Evaluation of airborne particles at a local high school

Stephanie Klender

University of Toledo

Follow this and additional works at: http://utdr.utoledo.edu/theses-dissertations

Recommended Citation
http://utdr.utoledo.edu/theses-dissertations/1713

This Thesis is brought to you for free and open access by The University of Toledo Digital Repository. It has been accepted for inclusion in Theses and Dissertations by an authorized administrator of The University of Toledo Digital Repository. For more information, please see the repository’s About page.
A Thesis

entitled

Evaluation of Airborne Particles at a Local High School

by

Stephanie J. Klender

Submitted to the Graduate Faculty as partial fulfillment of the requirements for the

Master of Science in Occupational Health Degree in

Industrial Hygiene

_________________________________________
Dr. Sheryl Milz, Committee Chair

_________________________________________
Dr. Michael Valigosky, Committee Member

_________________________________________
Professor April Ames, Committee Member

_________________________________________
Dr. Patricia R. Komuniecki, Dean
College of Graduate Studies

The University of Toledo

May 2014
An Abstract of
Evaluation of Airborne Particles at a Local High School

by

Stephanie J. Klender

Submitted to the Graduate Faculty as partial fulfillment of the requirements for the
Master of Science Degree in
Occupational Health

The University of Toledo

May 2014

This study examined the particulate matter (PM) in an urban, public high school in order to determine the potential exposure to students, faculty and staff. A TSI P-Trak Plus Model 8525 and a TSI DustTrak Model 8534 DRX were set to five-minute average log mode in five locations throughout the school. Generally, the levels of indoor PM were below that of the outdoors. Of the five indoor locations, the classroom had the highest levels of PM whereas the gym had the lowest. Overall, 5th period, the longest class period, had the highest median values for PM – except for PM1. The highest median values for PM1 was recorded in the breaks between classes. The results of this study indicate that the levels of PM within the high school are below outdoor standards.
I would like to dedicate my work to my family and friends for supporting me throughout my education.
Acknowledgements

I would like to thank my major advisor, Dr. Farhang Akbar; I would not have started this program without his enthusiasm and support. Additionally, I would like to thank Dr. Sheryl Milz, my Committee Chair and also the members of the Advisory Committee, Dr. Michael Valigosky and Professor April Ames, for their guidance throughout this project. I would like to thank Mr. Dave Bourland for his help and support in every step of data collection. Finally, I would also like to thank Annie Doerr, Julie Scardina, Greg Heldt and Hassan Moreer for their assistance.
# Table of Contents

Abstract ................................................................................................................................. iii

Acknowledgements ............................................................................................................. v

Table of Contents .................................................................................................................. vi

List of Tables ........................................................................................................................... viii

List of Figures ........................................................................................................................ ix

List of Abbreviations ............................................................................................................. x

List of Symbols ....................................................................................................................... xi

1 Introduction ....................................................................................................................... 1

1.1 Overview ....................................................................................................................... 1

1.2 Statement of the Problem ............................................................................................ 3

1.3 Significance .................................................................................................................... 4

1.4 Hypotheses .................................................................................................................... 4

1.5 Objectives ..................................................................................................................... 5

1.6 Approach ....................................................................................................................... 5

2 Literature Review .............................................................................................................. 7

2.1 History ........................................................................................................................... 7

2.2 Health Effects of PM ................................................................................................... 8

2.3 The School Environment ............................................................................................ 9

2.4 Academic Effects of PM ............................................................................................ 11
2.5 Composition of Indoor PM.................................12
3 Materials and Methods........................................14
  3.1 Materials.....................................................14
  3.2 Methods.....................................................16
4 Results....................................................................21
  4.1 Descriptive Statistics for Indoor Sampling Locations...21
  4.2 Median by Sampling Location............................22
  4.3 Median by Class Period.................................23
  4.4 Median by Week of Sampling............................24
  4.5 Kruskal-Wallis by Location............................25
  4.6 Kruskal-Wallis by Class Period.......................27
  4.7 Mann-Whitney by Day of Week and Location........29
  4.8 Kruskal-Wallis by Week of Sampling..................30
5 Discussion..........................................................34
  5.1 Criteria and Significance..................................34
  5.2 Comparison with Other Studies.........................34
  5.3 Recommendations..........................................35
  5.4 Limitations..................................................35
  5.5 Future Research............................................36
6 Conclusions..........................................................37
References..................................................................39
List of Tables

4.1.1 Descriptive Statistics for Indoor Sampling Locations During School Day ........21
4.2.1 Median Values by Sampling Location..........................................................22
4.2.2 Median Values by Sampling Location, Reference Week ................................23
4.3.1 Median Values by Class Period.......................................................................24
4.4.1 Median Values by Week of Sampling...............................................................25
4.5.1 Kruskal-Wallis by Location.............................................................................26
4.5.2 Mann-Whitney by Location............................................................................27
4.6.1 Kruskal-Wallis by Class Period, all Indoor Locations.......................................28
4.6.2 Mann-Whitney by Class Period, all Indoor Locations......................................30
4.7.1 Mann-Whitney by Day of Week and Location..................................................31
4.8.1 Kruskal-Wallis by Week of Sampling...............................................................32
4.8.2 Mann-Whitney by Week of Sampling...............................................................33
List of Figures

3-1-1  TSI P-Trak Plus Model 8525 ..................................................................................14
3-1-2  TSI Q-Trak Plus Model 7575 ..................................................................................15
3-1-3  TSI DustTrak Model 8534 DRX.............................................................................16
3-2-1  High School First Floor Plan ..................................................................................17
3-2-2  Picture of the Instrument Setup in the Gym..............................................................19
List of Abbreviations

AAAI..........................American Academy of Allergy, Asthma and Immunology
AMA..........................American Medical Association
ASHRAE....................American Society of Heating, Refrigerating and Air-conditioning Engineers

BRI.........................Building Related Illness
CAA .........................Clean Air Act
CDC ..........................Centers for Disease Control and Prevention

EI............................Environmental Illness
EPA ..........................Environmental Protection Agency

HEPA ........................High Efficiency Particulate Air
HVAC ........................Heating, Ventilating and Air-conditioning

IAQ ..........................Indoor Air Quality
MCS ..........................Multiple Chemical Sensitivity

NAAQS........................National Ambient Air Quality Standards
NIOSH .......................National Institute for Occupational Safety and Health

OSHA .........................Occupational Safety and Health Administration

PM ............................Particulate Matter
SBS ..........................Sick Building Syndrome

UFP ..........................Ultrafine Particles
List of Symbols

$\mu g/m^3$ .........................Micrograms per cubic meter

l/s.................................Liters per second

mg/m$^3$ Milligrams per cubic meter
Chapter 1

Introduction

1.1 Overview

Due to our lifestyles, people spend a majority of their time indoors. Estimates show that Americans spend 90% or more of their day inside a building (Ekmekcioglu and Keskin, 2007; EPA, 2009 and 2012b; Ligman et al., 1999; Ohio Department of Health, 2009; Sundell, 2004; Wu and Takaro, 2007). However, being indoors does not protect oneself from the harmful effects of air pollution. According to the United States Environmental Protection Agency (EPA), indoor air pollution is one of the top five environmental problems public health faces today. To put the problem into perspective, studies have seen levels of pollutants indoors that range from 2 times up to 100 times higher than those of outside. (EPA, 2009; Ohio Department of Health, 2009).

Pollutants found indoors can have many possible sources. Outdoor pollutants can become indoor pollution through openings (such as doors, windows or the Heating, Ventilating and Air-conditioning or HVAC system), penetration, or seeping into the building (Buonanno et al., 2013). Indoor environments also have their own unique sources of possible pollution. For example, building materials, carpets, cleaning
solutions, and technology (computers, scanners, fax machines, etc.) can all be sources of indoor pollution. Additionally, occupants themselves can contribute to the indoor pollutants.

