) and the outdoor site in 70 buildings and at all three randomly selected indoor sites and the outdoor site in 30 additional buildings. Outdoor air samples were collected near the air intake of the air handler servicing the test space. Samples were collected by inertial impaction onto pre-weighed Teflon air sampling membrane filters for 8-10 hours during normal business hours using a particle size selection device (impactor) at 20 L/min. The mass of the collected particulates was determined gravimetrically using a microbalance in an environmentally controlled laboratory. Co-located duplicate samples were collected at one randomly selected indoor site and outdoors for both PM_{10} and $PM_{2.5}$ samples.

The arithmetic mean was calculated for the duplicate and its co-located sample. Within a building, it is assumed that the sample concentrations are normally distributed. Therefore, the arithmetic mean of a sample and its co-located duplicate sample was used with the concentrations of the other two sites to calculate the arithmetic mean for the building. Across all buildings, it is assumed that PM sample concentrations are lognormally distributed. Therefore, the geometric mean of the building means was calculated.

RESULTS

Five hundred and eighty-eight PM_{10} and 453 $PM_{2.5}$ indoor and outdoor samples were collected from BASE buildings. Figure 1 presents box plots of the concentrations across all buildings. The 5th, 10th, 25th, 75th, 90th, 95th percentiles, as well as the minimum and maximum values are represented.

PM_{10} and $PM_{2.5}$ indoor concentrations ranged from 3.0 to 35.4 $\mu g/m^3$ with a geometric mean of 11.4 $\mu g/m^3$ and 1.3 to 24.8 $\mu g/m^3$ with a geometric mean of 7.2 $\mu g/m^3$, respectively. Outdoor concentrations ranged from 5.8 to 102.9 $\mu g/m^3$ with a geometric mean of 23.1 $\mu g/m^3$ for PM_{10} and 4.5 to 47.4 $\mu g/m^3$ with a geometric mean of 14.7 $\mu g/m^3$ for $PM_{2.5}$. The indoor concentration of PM_{10} and $PM_{2.5}$ was usually less than 16 $\mu g/m^3$ in the 100 BASE buildings with the largest frequency between 6 and 10 for $PM_{2.5}$ and 11 and 15 for PM_{10}. Frequency histograms of the data are presented in Figures 2 and 3.

In most BASE buildings the indoor PM concentration was lower or nearly equal to the measured outdoor level. However, an indoor to outdoor ratio greater than 1.0 was found for PM_{10} in 11 buildings, with a ratio equal or greater than 1.5 found in five of these buildings.

Indoor to outdoor $PM_{2.5}$ ratios were greater than 1.0 in 9 buildings, with 2 buildings having a ratio equal or greater than 1.5. Only five buildings had both PM_{10} and $PM_{2.5}$ indoor to outdoor ratios greater than 1.0. Indoor to outdoor ratios greater than 1.0 may indicate ineffective filtration or a prominent indoor source. Future analysis between building characteristics and PM data collected in these BASE buildings may explain this. The correlation between indoor and outdoor samples is low for both PM_{10} ($r = 0.29$) and $PM_{2.5}$ ($r = 0.44$) suggesting that filtration decouples indoor and outdoor air. Figure 3 presents the indoor to outdoor PM sample concentration relationship for both PM_{10} and $PM_{2.5}$. Indoor $PM_{2.5}$ to indoor PM_{10} and outdoor $PM_{2.5}$ to outdoor PM_{10} sample concentrations show a strong correlation with r values of 0.81 and 0.79, respectively. Figure 4 presents the relationships between outdoor PM_{10} and outdoor $PM_{2.5}$ and between indoor PM_{10} and indoor $PM_{2.5}$.

DISCUSSION

The total personal exposure of an individual to PM is based on the combined exposures that the individual experiences from various sources while in different microenvironments. It is reported that Americans spend as much as 90% of their time indoors. For many working adults, a large portion of that 90% (8-10 hours a day, 5 or more days per week) is spent in office buildings. Therefore, it is important to consider the PM exposure in this environment and its impact on total exposure to PM. The data presented indicate that PM concentrations in the office environment vary and may in some cases be a significant factor in the total exposure of an individual. In addition, these data represent an important part of the information needed to assess the impact of PM on health. The results from this study provide normative or baseline data on PM_{10} and $PM_{2.5}$ in U.S. office buildings which can be used for comparisons to data from complaint buildings, for examining the relationships of PM with other building factors collected, for conducting risk assessments, and for designing more focused studies.

