University of Kentucky
UKnowledge

Theses and Dissertations--Biosystems and Agricultural Engineering

Biosystems and Agricultural Engineering

2012

EVALUATION OF TRANSITIONS FOR TESTING AGRICULTURAL VENTILATION FANS WITH THE FAN ASSESSMENT NUMERATION SYSTEM (FANS)

Igor Moreira Lopes
University of Kentucky, igor.lopes@uky.edu

Click here to let us know how access to this document benefits you.

Recommended Citation
Lopes, Igor Moreira, "EVALUATION OF TRANSITIONS FOR TESTING AGRICULTURAL VENTILATION FANS WITH THE FAN ASSESSMENT NUMERATION SYSTEM (FANS)" (2012). *Theses and Dissertations--Biosystems and Agricultural Engineering*. 8.
https://uknowledge.uky.edu/bae_etds/8

This Master's Thesis is brought to you for free and open access by the Biosystems and Agricultural Engineering at UKnowledge. It has been accepted for inclusion in Theses and Dissertations--Biosystems and Agricultural Engineering by an authorized administrator of UKnowledge. For more information, please contact UKnowledge@lsv.uky.edu.

STUDENT AGREEMENT:

I represent that my thesis or dissertation and abstract are my original work. Proper attribution has been given to all outside sources. I understand that I am solely responsible for obtaining any needed copyright permissions. I have obtained and attached hereto needed written permission statements(s) from the owner(s) of each third-party copyrighted matter to be included in my work, allowing electronic distribution (if such use is not permitted by the fair use doctrine).

I hereby grant to The University of Kentucky and its agents the non-exclusive license to archive and make accessible my work in whole or in part in all forms of media, now or hereafter known. I agree that the document mentioned above may be made available immediately for worldwide access unless a preapproved embargo applies.

I retain all other ownership rights to the copyright of my work. I also retain the right to use in future works (such as articles or books) all or part of my work. I understand that I am free to register the copyright to my work.

REVIEW, APPROVAL AND ACCEPTANCE

The document mentioned above has been reviewed and accepted by the student's advisor, on behalf of the advisory committee, and by the Director of Graduate Studies (DGS), on behalf of the program; we verify that this is the final, approved version of the student's dissertation including all changes required by the advisory committee. The undersigned agree to abide by the statements above.

Igor Moreira Lopes, Student

Dr. Douglas G. Overhults, Major Professor

Dr. Dwayne Edwards, Director of Graduate Studies

EVALUATION OF TRANSITIONS

FOR TESTING AGRICULTURAL VENTILATION FANS

WITH THE FAN ASSESSMENT NUMERATION SYSTEM (FANS)

THESIS

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Biosystems and Agricultural Engineering in the College of Agriculture at the University of Kentucky

By

Igor Moreira Lopes

Lexington, Kentucky

Co-Directors: Dr. Douglas G. Overhults, Extension Professor of Biosystems and Agricultural Engineering

and Dr. George B. Day, Adjunct Instructor of Biosystems and Agricultural Engineering

Lexington, Kentucky

2012

Copyright© Igor Moreira Lopes 2012

ABSTRACT OF THESIS

EVALUATION OF TRANSITIONS
FOR TESTING AGRICULTURAL VENTILATION FANS
WITH THE FAN ASSESSMENT NUMERATION SYSTEM (FANS)

The Fan Assessment Numeration System (FANS) is an improved air velocity traverse method for measuring *in situ* fan performance. The FANS has been widely used, but variations of its test procedure are commonly employed to accommodate physical or operational barriers encountered in the field. This laboratory study evaluated the use of transitions to connect a 1.37m FANS unit to two smaller fans (1.22m and 0.91m diameter) and one 1.37m diameter fan. Tests were conducted with the FANS unit positioned on both intake and discharge sides of the fans. Three different transition angles (30^{o}, 45^{o} and 60^{o}) and the use of no transition were evaluated. Discharge tests were also performed with no enclosed connection between FANS and fan housings. A different experiment was conducted for each fan size. Data was analyzed by comparing test results to the control with Dunnett's procedure. Results showed significant differences as much as 5.3% ± 1.20% for intake treatments, 17.2% ± 3.04% for sealed discharge treatments and 37.1% ± 12.24% for discharge treatments with no enclosed connection. All transition angles produced similar fan test results. Differences between test results from the discharge and control treatments increased as differences between FANS and fan dimensions increased.

