

INDOOR AND OUTDOOR PM 2.5 MEASUREMENTS AT A UTAH ELEMENTARY SCHOOL

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ABSTRACT

Along the Utah Wasatch front, in winter conditions air quality often becomes problematic for the young and infirm. Strong temperature inversions cause outdoor urban pollutants levels such as particulate matter 2.5 (PM 2.5) to rise to unacceptable levels. Studies have shown that high PM 2.5 levels can be an asthma trigger for youth. The goal of this project was to determine if PM 2.5 levels were lower in the school than outdoors. In this study, PM 2.5 was measured in a Utah elementary school using a tapered element oscillating microbalance (TEOM) located in the library of the school. Indoor measurements during poor outdoor air quality days were compared to measurements collected by a similar TEOM in an EPA air-monitoring station already in place on the school property. In addition, on select days, a filter method (MiniVol) was also used to collect indoor PM 2.5 levels. Results of the study found that daily, 24-hour indoor air concentrations of PM 2.5 measured using the TEOM were lower than outdoors (n=55, p<0.0001).

INTRODUCTION

Increasing evidence shows that elevated levels of ambient particulate matter (PM) can exacerbate existing asthma (Gavett, 2001; Hrubá, 2001; Norris, 1999; Samet 2000). PM in ambient air has been associated with increased emergency room visits and medication use by asthmatics. Furthermore, ambient PM concentrations are associated with the risk of death from all causes and from cardiovascular and respiratory illnesses. Due to high particulate pollution in Utah, schools in Utah have asked for guidance in determining when to schedule indoor activities based on the air quality in their communities. A collaborative group from the Utah Asthma Program developed guidelines to assist schools with this question. Based on the epidemiologic data it seems reasonable to keep high risk children indoors on days with poor air quality.

The geography of Salt Lake City, Utah, USA, is a high mountain valley (elev.~1,188m) that is prone to winter temperature inversions. A temperature inversion is a condition in which the temperature of the atmosphere increases with altitude in contrast to the normal decrease with altitude (Columbia Electronic Encyclopedia, 2005). The temperature inversions occur most when high pressure weather systems trap cold air and moisture in the valley. This air is colder than the air at higher elevations, and can trap pollutants such as PM 2.5. The pollutants and cold,

inverted air stay trapped in the valley until a low pressure storm system or horizontal winds can break the inversion. The temperature inversions and resultant high PM 2.5 levels are the focus of this study and the future study.

METHODS AND MATERIALS

Sampling Site

Indoor and outdoor PM 2.5 measurements were collected continuously in a Utah elementary school during winter months. The elementary school was selected because it is the site of an outdoor EPA air-monitoring station. The station is operated by the Utah Division of Air Quality (UDAQ). The station was placed on this site because of its proximity to a sensitive group (elementary school aged children) and is a high auto-traffic corridor. The location of the elementary school adjacent to an EPA monitoring site was unique to this study. Many researchers must use either portable monitors set up on-site, or extrapolate PM data from sites that are a great distance from the indoor site (Lillquist, 1998). This outdoor monitoring station includes a tapered element oscillating microbalance (TEOM) and a filter dynamics measurement system (FDMS) for continuous PM 2.5 measurements, a 24-hour Filter for PM 2.5 measurements, and other instruments for measuring other pollutants such as PM 10, ozone, CO, SO₂ and NO_x.

The study was carried out during the winter months of December, January, and February of 2004-2005. These months were selected because most temperature inversions occur in the winter months, and thus airborne particulate levels would be appreciable. The library of the building was selected because it provided an area that was common to all students. Additionally, this area allowed for the placement of obtrusive monitoring equipment that would be of minimal impact to student learning.

Sampling Protocol

Indoor and outdoor PM 2.5 concentrations were monitored continuously using two methods. The indoor environment was monitored with a model 1400ab TEOM [Rupprecht & Patashnick Co., East Greenbush, NY] placed in the library. On select days, a MiniVol [Airmetrics, Eugene, Oregon] was used to collect 24-hour PM 2.5 measurements utilizing filter technology. Placed outdoors was a model 1400ab TEOM, and a Partisol Plus Model 2025 Air Sampler [Rupprecht & Patashnick Co., East Greenbush, NY]. The Partisol sampler is a 24-hour federal reference standard method (RFPS-0498-118) sampler.