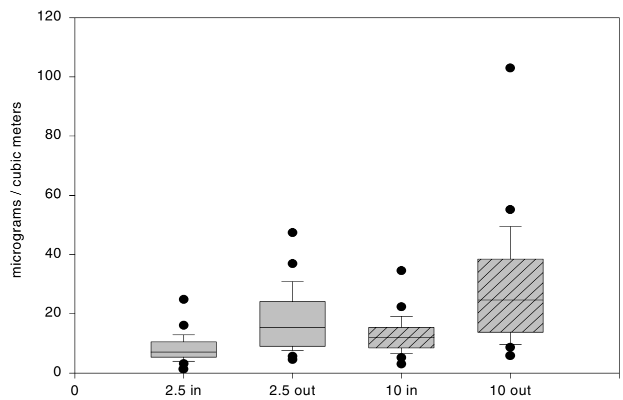

Figure 1. Minimum, 5th, 10th, 25th, 75th, 90th, 95th Percentile, and Maximum concentrations for Indoor and Outdoor PM_{10} and $PM_{2.5}$ Measured in BASE study.

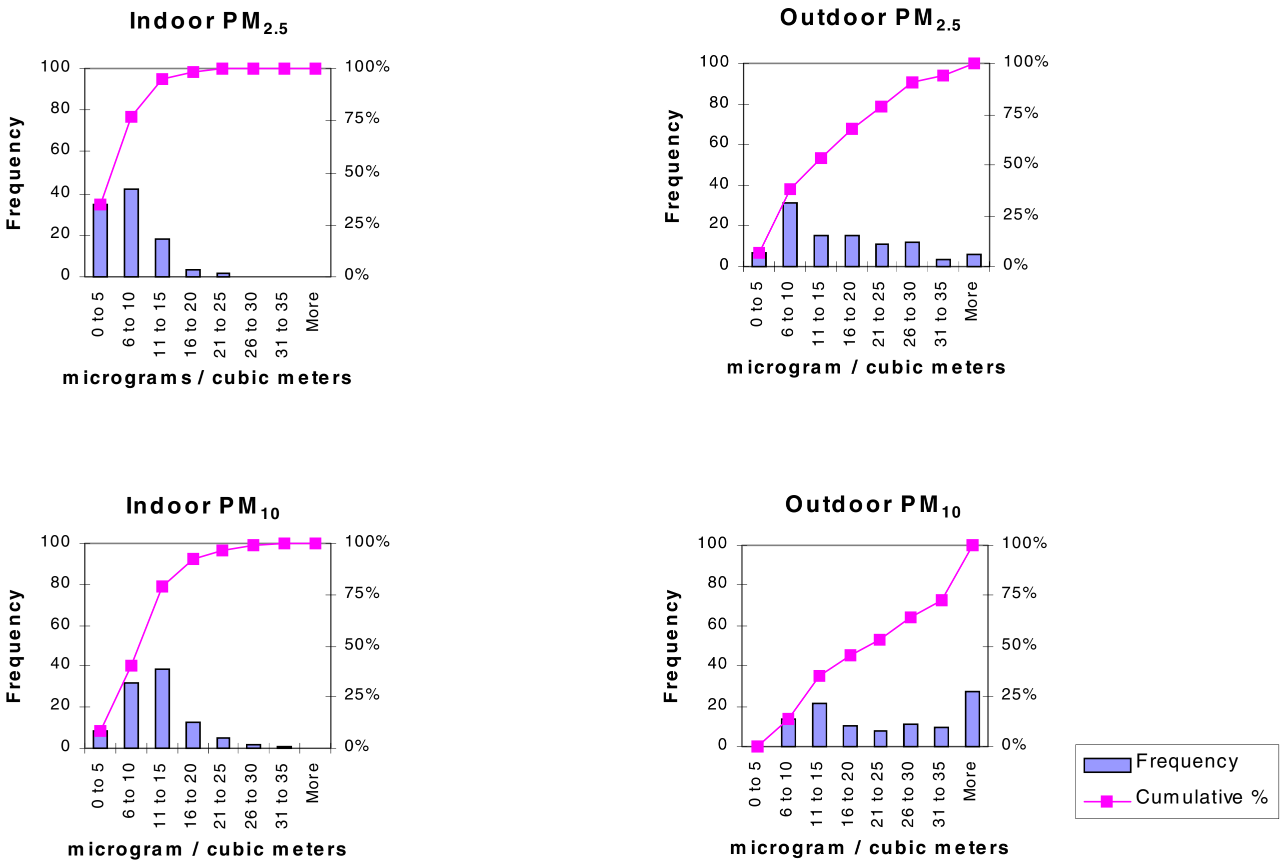

Figure 2. Histogram and Cumulative Frequency Plots of Mean Indoor and Outdoor $PM_{2.5}$ and PM_{10} for 100 BASE buildings

