VERTICAL PROFILE PARTICULATE MATTER MEASUREMENTS IN A CALIFORNIA DAYCARE

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ABSTRACT
As children are increasingly cared for outside the home due to the changing work force, indoor air quality studies in daycares have become more important. This study focuses on the difference between children's and adults' particulate matter (PM) exposure due to suspected differences in the vertical profile. We conducted experiments at a daycare center for a exposure analysis class at Stanford University, measuring PM_{10} concentrations in two rooms with children of different ages (12-24 and 24-36 months). The results showed that the children were exposed to higher amounts of PM_{10} than the adults in the same room, and indoor PM_{10} concentrations were considerably higher than those measured outdoors on the same day. The PM_{10} concentrations were related to the number of people and specific activities occurring in the room. The investigators hope that results from these types of studies will encourage legislation for indoor standards affecting children's increased exposure to PM_{10}.

INDEX TERMS
Particulate Matter, Daycare, Vertical Profile, Indoor Air Quality, Inhalation Exposure

INTRODUCTION
Indoor air quality is of concern because people spend more than 90% of their time indoors (Ott 1995). Changes in family lifestyle have altered the significance of certain environments in children's daily lives. In 1997, both members of 75% of American couples held full time jobs, thereby significantly increasing child care outside the home, compared with previous decades (Bond, Galinsky and Swanberg, 1998). The same study also showed that 45% of young children are cared for in daycares. Thus daycares now comprise a significant part of the childhood environment, possibly exposing children to air pollutants and conditions that may affect their health. Children's bodies may be more susceptible to adverse effects from exposure to poor indoor air quality because they are still developing.

One pollutant of great concern is particulate matter (PM), an EPA criteria air pollutant that can harm the respiratory system through physical effects and chemical toxicity. Studies have shown asthma development can be related to PM concentrations to which children are exposed (Asgari, Dubois, Asgari, et. al., 1998; Gomzi, 1999). PM includes allergens, heavy metals and pesticides. Since allergic sensitization occurs primarily in infancy, a young child's allergen exposures can contribute to their lifelong ill-health (Deandrade, Charpin, Birnbaum, et.al., 1995). Additionally, PM constitutes the major pathway for childhood exposure to heavy metals and pesticides (Tong and Lam, 1998). Exposure to both these substances have shown to retard growth and cause developmental problems in children PM.

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Because of the importance of PM exposure to children's health, it is important to study the concentrations in children's immediate surroundings, such as schools and daycares. It is possible that PM concentrations will be higher near the ground because of closer proximity to the carpet and the effects of gravitational settling. Children might be exposed to higher concentrations than adults due to their shorter stature and different activity patterns (e.g., crawling, playing on the ground, etc.).

METHODS

We took PM_{10} measurements in two different rooms (Figure 1) in a daycare at Stanford University. Measurements were made on an unusually hot sunny day in the spring of 2001. In each room, two Personal Data Ram Particulate Monitors (pDR-1200, MIE, Inc., Bedford, MA) were placed at two different heights. The monitors included a particle size selective inlet cyclone permitting real-time measurements. Users can select a specific sized particle by adjusting the flow rate (MIE, Inc., 2000). The flow rate was set at 1.1 L/min to measure PM with a diameter of 10 µm or less (PM_{10}). Monitors were secured to shelves in each room with the intake pointed toward the children's activity. To minimize disruption of the daycare's operations, we made measurements for 4 hours on one day. Concurrent with PM_{10} measurements, a log was kept of the number of people in the room, activities of the occupants, ventilation conditions and any incidents that may have affected the readings (Figure 2). To obtain the most realistic profile possible, windows and doors were opened or closed at the discretion of the daycare staff in accordance to their needs. In both rooms, the ceiling fan was operating during the experiment but the HVAC system was not on.