The TEOM continuous monitoring devices have U.S. EPA certification EQPM-1090-079 for continuous PM-10 particulate monitoring, and are a USEPA-recognized correlated acceptable continuous monitor for continuous PM-2.5 measurements. The outdoor TEOM readings were corrected for interferences caused by cold weather and high relative humidity by applying a correction factor. Studies have shown that TEOM monitors such as the monitor used in this study are biased systematically low with respect to the federal reference method measurements during the cold season (Schwab, 2004). The correction factor is necessary because cold weather

and high relative humidity combine to cause the TEOM to underreport PM 2.5 values. The corrected PM 2.5 (CPM 2.5) value is used in this study.

The TEOM calculates PM 2.5 readings every minute and the results are averaged for a 24-hour period. The TEOM sampler operates at a flow rate of 16.7 liters per minute (LPM) through the size selective intake and delivers 3.0 LPM to the filter. The data collected using continuous monitoring devices was stored on the collection device and then transferred to office computers for analysis. The Partisol sampler provides 24-hour measurements of PM 2.5 by collecting particulate onto filters which are then gravimetrically analyzed in the UDAQ laboratory. The Partisol sampler operates at a 16.7 LPM flow rate. Ring-mounted 47 mm Teflon® filters are conditioned and then weighed pre and post sampling with a microbalance. The MiniVol sampler utilizes ring-mounted 47 mm Teflon® filters which are gravimetrically analyzed in the UDAQ laboratory. The MiniVol sampler was calibrated pre and post sampling to 5 LPM and set to run for a 24-hour period utilizing a 2.5 um cut point cyclone.

HVAC System Design

The heating, ventilation, and air-conditioning system (HVAC) of the school utilizes a variable-air-volume (VAV) system. This system supplies a variable flow of conditioned air to meet the thermal and air quality needs of the building occupants. All classrooms and the library are served by this system. A 44,000 cfm fan supplies all HVAC service except for the multipurpose room and kitchen. The library is served by five diffusers supplying 520 cfm each, yielding 2,600 cfm in approximately a 22,500 ft³ space. Three return grills and two transfer grills handle return air duties. The approximate design percentage of outdoor air varies from a minimum of 10% to a maximum of 100% for the building. The HVAC system is designed with an Indoor Air Quality (IAQ) damper that operates independently of the main Outdoor Air (OA) damper. This IAQ damper is designed to provide minimum OA to the building per American Society of Heating, Refrigeration, and Air Conditioning Engineers (ASHRAE) standards (ASHRAE, 2004). The air intake of the indoor TEOM was placed in a neutral area away from supply air diffusers and return grills to minimize cross-currents from the HVAC system.

Statistical Methods

The indoor and outdoor data was analyzed with a variety of methods. The indoor and outdoor TEOM data was analyzed using paired T-tests at the 95% significance level. The indoor and outdoor filter methods (Partisol and MiniVol) were analyzed using paired T-tests at the 95% significance level as well. Indoor / outdoor ratios (I/O) were calculated and analyzed after a log-normal transformation using a single mean T-test. The means, standard deviations, and confidence intervals were calculated for all applicable tests. The STATA 8.0 for Mac (Stata Corp., College Station, TX) statistical package was utilized for the data analysis. Microsoft® Excel X for Mac® was used for graphics.

RESULTS

The daily PM 2.5 measurements utilizing the TEOM continuous monitor were collected from December 16, 2004 through February 16, 2005 (N=55 days) at the elementary school. There were seven (7) days where machine malfunctions or other issues prevented data collection. On select days (N=11), the MiniVol was utilized to collect 24-hour indoor PM 2.5 measurements in the school library. Graphs shown in Figures 1,2, and 3 show daily PM 2.5 TEOM measurements by month. Figure 4 shows daily PM 2.5 measurements taken with the MiniVol and Partisol filter samplers.

