A STUDY TO MEASURE THE SETTLEMENT VELOCITY AND THE RATE OF ACCUMULATION OF STANDARD DUST

A Thesis

by

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ABSTRACT

Healthcare and construction professionals maintain that understanding the extent of infection control measures to be taken to protect immunosuppressed and other types of patients from airborne infection agents during construction is crucial knowledge. Aspergillus spores migrate alone and on dust particles. These particles can be transported to an immune compromised individual into a hospital from an adjacent construction zone which can be fatal. Aspergillosis - related fatalities due to dust transmission during construction activity has decreased with the improvement of antifungal therapy, but it is still a significant and ongoing health hazard.

This study reviewed the reasons responsible for Aspergillus related infections and the behavioral aspect of the dust particles carrying the Aspergillus spores. The results from the study indicated a linear regression of settlement of dust particles at normal velocity ranges. The settlement of dust particles decreases with increase in air flow velocities. The suggested future work, is to use similar wind tunnels to accurately identify the particles which remain suspended in the air and are the principal transport vectors for the Aspergillus spores.

DEDICATION

Thanks to my family and professors for their encouragement.

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First and foremost I would like to express my heartfelt gratitude and respect to the chair of committee, Dr. John M. Nichols for the guidance and the inspiration he has given me to help pursue this research and complete it with success. I would also like to extend respect and thank my Committee members, Dr. John A. Bryant, Dr. Kevin Glowacki and the Head of Department, Mr. Joseph P. Horlen.

I thank Jim Titus, the woodshop supervisor for generously helping me in the construction of the apparatus, also the testing would not have been completed without the help of Nishant Gupta and Navaneeth Latha Ramakrishanaih.

Finally I would thank my parents and other family members for supporting me to pursue my Masters at Texas A & M University.

NOMENCLATURE

AIA	American Institute of Architects.
Antifungal	A drug used to treat infections caused by fungi.
Aspergillosis	Aspergillosis is a kind of disease that caused by Aspergillus. People who have a lung disease or have weakened immune systems are susceptible to get Aspergillosis. (Aspergillosis, 2014)
Aspergillus	Aspergillus spp. and especially Aspergillus fumigatus are a genus of ubiquitous filamentous fungi, representing up to 40% of hospital and home contamination. Aspergillus spores are liberated in large amounts during construction and renovation work. The diameter of the spores is about 2 to 3 μm, making it small enough to reach deep into the lungs.
Barrier	The currently accepted theory is that the first defense line to prevent the spread of Aspergillus. During the construction activity, barriers are used to divide the hospital into two areas – construction area and treatment area. It is a principle method for infection control. (Aspergillosis, 2014) However infections continue to occur at frightening regularity.
CDC	The Center for Disease Control and Prevention is the nation's disease prevention and wellness promotion agency, protecting people's health and safety, providing credible information to enhance health

decisions, and improving health through strong partnerships. CDC's work encompasses a wide range of health threats, including infectious and chronic diseases, injuries, birth defects, food and water safety, bioterrorism, environmental hazards, and occupational health and safety. CDC also administers funding for state and local health departments, community-based organizations and academic institutions for a wide array of public health programs and research." (CDC, 2012)

Construction	The building of new structures, or the additions, alterations, expansions, reconstruction, or renovations to existing building structures. Construction also includes any maintenance, repairs or installation work to mechanical, electrical, or plumbing systems within the existing structure.
EPA	Environmental Protection Agency
IA	Invasive Aspergillus
IAQ	Indoor Air Quality
ICRA	Infection Control Risk Assessment
Immunosuppressed	A state in which the patient's immune system is weakened due to their condition and treatment. The patient's immune system or ability to fight off infection is impaired or not effective, making the patient more susceptible and vulnerable to infection. This condition

	is also known as being immune-compromised. (Liloglou et al., 1994)
Infection Control	The most important part of Infection Control is to prevent nosocomial or healthcare-associated infection. Infection Control corresponds to the factors related in spreading of infections within a healthcare setting. The primary responsibilities of Infection Control include prevention, monitoring, investigation and management.
IPA	Invasive pulmonary Aspergillosis
Nosocomial	Infections contracted within the hospital that is unrelated to the patient’s initial illness or injury. Nosocomial infections are also known as hospital-acquired infections. Recent research links nosocomial infections to occur during a time of construction within the healthcare facility.
PM 2.5	Particles whose diameters are less than 2.5 micrometers are called “fine” particles. (newsbanner.com, 2015) Aspergillus fumigatus and Aspergillus Niger are the common fungal types associated with fine particles.

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CHAPTER I

INTRODUCTION

Background

Hospital stays can result in infections that can kill. The Association for Professionals in infection control (APIC) states that “airborne contaminants are more prominent during times of construction activity” (Bartley, 2000). The purpose of this study is to look to refine the measurement of the movement of the dust particles in a ducted air stream. The study seeks to show that a revised technique will provide data on dust dispersion at normal settlement rates. This thesis is set out as Chapter I, Introduction, Chapter II, Literature Review, Chapter III, Methodology, Chapter IV, Results, and Chapter V, Conclusions.

This chapter presents the problem statement, hypothesis, limitations and summarizes the research objectives. *Figure 1*, from Bartley (2000), shows the categories of risk levels with respect to operational components of a hospital.

Low Risk	Medium Risk	High Risk	Highest Risk
▪ Office areas	▪ Cardiology ▪ Echocardiography ▪ Endoscopy ▪ Nuclear Medicine ▪ Physical Therapy ▪ Radiology/MRI ▪ Respiratory Therapy	▪ CCU ▪ Emergency Room ▪ Labor & Delivery ▪ Laboratories (specimen) ▪ Medical Units ▪ Newborn Nursery ▪ Outpatient Surgery ▪ Pediatrics ▪ Pharmacy ▪ Post Anesthesia Care Unit ▪ Surgical Units	▪ Any area caring for immunocompromised patients ▪ Burn Unit ▪ Cardiac Cath Lab ▪ Central Sterile Supply ▪ Intensive Care Units ▪ Negative pressure isolation rooms ▪ Oncology ▪ Operating rooms including C-section rooms

Figure 1 : Risk levels for operational components of a hospital from Bartley (2000)

Indoor Air Quality (IAQ) is now seen by many healthcare professionals as an important environmental health problem. The causes of IAQ problems are poor or inadequate ventilation and exposure to one or more contaminant sources in the building (Riley et al., 2004). Two million patients are infected in U.S. hospitals every year, and this results in 88,000 deaths. About 5,000 of these are caused by construction and maintenance activities. Meanwhile specific, detailed information of how to protect the patients during the construction activity is limited.

Zhang (2014), noted that “The risk of nosocomial infections, or hospital acquired infections, to patients in hospital facilities has become an increasingly complex and challenging issue for the healthcare industry”. As time goes on, the need for building expansion, construction, and renovation in outdated hospital structures and equipment is pressing, but one of the underlying concerns is that recent research has reported causal links between construction in health care facilities and increased infection rates. *Figure 2* shows the graph of the Aspergillosis related fatality rate given by CDC.

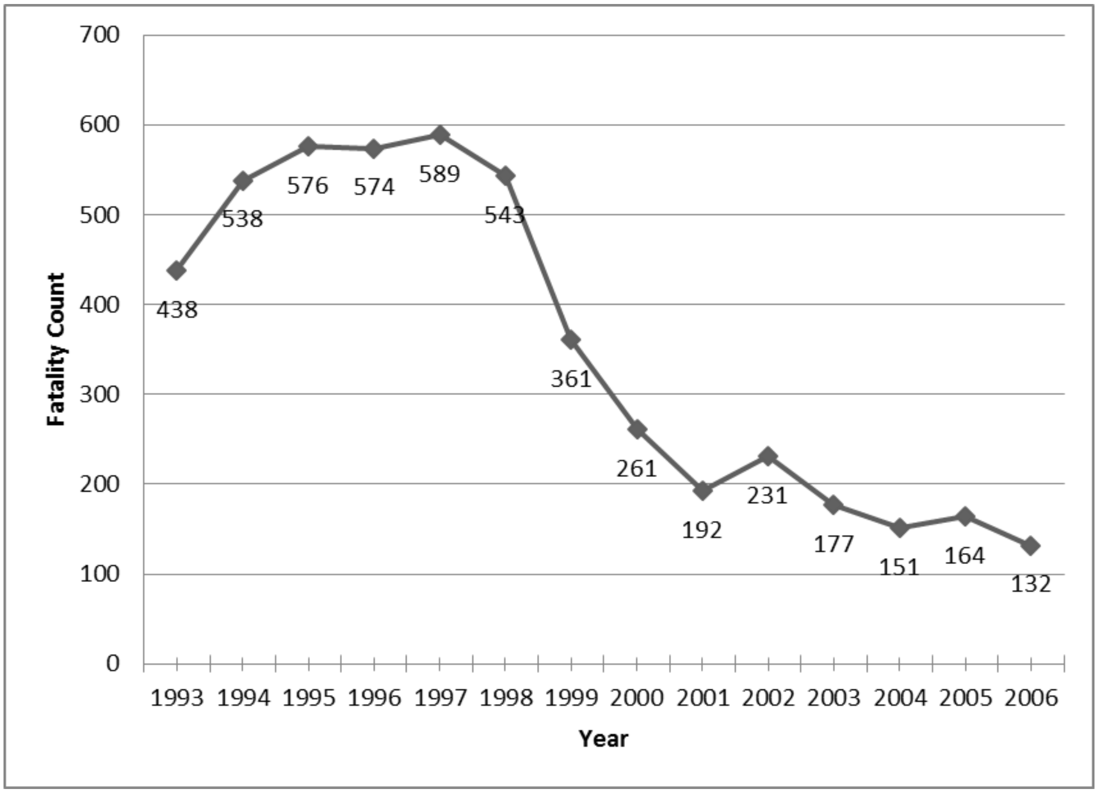

Figure 2 : CDC Aspergillosis related fatality rate after CDC (2009)

A number of factors may lead to fungal contaminants. These are disturbance of dust, mold or infectious organisms released into the air during. Spores remaining in the atmosphere for long periods of time due to low settling spores can spread to a distance (Riley et al., 2004). *Figure 3* shows a mold spore. Construction activity within a hospital can potentially release infection-causing particulates into the atmosphere, contaminating the air.

Figure 3 : Enlarged image of the aspergillus spore from Nader (2006)

Lee (2010), gives specific types of the most dangerous molds found during construction, “Water leaks resulting in mold growth have led to life-threatening and fatal infections with environmental fungi such as Aspergillus, Fusarium, Scedosporium, Zygomycetes, and soil-borne bacteria such as Nocardia”.

Cheple (1998), notes that “healthcare facility managers, engineers and construction managers need to be educated about the infection control during the construction”. This research experiment determines the rate of accumulation of dust particles in a standard type of air flow over a set range of velocities.

Problem Statement

To measure the settlement velocity and rate of accumulation for a standard dust at a set of velocities within the accepted range of air conditioning ducts.

Hypothesis

The basic hypothesis for this research is that there is no settlement occurs at the normal velocity ranges.

Limitations

The limitations for this research include:

- The experiment will use standard dust, which does not have the exact properties of common dust particle. If this can actually be defined.
- There is no guarantee of providing a clean atmosphere (air).
- The velocity range is limited to accept values.
- There is scope of error in the analysis because the study is self-designed and self-performed.

Research Objectives

The research objectives are:

- To develop an air flow that models a typical air conditioning duct.
- To apply different air speeds to flow in the duct to measure velocity distribution.
- To use a new dust powder to model red mold dust.
- To trap the dust particles when they settle in the flow.
- To measure the concentration of the particles in different size ranges and look to develop a movement model.

CHAPTER II

LITERATURE REVIEW

This chapter outlines a summary of the literature review. The topics include Aspergillus spores, Aspergillosis, risk, duct design standards.

Aspergillus Spores

Aspergillus causes serious and sometimes fatal illnesses. Aspergillus is a fungus whose spores are present in the air we breathe. These “opportunistic fungi" are distributed throughout the world; but are usually found more in the Northern hemisphere. Aspergillus mold is omnipresent, dangerous to the immune suppressed and difficult to stop. They are found in decaying leaves and compost. The spores are in air conditioning, heating and insulation ducts. Aspergillus causes most commonly an infection called Aspergillosis (Lee, 2015). Though they are found everywhere, they normally do not cause illness. Aspergillosis weakens a person’s immune system. People with damaged lungs or with allergies are more susceptible to infection and rapid death.

Tracking the movement of spores is important to understand how to prevent contact with possible patients, which is the clear point of this research. “Aspergillus causes health problems including allergic reactions, lung infections, and infections in other organs” as stated by Atherton & Bartholomew (2015). They further noted “When mold spores are inhaled by a healthy individual, the immune system cells surround the spores and destroy them. The immune system cells are lower in number for people who have a weakened immune system. This allows Aspergillus to enter the lungs and other parts of the body. Common Aspergillus infections include invasive Aspergillosis, aspergilloma, allergic Broncho pulmonary Aspergillosis (ABPA) and chronic pulmonary Aspergillosis (CPA)."

The risk of infection is dependent on the overall health of the individual and the extent of exposure to the Aspergillus mold. Some factors make an individual more vulnerable to infection, which are:

- "Weakened immune system - People who take immune-suppressing drugs usually after undergoing a transplant surgery and people with certain blood cancers are most vulnerable to invasive Aspergillosis. People in the later stages of AIDS are also vulnerable.

- Low white blood cell level - Post chemotherapy, organ transplant and chronic granulomatous disease or leukemia results in the dropping of white blood cell count levels which makes the individual more susceptible to invasive Aspergillosis.

- Lung cavities - People with cavities in their lungs are at higher risk of developing Aspergilloma. Cavities are areas damaged by radiation to the lung or by lung diseases such as tuberculosis or sarcoidosis.

- Asthma or cystic fibrosis - People with asthma and cystic fibrosis are more likely to have an allergic response to the Aspergillus mold.

- Long-term corticosteroid therapy - Long-term use of corticosteroids may increase the risk infections". (Lee, 2015)

As shown in the noted literature, fungal infections are dangerous and difficult to prevent. The impact on patients is often fatal. Spores are small and of low density and easily moved by air streams. *Figure 4* shows the microscopical image of an aspegillus spore.

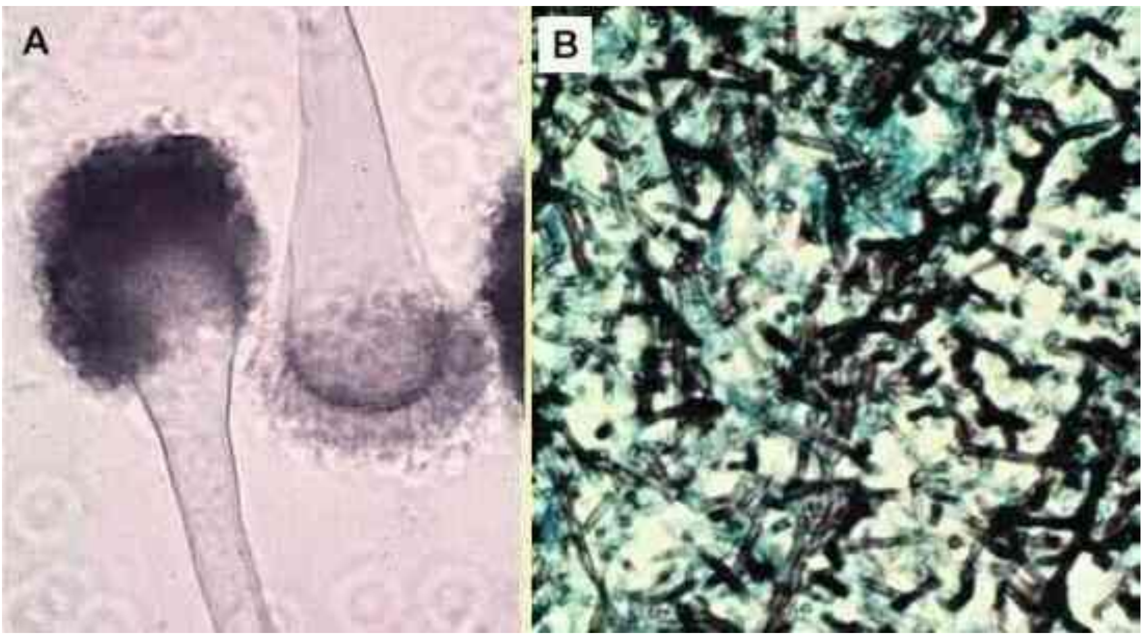

Figure 4 : Aspergillus fumigatus from Deacon (2015)

“Aspergillosis sporing heads of the fungus (in laboratory culture) Spores are produced upper part of a club-shaped swelling (vesicle) of an erect hypha.”