One major type of pollution that can occur indoors is particulate matter (PM). Some common sources include dust, smoke, by-products of combustion, mites, and pollen. PM is defined by the size and how far it can enter into the respiratory system. Coarse particles or PM10 have a diameter of 10 micrometers or smaller and can be inhaled. Respirable particles or PM4 have a diameter of 4 micrometers or less and can easily enter into the lungs. Fine particles or PM2.5 have a diameter of 2.5 micrometers or less and can pass through the bronchioles within the lungs. PM1 have a diameter of 1 micrometers or less and are also a type of fine particles which can reach the bronchioles. Ultrafine particles (UFP) have a diameter of less than 0.1 micrometers and can reach deep into alveoli of the lungs. Due to their size, UFP can travel in the air for long periods of time and are able to penetrate extremely small openings. When all types of PM are looked at together it is called PM total. (Crist et al., 2008; EPA, 2012a; Ligman et al., 1999; TSI, 2011). The smaller the size of the PM, the more deeply it can enter into the respiratory system. These foreign bodies in the lungs can cause adverse reactions as well as exacerbate respiratory ailments such as asthma (Diapouli et al., 2008; Ekmekcioglu and Keskin, 2007; Oeder et al., 2012; WHO, 2011).

There are guidelines for PM. The American Society of Heating, Refrigerating and Air-conditioning Engineers or ASHRAE Standard 62 sets a maximum exposure limit for PM10 of 0.15 mg/m³ for a 24-hour mean and a 0.05 mg/m³ for an annual mean. EPA offers the National Ambient Air Quality Standards (NAAQS). For PM2.5 the guidelines
are an annual mean of 12 μg/m$^3$ and a 24-hour mean of 35 μg/m$^3$. For PM10 their guidelines are a 24-hour mean of 150 μg/m$^3$ (EPA, 2012a). The World Health Organization (WHO) guidelines for PM2.5 are an annual mean of 10 μg/m$^3$ and a 24-hour mean of 25 μg/m$^3$. For PM10 their guidelines are an annual mean of 20 μg/m$^3$ and a 24-hour mean of 50 μg/m$^3$ (WHO, 2011).

This study will look at PM counts at a Toledo area high school to determine if the sampled locations are within the stated guidelines. Past studies have shown that school buildings around the world have PM concentrations exceeding WHO guidelines (Buonanno et al., 2013; Diapouli et al., 2008; Ekmekcioglu and Keskin, 2007; Lee and Chang, 2000). In Ohio, Crist et al. (2008) found indoor PM2.5 levels inside three elementary schools to be higher than that of the outdoors on days when school was in session. The individuals exposed to these concentrations are at risk for the associated adverse health and academic effects.

1.2 Statement of the Problem

High school students, faculty and staff are exposed to the PM in their building for approximately 180 days each school year. The typical school day is seven hours long. Additionally, many students and faculty members arrive at school early and stay late for before- and after-school activities. During this time, they are constantly at risk from exposure from PM. This study focuses on one Toledo high school.
1.3 Significance

Most of the current studies related to PM have been done in elementary or middle schools – not high schools. This study will look at a high school in Toledo, Ohio. This study will use quantifiable methods of detecting PM, which will allow the school to know which, if any, areas exceed stated guidelines of acceptable levels. These areas will need further studies to focus on possible solutions.

1.4 Hypotheses

**Hypothesis 1.** The statistically highest counts of indoor daily median airborne particles (PM1, PM2.5, PM4, PM10 and PM Total) and UFP will occur in the front hallway and cafeteria during the school day (8:00-14:45).

**Hypothesis 2.** There will be no statistically significant difference in daily median airborne particles (PM1, PM2.5, PM4, PM10 and PM Total) counts and UFP indoors between class periods (1-7) throughout the school day.

**Hypothesis 3.** There will be no statistically significant difference in daily median airborne particles (PM1, PM2.5, PM4, PM10 and PM Total) counts and UFP between sampling days (Monday and Thursday) at specific locations throughout the school.

**Hypothesis 4.** There will be no statistically significant difference in daily median airborne particles (PM1, PM2.5, PM4, PM10 and PM Total) counts and UFP between sampling weeks (1-15) at specific locations throughout the school.
Hypothesis 5. Indoor airborne particle counts (PM1, PM2.5, PM4, PM10 and PM Total) will be below the outdoor counts.

1.5 Objectives

The objectives of this thesis are to:

1) Quantify airborne particle counts over the course of the school day in five different locations for 15 weeks;

2) Determine if any count exceeds regulations or recommendations;

3) Determine relationships between PM counts and UFP counts between sampling locations and class periods;

4) Determine if PM counts and UFP counts are lower than those outdoors.

The goal of this research is to identify airborne particle counts throughout the school day. It will determine if airborne particle counts exceed regulations or standards.

1.6 Approach

The project was conducted at an area high school. Particulate counts were measured throughout the school day with a TSI Q-Trak Plus Model 7575, a TSI P-Trak Plus Model 8525, and a TSI DustTrak Model 8534 DRX. Monitoring occurred twice a week at each of five locations. The five locations included: a science classroom, the gymnasium, the cafeteria, the front hallway, and an outside courtyard. The monitoring occurred during a 15-week period, three weeks at each location and one full reference
week when the school was empty during their spring break. Particulate counts were compared to recommended levels and were analyzed for differences by day and location.
Chapter 2

Literature Review

2.1 History

Spending the majority of our time inside, it becomes apparent that the indoor environment is an important aspect of our health. Sundell (2004) outlines the history of indoor air quality (IAQ) from the ancient Greeks and Romans through the early 1900s. Through most of that time, the main focus was on ventilation, not on PM.

However, in 1847 Max Joseph von Pettenkofer lectured in Munich that trace organic materials from the skin and exhalation could pollute the air. He argued that high CO₂ levels were acting as an indicator of these expelled organic pollutants. Additionally, he believed these substances weakened human resistance against illness (Sundell, 2004).

At the Karolinska Institute in the 1880s, Elias Heyman studied schools in Stockholm. He discovered that none were adequately ventilated and discovered that air pollution from chimneys was also present in the schools. Occupants complained of ‘dry air’ which had symptoms similar to today’s sick building syndrome (SBS). After further studies on homes in the area and similar findings, Heyman concluded that natural ventilation cannot be adequate (Sundell, 2004).
Following a string of studies that found no toxic effects of organic material in the air, the questions of IAQ, ventilation and PM faded into one of merely comfort rather than health. It would stay that way until the 1960s. “Not until the problems that arose with regard to radon in the late 1960s, formaldehyde in the early 1970s, house dust mites and SBS in the late 1970s, and allergies during the last decade did health issues related to indoor air again enter the scientific agenda” (Sundell, 2004).

Additional problems arose with the energy crisis in the 1970s. Building construction methods changed which affected the exchange of indoor and outdoor air in ventilation. In order to save energy costs, ventilation was achieved by recirculating air instead of needing to condition outside air. Although it is an energy cost-saving method, it also allows for pollutants to become trapped indoors (TSI, 2011).

In 1963 the Clean Air Act (CAA) was signed into Federal law in order to control air pollution. The CAA required the EPA to set National Ambient Air Quality Standards (NAAQS) for harmful pollutants (EPA, 2012a). In 1997 the EPA established a standard for PM2.5. In both 2006 and 2012, the EPA strengthened their standards for particles. These refer to outdoor standards. The aim is for indoors to have lower levels of PM than that of outdoors.

2.2 Health Effects of PM

Research has consistently shown that there are negative health effects that occur because of the PM in the air. Symptoms vary from individual to individual based upon one’s sensitivities, but may include: eye irritation, headache, coughing, exacerbated allergies, sneezing, skin irritation or difficulties breathing. Extremely sensitive individuals could become unable to function due to their symptoms (TSI, 2011). When
exposed to PM, some children with heart problems experience chest pains (Ekmekcioglu & Keskin, 2007).

Sick Building Syndrome (SBS) and Building Related Illness (BRI) are two terms referring to ill health effects from the IAQ. BRI is a generic term for any medically diagnosable illness caused by, or related to, being in a building. SBS refers to negative health effects in more than 30% of occupants with no medically diagnosable illness (TSI, 2011). Additionally, one can also be or become sensitive to chemicals that are found indoors. There are two terms for this condition: Multiple Chemical Sensitivity (MCS) or Environmental Illness (EI). MCS or EI can even occur at low levels of exposure over a prolonged exposure (TSI, 2011). The condition is controversial; there are those who deny the veracity of such a condition exists. The Centers for Disease Control and Prevention (CDC), the American Medical Association (AMA) and the American Academy of Allergy, Asthma and Immunology (AAAAI) all do not view MCS or EI as a disorder due to the lack of research (Cleveland Clinic, 2008).

