MONITORING INDOOR AND OUTDOOR AIR POLLUTANTS IN A SALT LAKE CITY ELEMENTARY SCHOOL

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ABSTRACT

This study looks at the validity of the UDOH Guideline to keep respiratory sensitive students indoors during poor air quality days as defined by an Air Quality Index (AQI) >100 and particularly as it may affect elementary school children. Indoor and outdoor air measured particle mass, particle counts at different sizes, and volatile organic compounds (VOCs) were sampled at a Salt Lake City (SLC) elementary school. Three indoor/outdoor pairs of VOC samples were collected using evacuated canisters during different AQI values. Indoor particulate matter of aerodynamic diameter 2.5 microns or less, $PM_{2.5}$, was measured using a tapered element oscillating microbalance (TEOM) located in the school library. These were compared to outdoor TEOM Filter Dynamic Measuring System (FDMS) measurements. Particle counts were measured using Grimm aerosol spectrometers and segregated into particle sizes ranging from 0.3 to 20+ microns. All measurements were taken in the school library, at the nearby Utah Division of Air Quality's (UDAQ's) monitoring station, or on the roof of the school. The results suggest that staying indoors during elevated AQI days does reduce exposure to particulate matter, while only slightly increasing exposure time to low concentrations of VOCs normally found within schools.

INTRODUCTION

The UDAQ monitors air pollutants and reports those values in an AQI (see www.airquality.utah.gov). The Utah Department of Health (UDOH) uses this index to issue health advisories both to respiratory sensitive individuals and, when necessary, to the general populace. These advisories recommend respiratory sensitive individuals stay indoors during AQI levels >100, and that the public reduce outdoor activities during AQI levels >150. In the Utah Wasatch winter, the most common cause for elevated AQI levels is $PM_{2.5}$, which is often associated with temperature inversions that trap and hold exhaust from combustion sources like vehicle exhausts or smoke stacks.

One group particularly affected by these advisories is school districts. Elevated $PM_{2.5}$ is associated with increased asthma symptoms in asthmatic individuals. According to the UDOH,

there are an estimated 61,000 school age children with asthma in Utah. This represents 8% of the total Utah school population. A majority of these students attend schools in communities nestled near the Wasatch Mountain range where the effects of temperature inversions and high density populations combine to exacerbate unhealthy environmental conditions. Given these facts, the UDOH has published Guidelines that schools may consult as they consider whether to allow, recommend or require students stay indoors in response to the AQI based advisories.

To validate use of the UDOH Guidelines, a winter 2004-2005 study was performed which measured the indoor and outdoor $PM_{2.5}$ (Nye, 2005). That study reported indoor $PM_{2.5}$ levels were statistically lower than outdoor levels, especially during high outdoor particulate days. While these data suggest that respiratory sensitive individuals may experience a reduced exposure to particulate pollutants indoors on these days, there is also evidence that indoor environments may be linked to an increase in asthmatic symptoms (Richardson 2005).

Unknown

Although the initial study (Nye, 2005) identified lower levels of particulate matter inside, it did not identify the size of the particulates that are intruding into the building; nor did it consider other non-particulate components which may influence lung function.

Design Question

Is the guideline to keep Utah school children indoors during high particulate days justified? The goal of this study is to gain a better understanding of the relationship between outdoor and indoor air quality and the relative risks associated with staying indoors verse playing outside on high AQI days.

Design

The study took place in two parts on the Hawthorne Elementary School starting on January 25th and proceeding to February 28th 2006 (five weeks). Part 1) three indoor/outdoor volatile organic compound (VOC) sample pairs were collected using vacuum canisters on different AQIs and analyzed using gas chromatograph/mass spectrometer. Part 2) TEOM indoor and TEOM FDMS outdoor $PM_{2.5}$ mass was collected, analyzed, and compared hourly to Grimm aerosol spectrometer estimated mass during the aforementioned five week period.