KEYWORDS: Fan Assessment Numeration System (FANS), Fan testing, Ventilation rate, Fan performance, Wind tunnel

Igor Moreira Lopes

07/01/2012

EVALUATION OF TRANSITIONS

FOR TESTING AGRICULTURAL VENTILATION FANS

WITH THE FAN ASSESSMENT NUMERATION SYSTEM (FANS)

By

Igor Moreira Lopes

Douglas G Overhults

Co-Director of Thesis

George B. Day

Co-Director of Thesis

Dwayne Edwards

Director of Graduate Studies

07/01/2012

For my father and mother, thank you for always believing in me.

ACKNOWLEDGMENTS

This work would not be possible without the help, encouragement and company of many important people. I wish to thank Dr. Overhults, this thesis co-Chair, not only for his guidance on my Masters program but also for his friendship. Dr. Overhults attention and dedication towards this project is much appreciated. Dr. Overhults and his wife, Elaine, welcomed me in the United States and made me feel at home.

I wish to thank Dr. Day, co-Chair of this thesis, for his advice, thoughts and hard work throughout the whole process, especially for his help, knowledge and work on the laboratory apparatus construction. Dr. Day became a friend and part of my “Lexington family”. I would like to thank Dr. Gates for sharing his work experience and ideas which were essential for the quality of this work. Dr. Gates opened the first door that made this work possible by putting me in contact with the University of Kentucky and Dr. Overhults. I would like to acknowledge Dr. Inacio dal Fabbro and Dr. Raquel Gonçalves, from State University of Campinas (UNICAMP), Brazil, for encouraging me to pursue the academic career and being with me on my first steps in this journey.

My appreciation goes to all the friends that directly or indirectly contributed to this work. I wish to thank my “Lexington family”, Mr. Rodrigo Zandonadi, Dr. Maira Pecegueiro do Amaral, Ms. Tatiana Gravena Ferreira, Dr. Enrique Alves, Dr. Guilherme Del Nero Maia, Dr. Joe Luck, Mr. Lucas de Melo and Ms. Ester Buiate, who helped me with my personal life and work. The great moments shared with these people will always be joyfully remembered. I wish to acknowledge Flavio Damasceno for his hard work and friendship. Flavio not only helped with this research project but also made the work environment cheerful and positive. I would like to thank the Biosystems and Agricultural Engineering community for the friendship and for providing and great work environment and for welcoming me at the University of Kentucky.

Special thanks go to my family for always believing and encouraging me to follow my dreams. I wish to thank my father, Geraldo Magela Lopes and my mother, Gloria Lage Moreira Lopes for their support, friendship and love throughout my life. I wish to extend my appreciation to my sister, Xenia Moreira Lopes for always being my best friend. I would like to thank Ms. Gabriela Morello for her love, care and support. Gabriela's commitment and dedication in her life and work has always served as an inspiration and motivation to seek excellence.

Finally, I would like to thank the University of Kentucky, the College of Agriculture and the College of Engineering for the opportunity and for financial support of my project. I wish to thank Paula Underwood from GlassPac Kentucky for letting us borrow ventilation fans. I would like to acknowledge the Agricultural Engineering department (FEAGRI) at the State University of Campinas (UNICAMP), Brazil, where I had the privilege to study and where I developed the interest in research and the Biosystems and Agricultural department in University of Kentucky for the great education during my Masters program.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Chapter 1. Introduction

In situ airflow measurement represents a critical part of livestock facilities assessment and researchers have used several different methods to perform such measurement. Among the techniques used for airflow measurement, the Fan Assessment Numeration System unit (FANS unit) has become a reference method of *in situ* fan performance acquisition.

The FANS unit was originally developed at the United States Department of Agriculture – Agriculture Research Service (USDA-ARS), Southern Poultry Research Laboratory by (Simmons et al. (1998a)and later refined at University of Kentucky (Gates et al., 2004; Sama et al., 2008). There are currently three standard sizes of FANS units, 0.76, 1.22 and 1.37 m (30, 48 and 54 in). Each size was designed and calibrated to measure common sizes of livestock facility fans.

Researchers have used FANS units to measure fans with mismatched sizes in order to reduce the amount of equipment that has to be taken to the field or because they do not have the correct size of FANS unit available. They also have used the FANS unit on the discharge side of the fans, although the original design and calibration were for the intake side position. The use of a FANS unit that is not the same size of the fan housing, both on the intake and discharge side of the fan, may request the use of transitions in order to reduce pressure losses due to sudden convergence or divergence caused by the addition of the FANS unit.