Daily PM 2.5 measurements collected with TEOM samplers showed indoor PM 2.5 levels to be lower than outdoor levels on most days. Results of paired T-tests and descriptive statistics for indoor and outdoor TEOM and filter methods are summarized on Table 1. Mean outdoor CPM 2.5 levels and indoor PM 2.5 levels collected with the TEOMs are 17.0 and 7.6 ug/m³, respectively. The 95% confidence interval for outdoor and indoor PM 2.5 measurements are [13.3, 20.7] ug/m³ and [6.7, 8.5] ug/m³. The paired T-test performed on paired indoor and outdoor TEOM PM 2.5 measurements yielded a p-Value of <0.0001 at the 95% significance level. Results of the I/O ratio measurements are shown on Table 2. I/O ratios were calculated for the paired TEOM measurements and log-transformed for analysis. The p-value calculated from the single mean T-test of the log transformed I/O ratios is p<0.0001 at the 95% significance level. On the days where indoor PM 2.5 levels were higher than outdoor, the average indoor and outdoor PM 2.5 level was 4.3 and 3.0 ug/m³, respectively.

PM 2.5 measurements collected with the MiniVol and Partisol filter method showed lower indoor PM 2.5 levels on all days. Mean outdoor and indoor PM 2.5 levels collected using the filter methods are 27.3 ug/m³ and 7.4 ug/m³, respectively. The 95% confidence interval for outdoor and indoor PM 2.5 measurements are [18.4, 36.2] ug/m³ and [4.6, 10.2] ug/m³. The paired t-test performed on paired indoor and outdoor PM 2.5 measurements yielded a p-value of 0.0002 at the 95% significance level.

Table 1. Results of indoor and outdoor PM 2.5 measurements at the elementary school

	Measurement			
	Outdoor TEOM CPM 2.5	Indoor TEOM PM 2.5	Outdoor Partisol PM 2.5	Indoor MiniVol PM 2.5
N	55	55	11	11
Mean	17.0 ug/m ³	7.6 ug/m ³	27.3 ug/m ³	7.4 ug/m ³
Minimum	0.3 ug/m ³	2.8 ug/m ³	7.6 ug/m ³	3 ug/m ³
Maximum	51.7 ug/m ³	18.2 ug/m ³	45.4 ug/m ³	17 ug/m ³
SE	1.83 ug/m ³	0.45 ug/m ³	4.01 ug/m ³	1.25 ug/m ³
SD	13.62 ug/m ³	3.36 ug/m ³	13.29 ug/m ³	4.18 ug/m ³
95% CI	[13.3 20.7] ug/m ³	[6.7 8.5] ug/m ³	[18.4 36.2] ug/m ³	[4.6 10.2] ug/m ³
p-Value	<0.0001	<0.0001	0.0002	0.0002

“<” denotes a value less than the reported value by the software program

Table 2. Results of I/O ratios from paired TEOM PM 2.5 measurements at the elementary school

Measurement	N	Mean	SE	SD	95% CI	p-Value
Ln(I/O Ratio)	55	-0.46	0.10	0.71	[-0.66 -0.27]	<0.0001

“<” denotes a value less than the reported value by the software program

DISCUSSION

Overall, this study found that indoor PM 2.5 levels were statistically lower than outdoor levels using both filter and continuous monitors. The I/O ratios were significantly different, also showing that outdoor levels were higher than indoor levels. The design of the HVAC system appeared to prevent the accumulation of fine particles in the building during the study period. The winter of 2004-2005 did not include any extended periods of temperature inversion in the Salt Lake Valley. This absence of an extended temperature inversion and subsequent high PM 2.5 levels creates a gap in our study that cannot be addressed until a future study is undertaken. The effects of a long-term high outdoor ambient PM 2.5 concentration on this building is unknown. However, the data from this study suggests that the indoor level will be lower than the outdoor level.

It has been shown that the design of the building HVAC system has an effect on PM concentrations indoors, with occupants of VAV systems exhibiting less physical symptoms associated with PM than other designs (Kinshella, 2001). This could be partially due to the nature of VAV systems to draw less outdoor air when outdoor conditions are much colder than indoors. Other system designs, such as those with unit ventilators or constant volume systems, manage outdoor air differently and may provide greater percentages of outdoor air to the building. Typically, colder outdoor days are indicative of a potential temperature inversion in place with its requisite high ambient PM 2.5 levels. The intake of less contaminated outdoor air would naturally result in lower indoor levels of PM. It is important to note that there were days where indoor PM 2.5 levels were higher than outdoors, although not greatly so. Studies have shown that indoor sources of PM can have significant contribution to total measurements (Gauvin, 2002), so the possibility of indoor PM sources in this building may require more study. The TEOM was placed in only one area of the school, thus limiting the ability to correlate the ambient PM 2.5 concentration found in the library to other areas of the building.

