BASELINE INDOOR AIR QUALITY POLLUTANT CHARACTERIZATION IN FIVE UNITED STATES SCHOOLS

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ABSTRACT

This paper summarizes baseline results from the U.S. Environmental Protection Agency's (EPA) school demonstration studies. Indoor pollutants of concern were formaldehyde, sum of targeted volatile organic compounds (ΣVOC), carbon monoxide (CO), particulate matter less than 2.5 microns ($PM_{2.5}$), particulate matter less than 10 microns (PM_{10}), and bioaerosols (bacteria, fungi, and thermophiles). The five schools presented here had no significant indoor air quality problems. Locations of these schools were distributed throughout various climate zones in the United States. Bioaerosols results for four of the schools are presented in this paper. Samples were taken at fixed sites within the schools and were taken again a year later at the same locations after heating, ventilation and air conditioning (HVAC) upgrades were performed. This paper will present baseline maximum, minimum, average, outdoor averages and selected cumulative pollutant results for the five schools.

KEYWORDS: air quality, schools, particulate matter, $PM_{2.5}$, PM_{10}, VOC, radon, formaldehyde

INTRODUCTION

Comparative risk studies performed by EPA and its Science Advisory Board consistently rank indoor air pollution among the top five environmental risks to public health. Schools are unique since they have many occupants in close proximity; they have a variety of pollutants; strained budgets often contribute to inadequate infrastructure maintenance; and children breathe a higher volume of air relative to their body weight, making indoor air quality in schools of particular concern [1].

This paper provides baseline results of indoor air quality pollutant monitoring conducted within five U.S. elementary and secondary schools prior to indoor air quality improvement interventions. These baseline data are representative of expected pollutant levels in schools which were considered as having no significant indoor air pollution problems.

At each school, sampling was performed over a one-week period. Data were collected according to specified standardized EPA protocols [2]. Data were collected for pollutant as well as comfort parameters. Intervention data will be published in future papers.

METHODS

Building Selection

Schools were selected to be representative of typical kindergarten through twelfth grade, public schools in various U.S. climate zones [3]. Three of the five schools were in humid

climates and two were from mild to dry climates. None of the schools were selected because of known, serious indoor air quality (IAQ) problems. Candidate schools were also evaluated based upon building construction type, size and age; existing mechanical/HVAC systems and control strategies; and maintenance programs. Site visits were performed to verify selection criteria prior to final selection [4].

Monitoring Protocols

Baseline IAQ measurements and HVAC characterization were completed prior to upgrades of energy systems. IAQ ventilation measurements were conducted in accordance with the Building Assessment Survey and Evaluation (BASE) protocol [5] and modified for use in schools [2]. The schools were sampled over a three-day period during occupied school hours.

Monitoring instruments were deployed at four indoor sampling locations and one outdoor location, and near the outdoor air intake (where practical). Continuous IAQ measurements were taken for CO and for radon at four of the schools. One school was sampled using charcoal canisters. Integrated measurements included: respirable particles (PM_{10} and $PM_{2.5}$), ΣVOCs, formaldehyde, and bioaerosols.

Carbon monoxide measurements were made using an aqueous electrolyte-based detector. Data loggers were set up for data acquisition at a rate of one reading per second and averaging of data over five minutes for both indoor and outdoor CO sensors.

Two types of sampling methods were used to detect radon gas. At the New Jersey school, EPA-approved charcoal canisters were placed on the ground contact level of the building at a rate of approximately one canister for every 465 m^2 of floor area. Additionally, a sampler was placed at each indoor fixed sampling site. The canisters were set out on Monday and collected on Thursday (a three-day sample). At all the other schools listed in this paper, radon was detected using an ionization chamber connected to a data recorder. The recorder sampled and averaged the data every five minutes during occupied hours.

A modification to EPA Method TO-11 was used to measure formaldehyde. This method utilizes silica gel tubes coated with 2,4-dinitrophenylhydrazine reagent to collect the targeted compound. The silica gel was contained in a cartridge; samples were placed at each indoor site and at the outdoor site. Samples were collected over an eight- to ten-hour period. Personal sampling pumps were used to draw a known volume of air through the cartridges, which were set using a calibrated rotometer at nominal flow rates of 125 cubic centimeters (cc) of air per minute. Formaldehyde was trapped on the reagent-coated silica gel as air was drawn through the cartridge.

Sampling and analysis for 56 individual VOCs were conducted using validated protocols as specified in EPA Method TO-14 [6] using passivated stainless steel canisters.