“Taking a microscopic section of lung tissue, from an ill patient is common procedure. The species’ are stains to look for hyphae of Aspergillus in an air sac. If such a ball of hyphae growing saprotrophically in the lung, it is termed an aspergilloma. This is a clear indication of infection. Most cases of Aspergillosis are sporadic, sometimes invasive Aspergillosis spreads via hospital patients. Invasive Aspergillosis outbreaks are generally associated with hospital construction or renovation, as the increased dust activity appears to increase the amount of airborne Aspergillus" (Deacon, 2015). Although, this is far from proven

Risk

Aspergillosis is not contagious from person to person. The first reported case of invasive Aspergillosis occurred in 1953. It was identified in an immunocompromised patient, under the influence of corticosteroids and cytotoxic chemotherapy. Invasive Aspergillosis still continues to pose a significant threat to immunocompromised patients. "In the United States, a 160% increase in cases of Aspergillosis has been reported in an autopsy series from 1960 through 1970. Similarly, in Germany, a review of 11,000 autopsy cases from 1978 through 1992 demonstrated a 17%–60% proportional increase in cases of invasive Aspergillosis." (Lin, Schranz, & Teutsch, 2001)

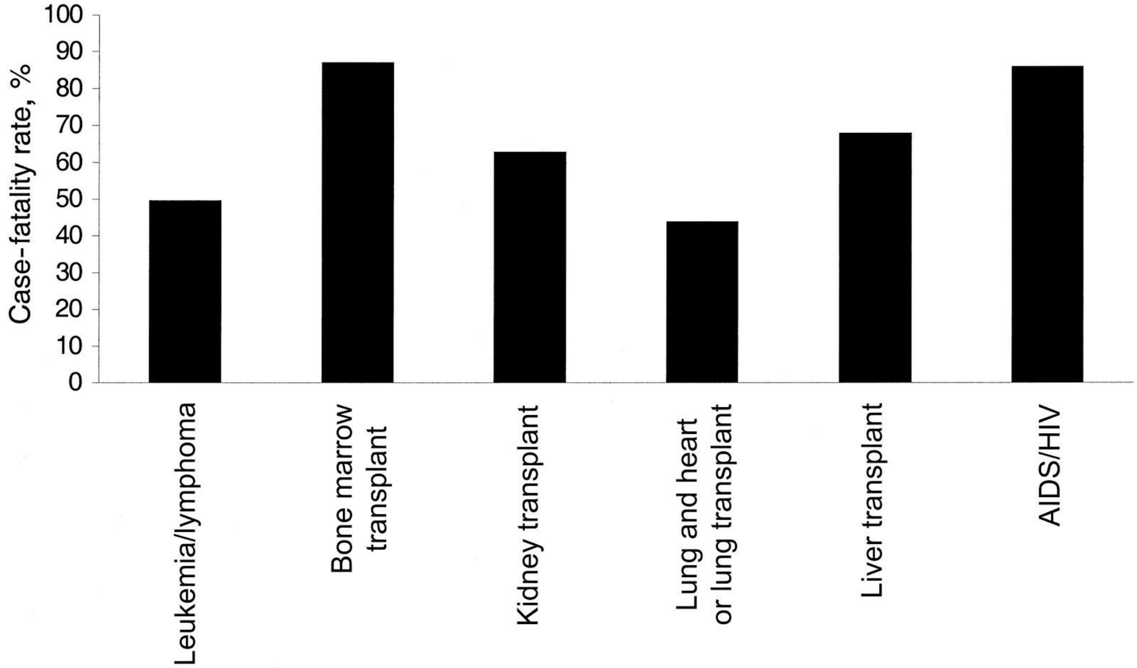

Figure 5 : Case-fatality rates for patients with aspergillosis, according to underlying diseases or conditions. (Right Diagnosis, 2009)

General Principles of Duct Design

The flow of air or any other fluid is caused by a pressure differential between two points on the duct. Flow will originate from an area of high energy, or pressure, and proceed to area(s) of lower energy or pressure. It is essential to be seen as a mass balancing exercise. Duct air moves according to three fundamental laws of physics: conservation of mass, conservation of energy, and conservation of momentum. These are explained in most classic physics textbooks.

There are three types of flow:

- Laminar Flow – This flow is parallel to a boundary layer. In HVAC system, the duct shape creates the edge of the boundary layer
- Transition Flow – This flow occurs between the laminar and turbulent flows
- Turbulent Flow – This flow is usually near the center of the duct. The Reynold's number increases above a set of values and depends on the roughness. HVAC applications typically exist in the transition range between laminar and turbulent flow (ASHRAE, 2012)

Pressures within a duct

The direct measure of potential energy that causes the air movement is pressure. Three types of pressures are found within a duct.

- Static Pressure – The pressure for non-moving air
- Dynamic (velocity) Pressure – The pressure of moving air.
- Total Pressure – The sum of the other two pressures.

The standard equation to convert velocity to pressure is shown in equation (1).

Dynamic pressure = (Density) * $(\text{Velocity})^2$ / 2 (1)

Static and dynamic pressures form the total pressure; the magnitude of each is dependent on the local duct cross section, which determines the flow velocity, state, space and inflow/outflow velocities.

Pressure Drop

Duct designs are typically based on the total pressure. These calculation techniques date back to the 1930's. The difference between the available static pressure of the system and the pressure loss of each component of the system must be calculated to determine the flow rates and velocities. It is imperative that the flow rates match the range required and that the velocity stays within an accepted range. The total pressure drop may be calculated by the sum of all the pressure losses within the various components using standard physics equations. *Figure 6* shows tabulated pressure limits.

Low pressure systems: Velocity $\leq$ 10 m/s, static pressure $\leq$ 5 cm H_2O (g)

Medium pressure systems: Velocity $\leq$ 10 m/s, static pressure $\leq$ 15 cm H_2O (g)

High pressure systems:Velocity > 10 m/s, static pressure $15 < ps \leq 25$ cm H_2O (g)

Figure 6 : Pressure limits from ASHRAE (2012)

High duct velocity – Duct velocity is an impartial design tool. The HVAC deign manual has set the acceptable ranges. The common observations are:

- Smaller ducts resulting in a lower initial cost and lower space requirement.

- Higher pressure drop.
- Larger fan power consumption.
- May lead to increased noise and hence a need for noise attenuation.

Low velocities result in

- Stale air.
- Settlement of particles.

Losses

Three types of loses exist in a pressure system. All are related to change in velocity and pressure. The first is dynamic loss which is proportional to dynamic pressure and can be calculated using equation (2).

Dynamic loss = (Local loss coefficient) * (Dynamic pressure) (2)

Where, the local loss coefficient, known as a C-coefficient, represents flow disturbances for particular fittings or for duct-mounted equipment as a function of their type and ratio of dimensions.

The second is frictional Pressure. Frictional losses in duct sections result from air viscosity and momentum exchange among particles moving with different velocities. Figure 7 shows a chart calculator based on the Darcy-Weisbach equation. This is the standard equation used to calculate flows in pipe systems.

The easiest way of defining frictional loss per unit length is by using the Friction Chart (ASHRAE 1997); however, this chart (*Figure 7*) should be used for elevations length 500 m (1,600 ft.), air temperature between 5°C and 40°C (40°F and 100°F), and ducts with smooth surfaces. The Darcy-Weisbach Equation should be used for "non-standard" duct type such as flex duct and non-rectangle ducts.

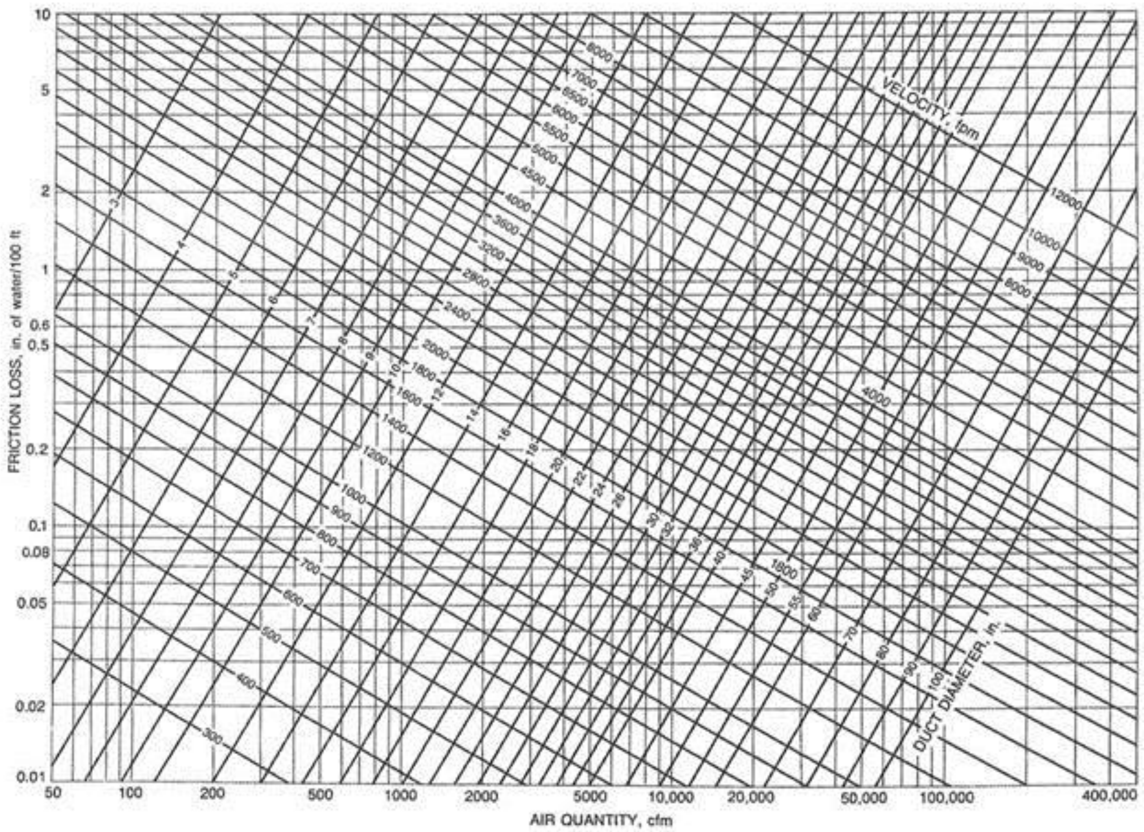

Figure 7 : Chart calculator on the basis of Darcy-Weisbach equation from ASHRAE (2012)

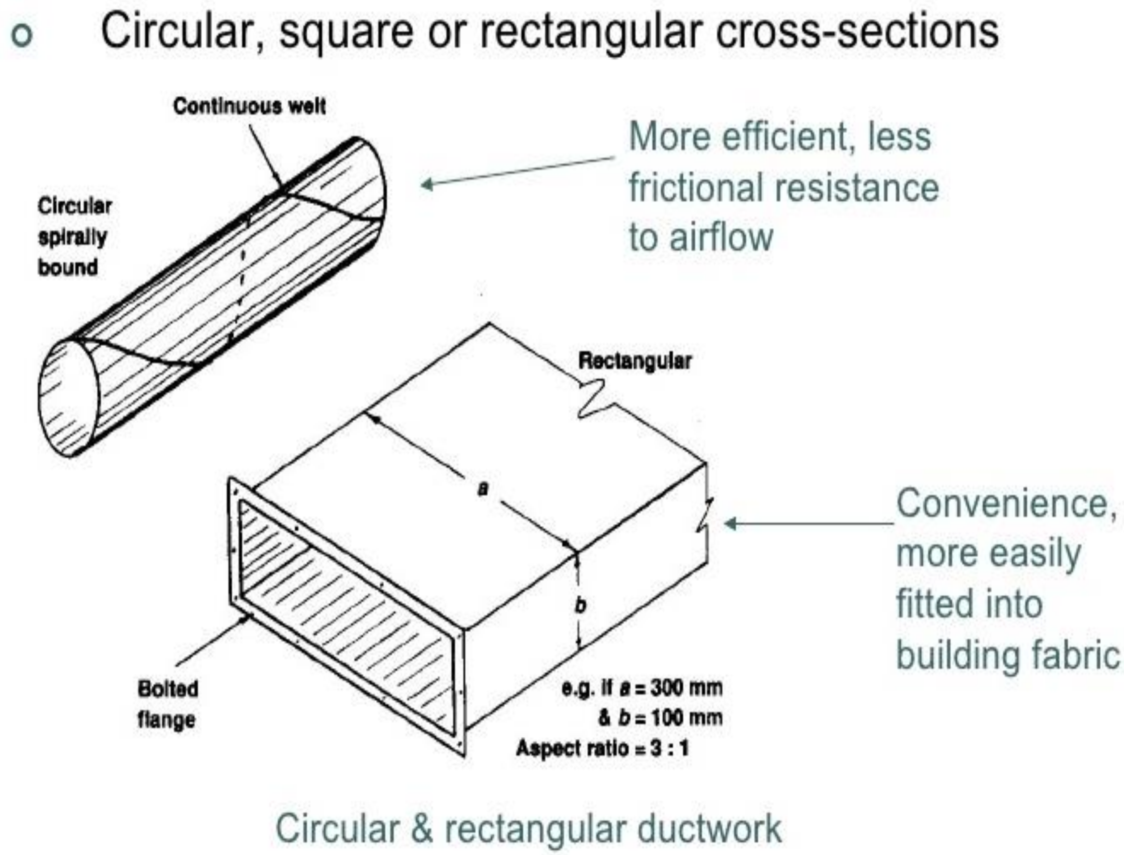

Figure 8 : Duct design from Howell & Coad (2009)

Figure 8 shows the two common duct types. The circular ducts are common in small roof spaces because of cost factors. The rectangular ducts are common when the height is a constraint.

Basset's Experiment

Bassset (2013) conducted an experiment to look at the materials that can be used to make an effective barrier for infection control. The study included the investigation of the relationship between barriers and particle transmission. The experiment mimicked a hospital setting showing that the dust particles which passed through the infection control barrier materials, on being disturbed during construction. A plastic sheeting barrier method commonly used in hospitals during construction was used for the test. The purpose of the experiment was to determine how well that sheeting system upheld and maintained its barrier, and how many particles were actually transmitted through the barrier.

The experiment tested the properties of a plastic barrier seal. Two plastic sheets were overlapped at the center of the two containments. They were taped together with a similar material used in hospitals. This taped joint simulates a sealed barrier joint found in hospitals. A substance of similar size to dust was released within the construction zone-replicated environment. Using a pressure controlled air compressor and two air filters, the barrier's ability to withstand an air pressure of 15 psi over a time span of 18 hours was tested. A sample from an unused filter was also taken to observe for particles that would already exist prior to the experiment for comparison with the filters being used. It was determined that there was no movement of the particles through the barrier (Basset, 2013).

The result was not expected due to the poor construction techniques used in the experimental work. *Figure 9* shows the schematic plan for this test equipment. *Figure 10* shows a photograph of the final arrangement.

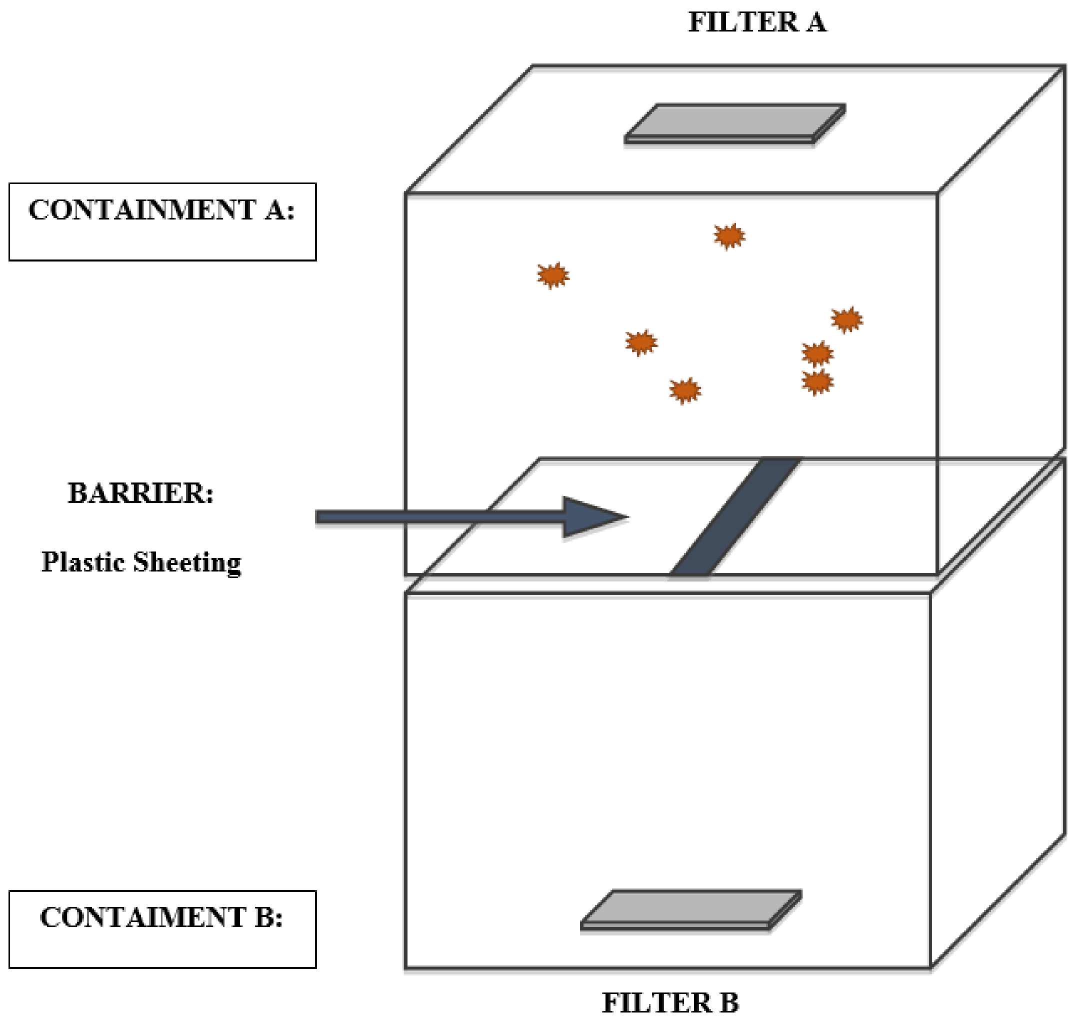

Figure 9 : Pictorial representation of Basset's experiment from Basset (2013)

Figure 10 : Photograph of Basset's apparatus from Basset (2013)

Zhang's Experiment

However in the real world it is not feasible to create a completely sealed barrier as Bassett did in her work. Real walls have openings and tears in the material that allow dust potentially laden with spores to pass through.