A future study is planned to assess children’s pulmonary function via spirometry before and after outdoor recess periods during high and normal outdoor ambient PM 2.5 levels. The planned study will compare indoor and outdoor PM 2.5 levels with student spirometry data. As a precursor to the planned study, the current research study aimed to compare indoor and outdoor PM 2.5 concentrations to determine if indoor PM 2.5 levels differ significantly from outdoor levels at the study site.

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REFERENCES

Abt, E., Suh, H.H., Allen, G., Koutrakis, P. Characterization of indoor particle sources: A study conducted in the metropolitan Boston area. *Environ Health Perspect.* 2000; 108: 35-44.

Allen, R., Larson, T., Sheppard, L., Wallace, L., Liu, L-J.S. Use of real-time light scattering data to estimated the contribution of infiltrated and indoor-generated particles to indoor air. *Environ Sci Technol*, 2003; 37: 3485-3492.

Blondeau, P., Iordache, V., Poupard, O., Genin, D., Allard, F. Relationship between outdoor and indoor air quality in eight French schools. *Indoor Air.* 2005; 15: 2-12.

Campbell, M.E., Li, Q., Gingrich, S.E., Macfarlane, R.G., Cheng, S. Should people be physically active outdoors on smog alert days? *Can J Public Health.* 2005; 96: 24-28.

Columbia Electronic Encyclopedia. Temperature inversion. Pearson Education, publishing as Infoplease, 2005. <http://www.infoplease.com/ce6/weather/A0848126.html>

Gauvin, S., Reungoat, P., Cassadou, S., Dechenaux, J., Momas, J.J., Zmirou, D. Contribution of indoor and outdoor environments to PM_{2.5} personal exposure of children-VESTA study. *Sci Total Environ.* 2002; 297: 175-181.

Gavett, S.H., Koren, H.S. The role of particulate matter in exacerbation of atopic asthma. *Int Arch Allergy Immunol.* 2001; 124: 109-112.

Hrubá, F., Fabiánová, E., Koppová, K., Vandenberg, J.J. Childhood respiratory symptoms, hospital admissions, and long-term exposure to airborne particulate matter. *J Expo Anal Environ Epidemiol.* 2001; 11: 33-41.

Kinshella, M.R., Van Dyke, M.V., Douglas, K.E., Martyny, J.W. Perceptions of indoor air quality associated with ventilation system types in elementary schools. *Appl Occup Environ Hyg.* 2001; 16: 952-960.

Lillquist, D.R., Lee, J.S., Ramsay, J.R., Boucher, K.M., Walton, Z.L., Lyon, J.L. A comparison of indoor/outdoor PM₁₀ concentrations measured at three hospitals and a centrally located monitor in Utah. *Appl Occup Environ Hyg.* 1998; 13: 409-415.

Liu, L-J.S., Slaughter, J.C., Larson, T.V. Comparison of light scattering devices and impactors for particulate measurements in indoor, outdoor, and personal environments. *Environ Sci Technol.* 2002; 36: 2977-2986.

Norris, G., Young, Pong, S.N., Koenig, J.Q., Larson, T.V., Sheppard, L., Stout, J.W. An association between fine particles and asthma emergency department visits for children in Seattle. *Environ Health Perspect.* 1999; 107: 489-493.

Samet, J.M., Dominici, F., Curriero, F.C., Coursac, I., Zeger, S.L. Fine particulate air pollution and mortality in 20 U.S. cities, 1987–1994. *N Engl J Med.* 2000; 343: 1742-1749.

Schwab, J.J., Spicer, J., Demerjian, K.L., Ambs, J.L., Felton, H.D. Long-term field characterization of tapered element oscillating microbalance and modified tapered element oscillating microbalance samplers in urban and rural New York State locations. *J Air Waste Manage Assoc.* 2004; 54(10): 1264-1280.

Ventilation for acceptable indoor air quality. Atlanta, GA: American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE), 2004. Standard 62.1.