2.3 The School Environment

Classrooms have a unique environment that makes their IAQ different from other indoor environments. For example, classrooms generally have more people in close proximity than other buildings. “Standard classrooms may have occupant levels anywhere from 32 square feet per person to 50 square feet per person. As a gauge of comparison, the typical commercial office environment averages over 140 square feet per person” (Clean Air Solutions, 2008). Those densely packed occupants can be a source of contamination. Additionally, some of the technology found in today’s classrooms, such as computers, is another possible source of contamination. Some factors that may
influence air quality in a school building are the number of students, length of class periods, or breaks, and their activities in the room (Guo, et al., 2010; Lee and Chang, 1999).

Schools are typically built on a limited budget and not always built to optimum standards. These buildings are often built by the lowest bid contractors who use simple and inexpensive building materials, such as slab-on-grade construction with flat roofs. There can be problems with poor drainage on school grounds. The school’s HVAC system may be set to a fixed and constant flow and exchange rate. Once the school is in session, over-crowded conditions and lack of funds for preventative maintenance exacerbate the original problems. These conditions lead to an increased risk of a school building having poor IAQ (Godwin and Batterman, 2007).

Mendell and Heath (2005) explain that there is not a lot of regulation regarding schools’ indoor environment. “Few states regulate indoor school environments, and fewer still have minimum ventilation standards for schools” (Mendell and Heath, 2005). Lack of proper ventilation can be an indicator that contaminants remain present in the building and can accumulate (Shaughnessy et al., 2006).

Studies have shown that indoor PM concentrations were higher than those of outdoors (Buonanno et al., 2013; Crist et al., 2008; Diapouli et al., 2008; Ekmekcioglu and Keskin, 2007; Lee and Chang, 2000). Oeder et al. (2012) found that classroom PM concentrations were higher than homes in the same local area. Ligman et al. (1999) demonstrated that PM concentrations in classrooms were also higher than office buildings.
2.4 Academic Effects of PM

In a school with high levels of PM, students, faculty and staff may not be able to function at their peak ability. The symptoms caused by the PM can cause a lack in concentration and focus (EPA, 2000; EPA, 2010; Mendell and Heath, 2005; Shaughnessy et al., 2006; Wargocki and Wyon, 2007). If the students’ learning ability is decreased, it could have an effect on their future – and possibly that of society once those children join the work force (Wargocki and Wyon, 2007).

Allergies and asthma, which are negatively affected by PM, are a major source of school absenteeism. The American Academy of Allergy, Asthma and Immunology reports that the prevalence of asthma is increasing (AAAAI, 2013). Mendell and Heath (2005) found asthma to be responsible for 20% of all absences in schools. In 2008, children averaged missing four days of school due to their asthma. Fifty-nine percent of the students who had an asthma attack missed school in 2008 (AAAAI, 2013). All of these missed days at school can lead to lower productivity and lower performance.

Some schools use unattached classrooms to deal with overcrowding. These portable classrooms have a separate unique environment from the school building. Shendell et al. (2004) found that traditional classrooms inside the school building, as opposed to portable classrooms, had overall higher attendance rates.

Due to the trapping of contaminants in the indoor air, poor ventilation can be used as a proxy indicator for PM. Performance by both students and teachers, higher test scores, and a reduction in airborne transmission of infection can all be improved by improving air ventilation (EPA, 2010). For example, a study by Shaughnessy et al. (2006) showed an association between test scores and ventilation rate. “By increasing the
ventilation rate from 5 to 10 l/s, the performance of school work improved significantly by more than 15%. An improvement of IAQ by a factor of two caused a remarkable improvement of the children’s school performance and learning” (Fanger, 2006). Wargocki and Wyon (2007) found that the effect of increased ventilation rate on performance is more pronounced in children than in adults. Daisey et al. (2003) explain that often ventilation rates are calculated for an entire building which, ultimately, overestimates the local classroom ventilation rate.

These negative effects on academic ability and performance may be additive. Studies done in offices show that two uncomfortable parameters cause a perceived reduction in the workers’ performance. The decrease in perception of performance increases with the number of symptoms of discomfort – a 3% loss with three symptoms and an 8% loss at five symptoms (EPA, 2000). Although these findings are from adults, it is not unreasonable to believe these findings would also hold for children. In school, children are often learning novel concepts, whereas office workers are often performing rote activities (Wargocki and Wyon, 2007). Discomfort is far more likely to impede one’s ability to learn a new concept.

2.5 Composition of Indoor PM

Indoor PM can have many sources. Outdoor air can enter the indoor environment. When outdoor air flows into the building through openings, such as joints or cracks, it is called infiltration. Natural ventilation is what occurs when air moves through open windows or doors. Devices such as air conditioners or fans are called mechanical ventilation. (EPA, 2012b). Once outside PM is trapped inside, it can become
re-suspended in the air due to activity in the room (Fromme et al., 2007; Oeder et al., 2012).

PM from outdoors is not the only source of indoor PM. For example, in schools, there are various teaching materials which can affect the indoor PM levels. Emissions can come from indoor sources. Occupants themselves are also a source of indoor PM. Organic particles, such as skin flakes, can be found. Oeder et al. (2012) found that in their study of six elementary schools in Munich, Germany the composition of classroom PM was different from that outside the schools. They found that their indoor samples contained more silicon and aluminum; however, their outdoor samples contained more sulfur and iron. Additionally, their study found that the PM in the classrooms was more toxic than that of outdoors or homes.

Indoor PM composition can vary based on the seasons of the year. Fromme et al. (2007) found that indoor PM concentrations were higher in the winter as compared to the summer. This difference is thought to be based on seasonal differences in ventilation. In the higher temperatures of spring and summer, more ventilation is used – bringing in more outside air along with outside PM. In the colder months of winter and fall, when the ventilation is lower, the indoor PM is more affected by the indoor environment.
Chapter 3

Materials and Methods

3.1 Materials

Three instruments were used to collect data: the TSI P-Trak Plus Model 8525, the TSI Q-Trak Plus Model 7575, and the TSI DustTrak Model 8534 DRX.

The P-Trak measures ultrafine particles 0.02 to 1 micrometer. Figure 3.1.1 shows the instrument. It uses an isopropyl alcohol wick to grow UFP into larger, easier to count droplets. The instrument range is from 0 to 500,000 pt/cc. The sample flow rate is approximately 100 cm$^3$/min. (TSI, 2013). The P-Trak gives results of a count.

![TSI P-Trak Plus Model 8525](http://www.tsi.com/p-trak-ultrafine-particle-counter-8525/)

Figure 3-1-1: TSI P-Trak Plus Model 8525. “TSI.” Retrieved February 26, 2013. http://www.tsi.com/p-trak-ultrafine-particle-counter-8525/
The Q-Trak measures temperature and relative humidity. The instrument can be seen in figure 3.1.2. The temperature range is 32 to 140°F (0 to 60°C) and the relative humidity range is 5 to 95% RH. TSI states the accuracy is ±1.0°F (±0.5°C) and ±3% RH (includes ±1% hysteresis). The temperature function uses a thermistor with a response time of 30 seconds. The relative humidity function uses thin-film capacitive and has a response time of 20 seconds. Temperature and relative humidity were collected because both affect PM (TSI, 2012b). For example, in the dry and cold weather, skin gets dry and flakes, causing more PM. Dry weather also allows more re-suspension of PM.


The DustTrak measures multiple sized particles (PM1, PM2.5, PM4, PM10 and PM Total). Figure 3.1.3 shows the equipment used. It is a Class-1 laser based counting instrument that uses a 90° light scattering sensor. TSI lists the range as 0.001 to 150 mg/m³. It can measure a range of particles from approximately 0.1 to 15 µm. The flow rate is 3.0 L/min. (TSI, 2012a). The DustTrak gives results in a concentration.
3.2 Methods

Data were collected at a local high school during the weeks of January 28, 2013 through April 29, 2013 on Mondays and Thursdays. Tuesdays were used in the event of a snow day. Since the school turns off the HVAC during the weekends, Mondays were chosen to determine the particle counts after the HVAC start up. Thursdays were chosen as the end of the week – the HVAC would have been running for the full week, during the day, but there were less likely to be the random absenteeism that may be seen on a Friday.

Construction on the school began in 2005 at an approximate cost of $36 million dollars. The school was opened in 2008. It is 232,818 square feet. The construction is tile and concrete. The school was built to serve 1,441 students. There are two levels to the building; however, all five locations used in this study were on the ground floor (Toledo Public Schools, 2011).