Background & Literature review

Current literature on potential causes of asthma is vast and complicated. In December 2004, the American Academy of Pediatrics concluded that the National Ambient Air Quality Standards were insufficient at protecting health in children, and called for a critical reevaluation of those standards (Pediatrics 2004). Richardson *et al* point out "there is currently not enough evidence to prove that reducing exposure to indoor allergens and pollutants will reduce respiratory illnesses, apart from reducing exposure to dust mite allergen" (Richardson 2005). Much of the evidence points to relationships between lung function or asthma and exposure to particulate matter (Delphino 2003; Delphino 2004; Koenig 2005). However, there is some evidence to

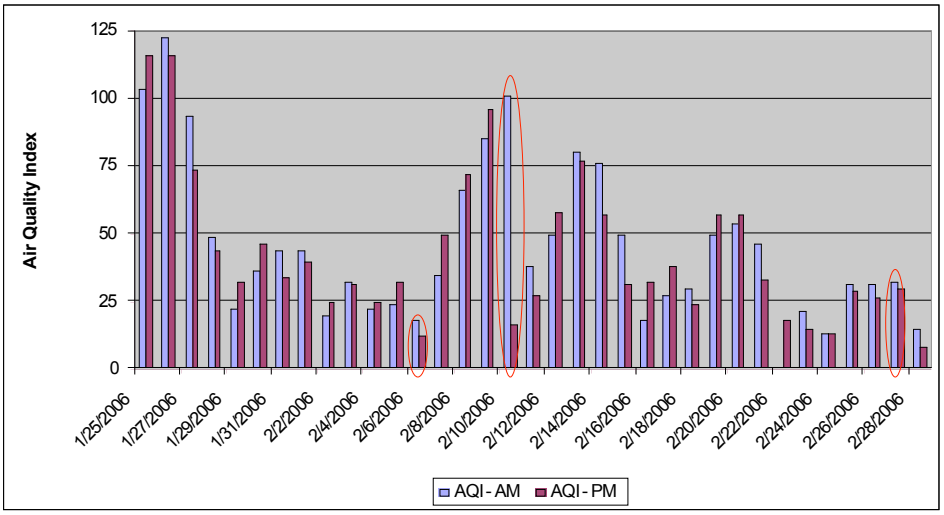
believe a similar relationship exists between lung function or asthma and ozone, sulfur dioxide, nitrogen dioxide, VOCs (Kim 2005) and other chemicals (Pediatrics 2004).

This study took place on the campus of the aforementioned SLC elementary school. It was chosen due to the presence of an UDAQ outdoor monitoring station for EPA air criteria pollutants. These stations provide continuous measurements for ozone, particulate matter (PM_{10} and $PM_{2.5}$), carbon monoxide, sulfur dioxide and nitrogen dioxide. Each pollutant level is associated with an AQI and twice daily (morning and afternoon) the highest of these values is reported as the current AQI for this location. At AQI > 100 the UDOH recommends that respiratory sensitive individuals stay indoors, and at AQI > 150 UDOH recommends the public reduce outdoor activity.

METHODS

VOC Monitoring

Figure 1: Air Quality Index values morning and also afternoon in SLC January 25th to February 28th; circled days are dates when VOC samples were taken.



Note: There were very few days where the AQI value exceeded 100, which indicates mild winter pollutant conditions.

Three indoor/outdoor pairs of VOC samples were collected on select days using Summa (evacuated) canisters during different AQI events (see figure 1). These canisters were placed indoors in the school library and outdoors either on the school roof or at the UDAQ monitoring station. Indoor canisters were placed on top of a 4 foot high bookshelf and 10 feet from any wall. Monitoring was begun between 9 and 10 am and lasted for 6 hours. Care was taken to ensure that at least one sample pair was taken during an elevated particulate event, AQI ≥100 (February 10th). The canisters were submitted to Datachem Laboratories Inc., which analyzed for 51 target VOCs and estimated levels of other chemicals as tentatively identified compounds. Post-analysis, an effort was made to determine the source of each VOC by looking at common uses of the identified chemicals and comparing with Material Safety Data Sheets (MSDSs) for known supplies.

