PRELIMINARY STUDY OF FLOORING IN SCHOOL IN THE U.S.: AIRBORNE PARTICULATE EXPOSURES IN CARPETED VS. UNCARPETED CLASSROOMS

RJ Shaughnessy[1*], B Turk[2], S Evans[3], F Fowler[3], S Casteel[3] and S Louie[3]

[1]University of Tulsa, Dept of Chemical Engineering, Tulsa, OK, USA
[2]Mountain West Technical Associates, Santa Fe, NM, USA
[3]Arkansas Dept of Health, Dept of Epidemiology, Little Rock, AR, USA

ABSTRACT
Data sets from 16 schools (grades K-6 and a Junior High), spanning 5 southwestern states in the USA, have been analyzed to examine classroom airborne particulate levels and the buildup of contaminants on flooring systems. The data have been collected from 2 separate sites (one carpeted, one hard flooring) within each of the schools. Measurements included indoor/outdoor airborne particulate mass concentration ($PM_{2.5}$), indoor/outdoor particulate counts (> 0.5 microns), and CO_2/T/RH to characterize ventilation in the classrooms. The study must be considered more of a preliminary survey due to the limited number of schools examined. A comparative analysis of the data sets suggests that school carpeted floor covering may present an increased exposure risk to children from particulate matter harbored on the flooring material as compared to hard-surfaced flooring. The study emphasizes the need for fastidious maintenance of all types of floor coverings in schools.

INDEX TERMS
Particulates, Carpets, Schools, Floor coverings, Exposures

INTRODUCTION
Floor Covering in schools has continued to create controversy in recent years as to what may be best suited for environments with susceptible populations (Dybendal and Elsayed, 1994; Hedge, 2001; Ott, 1998; Roberts, 1998; Hodgson, 1999; Chandra, 2000). Recognizing the trend toward dwindling budgets being allocated to school maintenance and operations, floor coverings that require diligent attention to prevent buildup of contaminants may present a challenge for school officials and maintenance personnel. Flooring materials can serve as a reservoir for bacteria, fungi, and other microorganisms which have been isolated from carpet and vacuum dust (Kozak,P., *et al.*, 1980; Wickman, M., *et al.*, 1992). Carpet cannot be considered as a homogeneous group of floor coverings. There are significant differences that may impact the flooring performance over time related to carpet weave type, face weight, pile height, density (including stitches/inch), backing, and adhesive requirements. Carpeted floor coverings have been promoted as acting as a filter for capturing dirt, contaminants and allergens that would otherwise become airborne. This would also directly imply that the dirt is then held until it is periodically removed by cleaning of the carpets. Hedge (Hedge, 2001) states that "As long as schools keep floors clean and use high-efficiency microfiltration vacuum bags, carpets can be a healthy, safe, and economical floor covering in schools and day-care centers." The validity of this statement may be more dependent on the ability of the school to properly maintain and keep carpets clean. Carpets may act as a reservoir for dirt,

* Contact author email: rjstulsau@aol.com

however if not kept clean, these contaminants may be re-released with occupant activity. A comprehensive study of flooring in 1996 (Cole, *et al.*) reported that flooring surface pollutants can contribute to and be reflective of airborne levels, and airborne levels can contribute to and be reflective of surface contamination. Previous studies indicate that carpeted floors accumulate significantly more dust, proteins and allergens per unit area than smooth floors (Dybendal and Elsayed, 1994). Studies have suggested elevated levels of fungal allergens and airborne particulate levels are not uncommon in schools (Shaughnessy, *et al.*, 1995; Levetin and Shaughnessy, 1995; Shaughnessy and Turk, 1997). In this paper, paired sets of data from 16 schools have been examined to explore differences in airborne particulate levels from rooms of carpeted vs. hard flooring surfaces. Rooms were selected based on flooring type, and similar occupant and ventilation characteristics.

METHODS

Sixteen schools were included in the study from 5 different states: New Mexico, California, Texas, Oklahoma, and Arkansas. Except for the Arkansas schools, the schools were randomly selected as part of individual district efforts to incorporate The US EPA's Tools for Schools Program (US EPA, 1996) in their district. The Arkansas schools were selected based on identification of children with asthma in the district. For each school a room with hard-surfaced flooring and room with carpeted flooring was selected for the study sites. The rooms were selected as best possible to have similar occupancy/activity throughout the school day, similar space allocation, and similar HVAC operation. The carpeted flooring typically was comprised of commercial loop pile carpet with flow-through backing, slab on grade. Average age of the carpet was 8 years. Cleaning regimen typically consisted of vacuuming carpets with lo-efficiency vacuums at the end of each school day, and dry mopping of hard surfaced flooring. None of the schools had engaged in deep cleaning of the carpets within 3 months of the measurements being taken. All classroom measurements were taken with windows close in the rooms and the HVAC system operating. Measurements taken at each location include:

