AIRBORNE PARTICULATE MATTER WITHIN SCHOOL ENVIRONMENTS IN THE UNITED STATES

B. Ligman[1], M. Casey[2], E. Braganza[2], A. Coy[2], Y. Redding[2], S. Womble[1]

[1]Indoor Environments Division, U.S. Environmental Protection Agency, USA
[2] Radiation and Indoor Environments National Laboratory, U.S. Environmental Protection Agency, USA.

ABSTRACT

The U.S. Environmental Protection Agency (EPA) has been conducting indoor environmental studies to characterize the impact different interventions have on the indoor environment of school buildings. Several indoor environmental measurements have been conducted including measuring time-weighted gravimetric airborne particulate matter (PM). Presented here are the results of PM data that are 10um aerodynamic diameter or less (PM_{10}) and those with 2.5um aerodynamic diameter or less ($PM_{2.5}$). These data were collected in elementary and secondary school (kindergarten - grade 12) indoor environments across the United States. Comparisons are made between these data and the PM data collected in the Building Assessment and Survey Evaluation (BASE) study, also conducted by the EPA. The BASE data represent typical concentration levels found in U.S. office buildings. In general, PM results were higher in schools than in office buildings. In addition, the school data show higher concentrations indoors than outdoors.

INTRODUCTION

Ambient airborne particulate matter has received recent attention in the U.S. due to the EPA's promulgation of a new National Ambient Air Quality Standards (NAAQS) for airborne particles smaller than 2.5 um in aerodynamic diameter ($PM_{2.5}$).

Despite the data that indicate Americans spend approximately 90% of their time indoors [1] limited research, relative to ambient air research, has been conducted to characterize exposure to indoor environmental pollutants such as PM. In response to a U.S. Congressional request, the Committee on Research Priorities for Airborne Particulate Matter was formed under the auspices of the National Academy of Sciences (NAS). The committee has been tasked with identifying the most important research priorities relevant to setting ambient air PM standards and to develop and monitor progress on a conceptual plan for the research. The committee's first report [2] (four more are expected over the next five years) presents 10 priority research topics. The data presented in this paper is relevant to one of these priority research areas, investigating the breathing-zone exposures of individuals to PM, taking into account indoor pollutant sources. In addition, the committee also recommends immediate research attention for potentially susceptible sub-populations such as children.

To date, limited pollutant data have been collected for the indoor environments of U.S. buildings. EPA's Building Assessment Survey and Evaluation (BASE) study is the only sizable study that attempts to characterize indoor air quality for a specific building type and usage [3]. Fewer data have been collected on pollutant concentrations in school environments. Presented here are PM concentration data that have been collected as part of EPA's indoor air quality studies in elementary and secondary schools (kindergarten - grade 12). EPA has been conducting limited research in school buildings since 1989. PM data collected during the earlier period ('89 - '95) were obtained from the School Evaluation Program [4]. Also presented, for comparison, are U.S. office building PM data collected as part of the BASE study.

METHODS

Two data sets are presented representing 1) BASE PM results, and 2) School Intervention (SI) PM results. All data was obtained using similar sampling equipment and following similar protocols. All data were collected during a normally occupied classroom school day or occupied office area (nominal sampling period of approximately 8-10 hours).

The BASE data represent a sample of randomly chosen office buildings across the U.S. All BASE data were collected following a standardized protocol [5]. The study is designed to collect large data sets of indoor pollutant concentrations (and other information such as building characteristics and occupant perceptions) representing baseline indoor air quality in large office buildings. PM_{10} and $PM_{2.5}$ data are two of the pollutants collected at each of the buildings. The BASE PM data set presented here was collected from three randomly selected areas of each randomly selected office building as well as one outdoor measurement for each building as specified in the protocol.

The SI data are comprised of two sets of data. The original data set was collected from 1989 to 1995 and consist of PM_{10} data from 10 school buildings. Data were collected from one classroom per building. The classroom selection was typically based on the highest radon concentration for the building. These data have been reported previously [4] and are not discussed here in detail. All of the SI buildings studied prohibited smoking within the building. The remaining SI data were collected as part of EPA's intervention studies following a modified BASE protocol [6]. The data were collected from two ongoing intervention studies that evaluate the impact of energy retrofits [7] and of implementing EPA's indoor air guidance for schools [8] on the quality of the indoor air. These data were collected from four classrooms per building. The selection was purely subjective with an attempt to select two special use classrooms (i.e., art, sciences, etc.) and two "normal" use classrooms for each building studied. Selecting special use classrooms proved difficult since most elementary schools lack these types of classrooms. Therefore, the data more closely represent normal use classrooms.

The entire SI data set does not represent random building selection or random sampling locations but rather schools that either a) had elevated radon gas concentrations (the original data collected from 10 school buildings), or b) willingness to participate in an indoor air quality intervention study. The selections were made with no known predisposition to high or low PM. All the school data represent buildings before any intervention activities were conducted.