This study focused on the evaluation of the use of transitions between the FANS unit and fan when they have different physical dimensions, on both the intake and discharge of the fan measured. Tests were conducted in a laboratory wind tunnel test chamber with the 1.22 and 1.37 m (48 and 54 in) FANS units and three different common fan sizes: 0.91, 1.22 and 1.37 m (36, 48 and 54 in). Three different transition angles were evaluated so the penalties to airflow could be minimized when compared to the original design test condition results.

1.1 Justification.

In situ ventilation fan testing allows an evaluation to be made for the operation and performance at actual operation conditions. Fans under operating conditions present different levels of maintenance, condition (blade, pulleys and belts) and cleanliness (dust and dirt on blades and shutters). Thus, it follows that the best way to determine a building ventilation rate is to actually measure the fan performance at its operation condition.

Wheeler et al. (2002) found fan manufacturer data 2% to 13% higher than actual field performance. Casey et al. (2008) reported up to 24% variation on ventilation performance of otherwise identical fans. The variation was attributed to accumulated dirt and corrosion, difference in the resistance imposed by shutters and differences in motor and bearing wear due to run time and aging.

Accurate ventilation measurement plays an important role in calculating emission rates from livestock buildings. Gates et al. (2009) estimated that ventilation uncertainty contributed 78% and 98.9% of emission rate uncertainty for a 5% and 25% standard uncertainty in fan ventilation rate measurement. The correct use of a ventilation measurement device is, therefore, essential to a more accurate emission rate determination.

Over the past decade the FANS device has been successfully implemented across the United States (Sama et al., 2008). Several studies have been conducted in order to evaluate the FANS device and its use. Wheeler et al. (2002) determined the FANS procedure repeatability in the field to be about 1% between two traverse readings performed one after the other and that some evidence of decreased performance was present when operating with other fans versus when operating alone. Casey et al. (2007) investigated fan performance impacts attributed to the FANS unit use and reported the device to be very repeatable, indicating that multiple repetitions of a single measurement are not necessary. It was also reported that there was no significant penalty when testing 1.22m diameter fans of less than $34{,}000 m^3 h^{-1}$, nor when testing

0.915m diameter fans. A 2% average penalty was encountered for a high flow 1.22m fan.

The device has been used in a wide variety of facilities and each facility type may present different obstacles when using the FANS. Researchers have also been studying different test setups from the original design in order to ease or in many cases allow use of the device where physical limitations prevent its use in a conventional test setup. Li et al. (2009) tested the FANS unit positioned downstream from the test fan (discharge side) versus the original design test condition (upstream). The study was conducted at a farm and concluded that the FANS device, although originally designed for upstream placement, may be used downstream of a ventilation fan for *in situ* calibration. The results of the study revealed 0.6%±0.4% to 4.0%±0.9% higher airflow rate for 1.22 and 1.32m diameter fans. Morello (2011) reported no significant difference in test results from the intake versus the discharge positioning of the FANS unit.

Simmons et al. (1998b) investigated the minimum distance between ventilation fans in adjacent walls of tunnel ventilated broiler houses. Simmons concluded that, in order to avoid detrimental effects to measured volumetric flow rate, fans should be at a distance greater than 0.3m from each other. Morello (2011) reported differences of up to 12.6±4.4% depending on adjacent fans operation.

The use of the FANS device to test fans with sizes different from the original designed use were also conducted. Wheeler et al. (2002) reported a 2.5% difference between results for a 0.915m diameter fan when tested with and without transition between the fan and the FANS under field conditions. These tests also indicated the importance of taping all gaps between the FANS and the test fan since it resulted in differences of up to 6% in airflow measurements. Casey et al. (2007) reported the use of a transition to a 0.45m diameter fan resulted in approximately 0.27% of the actual airflow difference (below the measurement accuracy of the FANS unit).

The literature reviewed suggests that further investigation into the effects of transitions to smaller fans than the FANS device may be beneficial. A better understanding of these effects will contribute to a proposal of a standard transition procedure to be used by researchers in the future.

1.2 Objectives.

This study aimed to evaluate the use of transitions and extensions to allow the 1.37m (54”) FANS unit to be used to test fans of different sizes on both the intake and discharge sides of the test fans. The overall goal is to obtain a better understanding of transition and test position effects. Results should contribute to future standardization of transitions and procedures for testing different fan sizes.