Zhang (2014) conducted a second experiment to measure the movement of particles through a hole in the wall system modelled in the Bassett Test Arrangement. This second study continued the study of the movement of particles between construction and non-construction zones in a hospital setting. The experiment involved the introduction of a door into the plastic wall to model a real construction zone where people and goods pass from one side of the barrier to the other for the usual reasons. A doorway with an area equal to five percent of the wall area was introduced into the Basset experimental setup. Basset's test arrangement was modified to introduce a recirculating fan system to increase the air flow between the chambers which eventually showed movement of the dust particles from one chamber to the other. Two locations were chosen on the outlet filter to test the differences in the concentrations of dust on the filters (Zhang, 2014). *Figure 11* shows the schematic plan for this test equipment. *Figure 12* shows a photograph of the final arrangement.

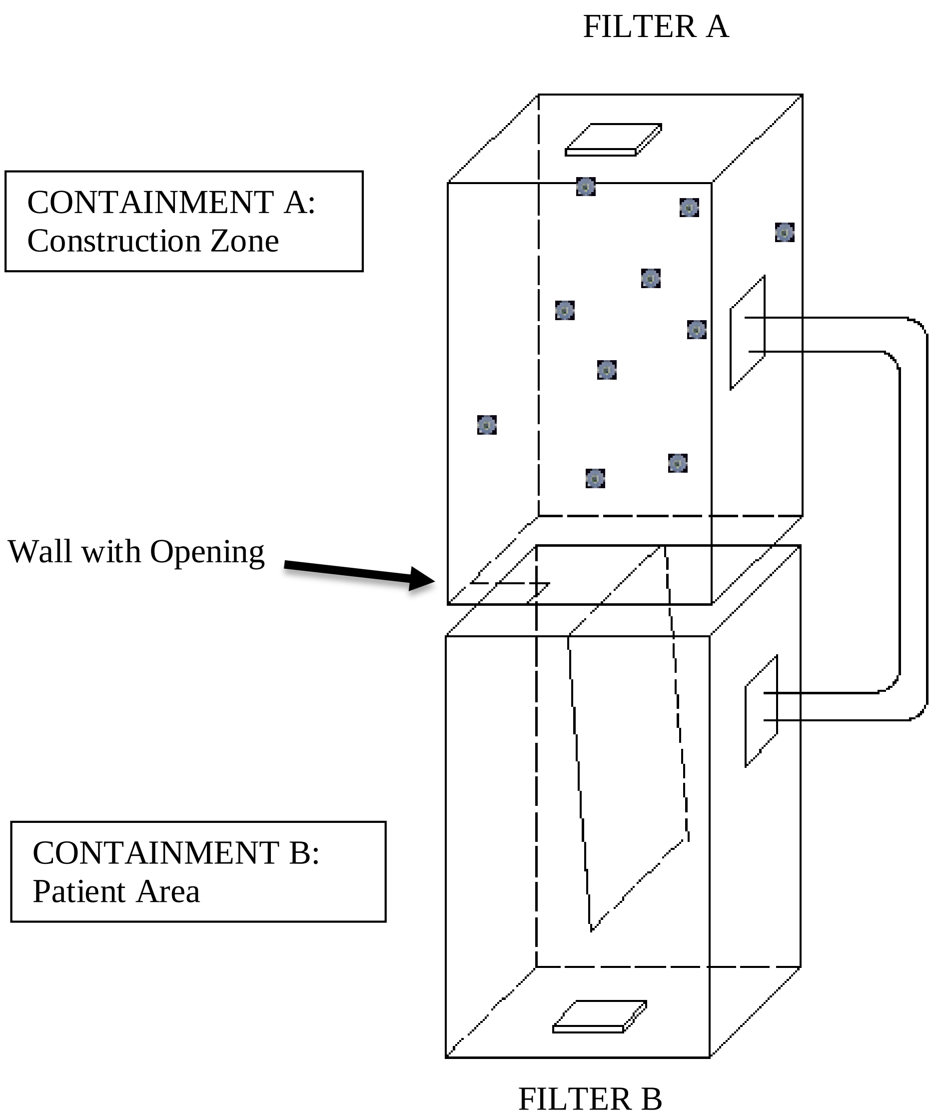

Figure 11 : Pictorial representation of Zhang's experiment from Zhang (2014)

Figure 12 : Photograph of Zhang’s apparatus from Zhang (2014)

The results showed a rapid settlement of the dust in the lower chamber. Zhang (2014), recommended a study on dust settlement velocity and particle sizes. The current experimental work leads from Zhang’s study.

CHAPTER III

METHODOLOGY

Introduction

This chapter gives a description of the methods used for the experimental work and the analysis techniques for the data collected by the study. This test is to measure the settlement velocity and rate of accumulation for the standard dust at a set of velocities within a simple duct shape. This chapter authors the experimental procedure, the material used, descriptions about the equipment and the data analysis methods. The duct design is a hybrid between a circular section and a rectangular section to improve the dust collection process and match the ability of the microscope used to count the particles.

Experimental Design

Figure 13 shows a picture of the complete manufactured duct.

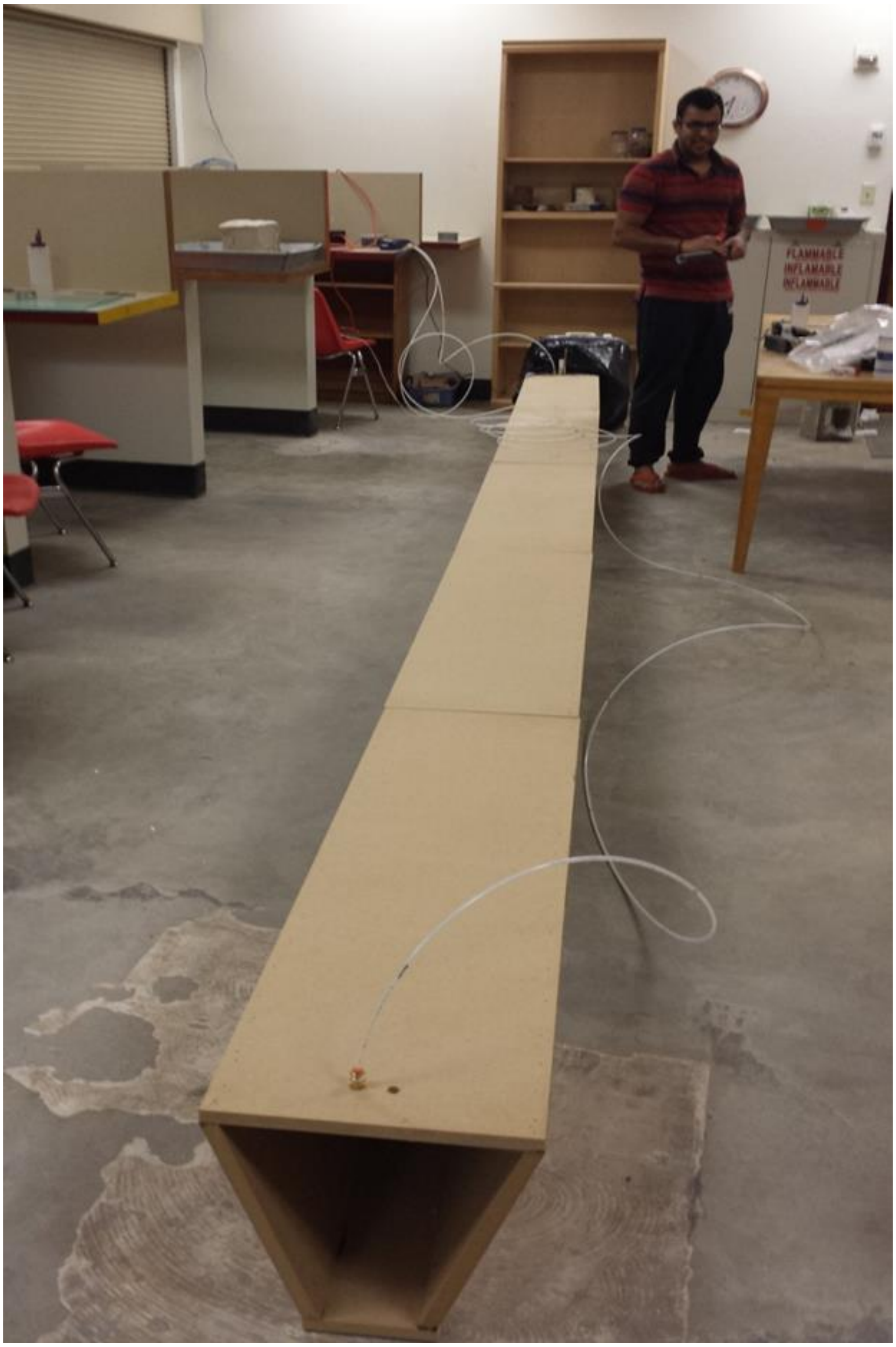

Figure 13 : Manufactured duct

The timber duct was constructed at the TAMU Woodshop in the College of Architecture. An air stream will be introduced through the duct using a table fan. The method to introduce the dust powder was, a pipe installed flush with the inner surface of the close to the end where the air flow will be generated. After turning on the air flow, dust will be dropped into the duct through the pipe installed. To recognize air velocity, two smaller holes were drilled at each end of the duct into which the anemometer will be placed to measure the wind velocity. The method to determine dust settlement, particle size brackets is using microscopic procedures. Black paper coated with lacquer will be placed at the bottom of the duct. Samples of the paper on which the dust has settled will be taken for analysis. *Figure 14* shows the dimensions.

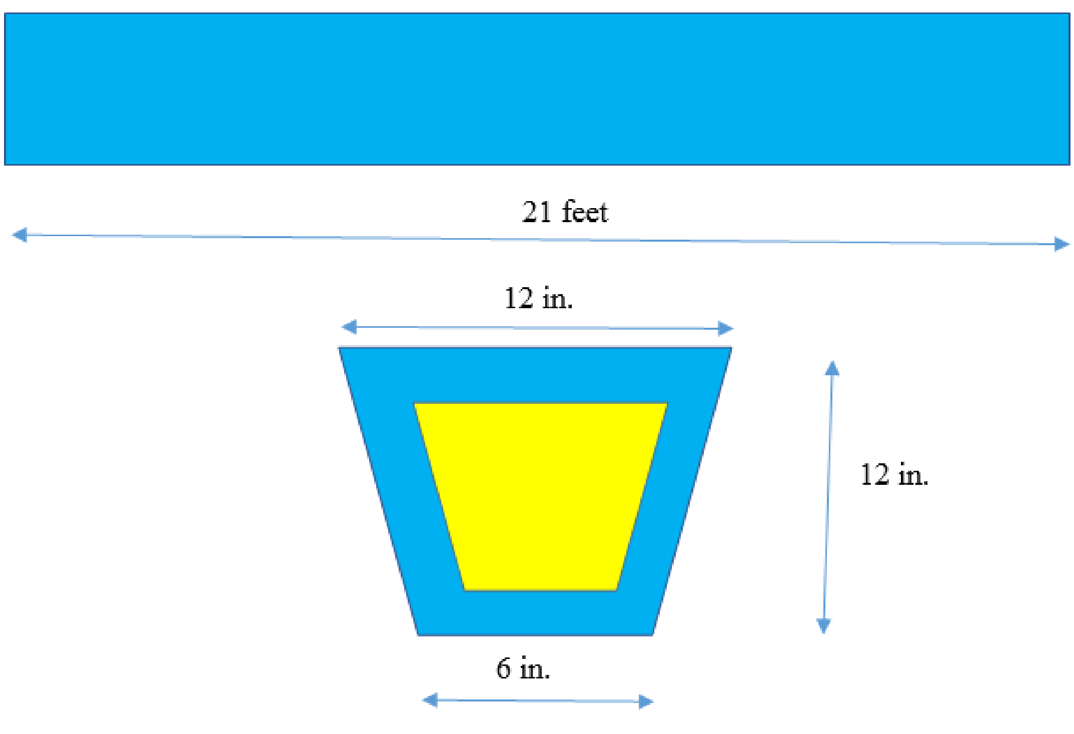

Figure 14 : Pictorial representation of the duct (plan and cross-section)

Apparatus Construction

Initially three medium density fiber sheets of dimensions 97in*49in*0.75in each were purchased. The twenty foot duct was to be built by connecting five smaller ducts (components) of 4 feet each. *Figure 15* shows the panel saw used to cut the sheets into planks.

Figure 15 : Panel saw

These sheets were cut into planks using the panel saw. The length of each plank was 48in (length of each component). 5 planks with width both 15 in and 7 in were cut to make the top and bottom faces of the components. 10 planks with width 14 in were cut to accommodate for the side faces.

Figure 16 shows the table saw to cut angles into the timber sheets. The edges of the planks to be used for the side faces were shaved parallel to each other at an angle of 18.5 degrees using the table saw. The width of these planks was reduced to 12.65 in. The planks to be used for the top and bottom faces were cut to 14 in and 6 in respectively on the table saw.

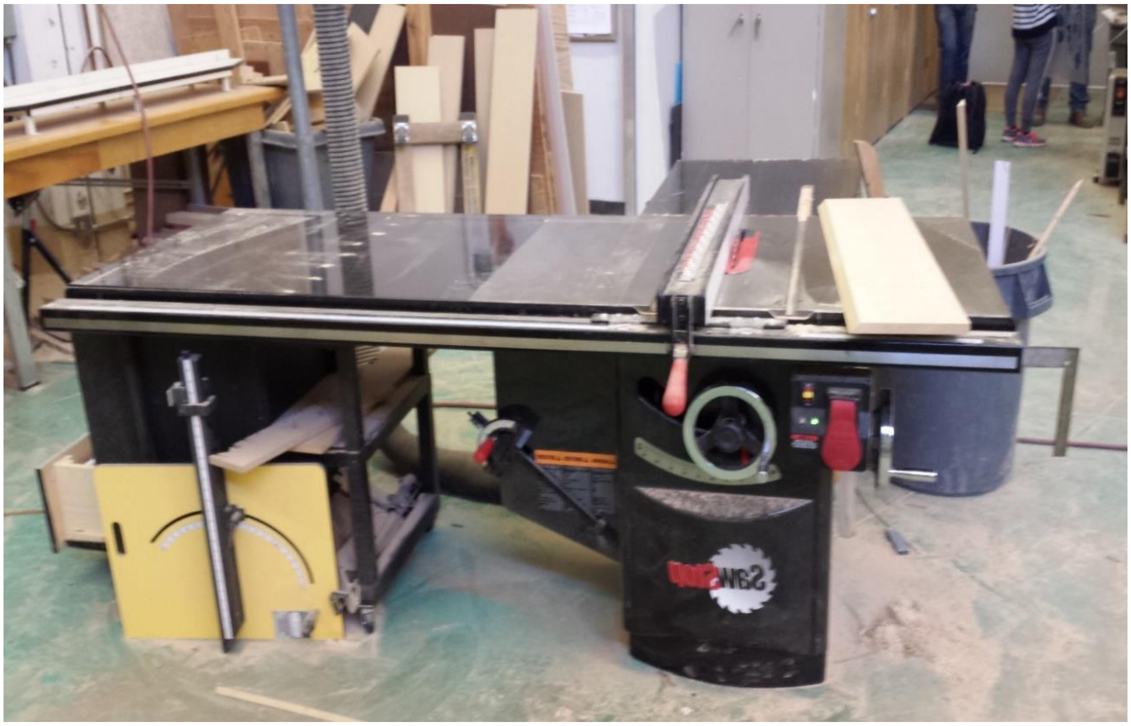

Figure 16 : Table saw

Props of wood were cut using a band saw. These props were clamped to the planks by clamps to hold them in place. An adhesive mixture of wood glue which is shown in *Figure 17* and wood dust was used to stick the planks to each other.

Figure 17 : Wood glue

A nail gun was used to nail the planks together and to hold it in place. *Figure 18* shows the picture of one of the five finished components of the duct.