Particulate samples were collected on filters through one of two impaction nozzles. Sizes presented here are results of PM_{10} and $PM_{2.5}$. Air was drawn through the filters at a rate of either 10 liters per minute (lpm) or 20 lpm for eight hours. Flow rates were measured pre and post sampling with calibrated rotameters. Filters were weighed before and after exposure in a temperature and humidity controlled room.

Samples for bioaerosols were collected using a single-stage impactor sampler operated at the manufacturer's suggested flow rate of 28.3 liters/min. Fungal isolates were cultured on malt extract agar and incubated at 23°C for three to five days. Samples were collected at an outdoor site and at four indoor sites at each school in the morning and the afternoon. Two sampler operation times were used at each location during each sampling period. At three of the schools, samples were collected for two and five minutes. At one school (Texas) samples were collected for two and four minutes. Fungal genera were classified based on colonial morphology and microscopic examination. The numbers of colony forming units (CFU) were recorded and coincidence corrected according to the sampler manufacturer's recommendations. The numbers of colony forming units per cubic meter of air sampled (CFU/m^3) were calculated for all air samples. Data within the quantitative range of the prescribed protocol were averaged for both indoor and outdoor locations. Plates with no growth were given a value of 0 CFU/m^3 for averaging the data.

RESULTS

Minimum and maximum and average data will be presented for each school. Two values were averaged for outdoor samples. Data will be compared to specified standards or similar industry guidance for the given pollutants.

Carbon Monoxide - While not an enforceable standard in indoor air, the U.S. EPA's National Air Quality Standard (NAAQS) for CO is 35 parts per million (ppm) for a one-hour average exposure and 9 ppm for an eight-hour exposure (EPA 40 CFR 50.8.1992) [7]. Based on this EPA standard, ASHRAE established an indoor air quality standard of 9 ppm of CO for an eight-hour average exposure [8]. All results were either less than the detection limit (2 ppm) or less than EPA's eight-hour exposure limit of 9 ppm.

Radon - The EPA action level for radon in air in residential and school occupancies is 4.0 picoCuries/liter (pCi/L). None of the data exceeded EPA guidelines. Table 1 lists the maximum, minimum, and average values for radon for five schools. No sampling for radon was performed outdoors.

Table 1. Results of Baseline Radon Sampling at Five U.S.A. Schools

Measured Radon Concentration (pCi/L)					
	California (CA)	Colorado (CO)	Minnesota (MN)	New Jersey (NJ)	Texas (TX)
Max.	1.6	2.2	1.3	1.3	3.3
Min.	0.8	1.1	< 1	< 1	1.2
Avg. ± s*	1.1 ±.4	1.6 ± .5	< 1	< 1	1.9 ±1.0

*Avg. ∀ s / Average ∀ One Standard Deviation.

Formaldehyde and Total VOCs - Maximum, minimum, and average results of formaldehyde and total VOCs sampling are listed in Table 2. Results are presented in ΣVOCs. The values listed represent the sum of 56 separate compounds.

Table 2. Results for Formaldehyde and Total Volatile Organic Compounds

Formaldehyde (ppb)*				
State	Maximum	Minimum	Indoor (I) Avg. ± s	Outdoor Avg.
CA	8.3	7.1	7.5 ± .5	2.2
CO	12.4	7.1	9.8 ± 2.5	3.6
MN	8.9	6.1	7.1 ± 1.1	1.4
NJ	26.8	7.4	13.2 ± 7.7	3.4
TX	11.3	7.1	8.1 ± 1.8	2.8
ΣVOCs ($\mu g/m^3$)***				
State	Maximum	Minimum	Avg. ± s	Outdoor Avg.
CA	242	90	134.7 ± 64	61
CO	195	161	180.0 ± 14	103
MN	135	81	108.6 ± 25	30
NJ	234	149	204.6 ± 39	80[1]
TX	268	193	230.1± 34	136

*The World Health Organization recommends 0.08 ppm (80 parts per billion [ppb]) as a maximum 30-minute average to prevent indoor air complaints from sensitive individuals in non-industrial buildings [9].
**No prescribed guidelines exist for the sum of targeted VOCs (ΣVOCs) reported in this study.
[1]Not an average, i.e., only one data point.