The school is a Toledo public high school. It is located in an urban environment. The school is situated at a busy intersection with a gas station at the corner. Floors are swept alternating days (first floor one day followed by the second floor the next day).
Whenever it is necessary, the floors are mopped, for example, in the case of snow or mud being tracked into the building. The gym is cleaned and mopped daily. Every two months, the HVAC filters are changed on the weekend.

There were five locations tested throughout the study: a science classroom, the gymnasium, the cafeteria, the main hallway and outside. On days when it was not raining, the outside location was a central courtyard – completely open air; on days with rain, the alternate location was at the car loop, under an overhang of the school. The classroom, gym, cafeteria and hallway are used by the majority of the school. The courtyard was a central outdoor location that was away from the parking lot. A layout of the school with arrows denoting the main locations can be seen in figure 3.2.1.

![Diagram of school layout](image)

**Figure 3-2-1**: High School First Floor Plan
Calibrations were performed following the manufacturers’ directions. The DustTrak and P-Trak were zeroed in accordance with manufacturer’s directions. After calibration, the instruments were taken to the outside location in order to measure background readings for the day. Outdoor readings were collected for five minutes before the instruments were taken to their destination for the day. These readings served as comparisons for the indoor locations collected during the day.

Following the outdoor reading, the equipment was set up in their pre-determined location for the day. This occurred as the school day was starting. The instruments were set to five-minute log mode for the day of sampling – meaning the instrument would collect and log readings every five minutes. The actual reading is an average over those five minutes.

At the end of the school day, the equipment was collected. Using an USB cord, the instruments were connected to a computer. The data was uploaded using the TrakPro software and saved as a .txt file. The .txt file was then imported into Microsoft Excel. Following the upload, the instruments were calibrated again.

Figure 3.2.2 shows a picture of the setup in the gym. As seen, the instruments were set out on a folding table at breathing height while sitting (approximately 3.5 ft) out of the way of foot traffic. All instruments were facing away from all walls and corners and oriented into the area where the occupants were located in order to collect their samples. The picture shows other equipment from additional experiments that were being done concurrently.

Both days in a single testing week were in the same location. Every week, the testing location changed. Each location was tested before any location was repeated.
The goal was for each location to have at minimum two separate weeks over the experimental timeframe.

![Image of Instrument Setup in the Gymnasium](image)

**Figure 3-2-2:** Picture of the Instrument Setup in the Gymnasium

The individual files imported into Excel from the TrakPro software were combined into a single Excel file. The single Excel file was transferred into SPSS for data analysis.

The data was assumed to be not normally distributed. Therefore, descriptive statistics were limited to minimum, maximum and median. Descriptive statistics were calculated for all of the data and then separately by location, by week, and by class period.

Further data analysis was conducted by using the Kruskal-Wallis test followed by the Mann-Whitney U test. Kruskal-Wallis nonparametric, distribution-free analysis was performed using the particle counts and concentrations from each sampling location,
sample week and class period. The significance level ($\alpha$) was 0.05. The Kruskal-Wallis test is the non-parametric version of a one-way ANOVA. For statistically significant (p<0.05) Kruskal-Wallis results, the Mann-Whitney U test was performed to determine which independent pairs of particle counts or concentrations differ statistically by sampling location, sample week, or class period. The Bonferroni adjustment was used to adjust the observed significance level for the number of multiple comparisons that were made for each group of data.
Chapter 4

Results

4.1 Descriptive Statistics for the Indoor Sampling Locations

The following table shows the descriptive statistics for the indoor locations’ sampling data. Of all the particulates measured, only the UFPs were detected in every sample. The temperature and relative humidity levels measured were all within the working range of all instruments used.

Table 4.1.1 – Descriptive Statistics for Indoor Sampling Locations during School Day

<table>
<thead>
<tr>
<th></th>
<th>N</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Median</th>
</tr>
</thead>
<tbody>
<tr>
<td>UFP (count/cc)</td>
<td>1819</td>
<td>382</td>
<td>67,559</td>
<td>2,376</td>
</tr>
<tr>
<td>PM$_1$ (mg/m$^3$)</td>
<td>1867</td>
<td>&lt;0.001</td>
<td>0.071</td>
<td>0.007</td>
</tr>
<tr>
<td>PM$_{2.5}$ (mg/m$^3$)</td>
<td>1867</td>
<td>&lt;0.001</td>
<td>0.071</td>
<td>0.008</td>
</tr>
<tr>
<td>PM$_4$ (mg/m$^3$)</td>
<td>1867</td>
<td>&lt;0.001</td>
<td>0.075</td>
<td>0.008</td>
</tr>
<tr>
<td>PM$_{10}$ (mg/m$^3$)</td>
<td>1867</td>
<td>&lt;0.001</td>
<td>0.16</td>
<td>0.010</td>
</tr>
<tr>
<td>PM Total (mg/m$^3$)</td>
<td>1867</td>
<td>&lt;0.001</td>
<td>0.39</td>
<td>0.014</td>
</tr>
<tr>
<td>Temperature (°F)</td>
<td>1873</td>
<td>30.4</td>
<td>78.3</td>
<td>72.9</td>
</tr>
<tr>
<td>Relative Humidity (%)</td>
<td>1873</td>
<td>11.8</td>
<td>85.6</td>
<td>22.0</td>
</tr>
</tbody>
</table>
4.2 Median by Sampling Location

Descriptive statistics were calculated separately for each sampling location. The median for each location is presented in Table 4.2.1. The highest medians for an indoor location were recorded in the classroom. The outdoor location had a higher median than the classroom for the UFP – giving it the overall highest UFP median. However, the medians for the remaining particulates were lower than those of the classroom. For all particle measures, the lowest medians were recorded in the gym.

<table>
<thead>
<tr>
<th></th>
<th>Classroom</th>
<th>Cafeteria</th>
<th>Gym</th>
<th>Front Hall</th>
<th>Outdoors</th>
</tr>
</thead>
<tbody>
<tr>
<td>UFP (count/cc)</td>
<td>3,724</td>
<td>2,368</td>
<td>1,448</td>
<td>2,843</td>
<td>10,269</td>
</tr>
<tr>
<td>PM₁ (mg/m³)</td>
<td>0.010</td>
<td>0.007</td>
<td>0.005</td>
<td>0.007</td>
<td>0.007</td>
</tr>
<tr>
<td>PM₂.₅ (mg/m³)</td>
<td>0.010</td>
<td>0.007</td>
<td>0.005</td>
<td>0.007</td>
<td>0.007</td>
</tr>
<tr>
<td>PM₄ (mg/m³)</td>
<td>0.011</td>
<td>0.007</td>
<td>0.005</td>
<td>0.008</td>
<td>0.007</td>
</tr>
<tr>
<td>PM₁₀ (mg/m³)</td>
<td>0.013</td>
<td>0.008</td>
<td>0.005</td>
<td>0.010</td>
<td>0.008</td>
</tr>
<tr>
<td>PM Total (mg/m³)</td>
<td>0.020</td>
<td>0.011</td>
<td>0.008</td>
<td>0.014</td>
<td>0.010</td>
</tr>
<tr>
<td>Temperature (°F)</td>
<td>72.5</td>
<td>73.0</td>
<td>71.3</td>
<td>74.5</td>
<td>71.5</td>
</tr>
<tr>
<td>Relative Humidity (%)</td>
<td>25.4</td>
<td>19.0</td>
<td>25.0</td>
<td>19.4</td>
<td>41.0</td>
</tr>
</tbody>
</table>

During school day indoors all weeks except for reference
Outdoors = during school day, all weeks except reference

Table 4.2.2 shows the median values by sampling location during the reference week. The reference week occurred during the school’s spring break in order to record background values. The outdoors medians were the highest in every category overall.

For the indoor locations, the location with the highest median for UFP was the classroom. The cafeteria had the lowest median for UFP. For PM₁, PM₂.₅ and PM₄, the classroom, cafeteria and front hall all shared the highest median from the indoor locations. Both the classroom and the front hall shared the indoor locations’ highest median of PM₁₀. The
classroom had the highest median for indoor locations for the PM total. For the remaining particulates, the lowest medians were recorded in the gym.