1.2.1 Specific Objectives

Evaluate the use of the 1.37m FANS unit to perform the following:

1) A 0.91m diameter fan calibration on both the intake and discharge side of the fan and the effects with and without a transition.

2) A 1.22m diameter fan calibration on both the intake and discharge side of the fan and the effects with and without a transition.

3) A 1.37m diameter fan calibration on both the intake and discharge side of the fan and the effects of an extension.

Copyright© Igor Moreira Lopes 2012

Chapter 2. Literature review

Mechanical ventilation systems that employ fans for air exchange represent an advantage for the air exchange measurement when compared to natural ventilation systems (Wheeler et al., 2002). The existence of a controlled ventilation system offers the possibility of measuring the fan performance and fan operation rate, resulting in an estimate of the ventilation rate. Ventilation rate in animal houses is a key parameter for environmental control in intensive livestock production (Calvet et al., 2010). Scientific measurements by definition have a degree of uncertainty associated with them which provides the reader with an idea of the error in that particular measurement. Ventilation rate uncertainty is reported to account for as much as 78% to 98.9% of emission rate uncertainty (when using photoacoustic gas concentration instruments with 1% of reading accuracy) for a 5% and 25% standard uncertainty in a ventilation rate measurement (Gates et al., 2009). Therefore, the use of an accurate method of airflow measurement is critical in emission rate studies.

Fan performance can drastically change as it operates in farm conditions. Casey et al. (2008) reported the ventilation performance of otherwise identical fans was shown to vary by up to 24%. The variation was related to dirt and corrosion, differences caused by shutters, motor maintenance and belt and pulley conditions. Bottcher et al. (1996) measured fan rotation speed and reported differences in the measured fan speeds of up to 4% for fans up to five years in age. Janni et al. (2005) measured 1.22m belt driven fans with the FANS unit and reported readings between 58% to 67% below airflow rates published by an independent laboratory for similar units operating at typical static pressures. Janni et al. (2005) also reported airflow readings from belt driven fans with dirty shutters, belt slippage and reduced drive shaft speed to be 18 to 38% lower than the same fans with tighter belts and fan speed levels at laboratory test conditions. Calvet et al. (2010) reported the uncertainty associated with measurement of airflow rate between 6 to 8% in small fans (0.68m diameter) and 12 to 14% in large fans (1.28m diameter). They also reported 11% and 16% lower ventilation rates than those reported by the manufacturer for large fans and small fans, respectively. The variability between fans of the same type was 8.2% of the average value for larger fans and 7.3% for the smaller fans.

2.1 Airflow measurement techniques.

The only reliable way to determine the air exchange rate of an existing building is to measure it (ASHRAE, 2009a). Casey et al. (2006) stated there are, basically, three methods that can be used for determining building ventilation rates. One method is the use of the FANS unit. The device is a motorized anemometer array developed by Simmons et al. (1998) and further developed and upgraded by Gates et al. (2004) and Sama et al. (2008). The second method uses heat production data and the relation to animal carbon dioxide (CO_2) production. The third method is the measurement of building static pressure and the use of fan manufacturer's performance data. One should also consider the traverse test, from which the FANS unit is derived and the use of a tracer gas (ASHRAE, 2009a).

2.1.1 Indirect measurement.

Any airflow or ventilation rate measurement that does not directly measure the airflow moved in a system is defined as indirect measurement. Three examples of indirect measurement methods include a) the use of a tracer gas, b) balance methods and c) static pressure measurement combined with manufacturer's fan performance data. Indirect methods to reasonably assess barn ventilation rate are particularly attractive when dealing with naturally ventilated barns or mechanically ventilated barns with many ventilation fans (Xin et al., 2009).

2.1.1.1 Balance methods.

The balance methods for ventilation rate determination are based on the same theory as the tracer method and use naturally occurring metabolic gases/heat. Therefore, these balance methods depend on literature values for the rates of production of the particular monitored gas/heat. The balance method depends on the reliability of the metabolic rate data of the animals (Xin et al., 2009). Equation 2-1 is used on the balance method calculation.

$$V\left(\frac{dC}{d\theta}\right) = F(\theta) - Q(\theta)C(\theta) \qquad \textit{Equation 2-1}$$

Where,

Θ = time variable;

V = building volume;

C(θ) = gas concentration at time θ;

F(θ) = gas injection rate at time θ;

Q(θ) = airflow rate out of building at time θ;

$\frac{dC}{d\theta}$ = time rate of change of concentration;

Groot Koerkamp et al. (1998) studied concentrations and emissions of ammonia in livestock buildings in Northern Europe. Carbon dioxide concentrations were measured at seven sampling points in the house and one point outside. Ventilation rates were than calculated by means of a computer program called “STALKL”. It used the heat and respiratory carbon dioxide balance to perform the calculations.