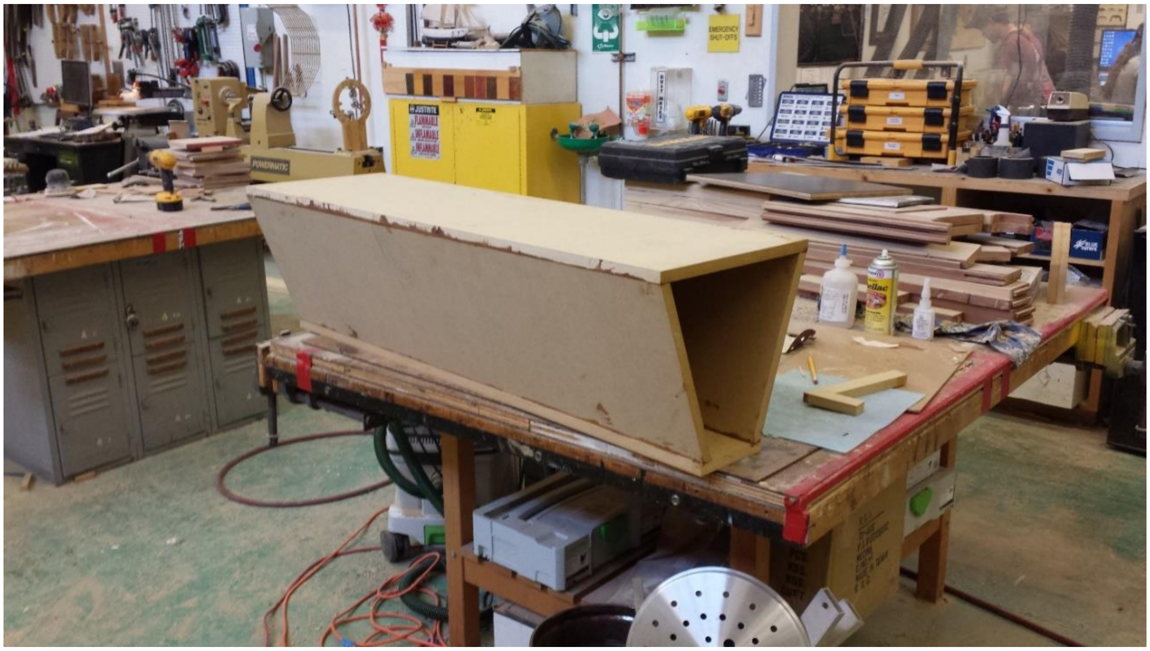

Figure 18 : Finished component

Once the component was finished, thin wooden strips were stuck to the perimeter of the cross-section. This would facilitate as a groove in connecting the components together to make the duct.

A garbage bag was cut and wrapped around a table fan to act as a source of air flow to be blown into the duct. *Figure 19* shows the table fan and garbage bag installation.

Figure 19 : Source of air flow

Figure 20 shows the entry portion of the duct. A hole of diameter 1 in was drilled into the duct close to the entrance. This was done to insert a poly vinyl chloride (PVC) pipe flush with the inner surface of the duct. This pipe would allow for introduction of dust particles into the duct.

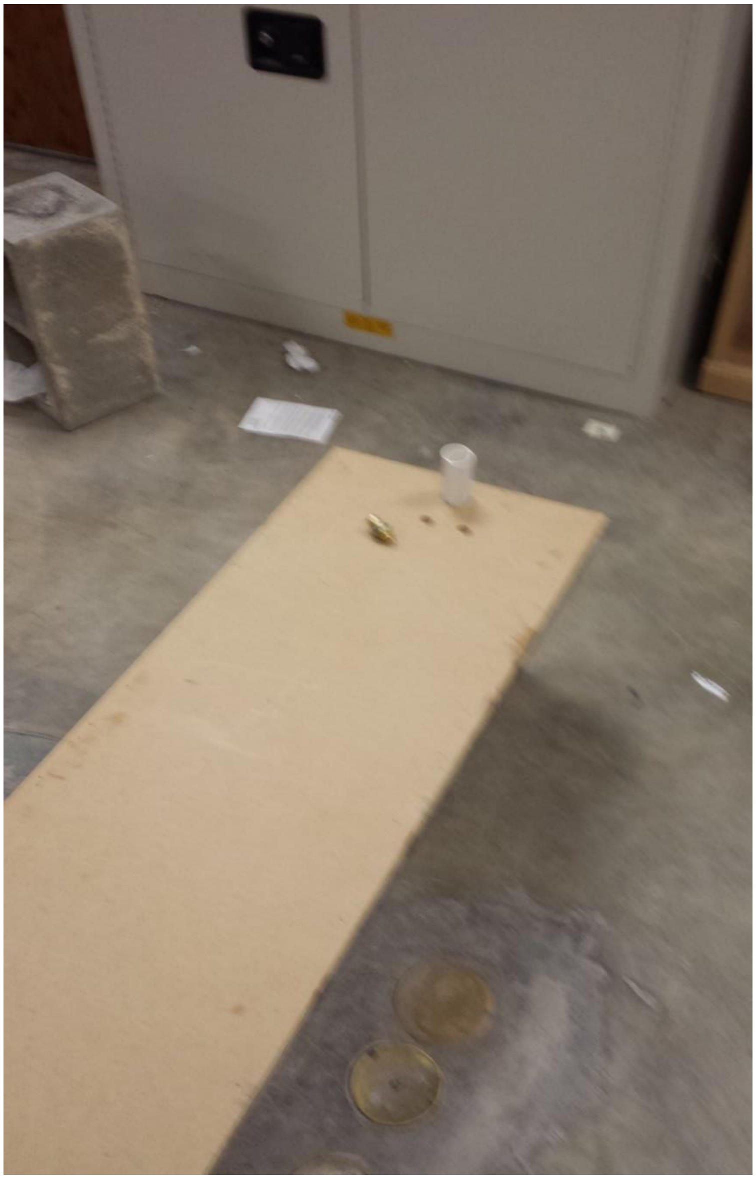

Figure 20 : Entry portion of the duct

Two holes were drilled at the beginning and the end portion of the duct to facilitate for the measurement of pressure inside the duct and the wind velocity of the air flow inside the duct.

A tube was connected at each end of the duct to measure the difference in pressure across the duct with the help of a pressure transducer as shown in *Figure 21*.

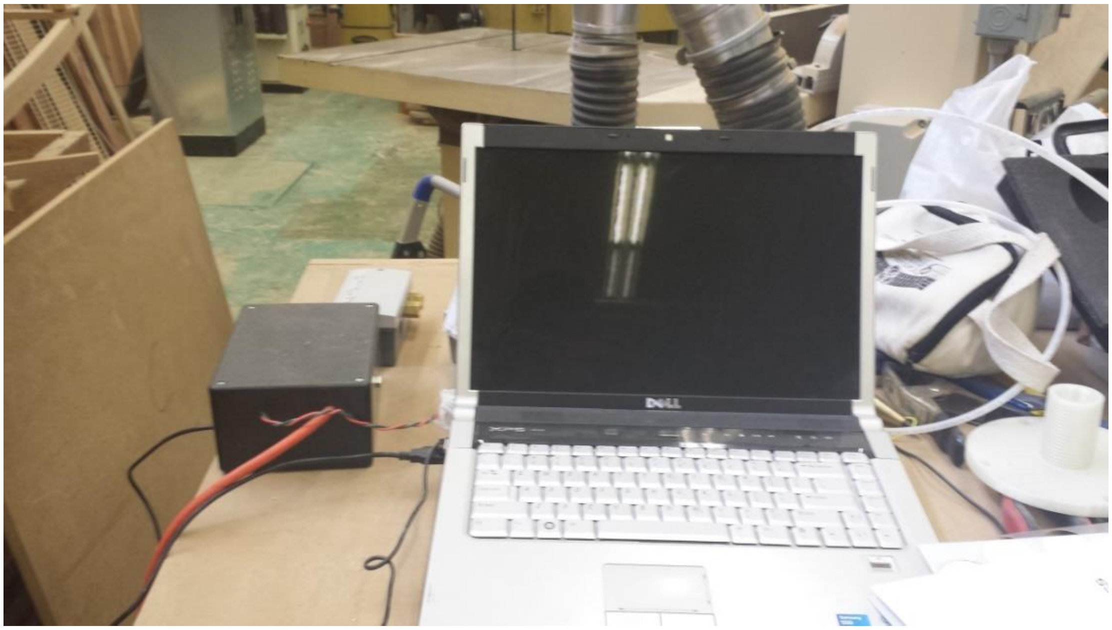

Figure 21 : Pressure transducer

Figure 22 shows the experimental setup of the study including the anemometer, pressure gauge, SETMA data log and the computer used to record the readings.

Figure 22 : Experimental setup

Figure 23 : Lacquer

Black paper coated with lacquer was placed at the bottom of the duct to analyze the settlement of the dust across the duct as shown in Figure 23.

Figure 24 : Black paper being placed in the duct

Black paper coated with lacquer was placed before the experiment for every iteration. Then the air from the fan was allowed to blow for 15 minutes to obtain a consistent air flow. The wind velocities for each iteration were measured during this time period. Keeping the fan on, one gram of dust was dropped into the air stream (duct) through the pipe constructed. The setting time for lacquer is 30 minutes, so the experiment was completed within that time. The black paper was removed after the experiment and samples were cut along the length of the duct namely at 2 feet, 6 feet, 10 feet, 14 feet and 18 feet. These samples were observed under the microscope and analyzed to gauge the number of dust particles settling along the length of the duct.

CHAPTER IV

RESULTS

This chapter outlines the experimental data and the graphical output obtained from the data to be used for analysis.

Air Velocity Measurement

The air flow velocity was measured using the anemometer and the entry and exit of the duct. This was done by placing the anemometer (shown in *Figure 25*) through the holes drilled in the duct. The velocity was measured at different depths to obtain an overall idea. A total of three different fan speeds were tested to gauge the behavior of the dust settlement at various speeds. These included fan speed 1, 2 and 3.

Figure 25 : Anemometer

Table 1 shows the air velocities through the duct at different fan speeds. The depth for each measurement was taken from the inner surface of the top plank as shown in *Figure 26*. This table also shows the maximum air velocities for a particular fan speed.

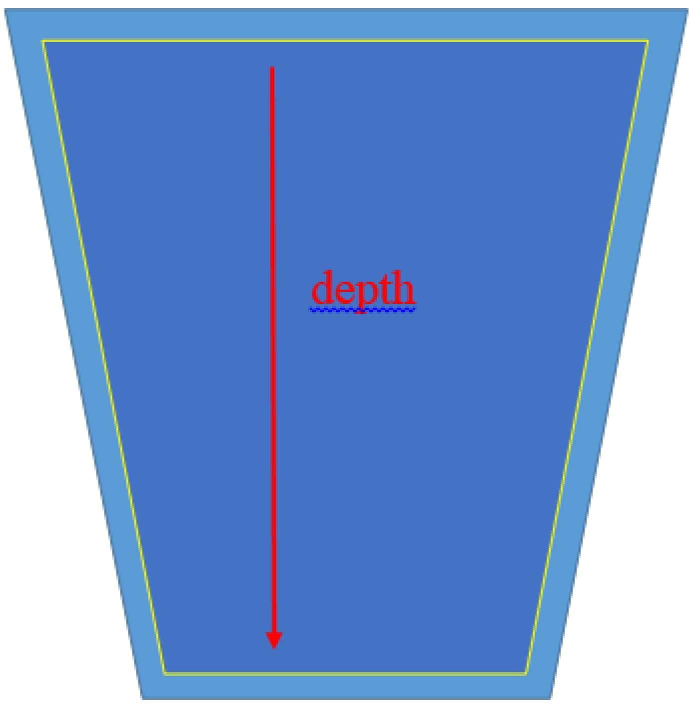

Figure 26 : Measurement of depth

Table 1 : Air flow velocities

		speed 1			speed 2			speed 3	(m/s)
depth (mm)		v11	v12		v21	v22		v31	v32
190		0.72	1.7		0.91	2.62		1.09	2.8
170		1.14	1.74		1.69	2.63		1.92	2.84
150		1.39	1.78		2.06	2.62		2.42	2.9
130		2.07	1.82		3.03	2.6		3.44	3.01
110		2.55	1.84		3.69	2.54		4.26	3.05
90		2.71	1.77		3.94	2.49		5.1	3.06
70		1.22	1.72		1.53	2.47		1.6	3.08
50		1.17	1.66		1.25	2.43		1.19	3.05
30		0.97	1.64		1.08	2.39		1.12	2.98
10		0.68	1.6		0.97	2.33		1.04	2.72

v11 - Entry velocity for fan speed 1
v12 - Exit velocity for fan speed 1
v21 - Entry velocity for fan speed 2
v22 - Exit velocity for fan speed 2
v31 - Entry velocity for fan speed 3
v32 - Exit velocity for fan speed 3

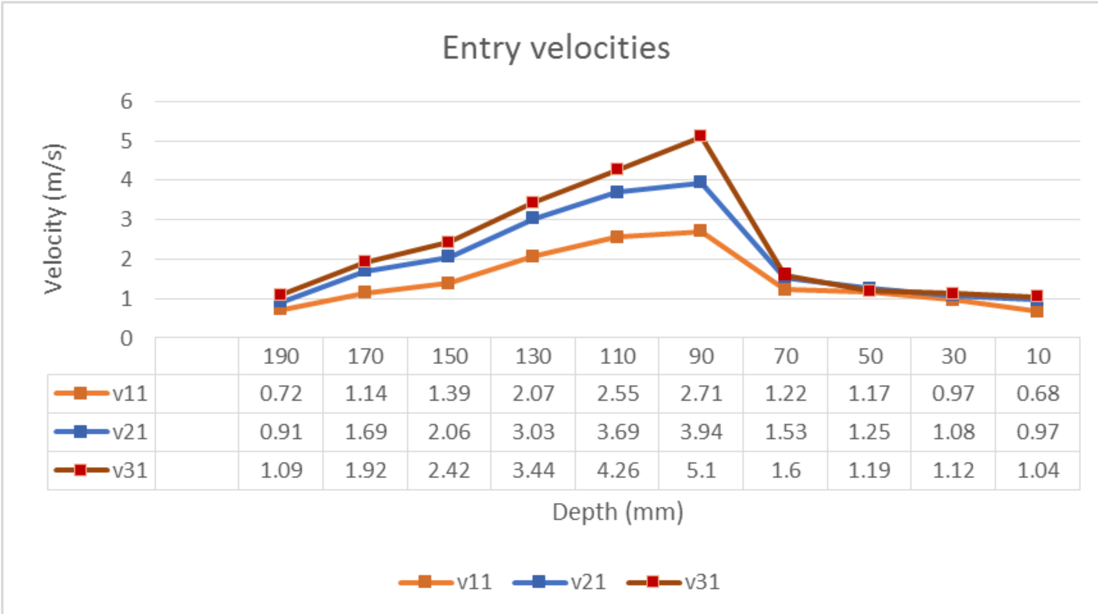

Figure 27 : Entry velocities

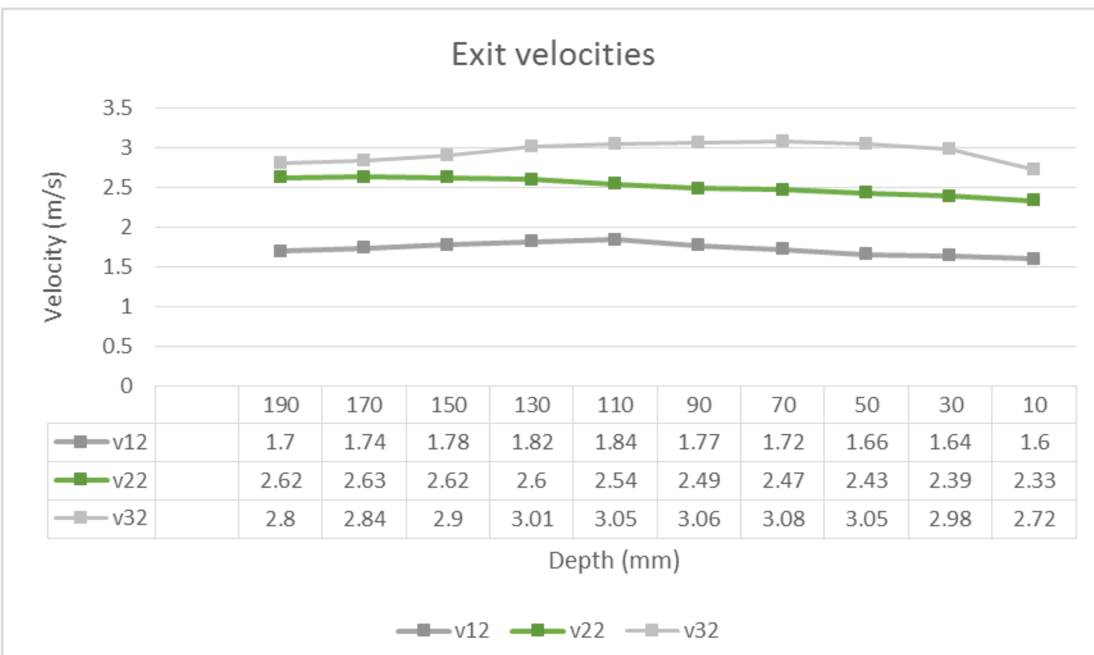

Figure 28 : Exit velocities

Five samples of the black paper were taken along the duct at 2 feet, 6 feet, 10 feet, 14 feet and 20 feet respectively for all the three fan speeds. These samples were analyzed under the microscope shown in *Figure 29*.