Particulates - The U.S. EPA's National Ambient Air and Quality Standards (NAAQS), as revised, September 16, 1997 set the twenty-four hour standard for PM_{10} at 150 $\mu g/m^3$. The current EPA criteria for $PM_{2.5}$ is an annual average of 15 $\mu g/m^3$ and a twenty-four hour average of 65 $\mu g/m^3$. Table 3 gives the maximum, minimum, and average values for each school. The data indicated that no values exceeded EPA's NAAQS twenty-four hour average standard for PM_{10} and $PM_{2.5}$.

Table 3.Results for PM_{10} and $PM_{2.5}$

PM_{10} ($\mu g/m^3$)				
State	Maximum	Minimum	I Avg. ± s	Outdoor Avg.
CA	42	25	34 ± 8	19
CO	61	29	43 ± 13	50
MN	72	23	48 ± 24	9
NJ	44	15	27 ± 12	10
TX	56	43	48 ± 5	10
$PM_{2.5}$ ($\mu g/m^3$)				
CA	10	5	7.5 ± 3	4
CO	21	12	16 ± 4	25
MN	10	3	7.2 ± 3	3
NJ	16	7	11 ± 4	8
TX	12	10	11 ± 1	6

Bioaerosols - The percent incidence of each fungal genus isolated at the four schools sampled is listed in Table 4. *Alternaria*, *Aspergillus*, *Cladosporium*, *Penicillium*, yeast, and other not identified fungi were isolated at every school studied. For all surveys, variations were observed in the mean concentrations of airborne microorganisms between the morning and afternoon sampling periods. The data also suggest that extended sampling times do not result

in higher concentrations per cubic meter of air sampled but that the extended sampling times contributes to overloading of the agar surfaces and may result in decreased number of CFU/m^3 due to sampling stress. The results of this study support the concept that the selection of sampling time (volume of air to be sampled) and time of day for sample collection are important considerations in designing an indoor air sampling protocol for bioaerosols.

Table 4. Incidence of Airborne Fungal Genera on Indoor and Outdoor Samples Collected at Four U.S. Schools Identified by State

(I = indoors; O = outdoors; Other = unknown fungi and non-sporulating mycelia; n = 20 for indoor samples at schools 1, 2 and 4; n = 12 for indoor samples at school 3; n = 8 for outdoor samples at schools 1 and 4; n = 7 for outdoor samples at schools 2 and 3).

Genus	Minnesota (1)		Colorado (2)		California (3)		Texas (4)	
	% Incidence		% Incidence		% Incidence		% Incidence	
	I	O	I	O	I	O	I	O
Acremonium	5	13			8	14		
Alternaria	35	50	35	29	58	100	95	63
Aspergillus	5	0	75	100	17	86	30	13
Aureobasidium							10	0
Beauveria	0	13	5	0				
Bipolaris			5	0	8	14	25	38
Botrytis					0	14		
Chaetomium					0	29		
Chrysosporium	10	0						
Cladosporium	85	75	80	100	100	100	100	100
Curvularia	0	13			25	0		
Doratomyces	5	0						
Epicoccum			20	14	33	29	70	100
Fusarium			15	0			15	0
Geotrichum			5	0				
Penicillium	20	13	60	86	100	100	60	38
Rhizopus			10	14			5	0
Sporotrichum			5	0				
Trichoderma					8	0		
Trichothecium			0	14				
Ulocladium					17	14		
Yeast	65	50	55	86	83	100	45	63
Other	50	63	85	86	100	100	100	100

There are currently no health-based guidelines for the concentration of airborne bacteria and fungi in the indoor air of classrooms. The American Conference of Governmental Industrial Hygienists (ACGIH), which previously published some numerical suggestions for standards [10], cites in a 1999 publication [11] several reviews by several research groups including Rao et al. [12] and Maroni et al. [13] to assist in data interpretation. The ACGIH no longer support numerical criteria for interpreting data on biological contaminants from air samples in non-manufacturing environments.

Table 5. Average of Total Airborne Fungi Isolated Indoors and Outdoors in Four U.S. Schools Identified by State (S.E. = standard error; * = mean of 8 samples, 12 out of20 samples were > 10^4 CFU/m^3).

School	Indoor	Outdoor
	Mean fungal CFU/m^3 ± 1 S.E.	
Minnesota (1)	121 ± 27	457 ± 179
Colorado (2)	184 ± 24	863 ± 84
California (3)	823 ± 149	6753 ± 2651
Texas (4)	1701* ± 268	> 10^4

DISCUSSION

The data presented here can provide a benchmark for future indoor air pollutant research in United States public schools from kindergarten through twelfth grades. In the future, the U.S. EPA will be providing results for the second phase of these studies, i.e., after HVAC system upgrades.

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