
UNIVERSITY OF NORTH TEXAS
HEALTH SCIENCE CENTER AT FORT WORTH
1970

Hill, Elizabeth G., Analysis of a particulate count loading in a water-damaged hospital. Master of Public Health (Environmental Health), December 2007, 44 pp., 8 tables, 12 figures, bibliography, 38 titles.

The purpose of this study was to determine whether data from particle counters placed on the ceiling in hospital rooms are comparable to data from particle counters placed on the wall in the same room. A baseline particulate concentration was also determined. An extensive literature review of the subject was performed as well as a statistical analysis of the data.

The Spearman's Rank Correlation showed that particulate concentrations from the ceiling and wall in the 0.3-5 μm size range were significantly correlated, while the particulate concentrations from the ceiling and the wall in the 5+ μm size range were not significantly correlated. The baseline concentrations were then found based on the descriptive statistics of the particulate concentrations taken from the ceiling.

ANALYSIS OF A PARTICULATE COUNT LOADING

IN A WATER-DAMAGED HOSPITAL

Elizabeth Hill, B.S.

APPROVED:

Major Professor

Committee Member

Committee Member

Department Chair

Dean

ANALYSIS OF A PARTICULATE COUNT LOADING IN A WATER-DAMAGED HOSPITAL

THESIS

Presented to the

University of North Texas Health Science Center
at Fort Worth School of Public Health

in Partial Fulfillment of the Requirements

for the Degree of

Master of Public Health

By

Elizabeth Hill, B.S.

Fort Worth, TX

December 2007

ACKNOWLEDGEMENTS

I would like to express my appreciation to Dr. Michael Larrañaga for guiding me through my thesis project. I would also like to thank Dr. Terry Gratton for taking over as major professor and for the valuable input given to me on my project. I extend a warm thank you to Dr. Ramphal for being a part of my committee and another to Dr. Sae-Jong Bae for being a valuable resource on statistical analysis.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Figure Pages

CHAPTER I

INTRODUCTION TO RESEARCH

Defining acceptable Indoor Environmental Quality (IEQ) is a growing public health challenge. According to the EPA, indoor air is often more polluted than the outdoor air of some of the largest cities in the United States (EPA, 1995). IEQ became a greater issue during the Oil Embargo in the 1970's when construction companies were required to construct buildings to be more energy efficient (Hill, 1992). This pursuit of energy-efficient buildings resulted in airtight structures that often re-circulated indoor air instead of replacing indoor air with fresh outdoor air. This method of building, while more cost efficient, resulted in the accumulation of indoor air pollutants, including particulate matter, which contributed to poor IEQ in home and work environments (Janghoo & Kato, 2007). Healthcare facilities such as hospitals were also affected by IEQ problems.

Hospitals not only provide medical care to patients, but also provide a sanitary space that will facilitate their treatment and recovery, not hinder it. Therefore, poor IEQ is counterproductive to the purpose of a hospital. Much of the particulate matter in hospitals are bioaerosols which are composed of microorganisms (Morawska, Jamriska, & Francis, 1998). Many of these are opportunistic pathogens that pose a greater risk to those patients whom are immunocompromised. Fungi such as *Aspergillus* and *Penicillium* pose significant health risks because they are allergenic and have been implicated in the development of asthma (Perdelli, 2006). *Aspergillus* species, an opportunistic pathogen that is transmitted via inhalation of its spores (Vonberg, 2006), is

one of the more prevalent fungi found in hospitals. Bacteria are also a health risk in hospitals. Not only do they produce spores, but they also produce enzymes that act as allergens (Pope, Patterson, & Burge, 1993). They can also reproduce in their human hosts. Among the species of bacteria that can be prevalent in hospitals is *Actinomycetes*. This is a common species of bacteria that can cause pulmonary infections and formation of abscesses among many other effects (McNeil & Brown, 1994). As a result of the adverse health effects that these pathogens can produce, it is important to maintain low levels of particulate matter in hospitals in order to control airborne pathogens (Morawska et al., 1998).

Very little information concerning the levels of particulate matter in hospital air is available. Therefore, monitoring airborne particulate concentrations prior to, during, and after remediation in a damp and water-damaged hospital is important. The first step is to monitor the air to establish baseline concentrations so that airborne particle concentrations during and after remediation can be compared to pre-remediation levels. Aerosols are not always uniformly distributed throughout a room; therefore, samplers must be strategically placed in order to sample the concentrations that people are exposed to (Whicker, Baker, & Wasiolek, 2000). Samplers are generally placed in the breathing zone or exposure zone because it is assumed that the particulate matter concentration in this area will be the concentration that is inhaled by a person (Guffey, Flanagan, & van Belle, 2001). However, the hospital in Texas that data was collected from did not want particle counters placed on the wall in plain view of the patients. They installed them in the ceiling in order to be more discrete.

This thesis investigates whether data from particle counters placed on the ceiling in hospital rooms is comparable to the data from particle counters placed on the walls at the level of the breathing zone. Also, a baseline particulate matter concentration was established in order to measure the effectiveness of remediation. This was accomplished by performing an extensive literature review and analyzing the continuous-feed data from particle counters within the hospital. SPSS statistical software was utilized in the data analysis.

Statement of Purpose

The purpose of this study is to determine whether data from particle counters placed on the ceiling in hospital rooms are comparable to the data from particle counters placed on hospitals walls in order to establish baseline particulate matter concentration at level of patient exposure zone.

Research Questions

Research Question 1

Are the concentrations of particulate matter sampled at the ceiling comparable with the concentrations of particulate matter sampled in the breathing zone?

Research Question 2

What are the baseline concentrations of particulate matter in each room?

Delimitations

The sample size for this project will be large. Samples were taken every 10 minutes for several days. This allowed for fluctuations of airborne particulate matter over time. The particle counters are in a fixed position and so they will sample air in the

same location every time. Seasonal variation will also be accounted for. Only peer-reviewed journals, credible books, and government documents were used for background information.

Limitations

Little research has been published on this topic. Also, the particle counters are placed on the walls where the air is not mixed as well as the air in the rest of the room.

Assumptions

Each air sampler had equal selectivity and sampling efficiency based on the manufacturer's data.

Definition of Terms

Air changes/ hour. The number of times in one hour that the air within a room is completely replaced by air pumped in from outside of the room (Airistar Technologies, 2005).

Air handling unit. A factory fabricated assembly consisting of fan, coils, filters, and other necessary equipment to perform one or more functions of circulating, cleaning, heating, cooling, humidifying, dehumidifying, and mixing of air (Department of Veterans Affairs, 2006).

Breathing zone. Region within an occupied space between 3 and 72 inches above the floor and more than 2 feet from the walls or fixed air-conditioning equipment (Fung, 2007).

HEPA filter. High Efficiency Particulate Air filter (EPA, 2003).

HVAC. Heat, Ventilating, and Air Conditioning System (EPA, 2007).

Inhalable particulate matter. Those materials which are hazardous when deposited anywhere in the respiratory tract (Paoletti, De Berardis, & Diociaiuti, 2002; Vincent 1999)

Mold remediation. The removal, cleaning, sanitizing, demolition, or other treatment, including preventive activities, of mold or mold-contaminated matter. Preventive activities include those intended to prevent future mold contamination of a remediated area, including applying biocides or anti-microbial compounds (EPA, 1975).

Nosocomial infections. an infection that is not present or incubating when the patient is admitted to hospital or other health-care facility (Vincent, 2003) .

Particle concentration. particles per cubic foot.

Particle counter. device that counts particle concentration.

Respirable particulate matter. those materials which are hazardous only when deposited in the gas exchange region of the lungs (Vincent, 1999).

Thoracic particulate matter. airborne particles, that by virtue of their aerodynamic size and airborne properties, are expected to penetrate the head airways beyond the larynx and enter the lung airways (tracheobronchial region and gas-exchange region) (Vincent, 1999).