Figure 29 : Microscope

Once the samples were collected. The number of dust particles were counted and classified into four sizes namely A, B, C and D. The range of particle sizes is shown in Table 2.

Table 2 : Size ranges for classifying the dust particles.

Classification	Particle size range (mm)
A	0.15 <
B	0..1 – 0.15
C	0.05 – 0.1
D	< 0.05

Microscopic Images

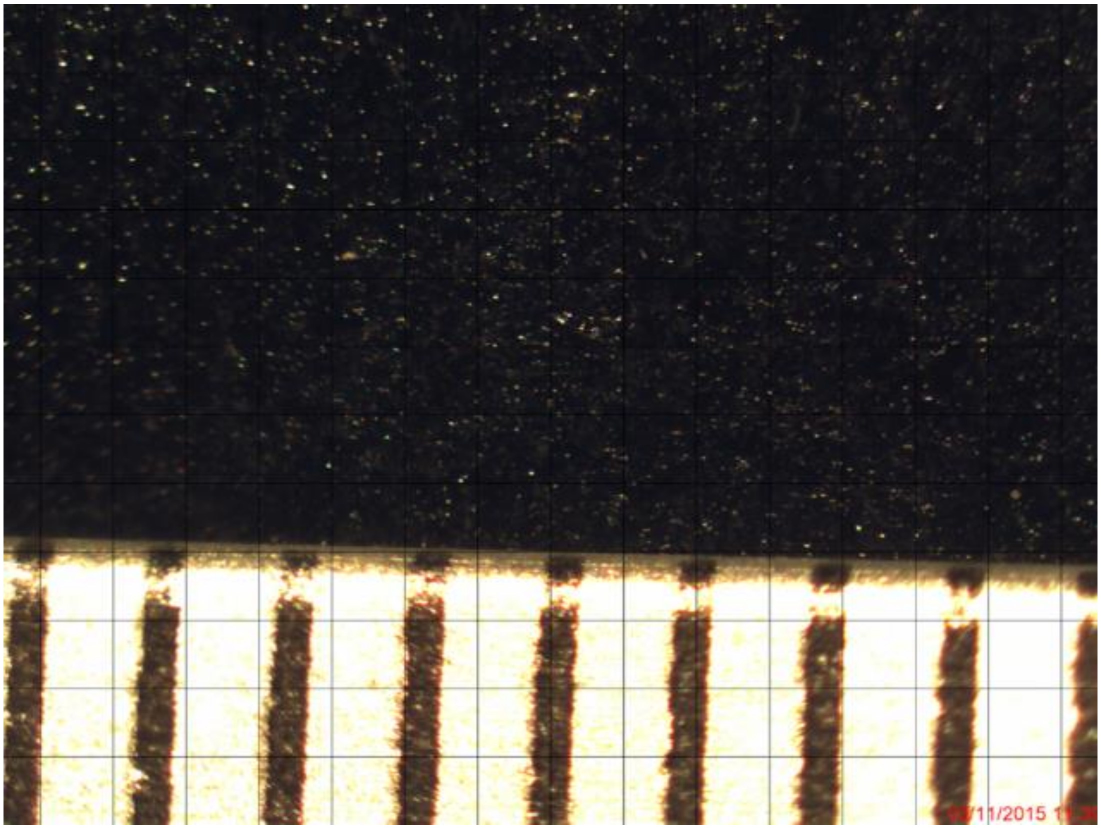

Figure 30 : Microscopic image at 2 feet for fan speed 1

A small portion of a ruler was also photographed along with the sample with the dust particles. This ruler was used to give a sense of measurement. The dust particles falling within a 5mm by 5mm sample were counted. Gridlines provided by the microscope were used to lower the least count to 0.05mm which helped in classifying the dust particles into four major size ranges.