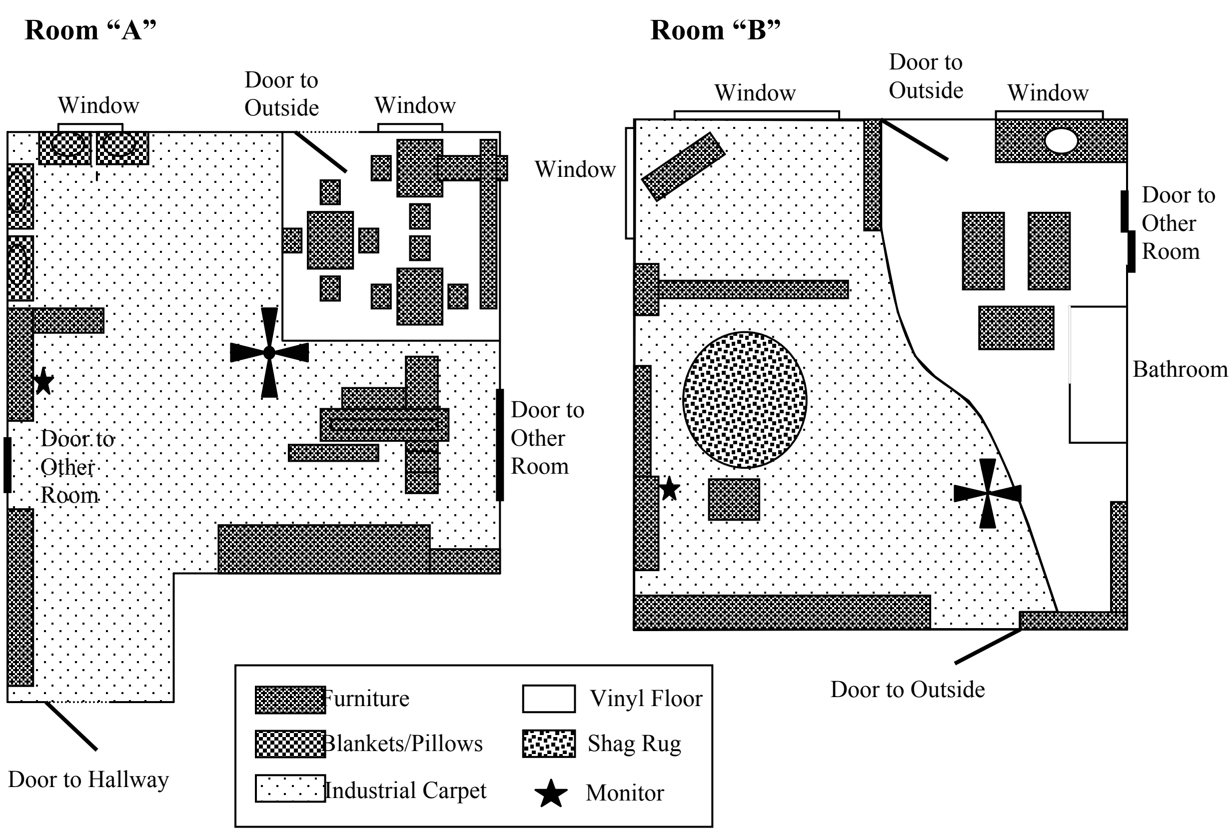

Figure 1. Layouts for Room "A" and Room "B." Note that the rooms were not adjacent to each other. Not drawn to scale.

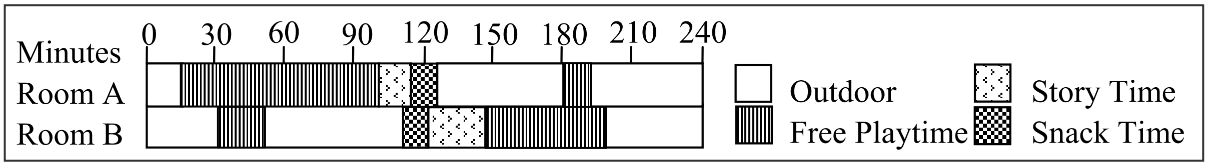

Figure 2. Summary of structured activities for both rooms.

In Room "A", with children approximately 12-24 months old, the monitor reflecting the children's breathing height was placed at 0.34 m (13.5 in.), chosen because children of this age do not walk well and spend most of their time sitting or crawling on the floor. The adult monitor height of 1.5 m (58.5 in.) was intended to reflect the average height of the breathing zone of the daycare workers in the room. The carpets in this room are vacuumed daily and shampooed biannually.