**Table 4.2.2 – Median Values by Sampling Location, Reference Week**

<table>
<thead>
<tr>
<th></th>
<th>Classroom</th>
<th>Cafeteria</th>
<th>Gym</th>
<th>Front Hall</th>
<th>Outdoors</th>
</tr>
</thead>
<tbody>
<tr>
<td>UFP (count/cc)</td>
<td>1,631</td>
<td>298</td>
<td>577</td>
<td>1,388</td>
<td>5,049</td>
</tr>
<tr>
<td>PM$_1$ (mg/m$^3$)</td>
<td>0.003</td>
<td>0.003</td>
<td>0.001</td>
<td>0.003</td>
<td>0.022</td>
</tr>
<tr>
<td>PM$_{2.5}$ (mg/m$^3$)</td>
<td>0.003</td>
<td>0.003</td>
<td>0.001</td>
<td>0.003</td>
<td>0.022</td>
</tr>
<tr>
<td>PM$_4$ (mg/m$^3$)</td>
<td>0.003</td>
<td>0.003</td>
<td>0.001</td>
<td>0.003</td>
<td>0.022</td>
</tr>
<tr>
<td>PM$_{10}$ (mg/m$^3$)</td>
<td>0.004</td>
<td>0.003</td>
<td>0.001</td>
<td>0.004</td>
<td>0.023</td>
</tr>
<tr>
<td>PM Total (mg/m$^3$)</td>
<td>0.005</td>
<td>0.003</td>
<td>0.001</td>
<td>0.004</td>
<td>0.025</td>
</tr>
<tr>
<td>Temperature (°F)</td>
<td>72.6</td>
<td>72.8</td>
<td>70.1</td>
<td>74.0</td>
<td>51.8</td>
</tr>
<tr>
<td>Relative Humidity (%)</td>
<td>12.1</td>
<td>10.9</td>
<td>11.8</td>
<td>10.1</td>
<td>27.8</td>
</tr>
</tbody>
</table>

During school day indoors reference week
Outdoors = during school day, only reference week

4.3 Median by Class Period

Table 4.3.1 shows the median values by class period. Overall, 5$^{th}$ period had the highest medians except for PM1. The highest median for PM1 was recorded between classes. For PM$_{2.5}$, the time between classes and 5th period had the highest median values. The highest median values for PM$_4$ were in 5$^{th}$ period and between classes. Between classes, 4$^{th}$ and 5$^{th}$ period shared in the highest median value for PM$_{10}$. Finally, for PM total, 4$^{th}$ and 5$^{th}$ period shared the highest median. Of all the class periods, 5$^{th}$ period was the longest, allowing for the school’s lunchtime.

First period showed the lowest median value for UFP. For PM1, the 1$^{st}$, 2$^{nd}$, 3$^{rd}$, 4$^{th}$, 6$^{th}$ and 7$^{th}$ periods had the lowest median. Periods 3, 6, and 7 had the lowest median for PM$_{2.5}$. Third and 6$^{th}$ periods were the lowest for PM$_4$. For PM$_{10}$, 2$^{nd}$ and 3$^{rd}$
periods shared the lowest median. Finally, for PM total, 2nd period had the overall lowest median.

**Table 4.3.1 – Median Values by Class Period**

<table>
<thead>
<tr>
<th></th>
<th>1st period</th>
<th>2nd period</th>
<th>3rd period</th>
<th>4th period</th>
<th>5th period</th>
<th>6th period</th>
<th>7th period</th>
<th>Between classes</th>
</tr>
</thead>
<tbody>
<tr>
<td>UFP (count/cc)</td>
<td>1,773</td>
<td>2,019</td>
<td>1,935</td>
<td>2,516</td>
<td>4,094</td>
<td>2,957</td>
<td>2,731</td>
<td>2,261</td>
</tr>
<tr>
<td>PM1 (mg/m³)</td>
<td>0.007</td>
<td>0.007</td>
<td>0.007</td>
<td>0.007</td>
<td>0.008</td>
<td>0.007</td>
<td>0.007</td>
<td>0.009</td>
</tr>
<tr>
<td>PM2.5 (mg/m³)</td>
<td>0.008</td>
<td>0.008</td>
<td>0.007</td>
<td>0.008</td>
<td>0.009</td>
<td>0.007</td>
<td>0.007</td>
<td>0.009</td>
</tr>
<tr>
<td>PM4 (mg/m³)</td>
<td>0.008</td>
<td>0.008</td>
<td>0.007</td>
<td>0.008</td>
<td>0.009</td>
<td>0.007</td>
<td>0.008</td>
<td>0.009</td>
</tr>
<tr>
<td>PM10 (mg/m³)</td>
<td>0.009</td>
<td>0.008</td>
<td>0.008</td>
<td>0.011</td>
<td>0.011</td>
<td>0.010</td>
<td>0.010</td>
<td>0.011</td>
</tr>
<tr>
<td>PM Total (mg/m³)</td>
<td>0.012</td>
<td>0.010</td>
<td>0.011</td>
<td>0.016</td>
<td>0.016</td>
<td>0.014</td>
<td>0.014</td>
<td>0.015</td>
</tr>
<tr>
<td>Temperature (°F)</td>
<td>71.2</td>
<td>72.0</td>
<td>72.7</td>
<td>73.7</td>
<td>73.6</td>
<td>73.5</td>
<td>73.1</td>
<td>72.8</td>
</tr>
<tr>
<td>Relative Humidity (%)</td>
<td>21.7</td>
<td>20.3</td>
<td>21.0</td>
<td>22.3</td>
<td>22.9</td>
<td>23.4</td>
<td>22.6</td>
<td>21.4</td>
</tr>
</tbody>
</table>

During school day indoors all weeks except for reference week

### 4.4 Median by Week of Sampling

Table 4.4.1 shows the median values by week of sampling. The classroom was tested weeks 1, 5 and 11. During weeks 2, 6 and 10, the cafeteria was tested. The gym was tested weeks 3, 7 and 13. During weeks 4, 8 and 12, the front hall was tested. Week 9 was the reference week. Week 15, an outdoor week, had the highest median for UFP. Of the indoor weeks, the highest median UFP was recorded on week 5, a classroom week. The lowest median value for UFP was recorded on week 3, a gym week. The highest medians for PM1, PM2.5 and PM4 overall were week 12, an outdoor week. The highest indoor median for PM1, PM2.5 and PM4 were week 2, a cafeteria week. Week 1,
a classroom week, saw the overall highest median values for PM10 and PM total. The lowest median values for PM1, PM2.5, PM4, and PM10 were an outdoor week 13; weeks 7 and 13 (both in the gym) were the lowest indoors. Week 13 inside the gym had the lowest median value for PM total.

### Table 4.4.1 – Median Values by Week of Sampling

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>10</th>
<th>11</th>
<th>12</th>
<th>13</th>
<th>9*</th>
<th>9**</th>
<th>12**</th>
<th>13**</th>
<th>14**</th>
<th>15**</th>
</tr>
</thead>
<tbody>
<tr>
<td>UFP (count/cc)</td>
<td>2.28</td>
<td>4.46</td>
<td>1.01</td>
<td>1.52</td>
<td>5.19</td>
<td>2.30</td>
<td>1.31</td>
<td>2.83</td>
<td>1.73</td>
<td>3.85</td>
<td>4.38</td>
<td>2.32</td>
<td>1.05</td>
<td>5.04</td>
<td>8.142</td>
<td>8.238</td>
<td>--</td>
<td>34.42</td>
</tr>
<tr>
<td>PM1 (mg/m³)</td>
<td>0.01</td>
<td>0.01</td>
<td>0.00</td>
<td>0.00</td>
<td>0.01</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.02</td>
<td>0.015</td>
<td>0.001</td>
</tr>
<tr>
<td>PM2.5 (mg/m³)</td>
<td>0.01</td>
<td>0.01</td>
<td>0.00</td>
<td>0.00</td>
<td>0.01</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>PM4 (mg/m³)</td>
<td>0.01</td>
<td>0.01</td>
<td>0.00</td>
<td>0.00</td>
<td>0.01</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>PM10 (mg/m³)</td>
<td>0.01</td>
<td>0.01</td>
<td>0.00</td>
<td>0.00</td>
<td>0.01</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>PM Total (mg/m³)</td>
<td>0.02</td>
<td>0.01</td>
<td>0.00</td>
<td>0.00</td>
<td>0.01</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.01</td>
<td>0.00</td>
<td>0.01</td>
<td>0.01</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Temperature (°F)</td>
<td>71.8</td>
<td>73.6</td>
<td>71.2</td>
<td>73.7</td>
<td>72.6</td>
<td>73.0</td>
<td>71.4</td>
<td>74.5</td>
<td>72.2</td>
<td>75.1</td>
<td>74.9</td>
<td>71.2</td>
<td>72.8</td>
<td>51.8</td>
<td>55.4</td>
<td>75.5</td>
<td>85.6</td>
<td>70.3</td>
</tr>
<tr>
<td>Relative Humidity (%)</td>
<td>22.3</td>
<td>15.8</td>
<td>25.0</td>
<td>14.9</td>
<td>22.4</td>
<td>17.8</td>
<td>18.4</td>
<td>18.5</td>
<td>32.3</td>
<td>41.5</td>
<td>23.0</td>
<td>53.1</td>
<td>12.1</td>
<td>27.8</td>
<td>31.5</td>
<td>44.3</td>
<td>50.5</td>
<td>35.9</td>
</tr>
</tbody>
</table>