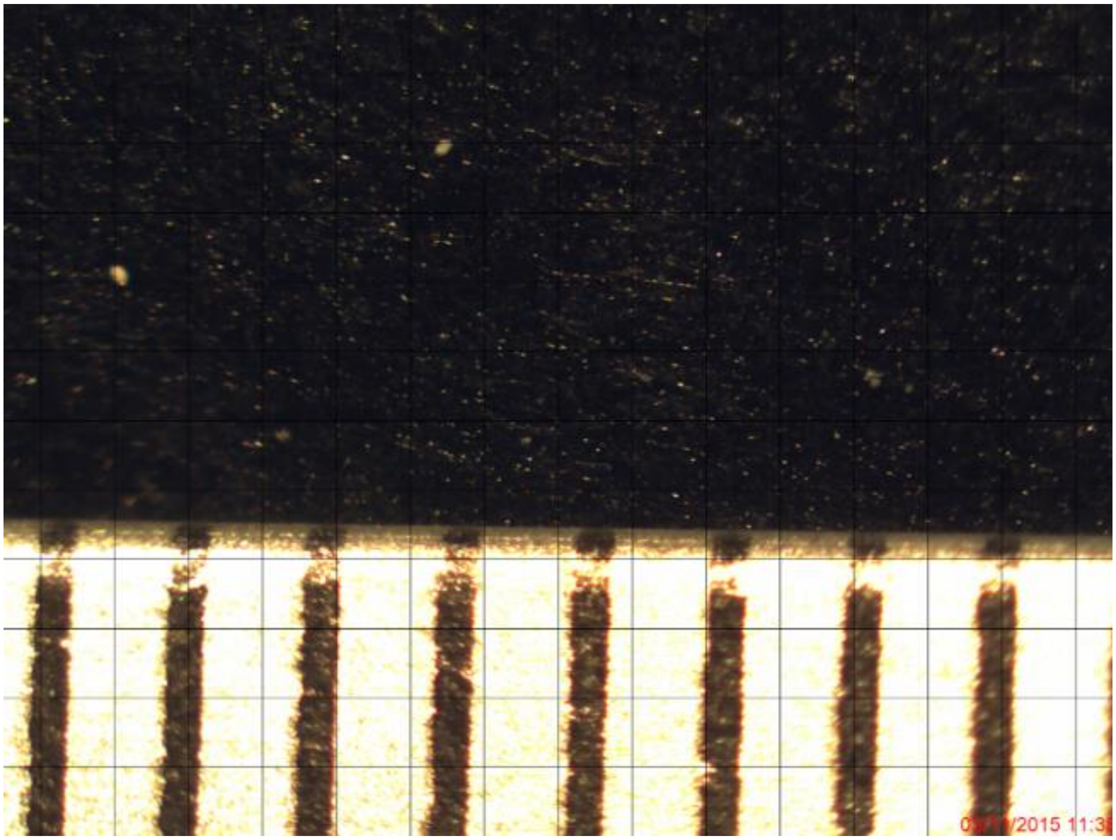

Figure 31 : Microscopic image at 6 feet for fan speed 1

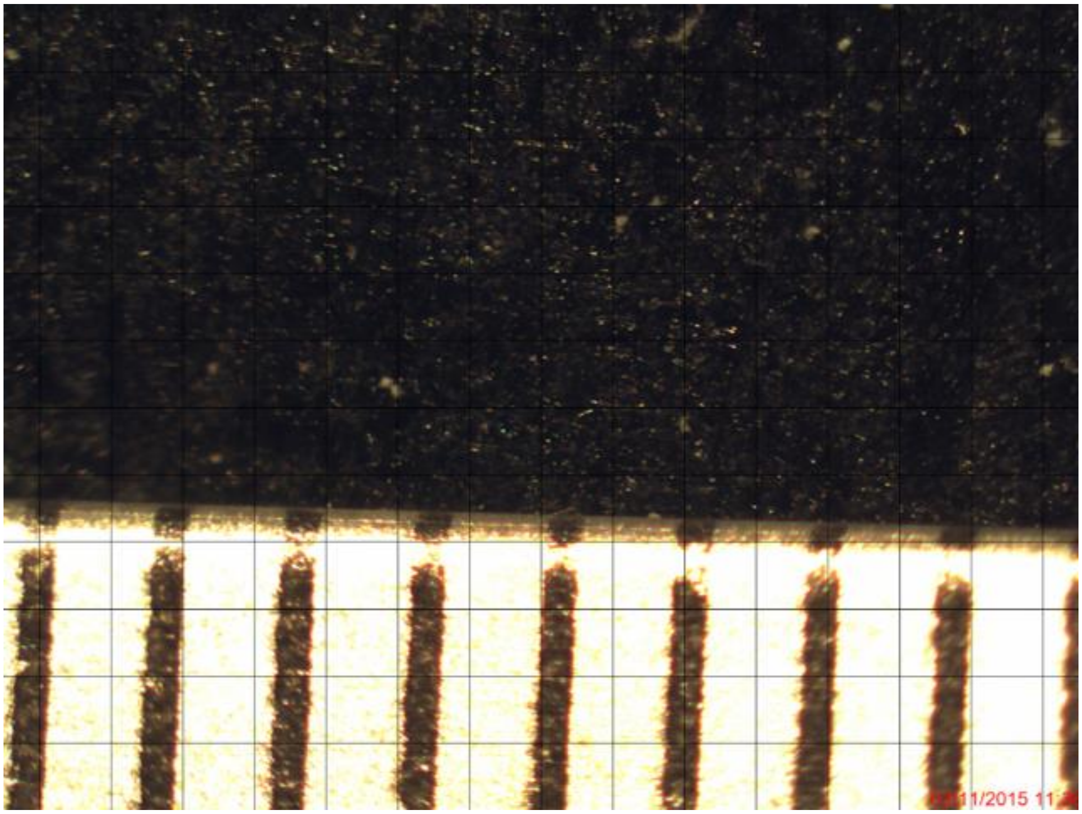

Figure 32 : Microscopic image at 10 feet for fan speed 1

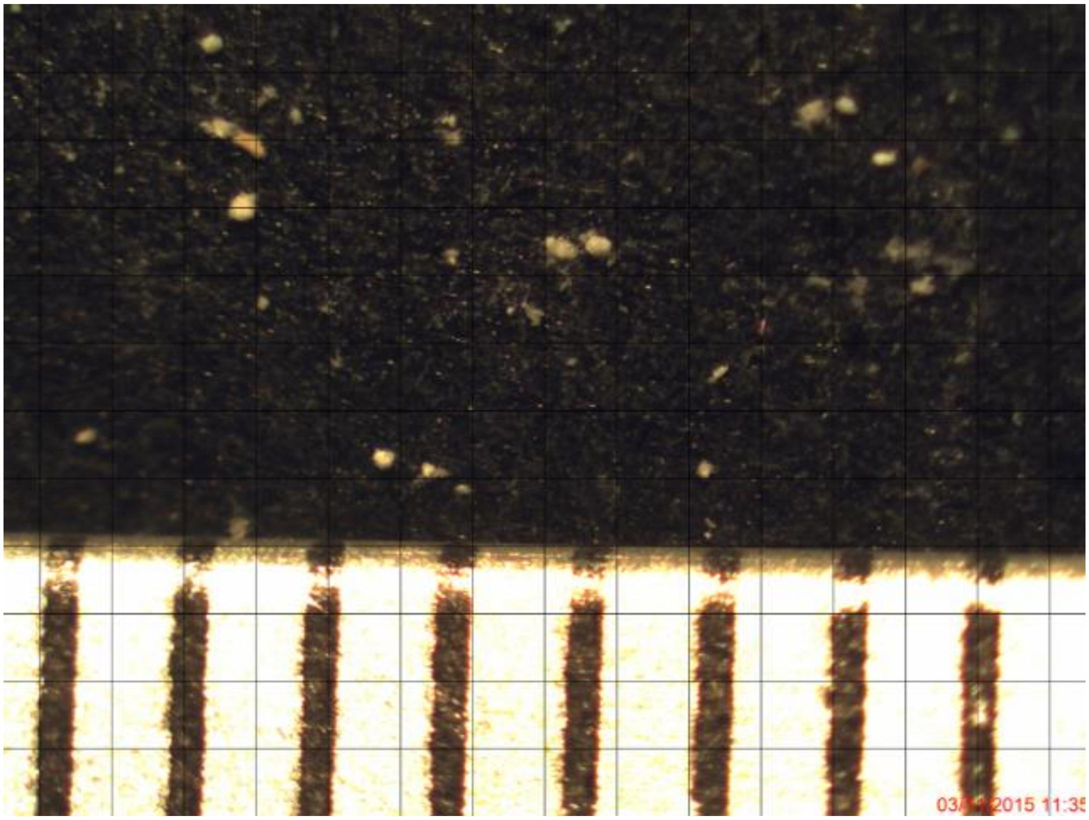

Figure 33 : Microscopic image at 14 feet for fan speed 1

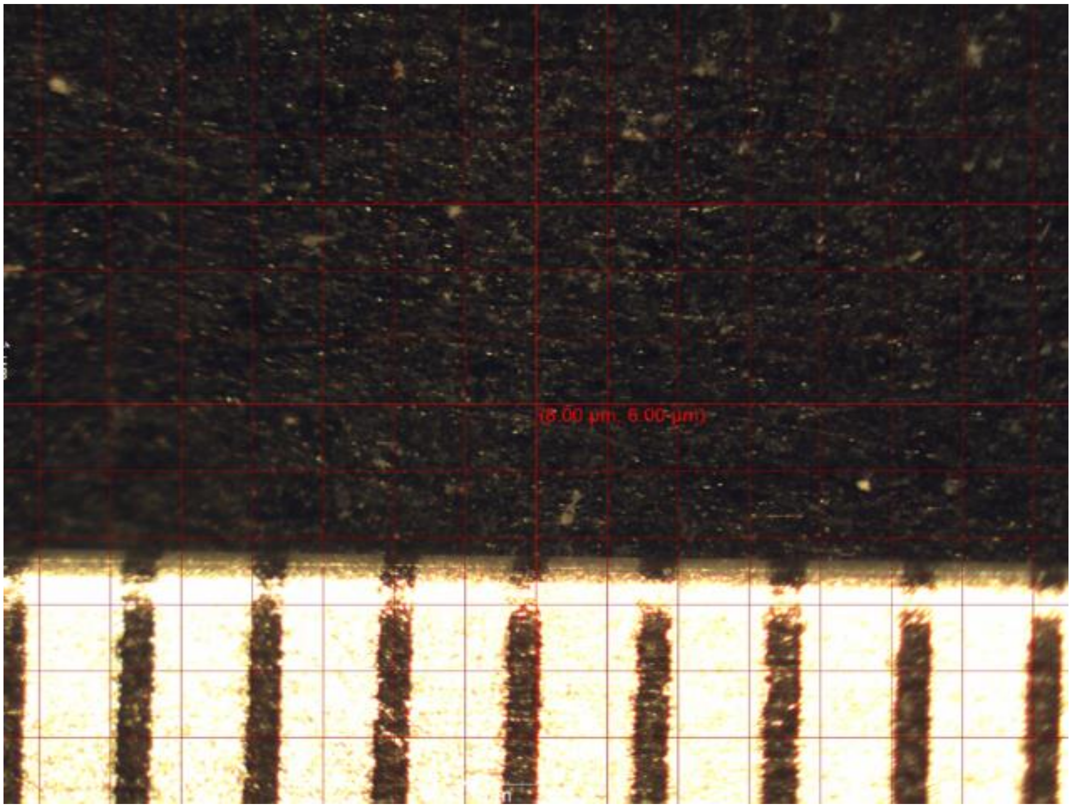

Figure 34 : Microscopic image at 18 feet for fan speed 1

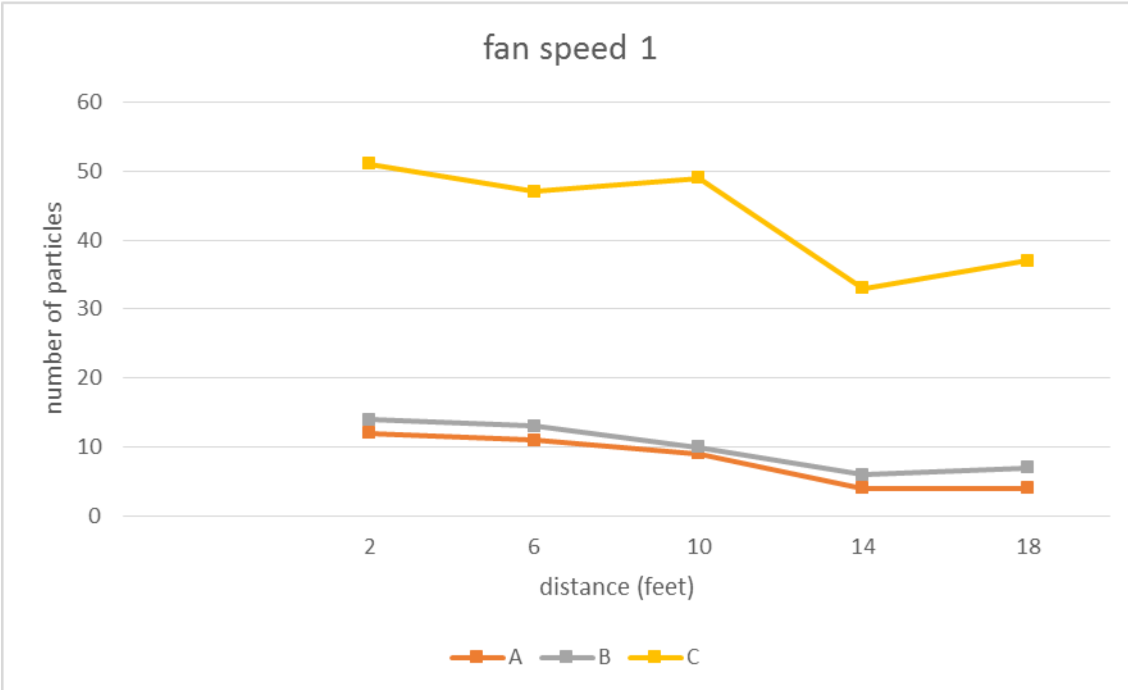

Figure 35 : Graph depicting the dust particle settlement for fan speed 1

Fan speed 1 = maximum of v11 = 2.71 m/s

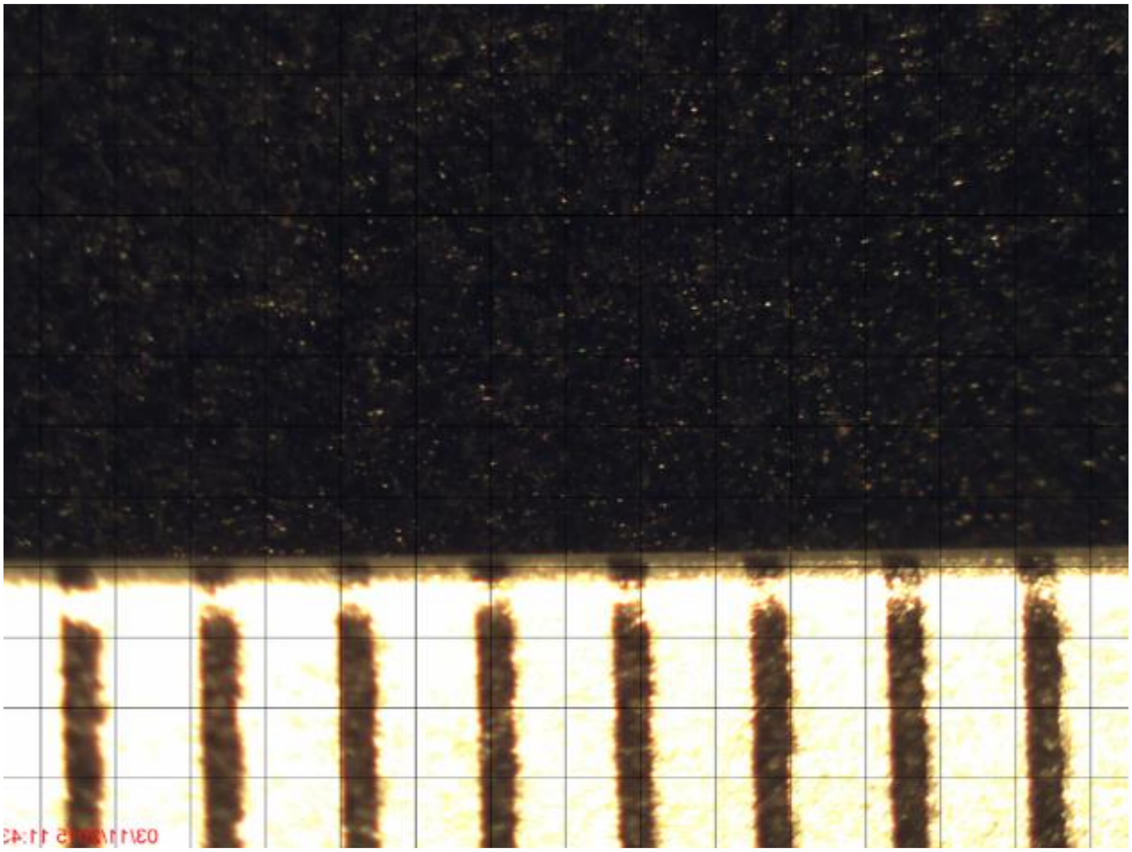

Figure 36 : Microscopic image at 2 feet for fan speed 2

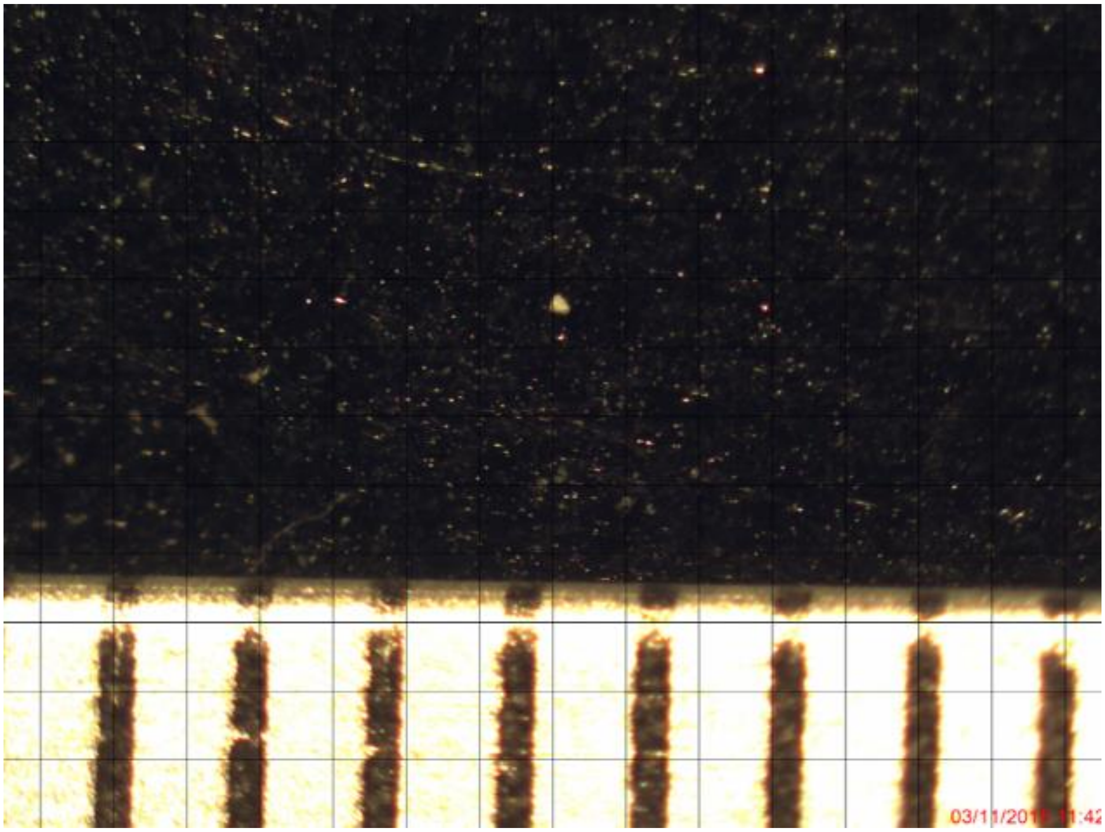

Figure 37 : Microscopic image at 6 feet for fan speed 2

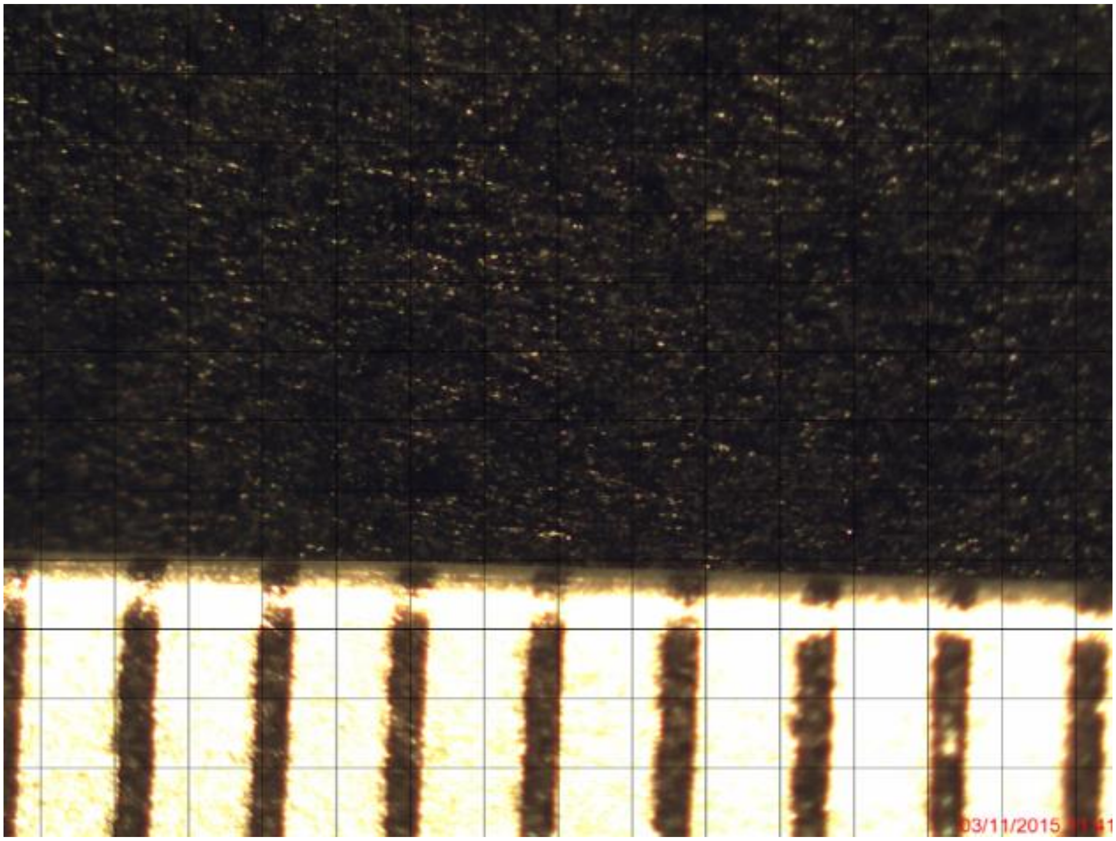

Figure 38 : Microscopic image at 10 feet for fan speed 2

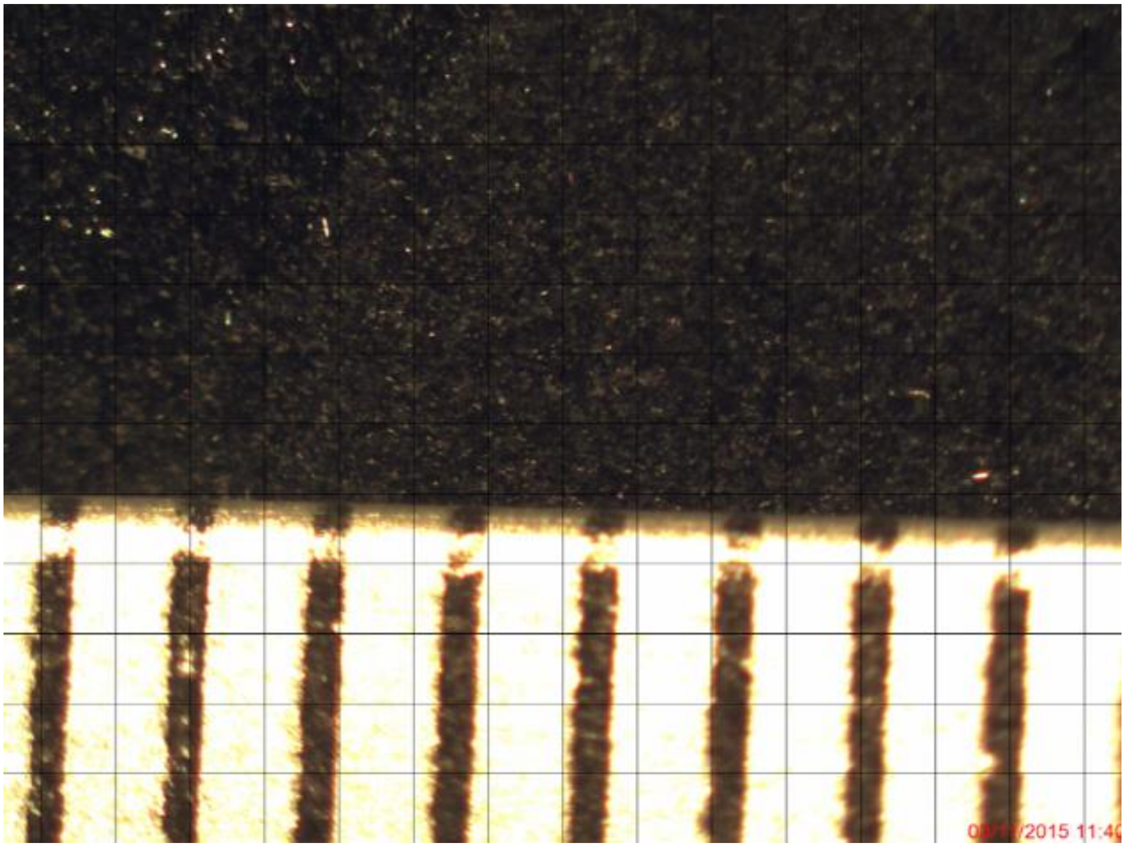

Figure 39 : Microscopic image at 14 feet for fan speed 2

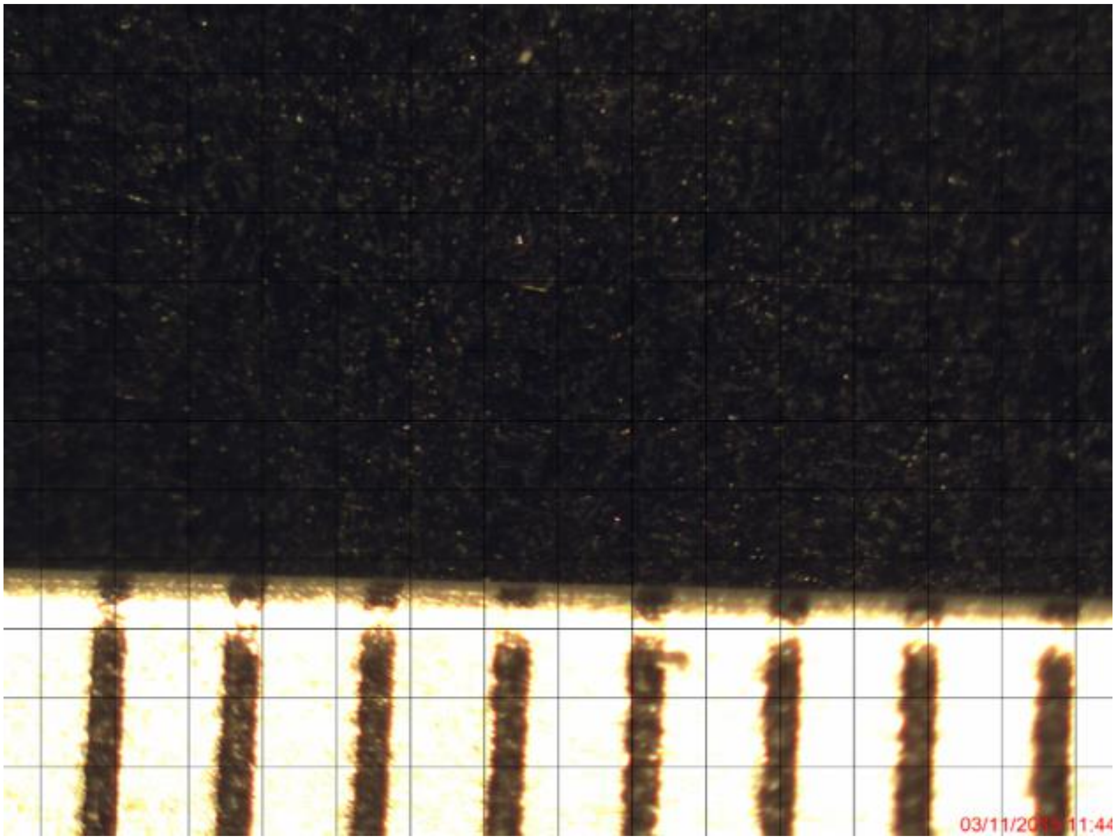

Figure 40 : Microscopic image at 18 feet for fan speed 2

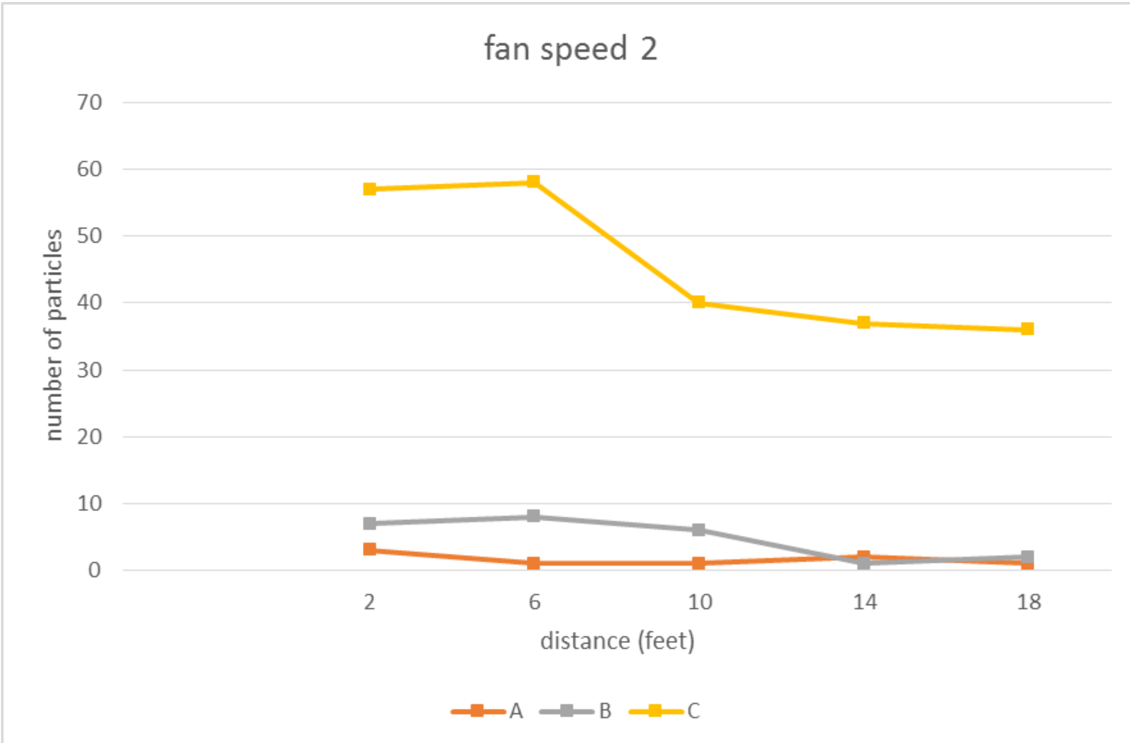

Figure 41 : Graph depicting the dust particle settlement for fan speed 2

Fan speed 2 = maximum of v21 = 3.94 m/s

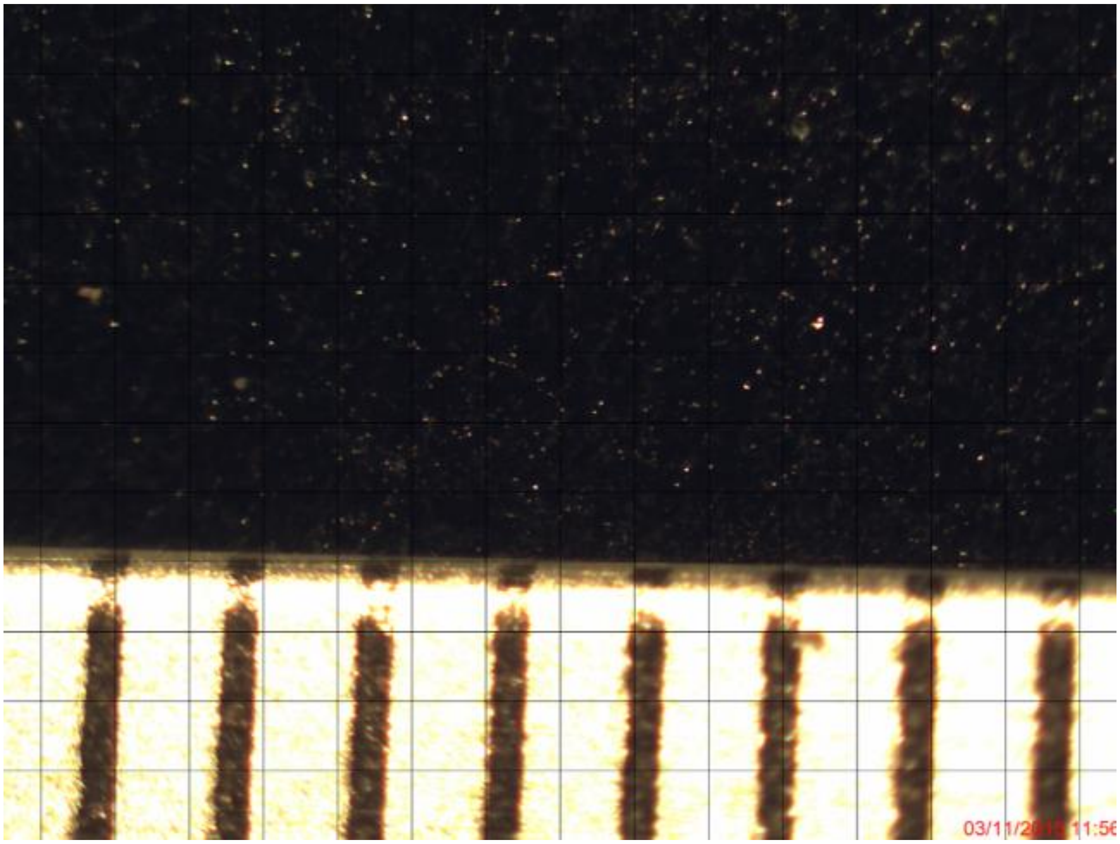

Figure 42 : Microscopic image at 2 feet for fan speed 3

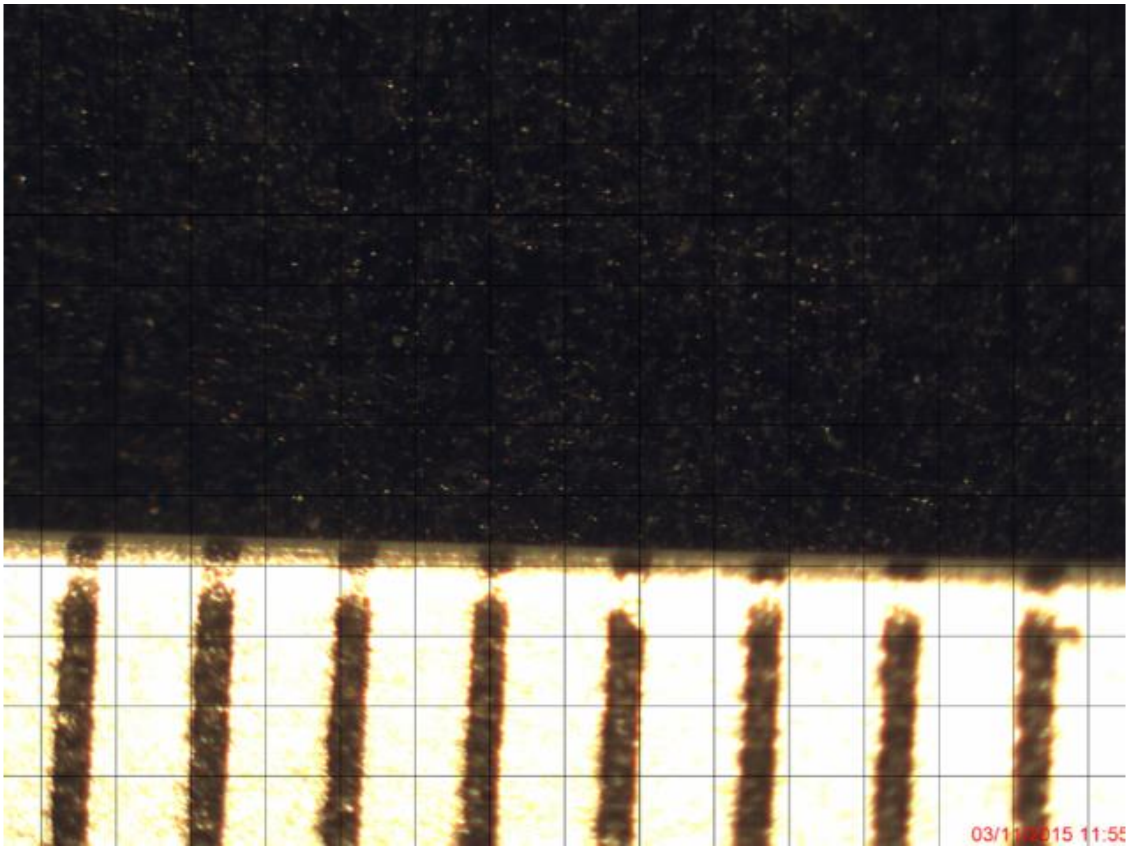

Figure 43 : Microscopic image at 6 feet for fan speed 3

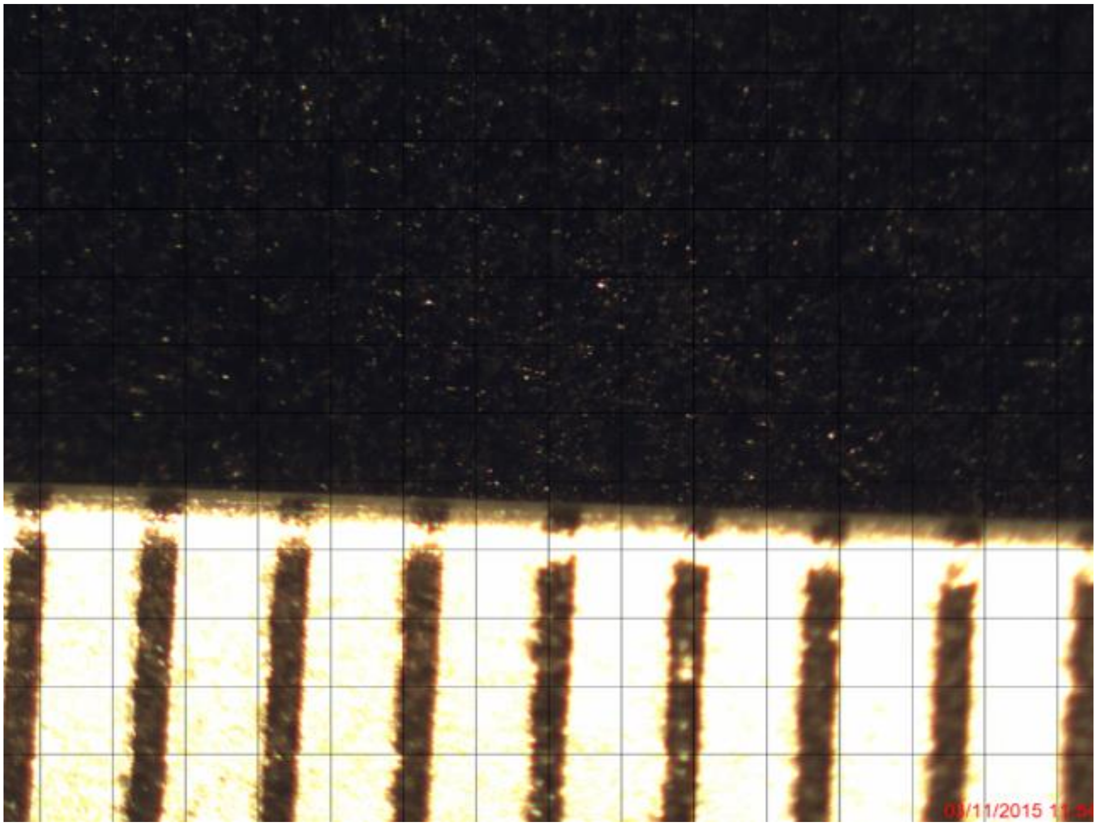

Figure 44 : Microscopic image at 10 feet for fan speed 3

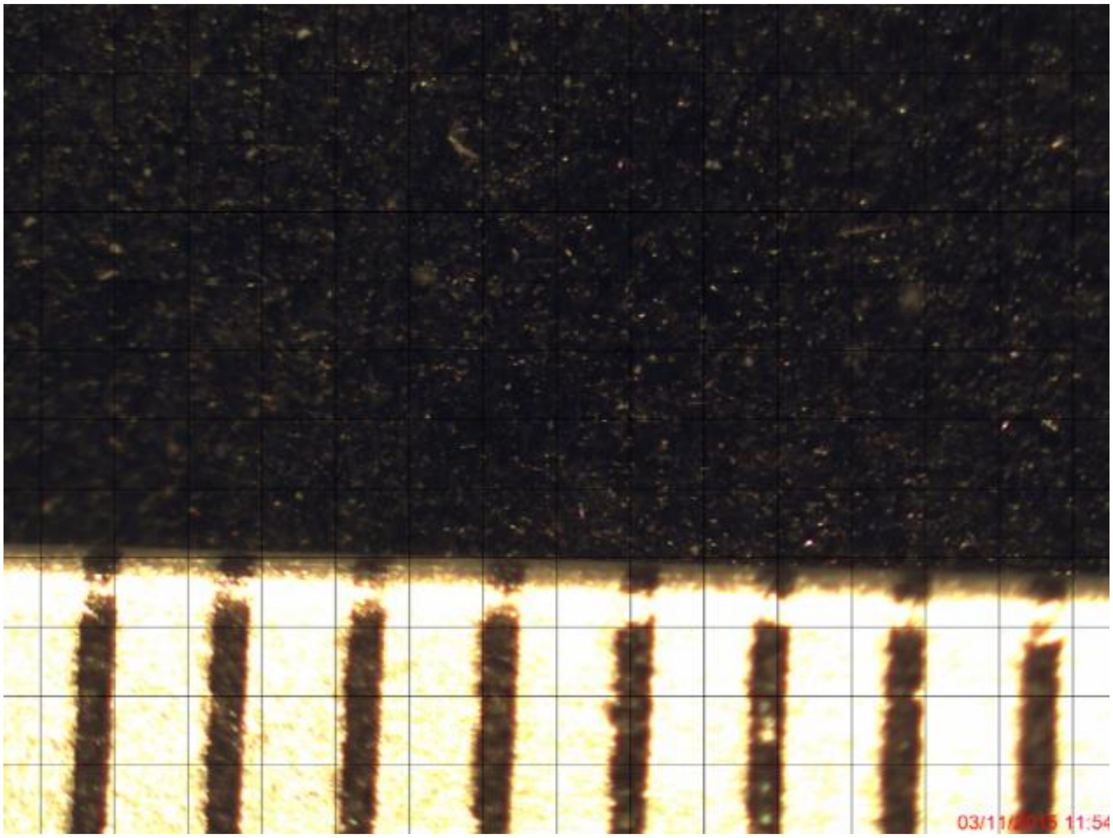

Figure 45 : Microscopic image at 14 feet for fan speed 3

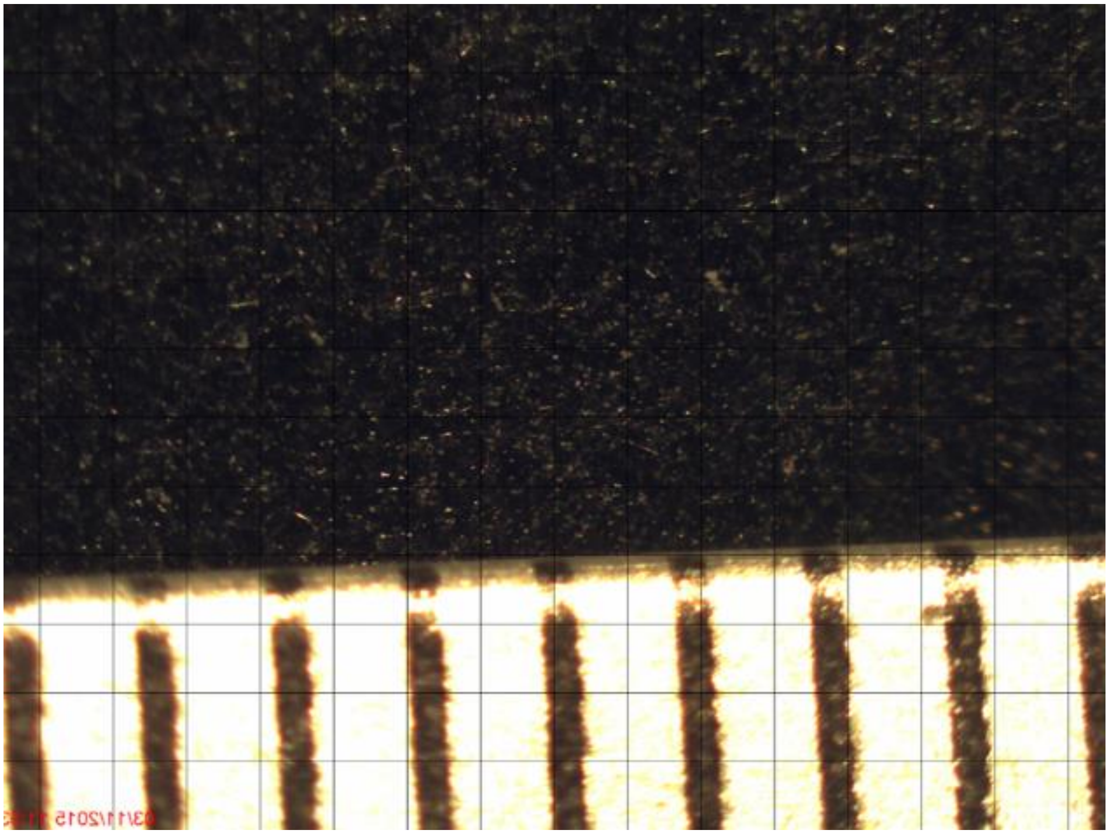

Figure 46 : Microscopic image at 18 feet for fan speed 3

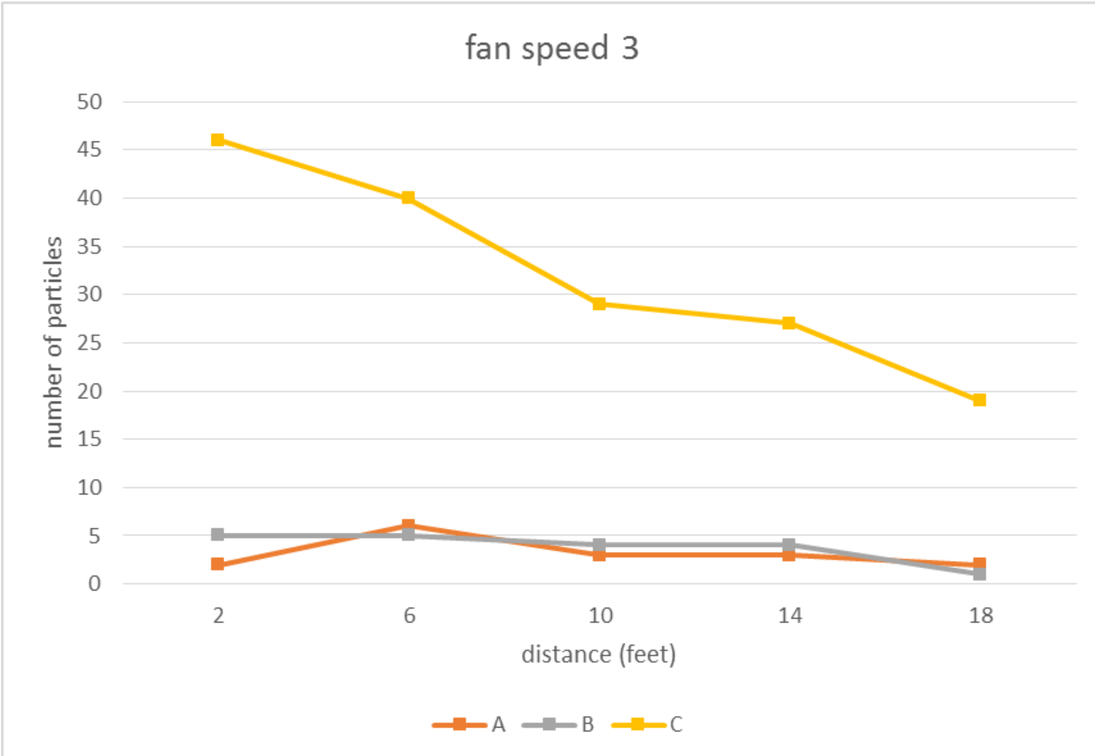

Figure 47 : Graph depicting the dust particle settlement for fan speed 3

Fan speed 3 = maximum of v31 = 5.1 m/s

Maximum air velocities for each fan speed were considered.

v1 – Maximum air velocity for fan speed 1 = 2.71 m/s

v2 – Maximum air velocity for fan speed 2 = 3.94 m/s

v3 – Maximum air velocity for fan speed 3 = 5.1 m/s

Table 3 : Classification of particles based on size – 1st iteration

	(ft.)		A	B	C	D
fan speed 1	2		12	14	51	100
	6		11	13	47	50
	10		9	10	49	40
	14		4	6	33	30
	18		4	7	37	35
fan speed 2	2		3	6	45	100
	6		2	7	56	80
	10		4	5	33	60
	14		2	2	31	35
	18		2	3	27	50
fan speed 3	2		3	2	41	70
	6		4	6	33	60
	10		0	3	25	20
	14		2	2	21	20
	18		4	3	13	10

Table 4 : Classification of particles based on size – 2nd iteration