Particulate Monitoring

Particulate mass and size counts were measured using different instruments in close proximity. Hourly averaged $PM_{2.5}$ indoor mass/m^3 was measured with a TEOM located along a wall in the school library. Hourly averaged $PM_{2.5}$ outdoor mass/m^3 was measured with a TEOM FDMS at the UDAQ monitoring station. Hourly averaged particle counts were measured using Grimm aerosol spectrometers (model 1.108) were likewise placed in the school library and UDAQ monitoring station. This equipment segregates particles into 15 sizes ranging from 0.3 to 20+ microns. The two largest sizes were considered unreliable due to inlet loses and excluded from analysis. All counts were converted to estimated mass/m^3 using the formula:

Equation 1

$$\frac{Mass_PM}{Volume_air} = \frac{\rho N \pi d^3}{6} = \frac{N}{m^3_air} x \frac{\rho g}{m^3_PM} x \frac{d(m)^3}{} x \frac{10^6 \mu g}{g}$$

where $\rho = density = \frac{10^6 g}{m^3_PM}$ and d is the diameter in meters

A comparison was made of TEOM vs Grimm mass/m^3. Hourly average particle mass/m^3 was compared using both methods in a linear regression model. Charts are shown at critical points for visual comparison of particle size count over time and mass under different AQI conditions.

RESULTS

VOC results

Table 1: Reported AQI values in morning and afternoon with detected levels of VOCs in parts per billion.

	February 6		February 10		February 27	
Chemical	Inside	Outside	Inside	Outside	Inside	Outside
Propene	3.3	1.7	2.3	1.8	3.8	2.6
Freon 12	3.5	0.6	1	0.63	3.7	0.62
Chloromethane	0.69	ND	0.58	**0.95**	1.1	0.91
Methylene Chloride	0.34	ND	0.35	ND	0.33	0.6
Hexane	1	0.35	1.1	ND	0.97	ND
Benzene	0.77	0.58	0.72	ND	0.45	0.24
Heptane	0.92	ND	1.9	ND	0.59	ND
4-Methyl-2-Pentanone (MIBK)	1.1	ND	0.86	ND	2.2	ND
Toluene	3.3	0.84	2.7	0.34	2	0.48
Ethylbenzene	ND	ND	ND	ND	0.19	ND
Tetrachloroethene (PCE)	0.15	ND	ND	ND	ND	ND
m, p-Xylene	0.64	0.32	0.63	ND	3.3	0.4
o-Xylene	0.21	ND	0.21	ND	0.28	ND
1,2,4-trimethylbenzene	0.12	ND	0.12	ND	0.14	ND
Acetone	9.7	4	16	12	12	3.7
Freon 11	6.1	0.24	6.7	0.38	22	0.27
Isobutane	ND	ND	ND	ND	4.9	ND
Butane	ND	ND	ND	**2.7**	2.9	ND
Hexane, 3-methyl	ND	ND	2.3	ND	ND	ND
Ethanol	140	1.6	340	11	160	5.3
Isopropyl Alcohol	35	0.76	45	ND	34	ND

VOC measurements are recorded in table 1. ND means the chemical was not detected. Highlighted values are below the limit of quantification. Highlighted chemicals are those tentatively identified by mass spectrometry analysis. Bolded values within the table indicate when the outdoor levels exceed the indoor levels. Bolded chemical names indicate chemicals that were traced to MSDSs of products in the school.

Table 2: Some known uses of the identified VOCs.

Chemical	Cleaning Supplies	Graffiti Remover	Dry Erase Marker	Refrigerant	Fragrance/ Deodorant	Oil/Fuel (Additive)	Solvent
Propene						X	
Freon 12	X*			X			
Chloromethane	X			X@			
Freon 11				X			
Methylene Chloride	X*				X		X
Hexane						X	
Benzene						X	
Heptane						X	
4-Methyl-2-Pentanone (MIBK)			X				X
Toluene	**X**	**X**	X			X	X
Ethylbenzene						X	X
Tetrachloroethene (PCE)							X
m, p-Xylene						X	X
o-Xylene						X	X
1,2,4-trimethylbenzene						X	
Acetone	**X**	**X**				X	X
Isobutane	**X,** X*	**X**		X	X	X	
Butane	**X,** X*			X@	X	X	
Hexane, 3-methyl							X
Ethanol	**X**	**X**	X			X	X
Isopropyl Alcohol	**X**	**X**			X	X	X