RESULTS AND DISCUSSION

Table 1 contains specific details for the data being presented. Table 1 also presents the coefficient of skewness resulting from performing the Davies' Test for Logarithmic Distribution [9]. The Davies' test states that if the coefficient is less than 0.20, the data are approximately logarithmic in distribution. With the exception of SI $PM_{2.5}$ indoor and the SI $PM_{2.5}$ outdoor data, the distributions are logarithmic. The coefficients greater than 0.20 may be due to the smaller sample size of the data sets which affect the parameters for the Davies' test. Since the distributions are logarithmic, the geometric means are presented in Table 1 and used for the comparisons below.

Table 1. Summary Information on Data

Data Set	No. Bldgs.	Location (States)	No. Samples		Davies' skewness coef.	Geometric Mean (ug/m^3)
BASE	71 (PM_{10} & $PM_{2.5}$)	AZ, CA, CO, FL, GA, LA, MA, MD, MI, MN, MO, NE, NV, NY, OR, PA, SC, TN, TX, WA	PM_{10} indoor	208	0.02	12
			$PM_{2.5}$ indoor	73	-0.30	8
			PM_{10} outdoor	71	-0.12	26
			$PM_{2.5}$ outdoor	71	0.04	16
SI	20 (PM_{10}) 10 ($PM_{2.5}$)	CA, CO, FL, KS, MN, NJ, NM, NY, TX, WA	PM_{10} indoor	50	0.06	46
			$PM_{2.5}$ indoor	40	0.22	13
			PM_{10} outdoor	20	-0.10	19
			$PM_{2.5}$ outdoor	10	0.48	9

Table 2 presents the results of performing the z Test for Measurements (zM Test) for determining whether the differences in geometric means are statistically significant. The table contains the z values for the data sets as well as the indoor/outdoor data for each set. According to the important probability levels (calculated from the Normal Probability Formula) [10], a z value greater than 2.58 indicates a probability of less than 1% in stating that the means are not statistically different. (i.e., mean differences are statistically significant). A z value less than 1.64 indicates a probability greater than 10% in stating that the means are not statistically different. (i.e. mean differences are not statistically significant). As Table 2 shows, all geometric mean comparisons are significantly different with the exception of the SI $PM_{2.5}$ indoor and outdoor comparison.

Figures 1, 2, and 3 present the results of the BASE PM, SI PM and both data sets respectively. The Figures contain box plots of the data plotted on a logarithmic scale with the whiskers representing the 5^{th} and 95^{th} percentile and the ends of the box representing the 25^{th} and 75^{th} percentiles. The solid line in the box is the median (50^{th} percentile). The black dots represent the data that fell outside of the 5^{th} and 95^{th} percentiles.

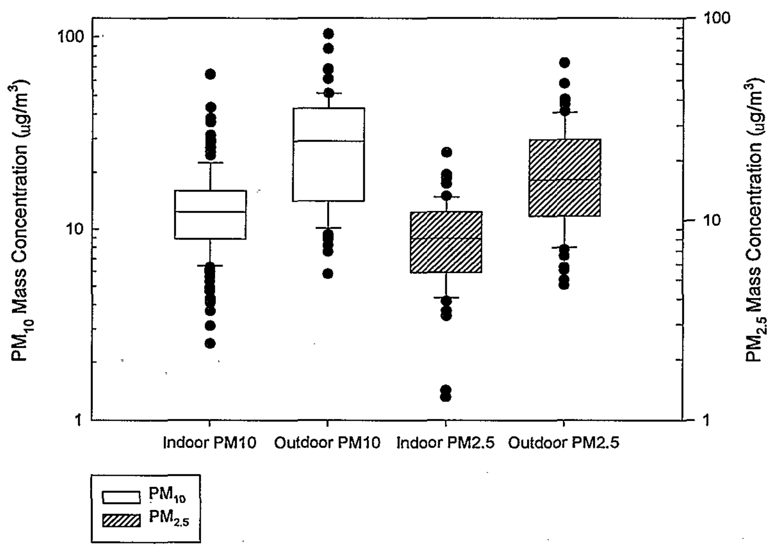
While differences in the collection of SI PM and BASE PM (e.g., random vs. non-random building selection, school buildings vs. office buildings) preclude any rigorous comparisons of the data, BASE PM data are used to lend perspective to the SI PM data. Comparing the BASE indoor PM mean to the outdoor PM mean shows that the indoor concentration data are approximately 53% lower than the outdoor means for both PM_{10} & $PM_{2.5}$. However, the same comparison for the SI data reveals just the opposite for school environments. The SI data's outdoor PM_{10} mean is 59% lower than indoor PM_{10} and the outdoor $PM_{2.5}$ is 45% lower than indoor $PM_{2.5}$. However, as noted above, the z value for the SI $PM_{2.5}$ comparison indicates the difference is not statistically significant.