Pedersen et al. (1998) compared balance methods for calculating ventilation rates in livestock buildings. The three methods for the calculation of the ventilation rate in Northern Europe were the balances of animal heat, moisture and carbon dioxide. Both heat and moisture balances were reported to need improvement by including a correction for evaporation of water from fresh food, feces and urine, and by adjusting the equations for partitioning total heat into sensible and latent heat.

The tracer gas method is a type of balance method which does not depend on metabolic rate of animals. There are several tracer gas measurement procedures. All procedures involve an inert or nonreactive gas used to label the indoor air. The tracer is released into the building in a specified manner and the concentration of the tracer in the building is monitored and related to the ventilation rate (ASHRAE, 2009a). The tracer gas method is based on a mass balance within the building (Equation 2-1)

ASHRAE (2009) describes three different tracer gas procedures:

1) Decay or growth: simplest technique. An amount of tracer gas is injected into a space and the decay/growth of the gas concentration is periodically measured.

2) Constant concentration: tracer gas is injected at a rate to keep concentration in the space constant.

3) Constant injection: tracer gas is injected at constant rate.

The tracer gas method assumes that the gas is uniformly distributed (well mixed) in the space, tracer gas is removed only through airflow building outlets (no absorption or chemical removal) and there is no unknown source of tracer gas. Applications of tracer gases in production facilities are often limited because the process requires uniform air-tracer mixing to ensure good results, which is difficult to achieve in commercial production settings (Xin et al., 2009)

2.1.2 Direct airflow measurement.

A wide range of instruments, such as Pitot tubes, hot wire anemometers and fan wheel anemometers, can be used to monitor the airflow through ventilation ducts and fans (Demmers et al. 1999). stated that direct measurement of volumetric ventilation rate through ducts is robust at a relatively low cost. Both wheel anemometers and tracer gas methods were compared. The tracer gas method underestimated the ventilation rate of a piggery and a broiler house by about 12 and 6%, respectively, compared with the ventilation rate measured using the direct approach.

Simmons et al. (1998a) briefly described an equal-area traverse method. The method consists of taking an extensive series of velocity (or velocity pressure) readings at specific locations across the discharge of the fan. The procedure involves 24 readings for a round duct and 32 readings for a square duct. The procedure is described as time consuming, tedious and to produce erratic and questionable results. The same method is also described by ASHRAE, 2009b. Problems were reported such as the technician obtaining the data causing physical interference with the airflow and the necessity of a mental averaging on a time weighted basis given that the flow at the traverse plane is never strictly steady. Common hand-held instruments to perform this test include hot-wire anemometer and manometers with Pitot tubes. The volumetric airflow is determined by multiplying the averaged air velocity for the traverse plane by the area of the plane.

Calvet et al. (2010) studied the measurement system for ventilation rates in mechanically ventilated commercial poultry buildings in Southern Europe. The exhaust air was ducted 0.5m from the fan and the air velocity was measured at 24 different locations across the section.

2.1.3 FANS unit.

Simmons et al. (1998a) originally designed what was called a portable anemometer to determine in-place ventilation fans performance at poultry houses. It was proposed that the poultry industry could benefit from a rapid, efficient method to accurately determine the total volumetric flow rate of a large ventilation fan at operational conditions. The device was designed to determine the volumetric flow of 1.22m (48”) ventilation fans. The device was tested and it was determined to be accurate to within 1% when used with a 1.22m fan. The use of the device for a 0.91m (36”) fan measurement was assumed to be accurate as well. The procedure could be related to an automated traverse method.

Gates et al. (2004) refined the device as part of a project for quantifying building emissions from mechanically ventilated poultry and livestock facilities. Described as the Fan Assessment Numeration System (FANS), the device design and fabrication were described.

Sama et al. (2008) documented further scaling and upgrades of the FANS unit. In addition to the existing 1.22m (48”) FANS unit, a 0.76m (30”) and 1.37m (54”) devices were designed and built. The new version also included the possibility of measuring the differential static pressure with the unit itself (sensor included at the FANS) reducing the number of instruments necessary to perform a fan performance test.