Bolded **X** is confirmed use
* – used as aerosol propellant
@ – historic use

The levels of VOCs reported in table 1 are well below occupational exposure limits. With the exception of two chemicals, chloromethane and butane, VOC levels indoors are slightly higher than outdoors. Table 2 shows that many of these chemicals are used in common everyday applications such as cleaning supplies and refrigerants, and in education-specific arenas like graffiti removal and dry erase markers. Staying indoors appears to expose people to slightly higher levels of VOCs, but the indoor levels observed in this study were about three orders of magnitude below the current recommended occupational exposure limits. Moreover, it appears that levels of VOCs are largely independent of outdoor particulate levels with one possible exception. On February 10th, a high particulate day, chloromethane and butane were identified outdoors in higher concentrations than indoors. It is not clear if this exception was due to some outdoor activity or has some relationship to particulate pollution (e.g. vehicle exhaust).

Particulate Results

Table 3: Particle Mass/m^3 statistics using TEOM and Particle Count methods

	Observations	Mean	Std Dev	Range
Outside (TEOM FDMS)	765	14.07	13.80	-4.5 to 82.6
Outside (GRIMM)	765	2.63	2.60	0.2 to 14.9
Inside (TEOM)	796	1.70	2.01	-0.3 to 12.8
Inside (GRIMM)	796	0.39	0.34	0 to 3.2

Note: negative values are a result of the TEOM's effort to self correct.

As indicated in the previous study (Nye, 2005), particulate mass is statically higher outdoors than indoors especially during periods of temperature inversions. Table 3 shows statistics on $PM_{2.5}$ mass/m^3 measured by the TEOM, TEOM FDMS and the Grimm aerosol spectrometer. In each case, there is a statistically higher value outside over inside. This is seen by comparing indoor hourly average mass to outdoor hourly average mass using a paired t-test. For the indoor TEOM $PM_{2.5}$ vs. outdoor TEOM FDMS $PM_{2.5}$ the test yields statistical difference ($n=765$, $p<0.0000$). The same result occurs when comparing indoor vs. outdoor Grimm estimated $PM_{2.5}$ ($n=765$, $p<0.0000$). Furthermore, the TEOM $PM_{2.5}$ mass/m^3 is consistently higher than the Grimm estimated mass/m^3.

Figure 2: Linear regression model comparing outdoor TEOM FDMS $PM_{2.5}$ mass/m^3 to outdoor Grimm estimated $PM_{2.5}$ mass/m^3.

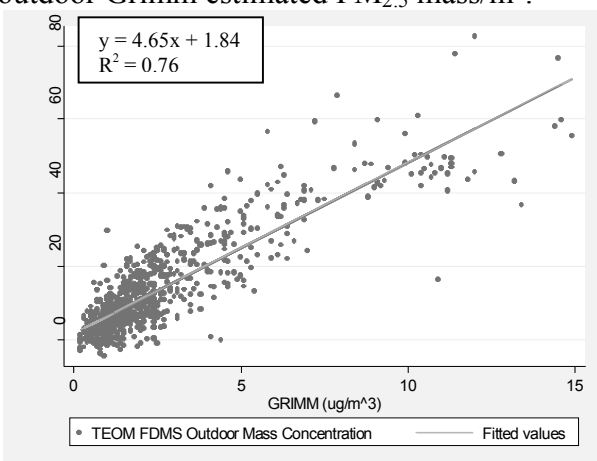
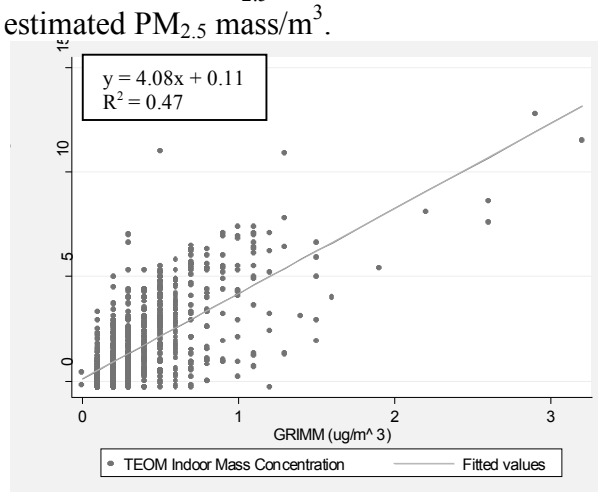