Importance

This research is relevant to public health today. As people continue to go to hospitals for their medical needs, they rely on the hospital to provide a safe environment for their treatment and recovery. Nosocomial infections not only increase the hospital stay patients such as those on the ICU and surgical floors, but may also cause death

(Alberti, Bouakline, Ribaud, et al., 2001; Haley, Culver, White, et al., 1985). Nosocomial infections also cause a great financial burden on the healthcare industry. The cost for extra time spent in adult ICU due to nosocomial infections alone is $3.5 billion a year (Vincent, 2003). Infections from *Staphylococcus epidermidis* alone costs the health industry one billon dollars every year (Yao, Sturdevant, Villaruz, et al. 2005). There is new research on antibiotic-resistant bacteria emerging from hospitals. Keeping bacterial levels low in hospitals can decrease the rate at which these resistant bacteria will spread into the community.

CHAPTER II

LITERATURE REVIEW

Indoor environmental quality (IEQ) is the "quality of the air and environment inside buildings, based on pollutant concentrations and conditions that can affect the health, comfort and performance of occupants -- including temperature, relative humidity, light, sound and other factors" (EPA, 2007). Indoor air quality (IAQ) is the component of IEQ that focuses on air. The quality of indoor air decreases when the amount of indoor air pollutants- particles, dust, fibers, mists, bioaerosols, gases or vapors (EPA, 2007)-increases.

Acceptable IAQ became of increasing importance after the Oil Embargo in the 1970's. During this time, energy conservation was a critical issue and so buildings were constructed to be more airtight and the amount of outdoor air provided to each building occupant decreased (Chih-Shan & Hsu, 1997; Hill 1992). This decrease in building ventilation is thought to be a contributing factor to the rise of Building Related Illnesses (BRI) (Menzies & Bourbeau, 1997). For this study, the air pollutants of interest are particulate matter.

The particulate matter that was studied in this hospital was fungi and bacteria. Controlling particulate matter such as microbial organisms, whether their origin is indoors or outdoors, is essential to the effectiveness of hospitals (Morawska et al., 1998). Microbial organisms can be carried into a hospital and can be transmitted within a hospital via human hosts (Casadevall & Pirofski, 2000), the water system (Anaissie, Penzak, & Dignani, 2002; Leoni, De Luca, Legnani, et al., 2005), or air (Olsson, Lidman,

Latouche, et al., 1998). Airborne transmission of microbial organisms generally happens through bioaerosols; and bioaerosols are an increasing concern because they are responsible for many illnesses acquired from buildings (Fung & Hughson, 2003). In hospitals, these illnesses are referred to as nosocomial infections. Nosocomial infections are acquired after a patient is admitted to a hospital and they generally cause increased morbidity and mortality within a hospital (Vincent, 2003).

One of the methods of determining the prevalence of microorganisms in the air is to use a particle counter to find the concentration of particulate matter in the air. Placing the particle counter in different places in the room will yield different results. There are specified particle size ranges in which the particle counter is set to measure. These ranges exist because the percentage of the particles that are deposited in the respiratory tract and the percentage of particulate matter that is cleared out of the body are contingent upon particle size (Vincent, 1999).

History of Ventilation

Prior to the 1970s, buildings received more natural ventilation than they do today. This shift was a result of the Oil Embargo of 1973 (Burge, 2004). During the embargo, energy conservation became a priority. Therefore, buildings were constructed to be more energy efficient, meaning that they were more airtight and that the mechanical ventilation standard was decreased from 15 cfm per person to 10 cfm per person (EPA, 2007). In 1989, the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) increased the minimum ventilation requirement for the first time since the 1970's due to increasing problems with indoor air quality. ASHRAE has raised the

ventilation rates for acceptable indoor air quality since then, and it is currently at 17 cfm per person in an office area (ASHRAE, 2007). In hospitals, ventilation standards range from ≥ 6-15 air changes per hour per room (Sehulster & Chinn, 2003).

Building-Related Illnesses

Building-related illnesses are classified as either specific building- related illnesses or non-specific building-related illnesses. Specific building- related illnesses are those illnesses from known contaminants in the indoor air environment such as biological pollutants (EPA, 2007; Menzies & Bourbeau, 1997). Non-specific building-related illnesses are those illnesses that do not have specific known causes. Sick Building Syndrome (SBS), which is a "group of mucosal, skin, and general symptoms that are temporally related to working in particular buildings" is classified as one of these (Burge, 2004; EPA, 2007). SBS is not only caused by decreased ventilation but also by indoor air pollutants, which include biological contaminants (Redlich & Sparer, 1997). There are many complaints related to Sick Building Syndrome. These include but are not limited to upper respiratory problems, headaches, fatigue, and rashes (Redlich & Sparer, 1997).

Bioaerosols

Bioaerosols are "airborne particles that are living or originate from living organisms" and they include bacteria, fungi, algae, and dust mites (Macher, 1999). They also include biological products such as proteins and endotoxins (Rengasamy, Zhuang, & Berryann, 2004). They are ubiquitous indoors and outdoors and can be anywhere between <0.01 μm- 100 μm (Macher, 1999; Tham & Zuraimi, 2005). They are dangerous because of their ability to incubate, grow, multiply, and produce toxic

substances. Respiratory disease, asthma, and Sick Building Syndrome can all be caused by these particles (Tham & Zuraimi, 2005).

Nosocomial Infections

Nosocomial infections arise as a result of pathogenic organisms colonizing an immunocompromised host in a healthcare setting with an incubation period of less than 48 hours (Vincent, 2003; Hugonnet, Villaveces, & Pittet, 2007). Pathogens such as the *Aspergillus spp.*(Vonberg, 2006), *Staphylococcus spp.* (Chambers, 2001; Diekema, BootsMiller, Vaughn, et al., 2004) and the *Fusarium spp.* (Dignani & Anaissie, 2004) have been implicated in these infections. These pathogens not only cause the rise of nosocomial infections but they also develop antibiotic resistance, making them even more dangerous for the immunocompromised patients as well as the healthy population (Bonten, Austin, & Lipstich, 2001; Diekema, et al., 2004; Vincent, 2003). Mortality rates due to nosocomial infections range from 12% to 80% (Vincent, 2003).

Aspergillus spp.

Aspergillus spp. are extremely virulent organisms. Some of the most prevalent species found in hospitals are *Aspergillus fumigatus* and *Aspergillus flavus* (Vonberg, 2006). Both of the organisms appeared in the hospital of interest in this study. The result of the presence of these organisms in the human body is invasive aspergillosis. This nosocomial disease is difficult to treat and the case-fatality rate in one study was between one-half and two-thirds (Vonberg, 2006). Another study showed aspergillosis as being the leading infection of mortality rates in bone marrow and organ transplant patients (Curtis, Cali, Conroy, et al., 2005).

Staphylococcus spp.

The *Staphylococcus spp.* are a formidable species of bacteria that colonize hospital patients. *Staphylococcus epidermis* is the number one cause of nosocomial infections in the United States. It invades the human body by breaking through epidermal and mucosal layers (Yao, et al., 2005). It is often found via medical devices inserted into the human body. It is difficult to fight because of its adaptability and genetic variability (Kozitskaya, Cho, Dietrich, et al., 2004). *Staphylococcus aureus* is another species of deadly bacterium. Treatment for this species is difficult because it is becoming increasingly drug-resistant, specifically methicillin-resistant, in the community and in hospitals (Lowy, 1998; Chambers, 2001; Diekema, et al., 2004). AIDS patients, surgical patients, and those with Type I diabetes are all more susceptible to this species than healthy people (Lowy, 1998).

Fusarium spp.

Fusarium spp. are fungi that causes a wide range of problems in the human body (Dignani & Anaissie, 2004). It generally enters the body through the lungs, catheters, or breaks in the skin (Groll & Walsh, 2001). In hematological cancer patients and those with bone marrow transplants, *Fusarium* is the second most pathogenic mold (Dignani & Anaissie, 2004). The mortality rate for people who contract fusariosis is between 52% and 70% (Groll & Walsh, 2001).

Particle Counter Placement

Particle counter placement is essential to determining human exposure of particulate matter. Placing the particle counter in different places in the room will yield

differing results (Whicker et al., 2000). According to the ASHRAE, the breathing zone is defined as between 3 and 72 inches above the floor and 2 feet away from the wall while the Occupational Safety and Health Administration's (OSHA) definition considers the breathing zone to be a radius of 6-9 inches around the subject's shoulder (Fung, 2007). Therefore, particle counters would ideally be placed in the breathing zone in order to determine human exposure to particulate matter.