$PM_{2.5}$ particles- Airborne particle mass concentration measurements were taken in 5 of the schools using a particulate mass impactor (particles < 2.5 microns) onto a 37mm Teflon pre-weighed filter at a flow of 10 Lpm. Impactors were placed approximately 1 meter from the floor for all samples. Filters were gravimetrically analyzed and results reported as micrograms/m^3 of air. Replicate samples were collected. Uncertainty in the $PM_{2.5}$ measurements based on replicate results and a previous study averaging propagation of error analyses is $\pm$ 9% of the reported value (Shaughnessy and Turk, 1995).

Particle counts/m3 > 0.5 microns- Airborne particle concentration measurements were taken indoors and outdoors with portable, laser-diode based optical particle counters and reported as particles/meter^3 for all particles > 0.5 micron. The optical particle counters were calibrated by the manufacturer prior to testing. All particle counter readings were $\pm$ 5% of the monitor readouts for all counters. The mean particle counts for the occupied classroom time are reported for each set of data.

Carbon dioxide/temperature/humidity- Measurements were taken with non-dispersive infrared based CO2 data-logging units with temperature/relative humidity capabilities. The units were calibrated with both zero and span gas prior to each set of tests in a school.

Floor dust samples- Dust samples were collected from flooring of 5 of the schools using a High Volume, Small-surface Sampler (HVS3). Procedures for collection of floor dust have been previously described (Cole, *et al.*, 1993). Samples were collected for a period of 10

Table 1. Classroom data; Hard surface vs Carpeted flooring

Site	*Flooring*	*Age carpet (yrs)*	*$PM_{2.5}$ (ug/m3)*	*Mean Particle cnts/m3 > 0.5 u*	*HVAC system*	*CO2 Max (ppm)*	*# kids*	*grams of dirt/m2*
Br, AR	Tile		9	3.3×10^6	closet ahu	950	15	.015
Br. AR	Carpet	9	22	7.4×10^6	closet ahu	1250	15	50
BR, AR	Outdoors		6	1.01×10^6				
Be, AR	Concrete		4	3.9×10^6	heat pump	2550	20	.21
Be, AR	Carpet	10	8	6.9×10^6	heat pump	3100	15	29
Be, AR	Outdoors		9	3.9×10^6				
Ma, AR	Tile		14	7.2×10^6	closet ahu	2550	17	.14
Ma, AR	Carpet	8	17	6.9×10^6	closet ahu	2050	10	7.7
Ma, AR	Outdoors		7	2.1×10^6				
Ca, AR	Tile		17	9.0×10^6	rooftop ahu	3450	15	.096
Ca, AR	Carpet		25	13.0×10^6	rooftop ahu	2400	16	23
Ca, AR	Outdoors		19	---				
Co, Ar	Tile		11	6.3×10^6	central ahu	------	24	.055
Co, AR	Carpet	10	19	7.5×10^6	central ahu	------	15	99
Co, AR	Outdoors		13	4.1×10^6				
Br, TX	Tile		---	5.3×10^6	heat pump	2500	16	---
Br, TX	Carpet	5	---	6.5×10^6	heat pump	2800	15	---
Br, TX	Outdoors		---	3.6×10^6				
Si, TX	Tile		---	8.9×10^6	unit ventilat	4400	27	---
Si, TX	Carpet	4	---	15.0×10^6	unit ventilat	3600	29	---
Si, TX	Outdoors		---	9.4×10^6				
Jh, TX	Tile		---	2.5×10^6	rooftop ahu	1250	4	---
Jh, TX	Carpet	10	---	5.6×10^6	rooftop ahu	1500	3	---
Jh, TX	Outdoors		---	2.7×10^6				
Fe, TX	Tile		---	5.6×10^6	closet ahu	3200	20	---
Fe, TX	Carpet	10	---	6.8×10^6	closet ahu	3100	17	---
Fe, TX	Outdoors		---	9.1×10^6				
Wo,TX	Tile		---	3.9×10^6	rooftop ahu	2800	21	---
Wo,TX	Carpet	5	---	7.7×10^6	unit ventilat	4950	17	---
Wo,TX	Outdoors		---	6.3×10^6				
Ce, CA	Tile		---	4.1×10^6	heat pump	3000	15	---
Ce, CA	Carpet	3	---	5.0×10^6	rooftop ahu	600	23	---
Ce, CA	Outdoors		---	5.3×10^6				
Cd, CA	Tile		---	5.0×10^6	rooftop ahu	650	8	---
Cd, CA	Carpet	2	---	7.2×10^6	rooftop ahu	750	16	---
Cd, CA	Outdoors		---	6.8×10^6				
Be, OK	Tile		---	8.0×10^6	radiant heat	2450	20	---
Be, OK	Carpet	15	---	14.0×10^6	radiant heat	2800	20	---
Be, OK	Outdoors		---	1.0×10^6				
Ce, OK	Tile		---	4.0×10^6	rooftop ahu	1500	22	---
Ce, OK	Carpet	16	---	3.5×10^6	rooftop ahu	1050	10	---
Ce, OK	Outdoors		---	3.6×10^6				
Cj, NM	Tile		---	8.1×10^6	rooftop ahu	3400	---	---
Cj, NM	Carpet	5	---	8.8×10^6	rooftop ahu	3650	---	---
Ce, NM	Tile		---	8.2×10^6	heat pump	2000	21	---
Ce, NM	Carpet		---	18.0×10^6	heat pump	2000	17	---
Ce, NM	Outdoors		---	1.7×10^6				