Figure 3: Linear regression model comparing indoor TEOM $PM_{2.5}$ mass/m^3 to indoor Grimm estimated $PM_{2.5}$ mass/m^3.



By performing linear regression (see Figures 2 and 3) we see that the TEOM and the Grimm aerosol spectrometer data are well correlated. The discrete values for the indoor Grimm data are an artifact of the data reduction process. The TEOM has been designed by the manufacturer to give a reading that closely matches filter weight methods for typical outdoor aerosols. The Grimm aerosol spectrometer, like all optical aerosol instruments, requires an experimentally determined calibration factor to convert the light scattering signal into equivalent mass. Using the data from the regression line the value of the calibration factor is 4.65 for the outdoor aerosol and 4.08 for the indoor aerosol. This calibration factor includes the effects of actual particle density (compared to the value of 1 g/cm^3 assumed in Equation 1); the shape, light adsorption, and index of refraction of the particles (which affect the signal) and artifacts from volatile

particles that generate a signal in the optical instrument but evaporate when collected by the TEOM or a filter.

Figure 4: Hourly particle averages 0.3 to 0.4 microns in size as measured by Grimm aerosol spectrometer

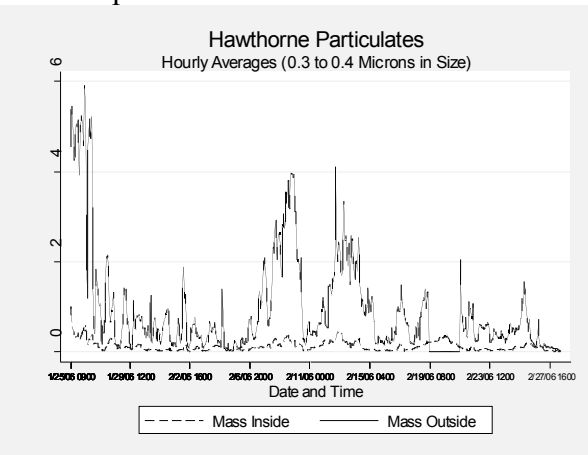


Figure 5: Hourly particle averages 1 to 1.6 microns in size as measured by Grimm aerosol spectrometer

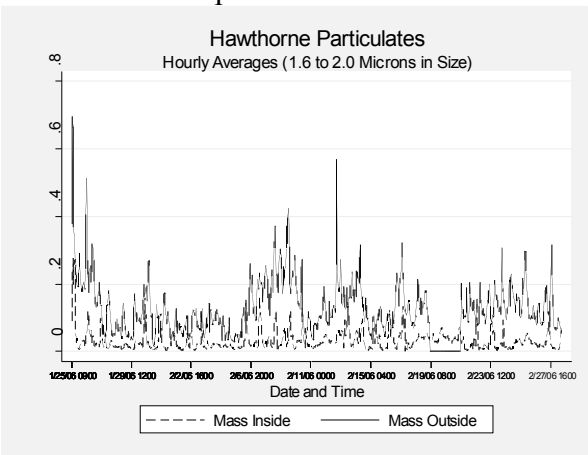


Figure 6: Hourly particle averages 4 to 5 microns in size as measured by Grimm aerosol spectrometer