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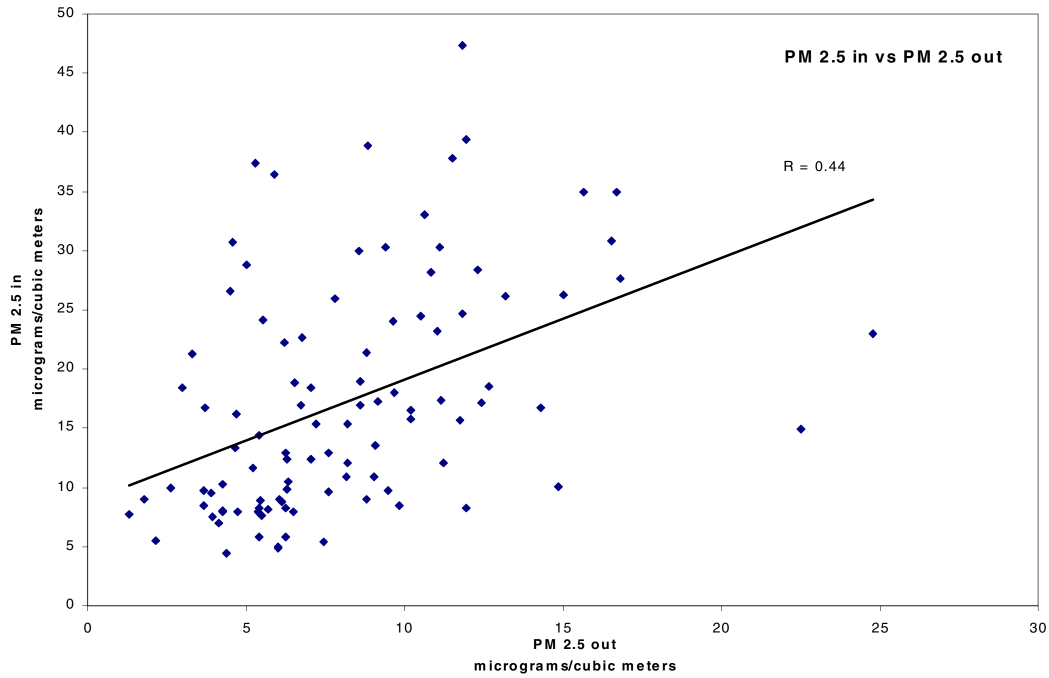


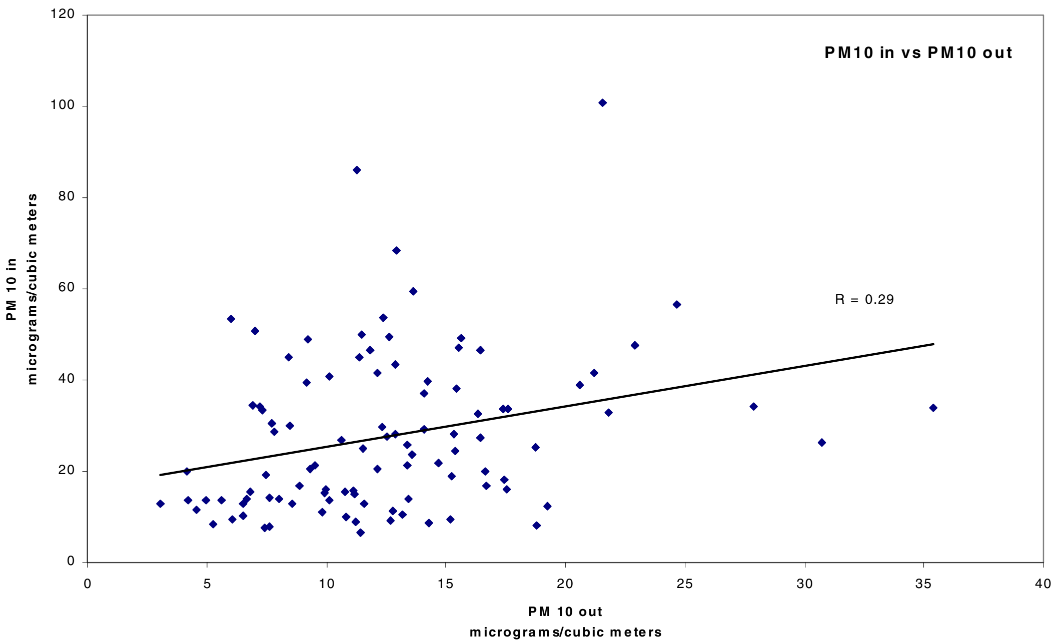
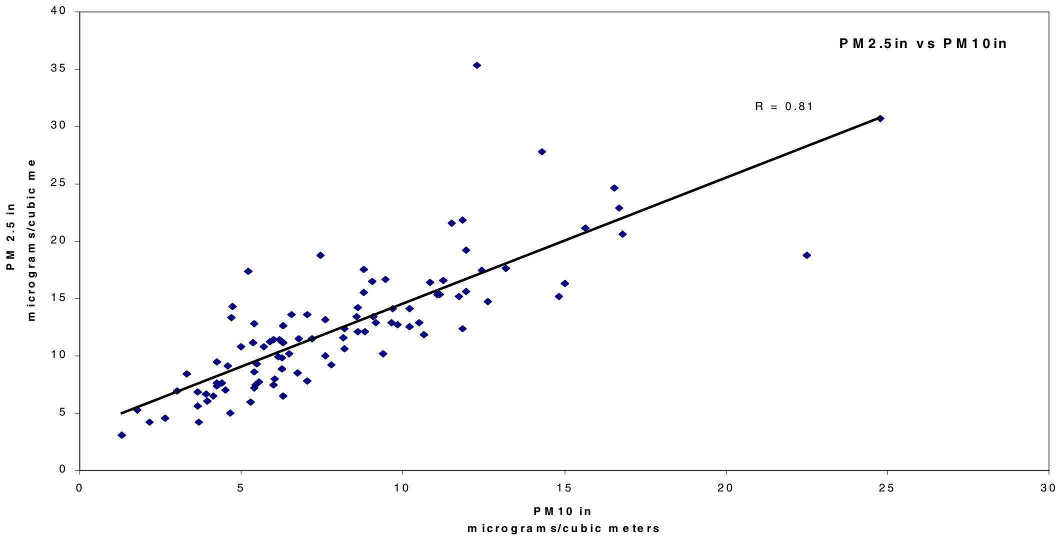