Size of Particulate Matter of Interest

There are three classifications of particulate matter size as they relate to human health inhalable, thoracic, respirable. The EPA considers thoracic particles to have a maximum size of 10μm and respirable particles to have a maximum size of 2.5 μm (EPA, 2006). However, the American Conference of Industrial Hygienists (ACGIH) considers inhalable particulate matter to be from 0 to 100 μm while they consider thoracic and respirable particulate matter to have masses of 0-30 μm and 0-10 μm, respectively (Vincent, 1999).

Table 2.1

Particle Size vs. Particle Penetration

Particle Aerodynamic Diameter (μm)	Inhalable Particulate (%)	Thoracic Particulate (%)	Respirable Particulate (%)
0	100	100	100
1	97	97	97
2	94	94	91
3	92	92	74
4	89	89	50
5	87	85	30
10	77	50	1
20	65	6	0
30	58	1	0
40	55	0	0
50	53	0	0
100	50	0	0

Note. Table adapted from Table 4.1 (Vincent, 1999)

CHAPTER III

METHODOLOGY

The methodology detailed in this chapter explains the population that was sampled and the means by which it was sampled. This chapter also covers the role that an air-sampling company had in this study as well as gives the descriptions of the instruments that were used to sample the air. The statistical analysis is then explained as it applied to this project.

Population and Sample

The air was measured on a hallway of the 4th floor of the hospital and in the Emergency Room (ER). There were four variables measured in each of these areas- temperature (°F), percent relative humidity, $PM_{0.3\text{-}5\ \mu m.}$, and $PM_{\geq 5\ \mu m.}$ On the 4th floor, the air was measured every ten minutes from 11:05 a.m., June 28, 2007 to 11:59 p.m., July 5, 2007. In the ER, the air was measured every 10 minutes from 5:18 a.m., June 27, 2007 to 4:15 p.m., July 3, 2007. This resulted in 896 measurements for each of the variables in each of the locations.

Data Collection Procedures

Particle counters measured the particulate matter concentrations in each location. An air-sampling company installed these particle counters and recorded the measurements. The company then produced Excel spreadsheets that contained the particulate matter concentration data. The data were then analyzed based upon the numbers in these spreadsheets.

Instrumentation

The devices used to measure particulate matter concentration were Remote 3012 Airborne Particle Counters designed by Lighthouse Worldwide Solutions. It had a flow rate of .1cfm and an external vacuum source. This particle counter was limited to the size range of 0.3 to 25 μm and had an upper concentration limit of 2,000,000 ppcf. Its counting efficiency was 50% for particles that are 0.3 μm and 100% for particles > 0.45 μm. Two channels were used on each instrument to simultaneously capture particle concentrations in the 0.3 to 5 μm range and for particles greater than five μm. Its direct output was in the range of 4-20 milliamps (mA) which was converted to Volts (V). For example, an output of 4 mA would be converted to 0.4 V. Therefore, Equation 3.4 was used to transform the direct output into particles per cubic feet (ppcf). The direct output was multiplied be 1000 in order to convert volts to millivolts. The zero offset is 439. This accounts for 0.4 Volts being the lowest output that the particle counter will give. It also accounts for the variation in the resistors in the particle counter. The span factor of forty-two was used because each millivolt accounted for forty-two particles (McMahan, 2007).

Figure 3.1

Transformation Equation

Particle Concentration (ppcf)= ((Direct Output in V)*1000)-439)*42 Span Factor= 42 Zero Offset=439 Conversion from V to mV= 1000

Data Analysis

The data was analyzed by performing a non-parametric statistical test using statistical software. A non-parametric test, Spearman's Rank Correlation, was used since the data does not follow a normal distribution (Seigel, 1957). This test produced a correlation coefficient that determined the strength of the relationship between the particulate matter concentration at the wall and the particulate matter concentration at ceiling level in each room (Vignola, Riccobono, Mirabella, et al., 1998). The null hypothesis was that there was not a significant relationship between the particulate matter concentration at the wall and the particulate matter concentration at ceiling level in each room.

Descriptive statistics were then recorded from the ceiling data were then recorded in order to establish the baseline particulate matter concentration.

Summary

The goal of this study was to determine the relationship between the particulate matter concentrations at the wall and the particulate matter concentrations at ceiling level. This was achieved by obtaining data from two different locations in the hospital. The data was gathered by an independent consulting firm who used particle counters to sample the air and then produced Excel spreadsheets of the particulate matter concentrations. Descriptive statistics for each of these locations were recorded in order to establish a baseline particle concentration. A non-parametric test, Spearman Rank Correlation, was run on these data to understand the similarities, and differences between

the particulate matter concentrations in the ceiling and the particulate matter concentrations in the breathing zone.

CHAPTER IV

RESULTS

The data were analyzed in two parts. First, these data were analyzed using the Spearman's Rank correlation to elucidate the similarities between the wall data and the ceiling data. Then, descriptive statistics were used to establish a baseline particulate matter concentration using the mean particle concentrations of the ceiling data.

Spearman's Rank Correlation for the ER

The null hypothesis for this test is that there is not a significant correlation between the wall data and the ceiling data. The 0.3-5 μm category yielded a p-value of 0.00 and a correlation coefficient of -0.158 (Figure 4.1). Therefore, the null hypothesis was rejected; and the ceiling particle concentrations and wall particle concentrations are significantly correlated at the .01 level.

Table 4.1

Results from the Spearman's Rank Correlation for the ER

	0.3-5 μm	5+ μm
p-value	0	0.445
Correlation Coefficient	-0.158	-0.026

For particles 5+ μm the p-value was 0.445. Therefore, the null hypothesis was not rejected, showing that there was no significant correlation between the wall particle concentrations and the ceiling particle concentrations for the 5+ μm category. Additionally, the correlation coefficient was -0.026 (Figure 4.2) and is not significant. However, a confounding factor could have contributed to these results.

Figure 4.1

0.3-5 μm Wall and Ceiling Data from the ER

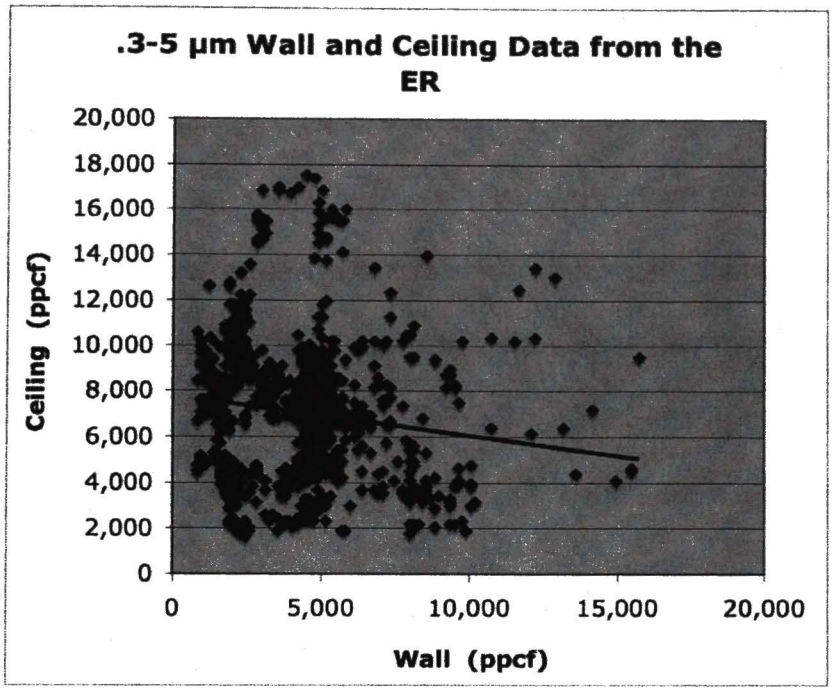
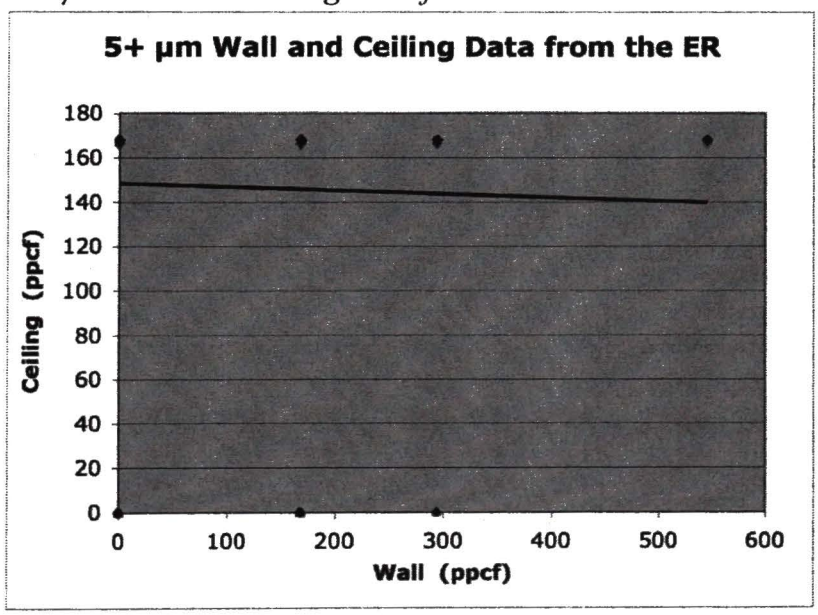