During school day indoors all
Classroom = 1, 5, 11
Cafeteria = 2, 6, 10
Gym = 3, 7, 13
Front Hall = 4, 8, 12
*Reference week (indoor locations)
**Reference week (outdoors)
***Outdoors

4.5 **Kruskal-Wallis by Location**

Table 4.5.1 shows the results of the Kruskal-Wallis test by location. All locations were statistically significant with a p-value of <0.001. Therefore, for each of the particle sizes at least two of the locations are significantly different from each other.
Table 4.5.1 – Kruskal-Wallis by Location

<table>
<thead>
<tr>
<th></th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>UFP (count/cc)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>PM$_1$ (mg/m$^3$)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>PM$_{2.5}$ (mg/m$^3$)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>PM$_4$ (mg/m$^3$)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>PM$_{10}$ (mg/m$^3$)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>PM Total (mg/m$^3$)</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

Table 4.5.2 shows the results of the Mann-Whitney U test by location. For the test by location, the Bonferroni adjusted level of significance was 0.0050. Using the adjusted level of significance, the classroom was not different from outdoors for PM$_1$, PM$_{2.5}$ and PM$_4$; the cafeteria was not different from the front hall for UFP, PM$_1$, PM$_{2.5}$ and PM$_4$; the cafeteria was not different from outdoor for PM Total; and the front hall was not different from outdoors for PM$_{10}$. All other comparisons were statistically significant (p<0.005).
Table 4.5.2 - Mann-Whitney by Location

<table>
<thead>
<tr>
<th></th>
<th>UFP (count/cc)</th>
<th>PM₁ (mg/m³)</th>
<th>PM₂.₅ (mg/m³)</th>
<th>PM₄ (mg/m³)</th>
<th>PM₁₀ (mg/m³)</th>
<th>PM Total (mg/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Classroom vs. Cafeteria</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Classroom vs. Gym</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Classroom vs. Front hall</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Classroom vs. Outdoors</td>
<td>&lt;0.001</td>
<td>0.136</td>
<td>0.128</td>
<td>0.060</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Cafeteria vs. Gym</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Cafeteria vs. Front hall</td>
<td>0.319</td>
<td>0.246</td>
<td>0.123</td>
<td>0.031</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Cafeteria vs. Outdoors</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>0.354</td>
</tr>
<tr>
<td>Gym vs. Front hall</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Gym vs. Outdoors</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Front hall vs. Outdoors</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>0.001</td>
<td>0.002</td>
<td>0.937</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

During school day, all weeks but reference

4.6 Kruskal-Wallis by Class Period

Table 4.6.1 shows the results of the Kruskal-Wallis by class period for indoor locations. All values were statistically significant. Therefore, for each of the particle sizes at least two of the class periods are significantly different from each other.
Table 4.6.1 – Kruskal-Wallis by Class Period, all Indoor Locations

<table>
<thead>
<tr>
<th>Measurement</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>UFP (count/cc)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>PM$_1$ (mg/m$^3$)</td>
<td>0.006</td>
</tr>
<tr>
<td>PM$_{2.5}$ (mg/m$^3$)</td>
<td>0.005</td>
</tr>
<tr>
<td>PM$_4$ (mg/m$^3$)</td>
<td>0.003</td>
</tr>
<tr>
<td>PM$_{10}$ (mg/m$^3$)</td>
<td>0.001</td>
</tr>
<tr>
<td>PM Total (mg/m$^3$)</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

During school day, all weeks but reference

Table 4.6.2 shows the results of the Mann-Whitney U test by class period for indoor locations. For the test by class period the Bonferroni adjusted level of significance was 0.005. Using the adjusted level of significance, 1$^{st}$ period was not different from 2$^{nd}$ or 3$^{rd}$ periods for UFP, PM$_1$, PM$_{2.5}$, PM$_4$, PM$_{10}$ and PM total; 1$^{st}$ period was not different from 4$^{th}$ or 5$^{th}$ periods for PM$_1$, PM$_{2.5}$, PM$_4$ and PM$_{10}$; 1$^{st}$ period was not different from 6$^{th}$ or 7$^{th}$ periods for PM$_1$, PM$_{2.5}$, PM$_4$, PM$_{10}$ and PM total; 1$^{st}$ period was not different from between classes for UFP, PM$_1$, PM$_{2.5}$, PM$_4$, PM$_{10}$ and PM total; 2$^{nd}$ period was not different from 3$^{rd}$ period for UFP, PM$_1$, PM$_{2.5}$, PM$_4$, PM$_{10}$ and PM total; 2$^{nd}$ period was not different from 4$^{th}$ or 5$^{th}$ periods for PM$_1$, PM$_{2.5}$, PM$_4$ and PM$_{10}$; 2$^{nd}$ period was not different from 6$^{th}$ or 7$^{th}$ periods for PM$_1$, PM$_{2.5}$, PM$_4$, PM$_{10}$ and PM total; 2$^{nd}$ period was not different from between classes for UFP, PM$_1$, PM$_{2.5}$, PM$_4$, PM$_{10}$ and PM total; 3$^{rd}$ period was not different from 4$^{th}$ period for PM$_1$, PM$_{2.5}$, and PM$_4$; 3$^{rd}$ period was not different from 5$^{th}$ period for PM$_1$, PM$_{2.5}$, PM$_4$ and PM$_{10}$; 3$^{rd}$ period was not different from 6$^{th}$ or 7$^{th}$ periods for PM$_1$, PM$_{2.5}$, PM$_4$, PM$_{10}$ and PM total; 3$^{rd}$ period was not different from between classes for UFP, PM$_1$, PM$_{2.5}$, PM$_4$, PM$_{10}$ and PM total; 4$^{th}$ period was not different from 5$^{th}$ period for
PM1, PM2.5, PM4, PM10 and PM total; 4\textsuperscript{th} period was not different from 6\textsuperscript{th} or 7\textsuperscript{th} periods for UFP; 4\textsuperscript{th} period was not different from between classes for UFP, PM1, PM2.5, PM4, PM10 and PM total; 5\textsuperscript{th} period was not different from 6\textsuperscript{th} or 7\textsuperscript{th} periods for PM1, PM2.5, PM4 and PM10; 5\textsuperscript{th} period was not different from between classes for PM1, PM2.5, PM4, PM10 and PM total; 6\textsuperscript{th} period was not different from 7\textsuperscript{th} period or between classes for UFP, PM1, PM2.5, PM4, PM10 and PM total; 7\textsuperscript{th} period was not different from between classes for UFP, PM1, PM2.5, PM4, PM10 and PM total. All other comparisons were statistically significant (p<0.005).
Table 4.6.2 - Mann-Whitney by Class Period, all Indoor Locations