Table 2. zM-Test Results (z value)

Data Compared	z value
BASE outdoor PM_{10} to BASE indoor PM_{10}	13.24
BASE outdoor $PM_{2.5}$ to BASE indoor $PM_{2.5}$	10.30
SI outdoor PM_{10} to SI indoor PM_{10}	6.46
SI outdoor $PM_{2.5}$ to SI indoor $PM_{2.5}$	1.30
SI indoor PM_{10} to BASE indoor PM_{10}	16.79
SI indoor $PM_{2.5}$ to BASE indoor $PM_{2.5}$	6.60

Figure 3 presents the indoor data for both data sets. Comparison of the geometric means show higher concentrations in these school environments than in office buildings with the mean PM_{10} concentration in offices to be 73% lower than in schools and 43% lower in offices for $PM_{2.5}$. These results are suggestive that exposures to PM may be higher in schools than in office buildings and may be of concern for school-aged children. Possible explanations for these results include poor filtration of the air, poor housekeeping (such as floor cleaning), and unknown indoor sources related to the uniqueness of school environments (such as chalk dust) and possibly the deteriorating building structures [11].

Figure 1. Gravimetric PM Concentrations (BASE data)



The results presented here support the need for additional personal exposure research. There is also a need for research on PM composition. It is not possible to determine the health effects associated with PM exposure unless PM composition is characterized and quantified. Understanding PM personal exposures must include indoor as well ambient air characterization. Indeed, the data presented here indicate that the characterization of the indoor school environment may be a higher priority than ambient air for children. These data provide additional information for consideration as PM research is prioritized.

In conclusion, the authors support the NAS's recommendation for determining actual personal exposures to airborne PM by characterizing the indoor environment, ambient air, and human time-activity patterns. Ambient PM has historically received more attention due to the regulatory concerns. However, the importance of the school indoor environment on children's exposure to PM may be greater than that of the ambient air as demonstrated in the data presented here. In the absence of specific data on PM composition, it is prudent to determine how to reduce PM concentrations in schools and disseminate this information to those who can act accordingly. This could include intervention studies that observe the effects different interventions have on PM concentrations in schools and prioritize those that show the greatest reduction.

Figure 2. Gravimetric PM Concentrations (SI data)

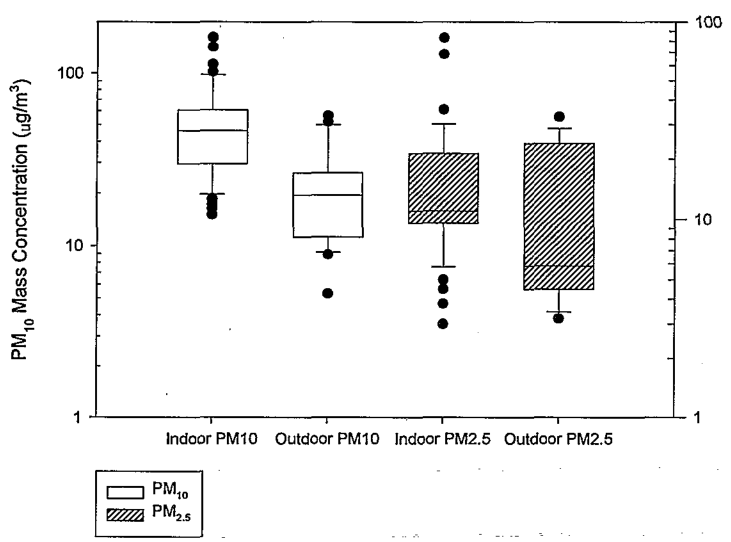
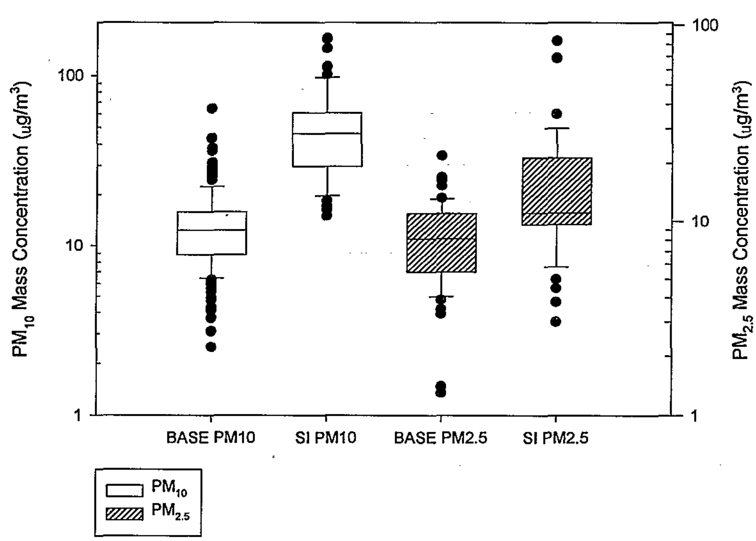


Figure 3. Indoor Gravimetric PM Concentrations (all data sets)



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