Figure 4.2

5+ μm Wall and Ceiling Data from the ER



Descriptive Statistics for the ER

The descriptive statistics for the emergency room data showed that the means for the data between the wall and the ceiling were almost equal in the 5+ μm category. However, the mean values of the 0.3-5 μm wall and ceiling data were separated by 2,649 ppcf. The mean value for the ceiling data was used to establish the baseline particulate concentration values because the hospital installed the particle counters on the ceiling. Therefore, the baseline concentration for measuring particulate concentrations in the range of 0.3-5 μm was 7,016.77 ppcf while the baseline concentration for the 5+μm range is 147 ppcf. Figures 4.3 and 4.4 illustrate these mean values and their standard deviations

Table 4.2

Descriptive Statistics for ER Data

	0.3-5 µm (ppcf)		5+ µm (ppcf)	
	Wall	Ceiling	Wall	Ceiling
N	896	896	896	896
Median	4344	6993	168	168
Mean	4380.19	7016.77	87.05	147
Standard Deviation	2348.43	3098.84	86.32	55.59
Minimum	816	1638	0	0
Maximum	15726	17514	546	168

Figure 4.3

0.3-5 µm Mean and Standard Deviation for ER

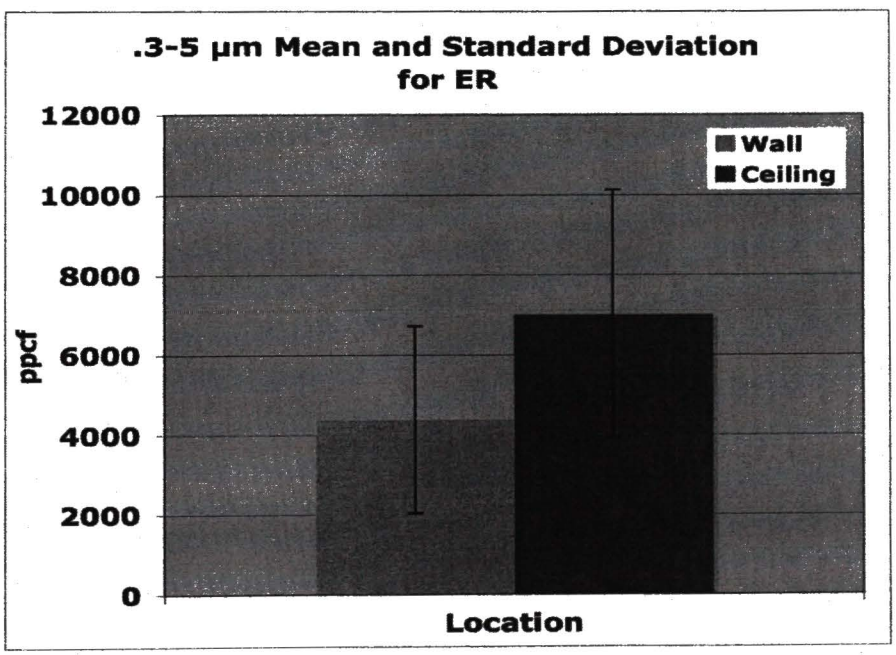
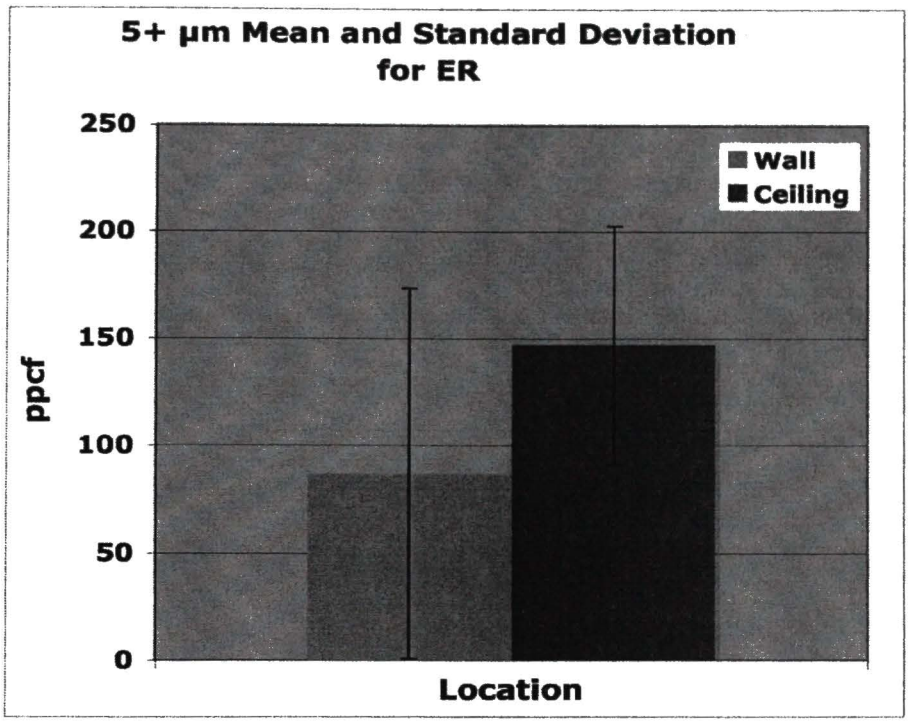


Figure 4.4

5+ μm Mean and Standard Deviation for ER



Spearman's Rank Correlation for the Fourth Floor

As in the emergency room data, the null hypothesis for this test was that there is not a significant correlation between the wall and ceiling data. For the 0.3-5 μm data, the Spearman's Rank correlation showed that there was a significant correlation between the particle concentrations for the wall and ceiling data. The p-value was 0.00, therefore, the null hypothesis is rejected. The correlation coefficient of 0.421 (Figure 4.5) was significant at the .01 level.

Table 4.3

Results from the Spearman's Rank Correlation for Fourth Floor

	0.3-5 µm	5+ µm
p-value	0	0.563
Correlation Coefficient	0.421	-0.019

The p-value for the 5+ µm data was 0.563. Therefore, the null hypothesis was not rejected, which in turn showed that there was no significant correlation between the wall and ceiling data for the 5+µm category. The correlation coefficient -0.019 (Chart 4.6) was not significant.