<table>
<thead>
<tr>
<th></th>
<th>UFP (count/cc)</th>
<th>PM₁ (mg/m³)</th>
<th>PM₂.₅ (mg/m³)</th>
<th>PM₄ (mg/m³)</th>
<th>PM₁₀ (mg/m³)</th>
<th>PM Total (mg/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1&lt;sup&gt;st&lt;/sup&gt; vs. 2&lt;sup&gt;nd&lt;/sup&gt;</td>
<td>0.286</td>
<td>0.635</td>
<td>0.740</td>
<td>0.790</td>
<td>0.797</td>
<td>0.452</td>
</tr>
<tr>
<td>1&lt;sup&gt;st&lt;/sup&gt; vs. 3&lt;sup&gt;rd&lt;/sup&gt;</td>
<td>0.809</td>
<td>0.949</td>
<td>1.00</td>
<td>0.997</td>
<td>0.833</td>
<td>0.862</td>
</tr>
<tr>
<td>1&lt;sup&gt;st&lt;/sup&gt; vs. 4&lt;sup&gt;th&lt;/sup&gt;</td>
<td>&lt;0.001</td>
<td>0.217</td>
<td>0.205</td>
<td>0.145</td>
<td>0.016</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>1&lt;sup&gt;st&lt;/sup&gt; vs. 5&lt;sup&gt;th&lt;/sup&gt;</td>
<td>&lt;0.001</td>
<td>0.373</td>
<td>0.352</td>
<td>0.406</td>
<td>0.081</td>
<td>0.002</td>
</tr>
<tr>
<td>1&lt;sup&gt;st&lt;/sup&gt; vs. 6&lt;sup&gt;th&lt;/sup&gt;</td>
<td>&lt;0.001</td>
<td>0.236</td>
<td>0.252</td>
<td>0.230</td>
<td>0.710</td>
<td>0.953</td>
</tr>
<tr>
<td>1&lt;sup&gt;st&lt;/sup&gt; vs. 7&lt;sup&gt;th&lt;/sup&gt;</td>
<td>&lt;0.001</td>
<td>0.064</td>
<td>0.068</td>
<td>0.067</td>
<td>0.370</td>
<td>0.720</td>
</tr>
<tr>
<td>1&lt;sup&gt;st&lt;/sup&gt; vs. BC</td>
<td>0.006</td>
<td>0.202</td>
<td>0.190</td>
<td>0.189</td>
<td>0.087</td>
<td>0.024</td>
</tr>
<tr>
<td>2&lt;sup&gt;nd&lt;/sup&gt; vs. 3&lt;sup&gt;rd&lt;/sup&gt;</td>
<td>0.213</td>
<td>0.768</td>
<td>0.807</td>
<td>0.851</td>
<td>0.992</td>
<td>0.617</td>
</tr>
<tr>
<td>2&lt;sup&gt;nd&lt;/sup&gt; vs. 4&lt;sup&gt;th&lt;/sup&gt;</td>
<td>&lt;0.001</td>
<td>0.387</td>
<td>0.299</td>
<td>0.197</td>
<td>0.009</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>2&lt;sup&gt;nd&lt;/sup&gt; vs. 5&lt;sup&gt;th&lt;/sup&gt;</td>
<td>&lt;0.001</td>
<td>0.638</td>
<td>0.548</td>
<td>0.557</td>
<td>0.065</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>2&lt;sup&gt;nd&lt;/sup&gt; vs. 6&lt;sup&gt;th&lt;/sup&gt;</td>
<td>&lt;0.001</td>
<td>0.118</td>
<td>0.154</td>
<td>0.171</td>
<td>0.777</td>
<td>0.648</td>
</tr>
<tr>
<td>2&lt;sup&gt;nd&lt;/sup&gt; vs. 7&lt;sup&gt;th&lt;/sup&gt;</td>
<td>0.002</td>
<td>0.024</td>
<td>0.033</td>
<td>0.040</td>
<td>0.393</td>
<td>0.797</td>
</tr>
<tr>
<td>2&lt;sup&gt;nd&lt;/sup&gt; vs. BC</td>
<td>0.055</td>
<td>0.406</td>
<td>0.336</td>
<td>0.300</td>
<td>0.080</td>
<td>0.007</td>
</tr>
<tr>
<td>3&lt;sup&gt;rd&lt;/sup&gt; vs. 4&lt;sup&gt;th&lt;/sup&gt;</td>
<td>&lt;0.001</td>
<td>0.217</td>
<td>0.189</td>
<td>0.116</td>
<td>0.005</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>3&lt;sup&gt;rd&lt;/sup&gt; vs. 5&lt;sup&gt;th&lt;/sup&gt;</td>
<td>&lt;0.001</td>
<td>0.558</td>
<td>0.504</td>
<td>0.551</td>
<td>0.092</td>
<td>0.001</td>
</tr>
<tr>
<td>3&lt;sup&gt;rd&lt;/sup&gt; vs. 6&lt;sup&gt;th&lt;/sup&gt;</td>
<td>&lt;0.001</td>
<td>0.135</td>
<td>0.161</td>
<td>0.168</td>
<td>0.755</td>
<td>0.973</td>
</tr>
<tr>
<td>3&lt;sup&gt;rd&lt;/sup&gt; vs. 7&lt;sup&gt;th&lt;/sup&gt;</td>
<td>&lt;0.001</td>
<td>0.031</td>
<td>0.037</td>
<td>0.037</td>
<td>0.269</td>
<td>0.682</td>
</tr>
<tr>
<td>3&lt;sup&gt;rd&lt;/sup&gt; vs. BC</td>
<td>0.008</td>
<td>0.308</td>
<td>0.273</td>
<td>0.252</td>
<td>0.089</td>
<td>0.020</td>
</tr>
<tr>
<td>4&lt;sup&gt;th&lt;/sup&gt; vs. 5&lt;sup&gt;th&lt;/sup&gt;</td>
<td>&lt;0.001</td>
<td>0.494</td>
<td>0.494</td>
<td>0.337</td>
<td>0.381</td>
<td>0.476</td>
</tr>
<tr>
<td>4&lt;sup&gt;th&lt;/sup&gt; vs. 6&lt;sup&gt;th&lt;/sup&gt;</td>
<td>0.052</td>
<td>0.002</td>
<td>0.002</td>
<td>0.001</td>
<td>0.002</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>4&lt;sup&gt;th&lt;/sup&gt; vs. 7&lt;sup&gt;th&lt;/sup&gt;</td>
<td>0.766</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>4&lt;sup&gt;th&lt;/sup&gt; vs. BC</td>
<td>0.286</td>
<td>0.896</td>
<td>0.925</td>
<td>0.834</td>
<td>0.723</td>
<td>0.279</td>
</tr>
<tr>
<td>5&lt;sup&gt;th&lt;/sup&gt; vs. 6&lt;sup&gt;th&lt;/sup&gt;</td>
<td>&lt;0.001</td>
<td>0.052</td>
<td>0.054</td>
<td>0.064</td>
<td>0.083</td>
<td>0.002</td>
</tr>
<tr>
<td>5&lt;sup&gt;th&lt;/sup&gt; vs. 7&lt;sup&gt;th&lt;/sup&gt;</td>
<td>&lt;0.001</td>
<td>0.008</td>
<td>0.007</td>
<td>0.008</td>
<td>0.010</td>
<td>0.001</td>
</tr>
<tr>
<td>5&lt;sup&gt;th&lt;/sup&gt; vs. BC</td>
<td>&lt;0.001</td>
<td>0.691</td>
<td>0.675</td>
<td>0.607</td>
<td>0.772</td>
<td>0.547</td>
</tr>
<tr>
<td>6&lt;sup&gt;th&lt;/sup&gt; vs. 7&lt;sup&gt;th&lt;/sup&gt;</td>
<td>0.030</td>
<td>0.432</td>
<td>0.413</td>
<td>0.423</td>
<td>0.357</td>
<td>0.622</td>
</tr>
<tr>
<td>6&lt;sup&gt;th&lt;/sup&gt; vs. BC</td>
<td>0.015</td>
<td>0.035</td>
<td>0.032</td>
<td>0.032</td>
<td>0.059</td>
<td>0.027</td>
</tr>
<tr>
<td>7&lt;sup&gt;th&lt;/sup&gt; vs. BC</td>
<td>0.533</td>
<td>0.008</td>
<td>0.007</td>
<td>0.006</td>
<td>0.013</td>
<td>0.014</td>
</tr>
</tbody>
</table>

BC = Between Classes

4.7 Mann-Whitney by Day of the Week and Location

Table 4.7.1 shows the results of the Mann-Whitney U test by day of the week and location. For this test the Bonferroni adjusted level of significance was 0.0025. Using the adjusted level of significance, the classroom showed no difference for Mondays and Thursdays for UFP; the cafeteria showed no difference for Mondays and Thursdays for
PM1, PM2.5, PM4, PM10 and PM total; the front hall showed no difference for Mondays and Thursdays for PM10 and PM total. All other comparisons were statistically significant (p<0.025).