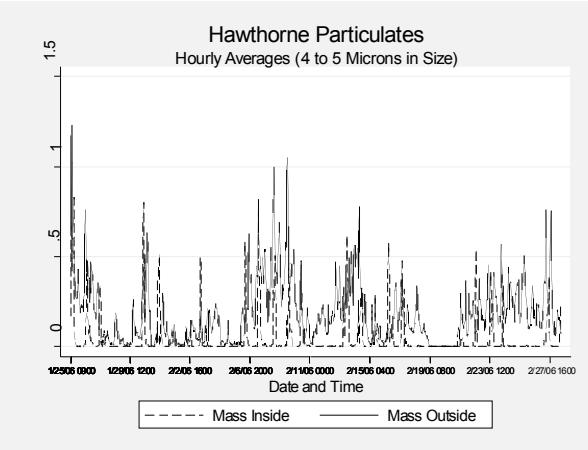
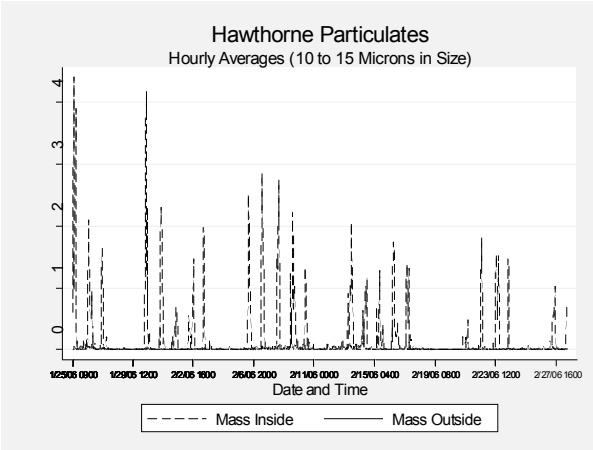


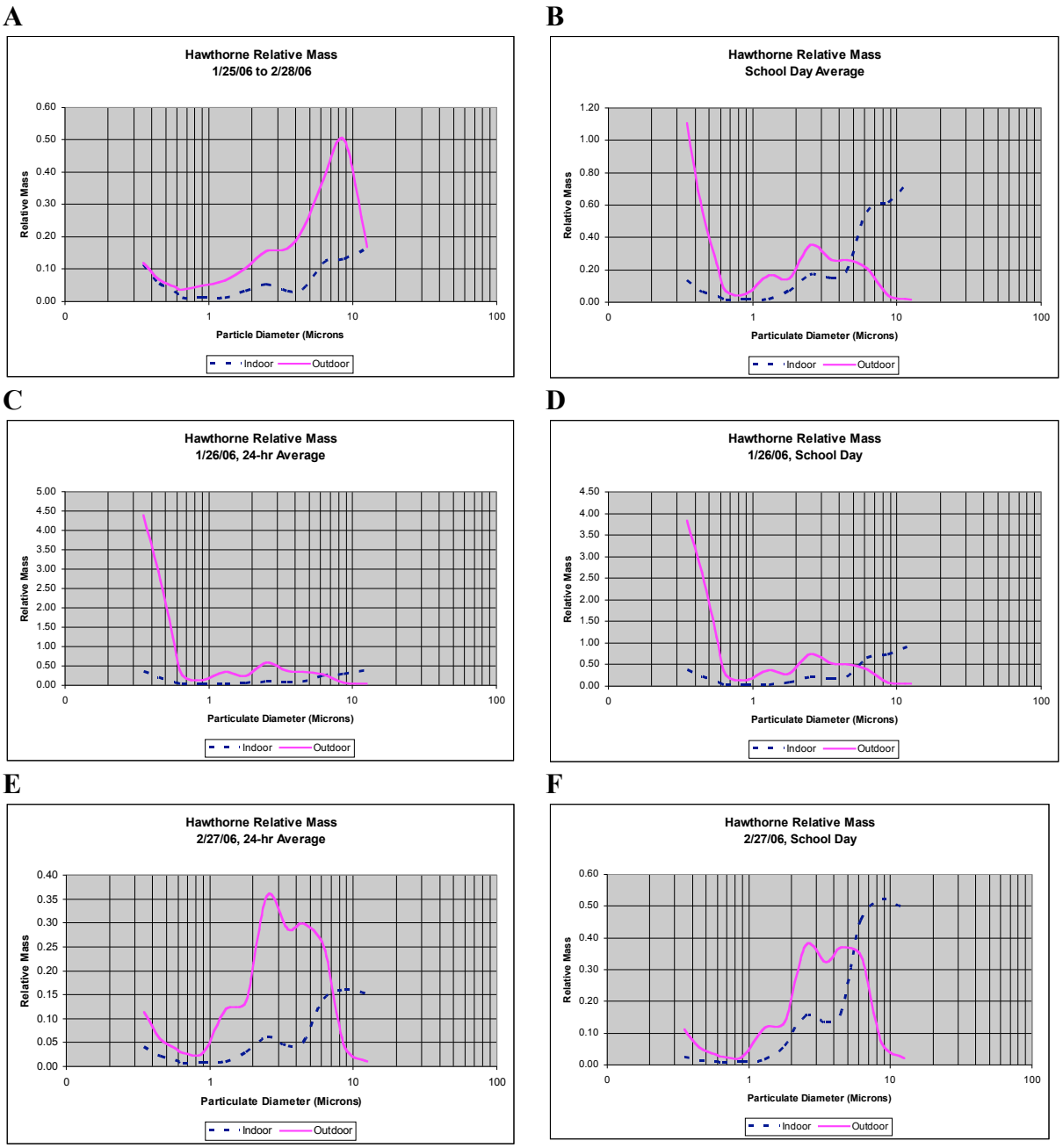
Figure 7: Hourly particle averages 10 to 15 microns in size as measured by Grimm aerosol spectrometer