Figure 4.5

0.3-5 µm Wall and Ceiling Data

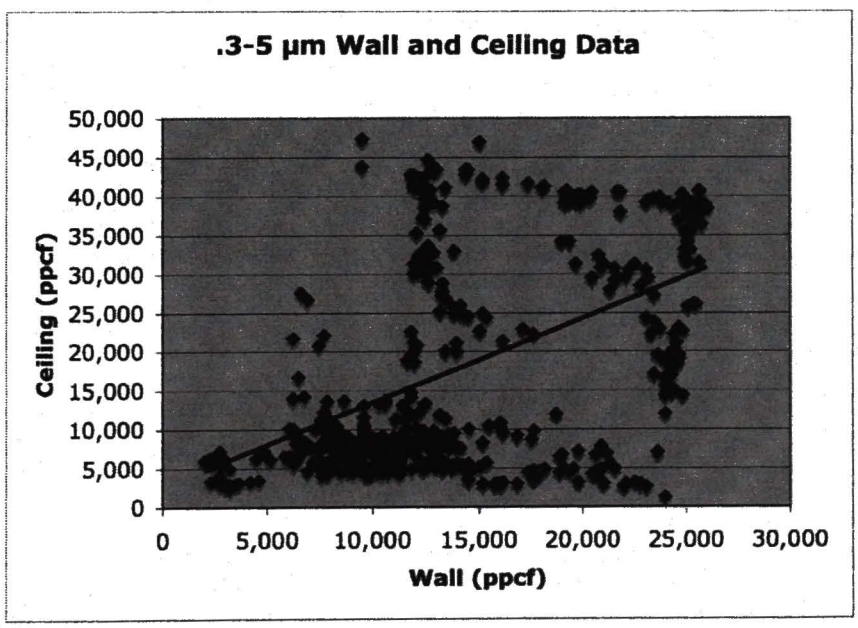
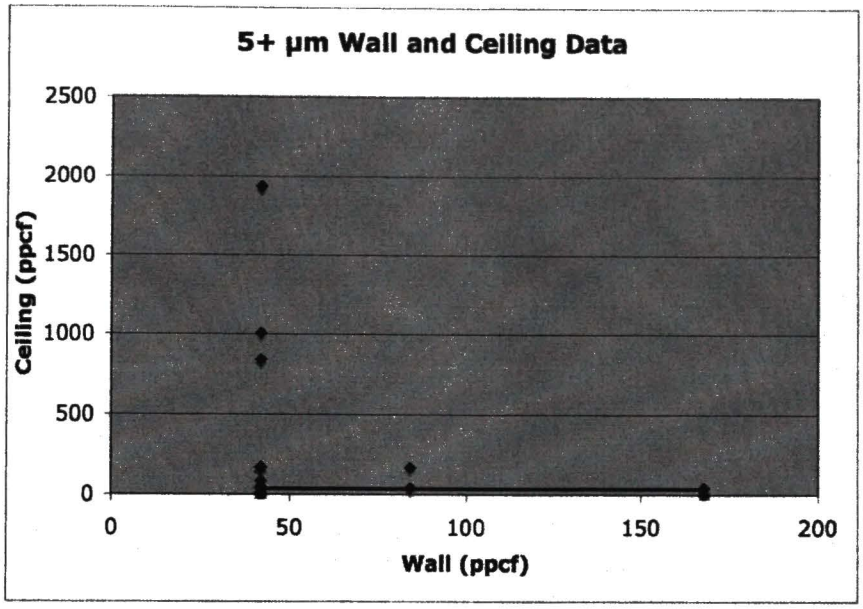


Figure 4.6

5+ Wall and Ceiling Data



Descriptive Statistics for the Fourth Floor

The mean value for the wall data in the 0.3-5 µm category was less than the mean value for the ceiling data. In 5+ µm category, the wall data mean value was 16% greater than the mean value for the ceiling. The mean value for the ceiling data were used to establish the baseline particulate concentration values because the hospital installed the particle counters on the ceiling. Therefore, the baseline concentration for measuring particulate concentrations in the range of 0.3-5 µm was 18,964.54 ppcf while the baseline concentration for the 5+µm range is 36.98 ppcf. Figures 4.7 and 4.8 illustrate these mean values and their standard deviations.

Table 4.4

Descriptive Statistics for the Fourth Floor Data

	0.3-5 μm (ppcf)		5+ μm (ppcf)	
	Wall	Ceiling	Wall	Ceiling
N (# of samples)	896	896	896	896
Median	13289.64	11718	42	42
Mean	15113.95	18964.54	43.07	36.98
Standard Deviation	6185.75	14006.45	11.27	107.25
Minimum	2018.1	1224	42	0
Maximum	26057.64	47386.08	168	1932

Figure 4.7

0.3-5 μm Mean and Standard Deviation for Fourth Floor

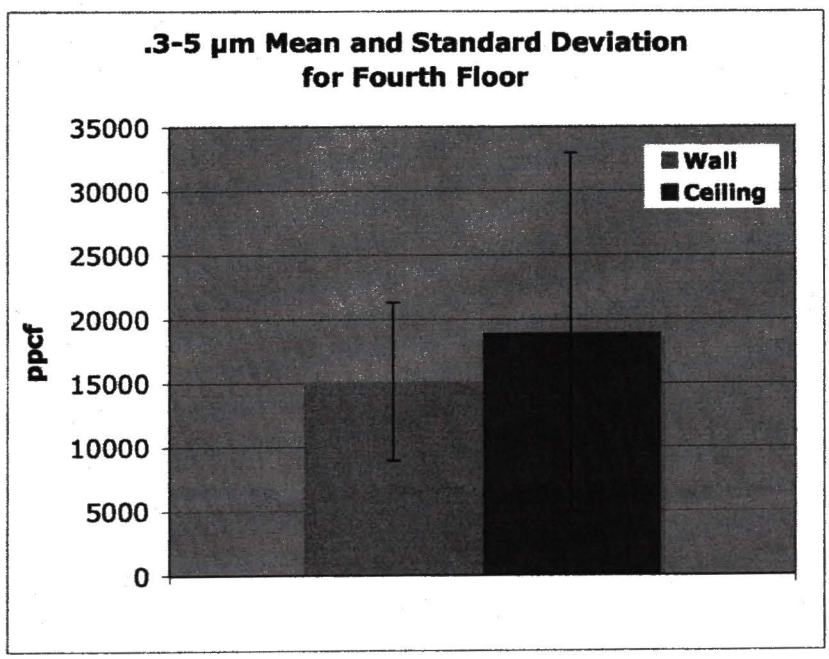
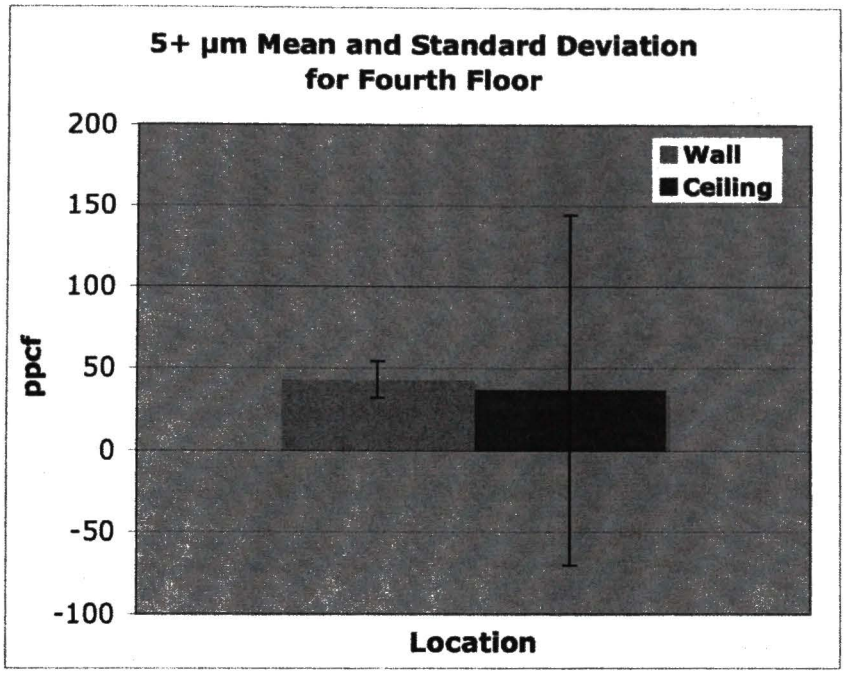


Figure 4.8

5+ μm Mean and Standard Deviation for Fourth Floor



Summary

For both the ER and the fourth floor, the particle concentrations at the wall and ceiling in the 0.3-5 μm category were significantly correlated. For both the ER and the fourth floor, the particle concentrations at the wall and the ceiling in the 5+ μm category were not significantly correlated. The lack of significant correlations among the 5+ μm category could have been the result of the particle concentrations being measured in 42 ppcf increments. Also, the baseline concentrations for each of the categories were established based on the mean values of the ceiling data.

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

This chapter will highlight the important results, answers to research questions and describes how this study is relevant to the field of public health. It will conclude with recommendations to further investigate the indoor air quality of hospitals.