**Table 4.7.1 – Mann-Whitney by Day of Week and Location**

<table>
<thead>
<tr>
<th>Location</th>
<th>Days of week</th>
<th>UFP (count/cc)</th>
<th>PM1 (mg/m³)</th>
<th>PM2.5 (mg/m³)</th>
<th>PM4 (mg/m³)</th>
<th>PM10 (mg/m³)</th>
<th>PM Total (mg/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Classroom</td>
<td>Monday vs. Thursday</td>
<td>0.051</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Cafeteria</td>
<td>Monday vs. Thursday</td>
<td>&lt;0.001</td>
<td>0.150</td>
<td>0.124</td>
<td>0.107</td>
<td>0.092</td>
<td>0.122</td>
</tr>
<tr>
<td>Gym</td>
<td>Monday vs. Thursday</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>0.001</td>
</tr>
<tr>
<td>Front Hall</td>
<td>Monday vs. Thursday</td>
<td>&lt;0.001</td>
<td>0.001</td>
<td>0.002</td>
<td>0.013</td>
<td>0.334</td>
<td>0.642</td>
</tr>
</tbody>
</table>

During school day, all weeks but reference, indoor

### 4.8 Kruskal-Wallis by Week of Sampling

Table 4.8.1 shows the results of the Kruskal-Wallis by week of sampling. All categories of particulate matter showed statistically significant results. Therefore for each of the particle sizes, at least two of the weeks of sampling are significantly different from each other.
Table 4.8.1 – Kruskal-Wallis by Week of Sampling

<table>
<thead>
<tr>
<th>Location</th>
<th>UFP (count/cc)</th>
<th>PM$_1$ (mg/m$^3$)</th>
<th>PM$_{2.5}$ (mg/m$^3$)</th>
<th>PM$_4$ (mg/m$^3$)</th>
<th>PM$_{10}$ (mg/m$^3$)</th>
<th>PM Total (mg/m$^3$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Classroom</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Cafeteria</td>
<td>&lt;0.001</td>
<td>0.003</td>
<td>0.004</td>
<td>0.005</td>
<td>0.003</td>
<td>0.001</td>
</tr>
<tr>
<td>Gym</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Front Hall</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

During school day, all weeks but reference, indoor

Table 4.8.2 shows the results of the Mann-Whitney U test by week of sampling.

For the test by week of sampling the Bonferroni adjusted level of significance was 0.017.

Using the adjusted level of significance, the classroom showed no differences for 1$^{st}$ from 5$^{th}$ weeks for PM$_1$, PM$_{2.5}$ and PM$_4$; the classroom showed no differences for 5$^{th}$ from 11$^{th}$ weeks for PM Total; the cafeteria showed no differences for 2$^{nd}$ from 6$^{th}$ weeks for PM$_1$, PM$_{2.5}$, PM$_4$, PM$_{10}$ and PM Total; the cafeteria showed no differences for 6$^{th}$ from 10$^{th}$ weeks for PM$_{2.5}$, PM$_4$, PM$_{10}$ and PM Total; and the gym showed no differences for 7$^{th}$ from 13$^{th}$ weeks for PM$_1$, PM$_{2.5}$, PM$_4$, PM$_{10}$ and PM Total. All other comparisons were statistically significant (p<0.017).
### Table 4.8.2 - Mann-Whitney by Week of Sampling

<table>
<thead>
<tr>
<th>UFP (count/cc)</th>
<th>PM$_1$ (mg/m$^3$)</th>
<th>PM$_{2.5}$ (mg/m$^3$)</th>
<th>PM$_4$ (mg/m$^3$)</th>
<th>PM$_{10}$ (mg/m$^3$)</th>
<th>PM Total (mg/m$^3$)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Classroom</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1$^{st}$ vs. 5$^{th}$</td>
<td>&lt;0.001</td>
<td>0.222</td>
<td>0.198</td>
<td>0.074</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>1$^{st}$ vs. 11$^{th}$</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>5$^{th}$ vs. 11$^{th}$</td>
<td>0.012</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td><strong>Cafeteria</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2$^{nd}$ vs. 6$^{th}$</td>
<td>&lt;0.001</td>
<td>0.332</td>
<td>0.338</td>
<td>0.316</td>
<td>0.366</td>
</tr>
<tr>
<td>2$^{nd}$ vs. 10$^{th}$</td>
<td>&lt;0.001</td>
<td>0.001</td>
<td>0.001</td>
<td>0.001</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>6$^{th}$ vs. 10$^{th}$</td>
<td>&lt;0.001</td>
<td>0.017</td>
<td>0.024</td>
<td>0.030</td>
<td>0.108</td>
</tr>
<tr>
<td><strong>Gym</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3$^{rd}$ vs. 7$^{th}$</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>3$^{rd}$ vs. 13$^{th}$</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>7$^{th}$ vs. 13$^{th}$</td>
<td>&lt;0.001</td>
<td>0.073</td>
<td>0.081</td>
<td>0.086</td>
<td>0.204</td>
</tr>
<tr>
<td><strong>Front Hall</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4$^{th}$ vs. 8$^{th}$</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>4$^{th}$ vs. 12$^{th}$</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>8$^{th}$ vs. 12$^{th}$</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>
Chapter 5

Discussion

5.1 Criteria and Significance

The results of this study indicate there are not potentially harmful levels of particulate matter exposures within this Toledo high school. The median values were below WHO and NAAQS outdoor standards. The outdoor measurements were higher than those of the indoors. As this is a relatively new school building (5 years old), it appears that it is well-maintained for and minimizes the flow of outdoor particulate matter into the school.

5.2 Comparison with Other Studies

While other studies have looked at levels of particulate matter in schools, most were done in elementary schools. Many of those found levels of indoor PM higher than those of outdoors. In this study of an urban public high school, the levels of indoor PM were generally below those of outdoors. For example, the results from this study disagree with Buonnanno et al. (2013), Crist et al. (2008), Diapouli et al. (2008),
Ekmeckioglu and Keskin (2007) and Lee and Chang (2000), all of whom found that PM levels indoors were higher than those outdoors.

5.3 Recommendations

It is recommended that the school personnel continue to maintain the building and HVAC system. The school needs to continue to keep the building clean and in working order so that the occupants are protected from potential hazards.

5.4 Limitations

There were several limitations to this study. All monitoring was general area, not personal. Therefore, all results merely signify the potential exposure for the occupants. However, the equipment was placed in order to estimate a breathing zone count or concentration but from an area of minimal interference with school activities.

Although constant monitoring of the equipment during the day did not occur, there was no evidence of any tampering. The school occupants seemed to ignore the instruments. Periodic checks on the equipment showed no signs of disturbance or tampering.

As with any long-term monitoring projects, there were some problems with the equipment itself. Specifically, the DustTrak exhibited some unreliable tendencies due to inexperience. Once the issue was corrected, the monitoring plan was extended to ensure adequate data collection.
5.5 Future Research

Future research should look at the exposure to particulate matter in other Toledo schools. The comparisons would be beneficial to see which buildings need to be renovated. Future studies done within the same high school can look at different locations, such as art or shop classrooms – both of which have the potential to have high levels of particulate matter.
Chapter 6

Conclusions

The results showed the highest levels of PM in the classroom. Therefore, the hypothesis that “The statistically highest counts of indoor daily median airborne particles (PM1, PM2.5, PM4, PM10 and PM Total) and UFP will occur in the front hallway and cafeteria during the school day (8:00-14:45)” is rejected.

There were several statistically significant differences in PM during the class periods. The hypothesis that “There will be no statistically significant difference in daily median airborne particles (PM1, PM2.5, PM4, PM10 and PM Total) counts and UFP indoors between class periods (1-7) throughout the school day” is rejected.

There were statistically significant differences in PM during the sampling days. Therefore, the hypothesis that “There will be no statistically significant difference in daily median airborne particles (PM1, PM2.5, PM4, PM10 and PM Total) counts and UFP between sampling days (Monday and Thursday) at specific locations throughout the school” is rejected.

There were statistically significant differences in PM that occurred between sampling weeks. The hypothesis that “There will be no statistically significant difference in daily median airborne particles (PM1, PM2.5, PM4, PM10 and PM Total) counts and...
UFP between sampling weeks (1-15) at specific locations throughout the school” is rejected.

Overall, the outdoor PM counts were above those of the indoor counts. Therefore, the hypothesis that “Indoor airborne particle counts (PM1, PM2.5, PM4, PM10 and PM Total) will be below the outdoor counts” is not rejected.
References