Figures 4 through 7 show the Grimm estimated mass/m^3 of air over time in only four particle size bins. These include the smallest (0.3 to 0.4 microns), 1.0 to 1.6 microns, 4 to 5 microns, and the largest (10 to 15 microns). Looking at figure 4, it is evident there is some infiltration of the smallest measured particles into the building. However, it is relatively small compared to total mass concentration available in outdoor air. In figure 5, this relationship is even more pronounced. In figure 6, indoor particle mass concentration for 4 to 5 µm size begins to approach the outdoor mass. By the time we reach the largest particle size, figure 7, we see that indoor particle mass concentration in the 10 to 15 µm size clearly overtakes the outdoor mass. This information implies that there is low overall exchange of particles between indoor and outdoor sources. Essentially, indoor and outdoor environments appear to be separate and distinct

in terms of particle mass. Additionally, indoor spikes in the coarse particles appear to be due to indoor sources since they do not correlate with outside concentrations.

Figure 8: A comparison of Indoor to Outdoor Relative Mass averaged over (A) the entire study period, (B) the 6-hour school day, (C) January 26th – 24-hours, (D) January 26th – 6 hour school day, (E) February 27th – 24 hours, and (F) February 27th – 6 hour school day.



Note the difference in scales for each graph.

Figure 8 plots relative indoor to outdoor mass at different dates over the study period. Figure 8A shows total average particle mass concentration over the study period and figure 8B shows the average over the 6 hour period of a school day (9AM to 3PM) over the study period. Figures 8C

and 8D compare estimated indoor and outdoor mass on January 26th, a high particulate day, as a full day and a school day average. Figures 8E and 8F compare estimated indoor and outdoor mass on February 27th, a low particulate day. Notice that the indoor and outdoor particle size distributions are distinctly different. Average School days and high particulate days show an outdoor aerosol with a peak in the submicron range. Low particulate days have the outdoor size peak in the coarse particle (2.5–10 micron) range. During school days the concentration of larger particles is higher indoors than outdoors, implying that indoor sources such as floor dust are set into circulation due to activities conducted during school hours.

DISCUSSION/CONCLUSIONS

This study demonstrates large measured differences between indoor and outdoor pollutants. It appears that VOCs that are generated indoors remain indoors at least during the school period and that there is a low infiltration of particulates into the school even during high particulate days. These conditions may be generally true anytime we have a properly designed and functioning heating, ventilation, and air conditioning (HVAC) system in a public or commercial tight building. That is to say, the outdoor and indoor environments may be considered separate and distinct, only partially influencing each other. Thus, staying indoors during a high pollutant day is an acceptable method to reduce student exposure to smaller airborne particulates that may adversely impact their health.

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