Summary

This study was performed in order to determine if a correlation exists between the particle concentrations collected at the wall and the particle concentrations collected at ceiling level. Additionally, it determined the baseline particulate matter concentrations based on the mean ceiling concentrations. Air samples were collected in the emergency room as well as a hallway on the fourth floor of the hospital. There were 896 particulate matter concentration samples taken in each location by remote particle counters. The raw data from these samples were transformed to reflect temperature, humidity, and particle concentration. These numbers were then put into an Excel file so that they could be charted and analyzed.

Conclusions

Research Questions 1: Are the concentrations of particulate matter sampled at the ceiling comparable with those sampled at the wall?

The mean particle concentrations for the ceiling were higher than the particle concentrations for the wall except for the 5+ μm category on the Fourth Floor. In this instance, the wall particle concentrations exceeded the ceiling concentrations. Figures

4.3, 4.4, 4.7 and 4.8 illustrate the mean values for the particle concentrations at the wall and ceiling for each category in the ER and on the Fourth Floor.

Even though the ceiling particle concentrations were generally higher than the wall particle concentrations, the ceiling and wall data were significantly correlated in the 0.3-5 μm category. For the ER, the correlation coefficient was -0.158 which means that as the particle concentrations for the ceiling increased, the particle concentrations for the wall decreased. Even though, this correlation is technically significant because of it's p-value of 0.00, the particle concentrations did not appear like they would be correlated because the correlation coefficient was on the lower end. Figure 5.1 illustrates that the ceiling particle concentrations were generally higher than the wall particle concentrations. It also illustrates that the wall particle concentrations tended to increase relative to the ceiling particle concentrations, and also the weak correlation between the ceiling and wall particle concentrations.

Figure 5.1

0.3-5 μm Particle Concentration in ER

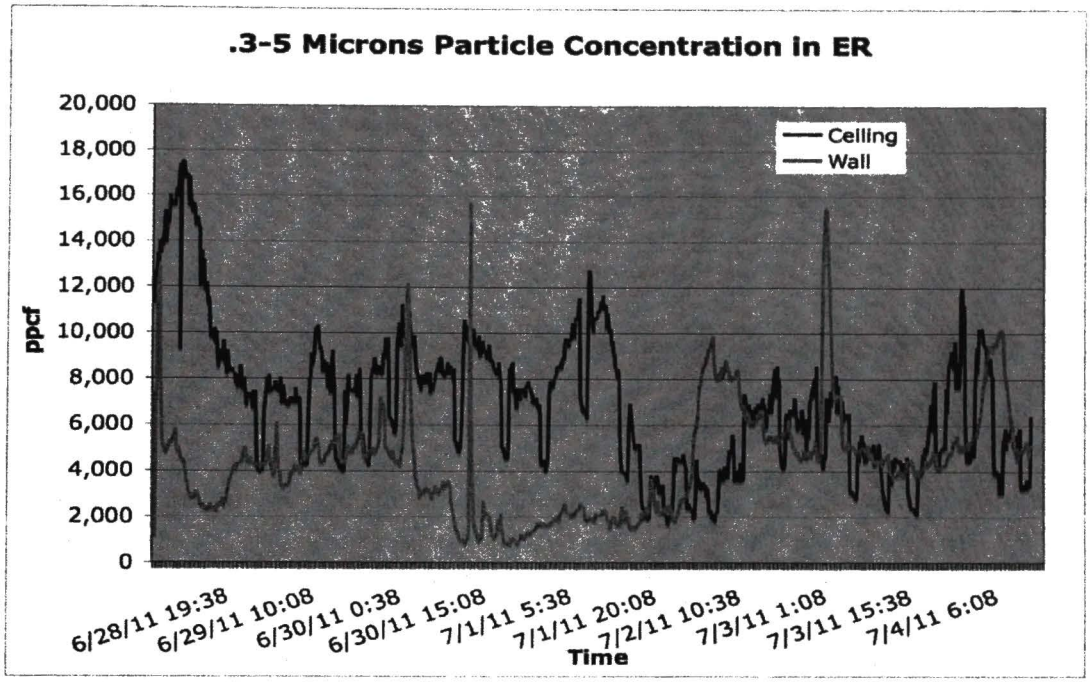
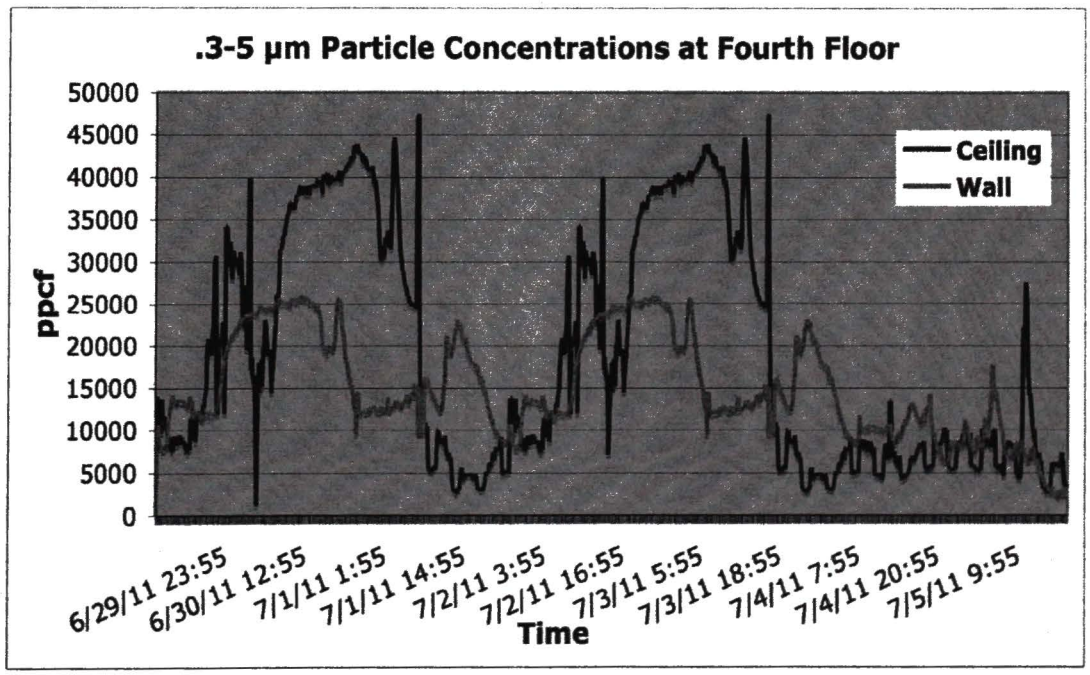


Figure 5.2

0.3-5 μm Particle Concentration in Fourth Floor



The Fourth Floor data in the 0.3-5 μm category were positively correlated with a stronger correlation coefficient of 0.421. This shows that as the ceiling particle concentrations increased, the wall particle concentrations also increased. Figure 5.2 illustrates that the ceiling particle concentrations were on average higher than the wall concentrations, that the ceiling and wall particle concentrations were both increasing, and the correlation between the particle concentrations.

However, the ceiling and wall data are not significantly correlated in the 5+ μm category. The correlation coefficient for the ER in this category was -0.026 while the correlation coefficient for the Fourth Floor was -0.019. This could be due to the fact that the particle counters measured in increments of 42 as shown in Equation 3.4. This was not an issue in measuring the 0.3-5 μm data because there are thousands of particles per cubic feet in this category (Table 5.1), therefore counting in increments of 42 was insignificant. However, in the 5+ μm category where there was generally less than 200 particles for cubic feet, measuring in increments of 42 had greater potential of skewing the data.

Table 5.1

Sample of Data That Was Analyzed From the Excel Sheet

4th Floor Data				ER Data			
0.3-5 µm		5+ µm		0.3-5 µm		5+ µm	
Wall	Ceiling	Wall	Ceiling	Wall	Ceiling	Wall	Ceiling
10,602	13,734	42	42	7,326	12,348	168	168
10,602	13,734	42	42	7,326	11,256	168	168
8,670	13,734	42	42	1,194	12,642	168	168
8,124	10,080	42	42	7,326	12,348	168	0
7,872	9,660	42	42	11,652	12,474	294	0
7,872	13,608	42	42	12,198	13,440	294	168
7,578	11,172	42	42	12,870	13,020	294	168
7,872	11,592	42	168	8,544	13,986	168	168
7,998	11,172	42	42	6,780	13,440	168	0
8,292	10,500	42	42	5,688	14,112	168	168

Table 5.2

Results of Spearman's Rank Correlation

	ER 0.3-5 µm	ER 5+ µm	4th Floor 0.3-5 µm	4th Floor 5+ µm
Spearman's Rank Correlation coefficient	-0.158	-0.026	.421	-0.019
Significant	yes	no	yes	no

What are the baseline concentrations of particulate matter in each location?