Concurrently, two monitors were placed in Room "B", where the children were slightly older, 24-36 months. These children spent more time walking and running around, and were taller than the children in Room "A"; therefore the monitor representing the children's breathing zone was placed slightly higher at 0.76 m (30 in.). The adult monitor was again placed at 1.5 m (58.5 in.). The carpets are cleaned as in Room "A". The layout for Room "B" is similar to that of Room "A" (See Figure 1); however there are a few key differences. Both of the doors in Room "B" open to the outside. Although they were closed, people constantly opened the doors to enter and leave. While there was a door to another classroom it was not opened during the measurement period. In addition to the industrial carpet and vinyl flooring, there was a shag rug (Figure 1).

Immediately following the indoor measurement period, we placed one monitor from each room outside the daycare for 30 minutes at a height of 0.36 m (14 in) to measure outdoor PM_{10} concentrations. Because the outdoor PM concentrations change slowly, we believe that these brief measurements were adequate to reflect outdoor concentrations for our purposes.

RESULTS

The PM_{10} concentration time series showed that in both rooms the lower monitors recorded, on average, greater concentrations than the higher monitors (Figures 3 and 4 and Table 1). Indoor concentrations were much higher than the outdoor concentrations.

In Room "A", there was a 9.8% difference between the lower monitor and the higher monitor, and the PM_{10} concentrations for both monitors increased as people entered the room (Figure 3), decreasing after people left the room. The maximum number of people in the room was 20, 15 children and 5 adults. While structured activities like story time and snack time were planned (Figure 2), the younger children moved about the room more than the older children in Room "B". In between, there is a period when the children were outdoors, but people kept returning to the room for diaper changes. The first pronounced peak occurred when one of the teachers reached for a stuffed animal from right above the monitor. The other sharp peak occurred when a blanket was dragged near the lower monitor.

In Room "B" there was a 5.5% difference between the two monitors. There were dramatic increases when people entered and exited for outdoor time (Figure 4). In this room the maximum number of people was 21, 16 children and 5 adults. Again, there were scheduled activities. Because the children were indoors during two distinct periods, averages and

Table 1. PM concentrations (μg/m³) in Room "A", Room "B" and Outdoors

	Child Monitor			Adult Monitor			
	μ	σ	Range	μ	σ	Range	% Diff.
Room "A"	47.27	9.36	26-90	42.60	10.56	20-98	9.88%
Room "B"	68.93	24.65	30-116	65.14	22.35	30-110	5.50%
Activity Period 1	62.64	8.96	48-91	56.72	5.03	46-64	9.45%
Activity Period 2	93.64	0.01	64-116	87.33	8.38	61-110	6.74%
Outdoor[1]	26.71	30.52	22-33	28.29	3.23	23-37	

[1] Measurements were only taken at one height (m)

standard deviations were calculated for the different periods (Table 1). During the second indoor period, the concentrations reached high levels, partially due to the increased number of people in the room, but also due to the children spending time near the shag rug for story time. In addition to the large shag rug, each child pulled out an individual shag rug (carpet sample) for him/herself. A considerable period of story time was spent dancing and jumping on the large shag rug, which apparently resuspended considerable amounts of PM_{10}.

DISCUSSION

PM_{10} concentrations recorded by the lower monitors were greater than concentrations recorded by the higher monitors (Table 1). Other studies have shown that there is a vertical PM concentration gradient (Micallef, Deuchar, and Colls, 1998; Monn, Carabias, Junker, et.al., 1997, Chen and Mao, 1998). These studies were conducted over larger vertical ranges than the current study. The vertical profile most comparable to our study, by Micallef, Deuchar, and Colls (1998), was conducted with one monitor that moved uniformly over different heights, giving measurements that are not necessarily concurrent. However, they still found that different height groups of the population are exposed to different concentrations.

While our purpose was to investigate the vertical profile of PM_{10} concentrations in a daycare, our findings showed that the concentrations indoors were considerably greater than those

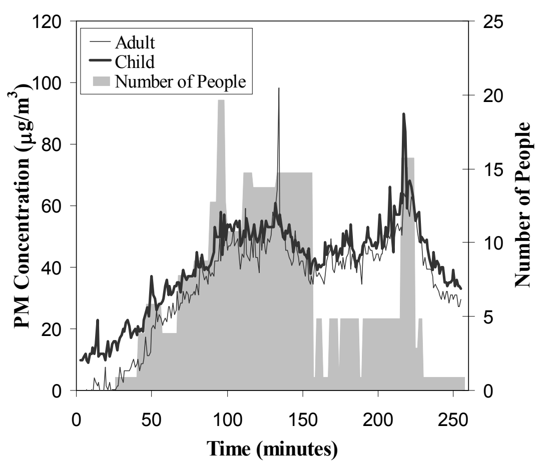

Figure 3. Time Series in Room "A"