Figure 3. Indoor to Outdoor Relationship of $PM_{2.5}$ and PM_{10} in BASE Buildings



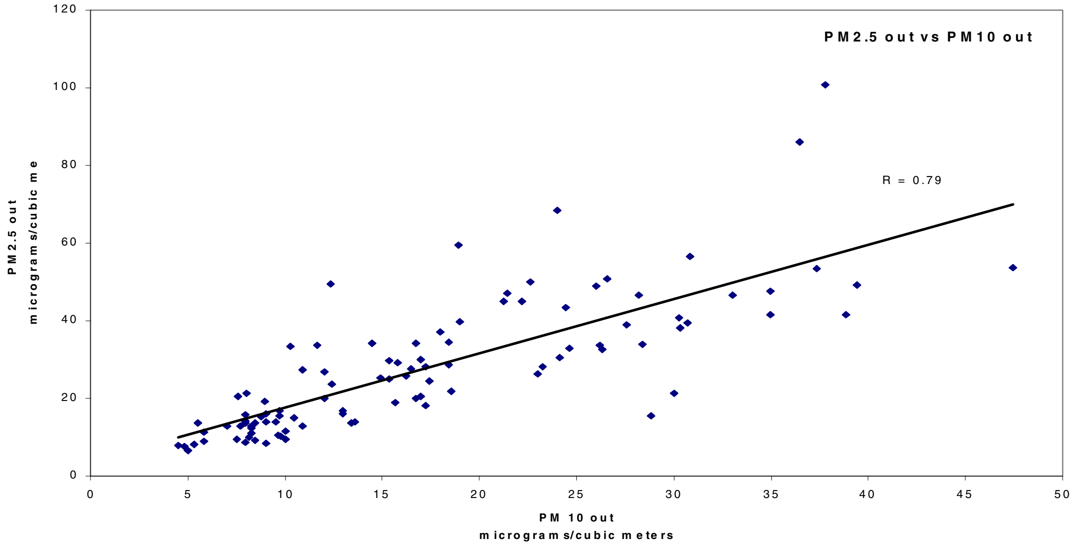


Figure 4. Indoor and Outdoor Relationship of $PM_{2.5}$ and PM_{10} in BASE Buildings

ACKNOWLEDGMENTS

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REFERENCES

1. U.S. Environmental Protection Agency. 1999. *Air Quality Criteria for Particulate Matter. External Review Draft.* Washington, DC, Office of Research and Development, U.S. Environmental Protection Agency.
2. U.S. Environmental Protection Agency. 1994. *A Standardized EPA Protocol for Characterizing Indoor Air in Large Office Buildings*, Washington, DC, Office of Research and Development and the Office of Air and Radiation, U.S. Environmental Protection Agency.
3. Womble, S E, Girman, J R, Ronca, E L, et al. 1995. Developing Baseline Information on Buildings and Indoor Air Quality (BASE '94): Part I – Study Design, Building Selection, and Building Descriptions. *Proceedings of Healthy Buildings '95*, Vol. 3, pp 1305-1310.