The baseline concentrations of particulate matter were determined by finding the mean particle concentration of the ceiling data. The ceiling data were used because the hospital is going to use the ceiling particle counters for long term monitoring. The baseline particle concentrations are shown in Table 5.3 and also in Figures 5.3 and 5.4.

Table 5.3

Baseline Particle Concentrations (Mean Values for Ceiling Data)

	ER 0.3-5 µm	ER 5+ µm	Fourth Floor 0.3-5µm	Fourth Floor 5+ µm
Mean	7016.77 ppcf	147 ppcf	18964.54 ppcf	36.98 ppcf

Figure 5.3

0.3-5 µm Baseline Concentrations

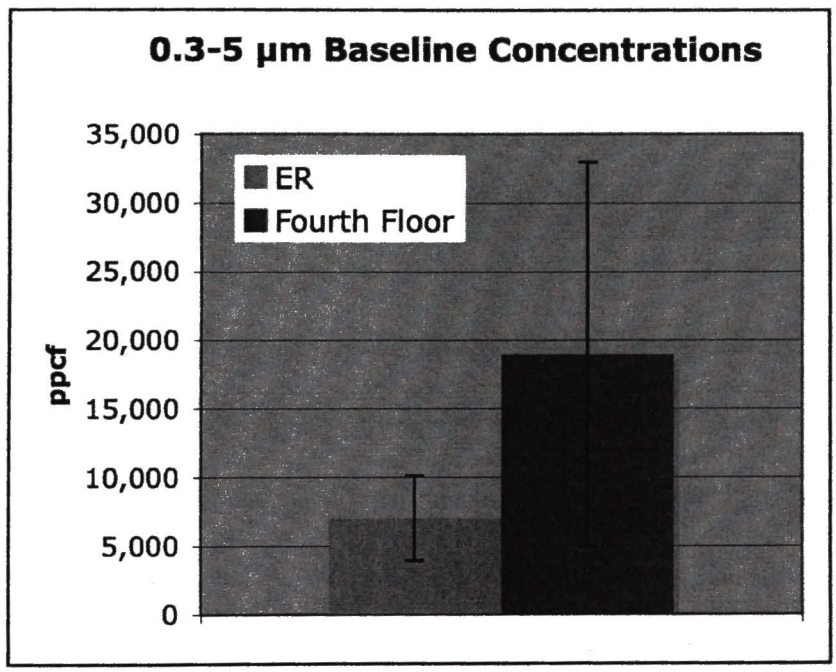
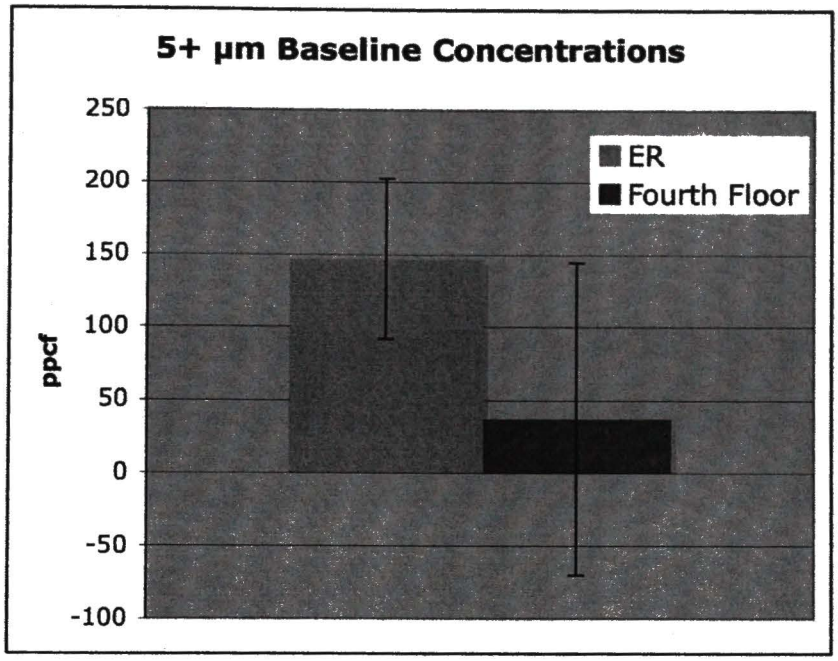


Figure 5.4

5+μm Baseline Concentrations



Discussion and Implications

This study is relevant to those who research indoor air quality of hospitals. First, it is important to know if particle concentrations taken by the wall will behave in the same way as particle concentrations taken from the ceiling. This is because hospitals do not want particle counters placed on the walls in plain sight of the patients and visitors. It is better for the particle counters to remain out of sight when the hospital air is being sampled while the hospital is still in use. Secondly, since very little research has been performed on the indoor air quality of hospitals, it is important to establish baseline particle concentrations. Currently, there are no guidelines for particle concentrations in hospitals. Therefore, the established particle concentration in this study can be used as a resource for other hospitals who are investigating their own indoor air quality. Resolving

the problem of indoor air quality is of increasing importance because of the great number of nosocomial infections (Vincent, 2003).

Recommendations

Further research should repeat the same kind of study that was performed in this paper. It should investigate the effects of temperature and humidity on the particle concentration in a hospital. Also, the factors that cause hospital air to be contaminated in the first place should be studied. As a result of the small amount of research available on this subject, any study on indoor air quality of hospitals would be helpful in progressing towards uncontaminated hospitals.

REFERENCES

Texas Administrative Code. (1975). *Texas administrative code: Texas mold assessment and Remediation Rules.* Retrieved August 18, 2007, from http://info.sos.state.tx.us/pls/pub/readtac$ext.TacPage?sl=R&app=9&p_dir=&p_rloc=&p_tloc=&p_ploc=&pg=1&p_tac=&ti=25&pt=1&ch=295&rl=302

Airistar Technologies, L. L. C. (2005). *Frequency of air changes per hour- A key consideration in selecting air purification systems.* Retrieved on August 18, 2007, from www.touchbriefings.com/pdf/1140/Airistar_tech.pdf

Alberti, C., Bouakline, A., Ribaud, P., Lacroix, C., Rousselot, P., Leblanc, T., & Derouin, F. (2001). Relationship Between Environmental Fungal Contamination and the Incidence of Invasive Aspergillosis in Haematology Patients. *Journal of Hospital Infection, 48*(3), 198-206.

Anaissie, E. J., Penzak, S.R., & Dignani, M.C. (2002). The Hospital Water Supply as a Source of Nosocomial Infections: A Plea for Action. *Archives of Internal Medicine,* 162(13), 1483-1492.

ASHRAE (2007). *Ventilation for acceptable indoor air quality.* Retrieved August 18, 2007, from www.ashrae.org

Bonten, M. J. M., Austin, D.J., Lipstich,M. (2001). Understanding the Spread of Antibiotic Resistant Pathogens in Hospitals: Mathematical Models as Tools for Control. *Clinical Infectious Diseases,* 33(10), 1739.

Burge, P. S. (2004). Sick Building Syndrome. *Occupational Environmental Medicine, 61*(2), 185-90.

Casadevall, A. & Pirofski, L. A. (2000). Host-Pathogen Interactions: Basic Concepts of Microbial Commensalism, Colonization, Infection, and Disease. *Infection and Immunity, 68*(12), 6511-6518.

Chambers, H. F. (2001). The Changing Epidemiology of Staphylococcus aureus? *Emerging Infectious Diseases, 7*(2), 178.

Chih-Shan, L. & Hsu, C.-W. (1997). Indoor Pollution and Sick Building Syndrome Symptoms. *Archives of Environmental Health, 52*(3), 200.

Curtis, L., Cali, S., Conroy, L., Baker, K., Ou, C.H., Hershow, R., Norlock-Cruz, F., Scheff, P. (2005). Aspergillus Surveillance Project at a Large Tertiary-Care Hospital. *Journal of Hospital Infection, 59*(3), 188-196.