minutes /m2 floor area. Carpeted areas were drawn out in random templates for collection. Dust was sieved and all dust < 300 microns was weighed and recorded.

RESULTS

A summary of site information and measurements is presented in Table 1.A review of Table 1 reveals several important notes. T-tests for the paired measurements of particle counts and particle mass, $PM_{2.5}$, show that the airborne particle concentrations are significantly higher in rooms with carpeted floors vs. hard-surfaced floors ($P < 0.02$). (Summary statistic means on the particle count concentrations and $PM_{2.5}$ data are provided as follows: [**Carpeted particle count (pt cnt) and $PM_{2.5}$ means**: pt cnt average = 8.7×10^6; pt cnt geo mean = 7.9×10^6; $PM_{2.5}$ average = 18; $PM_{2.5}$ geo mean = 17; **Hard-surfaced particle count (pt cnt) and $PM_{2.5}$ means**: pt cnt average = 5.8×10^6; pt cnt geo mean = 5.4×10^6; $PM_{2.5}$average = 11; $PM_{2.5}$ geo mean = 9.9; **Outdoor particle count (pt cnt) and $PM_{2.5}$ means**: pt cnt average = 4.3×10^6; pt cnt geo mean = 3.5×10^6; $PM_{2.5}$ average = 11; $PM_{2.5}$ geo mean = 9.9]) In addition, carpet flooring retains significantly more dust/m2 of floor area than hard-surfaced floors as noted by the floor dust samples/m2 collected in the classrooms. Changes in indoor particle concentrations showed little dependence on outdoor concentrations and appear to be more related to occupancy patterns in the rooms. Figure 1 displays a representative plot of indoor and outdoor particle concentrations during the course of the occupied school day for carpeted and tiled classrooms. The figure again demonstrates the poor relation between indoor and outdoor particle counts.

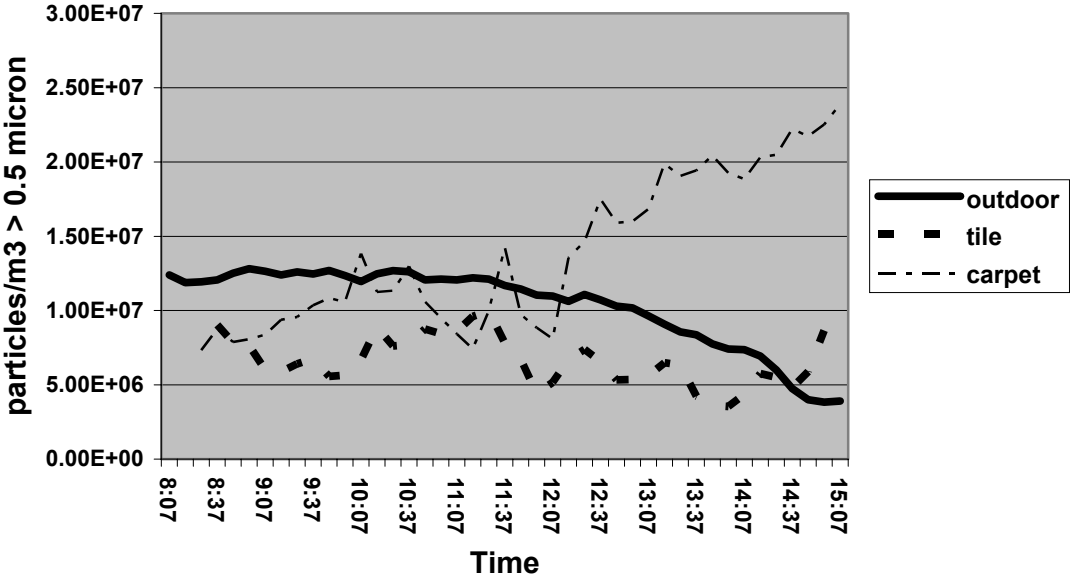

Figure 1. Indoor/outdoor particle counts/m3 during occupied school day; carpeted and tiled classrooms; School site Si, TX, tiled floor room and carpeted room.