	(ft.)		A	B	C	D
fan speed 2	2		4	9	59	100
	6		4	5	51	80
	10		3	5	41	60
	14		1	3	45	35
	18		1	0	38	50
fan speed 3	2		2	5	46	70
	6		6	5	40	60
	10		3	4	29	20
	14		3	4	27	20
	18		2	1	19	10

Table 5 : Classification of particles based on size – 3rd iteration

	(ft.)		A	B	C	D
fan speed 2	2		3	7	57	100
	6		1	8	58	80
	10		1	6	40	60
	14		2	1	37	35
	18		1	2	36	50
fan speed 3	2		5	4	39	70
	6		4	5	42	60
	10		2	2	37	20
	14		1	1	32	20
	18		3	2	21	10

Table 6 : Distribution of size A particles across different fan speeds

Distance (ft.)	Air Speed (m/s)	2.71	3.94	5.1
2		12	3	2
6		11	1	6
10		9	1	3
14		4	2	3
18		4	1	2

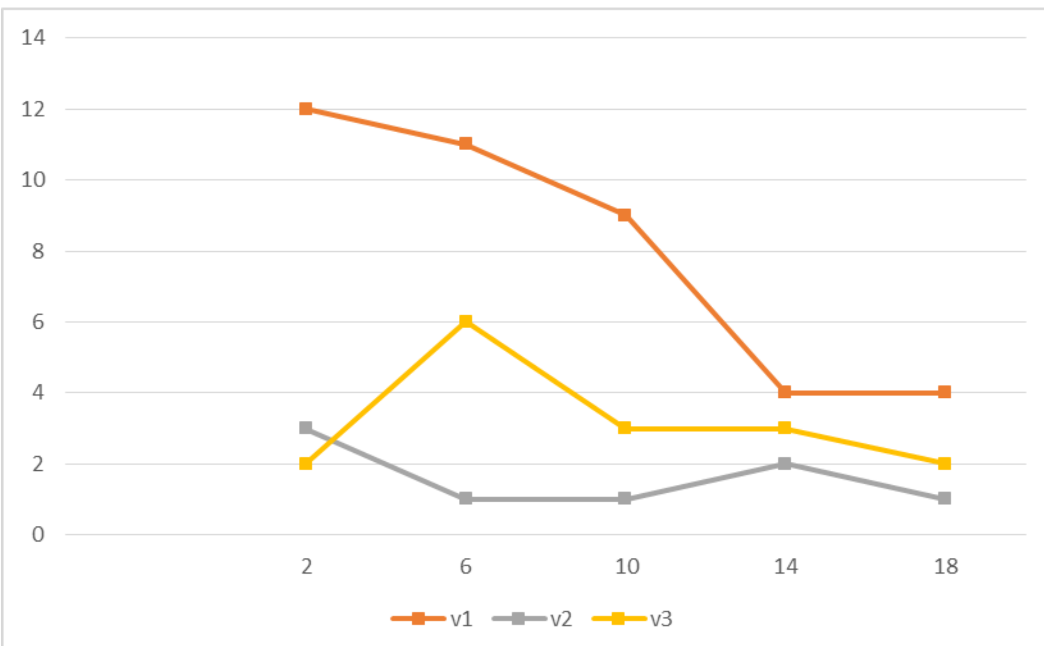

Figure 48 : Depiction of the distribution of size A particles across different fan speeds

Table 7 : Distribution of size B particles across different fan speeds

Distance (ft.)	Air Speed (m/s)	2.71	3.94	5.1
2		14	7	5
6		13	8	5
10		10	6	4
14		6	1	4
18		7	2	1

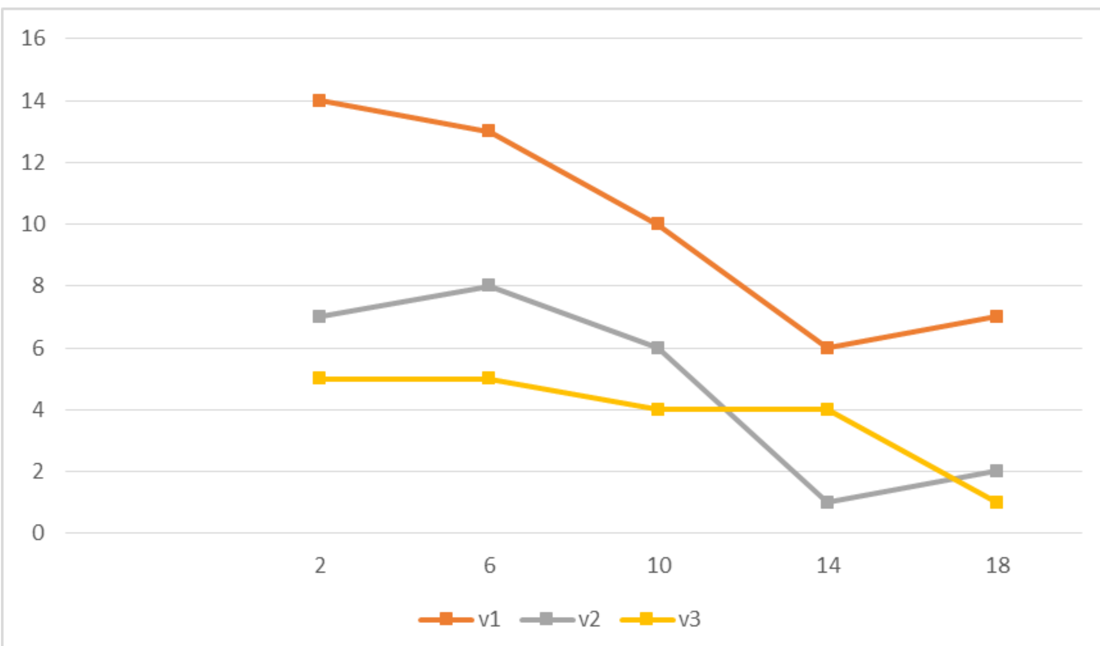

Figure 49 : Depiction of the distribution of size B particles across different fan speeds

Table 8 : Distribution of size C particles across different fan speeds

Distance (ft.)	Air Speed (m/s)	2.71	3.94	5.1
2		51	57	46
6		47	58	40
10		49	40	29
14		33	37	27
18		37	36	19

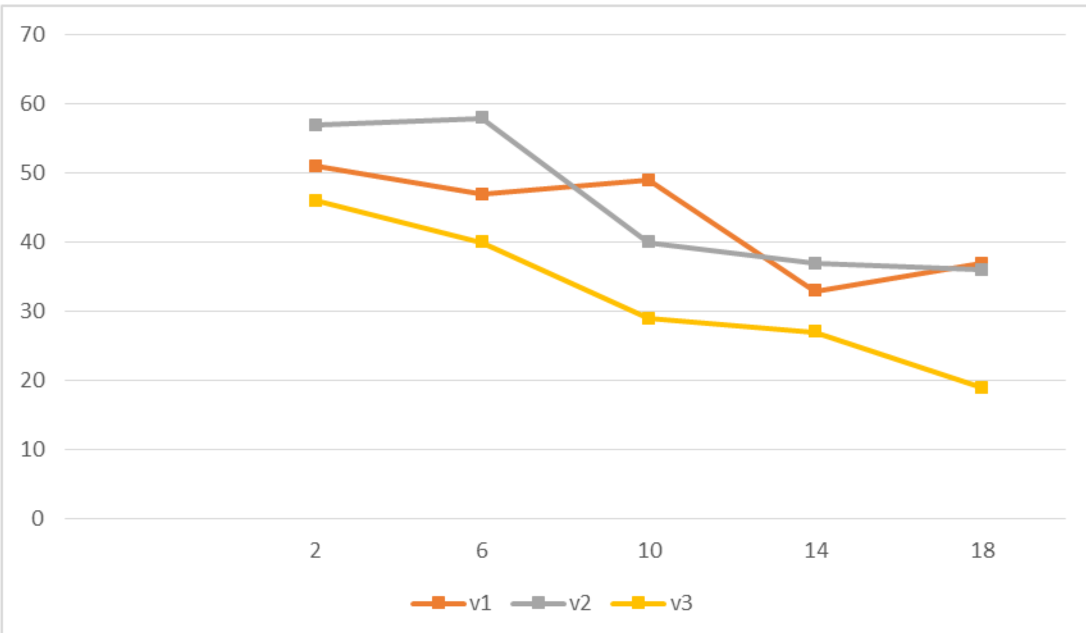

Figure 50 : Depiction of the distribution of size C particles across different fan speeds

Table 9 : Distribution of size D particles across different fan speeds

Distance	Air Speed m/s	2.71	3.94	5.1
2		100	100	70
6		50	80	60
10		40	60	20
14		30	35	20
18		35	50	10

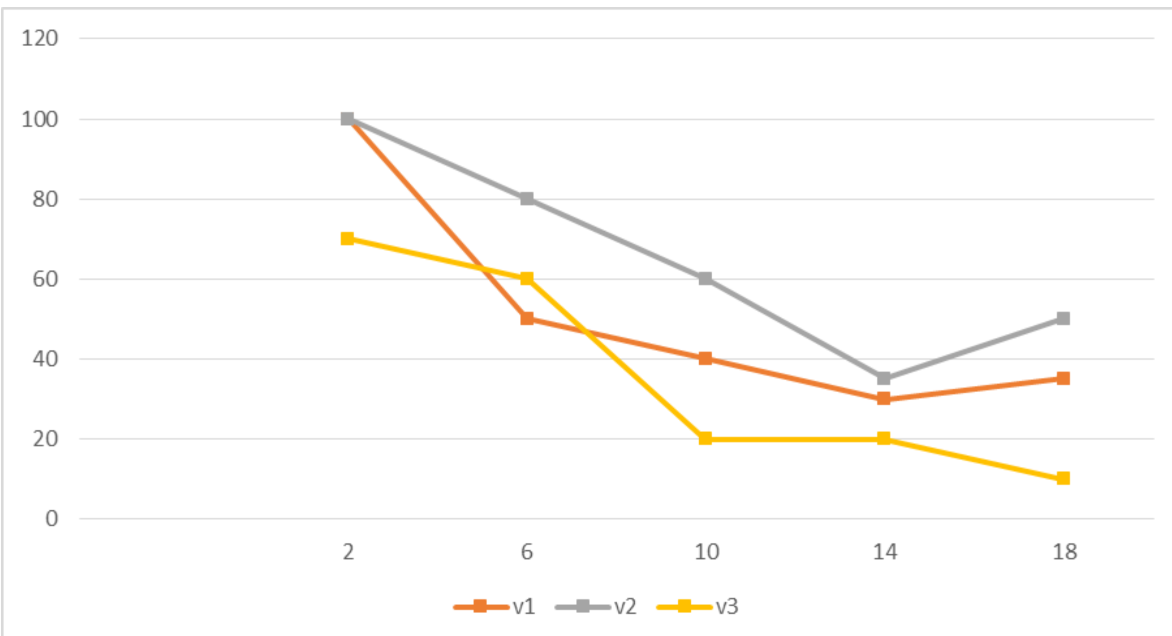

Figure 51 : Depiction of the distribution of size D particles across different fan speeds

CHAPTER V

CONCLUSIONS

This chapter outlines the analysis of the results obtained, the conclusions drawn from the analysis and the topics for future research.

The menace caused by the suspended dust particles carrying the aspergillus spores is significant. The principle motive of this study was to find out more information about these suspended dust particles and their behavior. A mock wind tunnel was created to obtain a better understanding of the behavior of the dust particles which act as disease spreading vectors.

The results show that the hypothesis is false and that settlement of dust occurs at normal velocity ranges. It also shows that this apparatus can be used to test barriers, which was not possible in the previous studies conducted.