Department of Veterans Affairs (2006). *Department of veterans affairs master specifications: air handling units.* Retrieved August 18, 2007 from http://www.va.gov/facmgt/standard/spec_15.asp

Diekema, D. J., BootsMiller, B. J., Vaughn, T. E., Woolson, R. F., Yankey, J. W., Ernst, E. J., Flach, S. D., Ward, M. M., Franciscus, C. L. J., Pfaller, M. A., & Doebbeling, B. N. (2004). Antimicrobial Resistance Trends and Outbreak Frequency in United States Hospitals. *Clinical Infectious Diseases, 38*(1), 78-85.

Dignani, M. C. and E. Anaissie (2004). Human Fusariosis. *Clinical Microbiology and Infection, 10*(s1), 67-75.

EPA (1995). T*he inside story: a guide to indoor air quality.* Retrieved August 18, 2007 from http://www.epa.gov/iaq/pubs/insidest.html

EPA (2003). *Air pollution control technology fact sheet.* Retrieved August 18, 2007 from http://www.epa.gov/ttn/catc/dir1/ff-hepa.pdf

EPA (2006). *National ambient air quality standards for particulate matter.* Retrieved August 18, 2007 from http://www.epa.gov/air/criteria.html

EPA. (2007). *Glossary of terms.* Retrieved on August 18, 2007 from http://www.epa.gov/iaq/glossary.html

EPA. (2007). *Green indoor environments.* Retrieved July 17, 2007 from http://www.epa.gov/iaq/greenbuilding/index.html

EPA. (2007). *Heating, ventilation, and air-conditioning (HVAC) systems.* Retrieved August 18, 2007 from www.epa.gov/iaq/schooldesign/hvac.html

EPA. (2007). *Indoor air fact no. 4 (revised).* Retrieved August 10, 2007 from http://www.epa.gov/iaq/pubs/sbs.html

Fung, F. (2007). Health Effects Associated with IAQ. *ASHRAE IAQ Applications, 8*(3).

Fung, F. and W. G. Hughson (2003). Health Effects of Indoor Fungal Bioaerosol Exposure. *Applied Occupational and Environmental Hygiene, 18*(7), 535-44.

Groll, A. H. and T. J. Walsh (2001). Uncommon Opportunistic Fungi: New Nosocomial Threats. *Clinical Microbiology and Infection, 7*(s2), 8-24.

Guffey, S. E., Flanagan, M. E., van Belle, G. (2001). Air Sampling at the Chest and Ear as Representative of the Breathing Zone. *AIHA Journal, 62*(4), 416-427.

Haley, R. W., Culver, D. H., White, J. W., Morgan, W. M., Emori, T. G., Munn, V. P., & Hooton, T. M. (1985). The Efficacy of Infection Surveillance and Control Programs in Preventing Nosocomial Infections in US hospitals. *American Journal of Epidemiology, 121*(2), 182-205.

Hill, B. A., Craft, B. F., & Burkart, J. A. (1992). Carbon Dioxide, Particulates, and Subjective Human Responses in Office Buildings without Histories of Indoor Air Quality Problems. *Applied Environmental Hygiene, 7*(2), 101-111.

Hugonnet, S., Villaveces, A., & Pittet, D. (2007). Nurse Staffing Level and Nosocomial Infections: Empirical Evaluation of the Case-Crossover and Case-Time-Control Designs. *American Journal of Epidemiology, 165*(11), 1321-1327.

Janghoo & S. Kato (2007). Adsorptive Materials and VOCs. *ASHRAE IAQ Applications, 8*(3), 9-12.

Kozitskaya, S., Cho, S-H, Dietrich, K., Marre, R., Naber, K., & Ziebuhr, W. (2004). The Bacterial Insertion Sequence Element IS256 Occurs Preferentially in Nosocomial Staphylococcus epidermidis Isolates: Association with Biofilm Formation and Resistance to Aminoglycosides. *Infection and Immunity, 72*(2), 1210-1215.

Leoni, E., De Luca, G., Legnani, P., Sacchetti, R., Stampi, S., & Zanetti, F. (2005). Legionella Waterline Colonization: Detection of Legionella Species in Domestic, Hotel and Hospital Hot Water Systems. *Journal of Applied Microbiology, 98*(2), 373-9.

Lowy, F. D. (1998). Staphylococcus aureus Infections. *New England Journal of Medicine, 339*(8), 520-532.

Macher, J. (Ed.). (1999). *Bioaerosols: assessment and control: developing and investigation strategy*. Cincinatti: ACGIH.

McNeil, M. M. & Brown, J. M. (1994). The Medically Important Aerobic Actinomycetes: Epidemiology and Microbiology. *Clinical Microbiology Reviews 7*(3), 357-417.

Menzies, D. & J. Bourbeau (1997). Building-Related Illnesses. *New England Journal of Medicine, 337*, 1524-31.

Morawska, L., Jamriska, M., & Francis, P. (1998). Particulate Matter in the Hospital Environment. *Indoor Air, 8*(4), 285.

Olsson, M., Lidman, C., Latouce, S., Bjorkman, A., Roux, P., Linder, E., & Wahlgren, M. (1998). Identification of Pneumocystis carinii f. sp. hominis Gene Sequences in Filtered Air in Hospital Environments. *Journal of Clinical Microbiology, 36*(6), 1737-1740.

Paoletti, L., De Berardis, B., & Diociaiuti, M. (2002). Phyico-Chemical Characterization of the Inhalable Particulate Matter (PM10) in an Urban Area: an Analysis of the Seasonal Trend. *The Science of the Total Environment, 292*(3), 265-275.

Perdelli, F., Christina, M. L., Sartini, M., Spangolo, A. M., Dallera, M., Ottria, G., Lombardi, R., Grimaldi, M., & Orlando, P. (2006). Fungal Contamination in Hospital Environments. *Infection Control and Hospital Epidemiology, 27*(1), 44-47.

Pope, A. M., Patterson, R., & Burge, H. (1993). *Indoor allergens: assessing and controlling adverse health effects*. Washington, D.C., National Academy Press.

Redlich, C. A. & Sparer, J. (1997). Sick-Building Syndrome. *Lancet, 349*(9057), 1013.

Rengasamy, A., Zhuang, Z., & Berryann, R. (2004). Respiratory Protection Against Bioaerosols: Literature Review and Research Needs. *American Journal of Infection Control, 32*(6), 345-54.

Sehulster, L. & Chinn, R.Y. (2003). Guidelines for Environmental Infection Control in Health-Care Facilites. *MMWR Recommendations and Report,s 52*(RR10), 1-42.

Seigel, S. (1957). Nonparametric Statistics. *The American Statistician, 11*(3), 13-19.

Tham, K. W. & Zuraimi, M. S. (2005). Size Relationship Between Airborne Viable Bacteria and Particles in a Controlled Indoor Environment Study. *Indoor Ai,r 15*, 48-57.

Vignola, A. M., Riccobono, L., Mirabella, A., Profita, M., Chanez, P., Bllia, V., Mautino, G., D'Accardi, P., Bousquet, J., & Bonsignore, G. (1998). Sputum Metalloproteinase-9/Tissue Inhibitor of Metalloproteinase-1 Ratio Correlates with Airflow Obstruction in Asthma and Chronic Bronchitis. *American Journal of Respiratory Critical Care Medicine, 158*(6), 1945-1950.

Vincent, J.-L. (2003). Nosocomial Infections in Adult Intensive-Care Units. *The Lancet, 361*(9374), 2068-2077.

Vincent, J. H. (Ed.). (1999). *Particle size-selective sampling for particulate air Contaminants.* Cincinnati, ACGIH.

Vonberg, R. P., & Gastmeier, P. (2006). Nosocomial aspergillosis in outbreak settings. *Journal of Hospital Infection, 63*, 246-254.

Whicker, J. J., Baker, G. D., Wasiolek, P. T. (2000). Quantitative measurements of airflow inside a nuclear laboratory. *Health Physics, 79*(6), 712-21.

Yao, Y., Sturdevant, D. E., Villaruz, A., Xu, L., Gao, Q., & Otto, M. (2005). Factors Characterizing Staphylococcus epidermidis Invasiveness Determined by Comparative Genomics. *Infection and Immunity, 73*(3), 1856-1860.