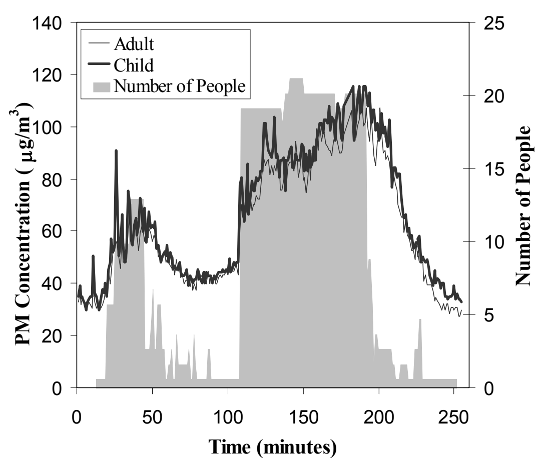

Figure 4. Time Series in Room "B"

outdoors. This finding agrees with other studies conducted on indoor and outdoor PM concentrations (Janssen, Hoek, Harssema, et.al., 1997; Monn, Fuchs, Högger, *et. al.*, 1997).

The first study found classroom concentrations were significantly higher than outdoor concentrations.

An interesting secondary finding of our study was that the number of people in the room had a dramatic effect on the PM_{10} concentrations (see Figures 3 and 4). A previous study (Monn, C., Fuchs, A., Höeger, D., *et. al.* 1997) also found that increasing numbers of people conducting ordinary activities contributed to the resuspension of PM.

While the rooms cannot necessarily be compared because there are so many structural variations between them, the difference between the lower and higher monitors in Room "A" is greater than the difference between the monitors in Room "B" (Table 1). A plausible explanation may be that the monitor in Room "A" is closer to the ground than the monitor in Room "B", resulting in a larger height difference between the monitors in Room "A". Another key difference between the two rooms is the much higher PM_{10} concentrations in Room "B". There is a 31% difference between the means of the lower monitors in the two rooms, and a 35% difference between the means of the higher monitors. If the large shag rug in Room "B" is not cleaned or shampooed, it could accumulate significant amounts of PM. The individual shag rugs in Room "B" could also contribute to PM_{10} concentrations, especially if they are cleaned infrequently. Another important difference between the rooms is that Room "B" has two doors that open to the outdoors, while Room "A" has only one. Since most PM originates outdoors and is then entrained indoors, the two doors in Room "B" could explain higher concentrations of PM_{10}. Furthermore, Room "B" is also closer to a construction site located near the daycare. Particles from the construction could be entering Room "B" more than Room "A".

While national and California statewide PM_{10}standards are evaluated over longer averaging periods than this experiment, it is still interesting to compare the results with these standards. California standards are more stringent and apply to the daycare in question. The California 24-hour standard for PM_{10} is 50 $\mu g/m^3$ and the annual standard is 35 $\mu g/m^3$. The annual average was exceeded in both rooms for averaging times of 4 hours (Table 1). In Room "A", the 24-hour average standard was exceeded and the annual average was exceeded whenever people were in the room. However, in Room "B" the 24-hour average was exceeded whenever people were in the room and the annual average was exceeded even when people were not in the room. It is possible that the annual average for Room "B" exceeds California's annual standard.

CONCLUSIONS AND IMPLICATIONS

The experiment showed that a vertical PM_{10} concentration profile existed in both rooms. Also, the PM_{10} concentrations increased substantially when people were in the room and indoor concentrations were confirmed to be higher than outdoor concentrations. The California annual average was exceeded in Room "A" and Room "B" 72% and 97% of the time, respectively (Figures 3 and 4). These results are based on a single day of measurement so additional measurements could improve the statistical confidence in our findings. More representative and accurate measurements could be obtained by attaching personal monitors to the child, although this would be difficult for young children.

Potential occupational exposure has been analyzed extensively in the adult environment. Equal attention should be given to children's environments. Many children in the United States spend significant amount of time in daycares. This study has showed that these children can be exposed to substantial amounts of PM_{10}. While we hope that these findings will encourage indoor standards to reflect the observations of this study, the effects of more practical changes (e.g., cleaning, ventilation, floor covering, etc.) should be assessed further.

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