The graphs plotted for the air velocities within the duct for different fan speeds shows that the maximum speed is obtained at roughly the center of the duct. This maximum speed is used as a reference to compare the other results.

The microscopic images of the samples taken along the duct for different fan speeds were analyzed and compared. The dust was white in color prompting the use of a black paper coated with lacquer. The number of particles were calculated and classified into size ranges. This was done to understand the behavior of the dust particles even more minutely. The trends for each size range were observed. Three different fan speeds were also introduced to get extensive knowledge with regards to the dust particles.

There is a common phenomenon associated with all the particle size ranges as indicated in the graphical representation. As the distance from the fan increases along the duct, the number of dust particles per sample area (5 mm by 5 mm) decreases. This behavior is observed for all the particle size ranges namely A, B, C and D. This commonality leads to conclude that the gradual decrease in concentration of the dust particles along the duct implies a linear regression of settlement as indicated by the graphs.

The trend of a particular size range at different air velocities was also observed. It was significantly evident from the graphs that there is lower settlement of dust particles at higher velocities. This concludes that the dust carrying capacity of the air decreases with increase in wind velocity. The linear regression of settlement for all the particle size ranges is also clearly apparent.

If a similar situation is replicated in the real world, (for example, hospitals) the precautions to be taken can be deduced. The movement of the dust particles will depend on their size and the air velocity in the surroundings. The distance of the patient from the source and the air velocity in that particular surrounding should be controlled in accordance to the findings.

Further research using similar apparatus is recommended. The dust used can be switched to, standard ASHRAE dust as it will give more accurate results with regards to dust at a construction site. A new apparatus can be constructed with the purpose of obtaining a more consistent air velocity. There needs to be more research done to identify these suspended dust particles laden with the aspergillus spores accurately and also to provide defensive measures to guard against them.

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