Table 1 also reveals the similarities in the selected rooms from each school. The maximum CO2 readings give an estimate of the ventilation characteristics of each room. In most instances (due to children coming in and out during the day and lunch breaks) it cannot be assumed that equilibrium levels of CO2 have been achieved in the individual classrooms, so these maximum values cannot be used to directly calculate ventilation rates. Nonetheless, they provide some indication of the occupancy in the classrooms and at best a conservative overestimate of what the actual ventilation rates may be in the rooms. Figure 2 displays a

typical plot of carbon dioxide concentrations throughout the school day and particle counts in a classroom and outdoors. A review of the figure reveals (as in Figure 1) that indoor particle counts appear independent of outdoor particle concentrations. However, the graph demonstrates a relation between CO2 levels (occupant activity) and indoor particle concentrations, as noted by the particle concentration spikes with increases in CO2, as occupants enter the room at 8:45 am and re-enter shortly after noon from lunch. Figure 2 displays data from a tiled classroom; carpeted classrooms reveal like trends in particle behaviour related to occupant activity.

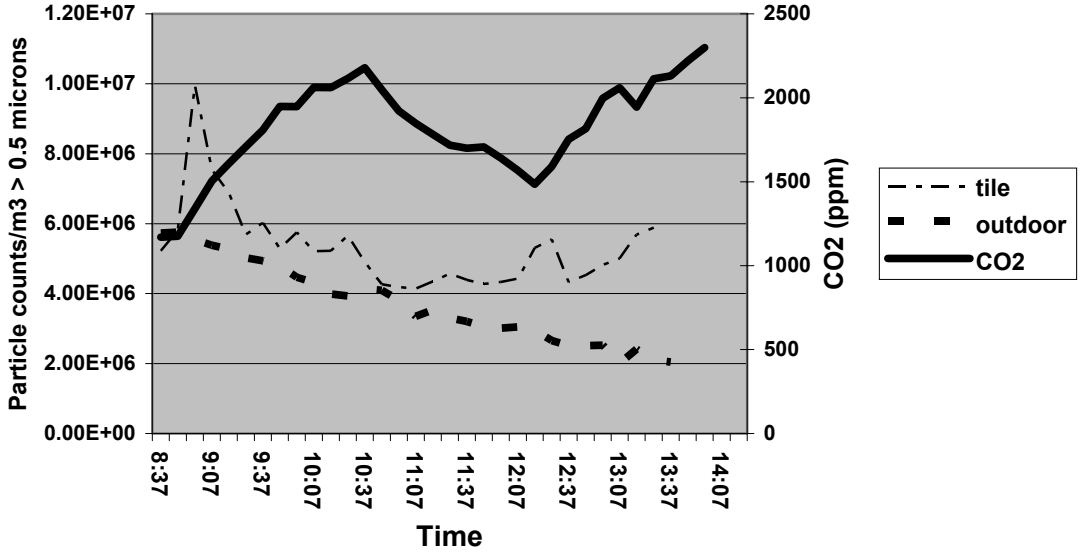

Figure 2. Indoor/outdoor particle counts and carbon dioxide concentrations during occupied school day; School Br, TX, tiled floor room.

DISCUSSION

These data suggest that children's exposure to particles in typical school classrooms may be highly dependent on type of flooring surfaces, and on occupant activity. Whereas the indoor airborne concentrations were not strongly affected by outdoor concentrations, the data indicate a marked dependence on occupant activity in the classrooms. This dependence was clear for both hard-surfaced and carpeted classrooms. In addition, carpeted classroom particulate exposures were significantly higher (as revealed by the paired t-test analyses on both $PM_{2.5}$ and particle count measurement data) than hard-surfaced flooring types. The amount of dust loading on carpeted floors as compared to the hard-surface flooring demands careful attention be paid to proper cleaning of carpeted environments. The effect of cleaning regiment on indoor airborne concentrations was not discerned from this random selection of schools due to the limited school population base. These data are suggestive of conditions that may commonly exist in schools throughout the USA.

IMPLICATIONS

Airborne particle concentrations in classrooms appear to be dependent on occupant activity during the occupied school day. This study suggests that different flooring types may impact airborne concentrations of particulates. Carpeted flooring has the potential to retain more dirt per square meter of floor area than hard surfaces. Fastidious cleaning and maintenance of all flooring surfaces in schools would appear to be a prudent course of action due to floor dust representing a biopollutant sink (reservoir) with source potential.

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