The FANS unit represented a step forward in the *in situ* volumetric rate measurement of ventilation fans. The device resulted in better accuracy, reduced test time and better repeatability when compared to the direct airflow measurement on which its development was based on. The FANS unit has been constantly used by researchers, especially for the livestock facilities ventilation rate determination for animal production emission problems. Lim et al. (2010) reported that after recalibration, eight FANS (1.22m and 1.37m)showed very low drift with differences between the new and actual airflow measurements values ranging from -1.94% to 2.58%.

Li et al. (2005) compared direct vs indirect ventilation rate determinations in layer barns. The methods used were CO_2 balance and the FANS unit (indirect and direct respectively). Results showed that indirect method result were not statistically different to the FANS method, when the averaging and or integration time was 2 hours or longer. The indirect method however, depended on reliable and updated metabolic hate data of the birds.

Pescatore et al. (2005) studied ammonia emission from broiler houses. The FANS unit was used to determine the fan capacity *in situ* in order to determine the emission rate values for the broiler houses.

Wheeler et al. (2006) described a multi-state, multi-disciplinary project for development of a database of ammonia emissions from US poultry facilities. Twelve broiler houses in Kentucky and Pennsylvania were tested. The FANS unit was used to determine the fan airflow rates for the study.

Burns et al. (2008) determined ventilation rates by monitoring building static pressure and operational status of ventilation fans combined with individual performance curves developed by *in situ* testing with the FANS unit. The ventilation rate was used in the quantification of particulate emissions from broiler houses in the southeastern United States.

Wheeler et al. (2008) studied ammonia emissions from USA broiler chicken houses with three different litter management technique (new bedding, built-up litter and acid-treated litter). The ventilation rate in the study was determined with the use of the FANS unit on the intake side of the fan with sealed gaps. The fan testing was performed for six static pressure values varying from 0 to 50 Pa.

Topper et al. (2008) measured ammonia emissions from two empty broiler houses with built-up litter. The ventilation rate was determined with the use of the FANS unit to determine fan performance at several different static pressure values.

Burns et al. (2008b) measured greenhouse gases emission from broiler houses. The FANS unit was used to perform *in situ* fan calibration. The fan performance information was combined with static pressure and operational status of all fans to perform the greenhouse emission rate determination.

Casey et al. (2010) studied three different technologies for ammonia emission measurements in broiler houses. The FANS unit was used to obtain the fan performance used to calculate the emission rate. It was reported substantial variation among otherwise identical fans and an airflow overestimation when using manufacturer's data (13.6%-26.8%).

2.1.3.1 FANS characteristics.

The FANS unit (Figure 2-1) utilizes a row of propeller anemometers, which traverse the inlet, to generate an *in situ* velocity profile of a ventilation fan (Sama et al., 2008).

Figure 2-1 – FANS unit; a) interface panel, b) anemometer array, c) electric motor, d) vertical guide rail

The main components of the FANS unit are:

a) Interface panel: location for connection of power, communication cord and building static pressure. Manual override controls and power are also located at the interface panel.

b) Anemometer array: straight aluminum bar with five or six (1.22m and 1.37m FANS respectively) propeller anemometers mechanically fastened to the bar. The anemometers are maintained parallel to the ground. The spacing center to center of the anemometers is also kept constant.

c) Driving force: electric motor that operates the lead screws moving the array bar. There are two lead screws (one on each side), and their rotational speed is kept constant with the use of a chain that transfers the rotation from the lead screw connected to the motor to the opposite side lead screw.

d) Guide rails: the array bar travels along the guide rails which keep it parallel within the enclosure.

e) Electronics enclosure: it houses the circuit board, power supply and pressure transducer.

The FANS unit operates by moving the anemometer array vertically and recording airflow measurements as it moves. Raw data collection rates over 5 kilosamples/second and an oversampling technique were implemented to reduce the data rate (Sama et al., 2008). The oversampling used results of 1000 samples per observation (Gates et al., 2004). The velocities are averaged and multiplied by the frame cross section to obtain the volumetric flow rate. Gates et al. (2004) described fabrication and calibration of ten FANS units. The units predicted airflow rate within 1% and after calibration had an imprecision of 71 to 232 m^3h^{-1} over the ten minutes.

2.1.3.2 FANS interface software.

The FANS interface software is currently on its 4th version. This study used version 1.4.0.0 of the software (Figure 2-2).

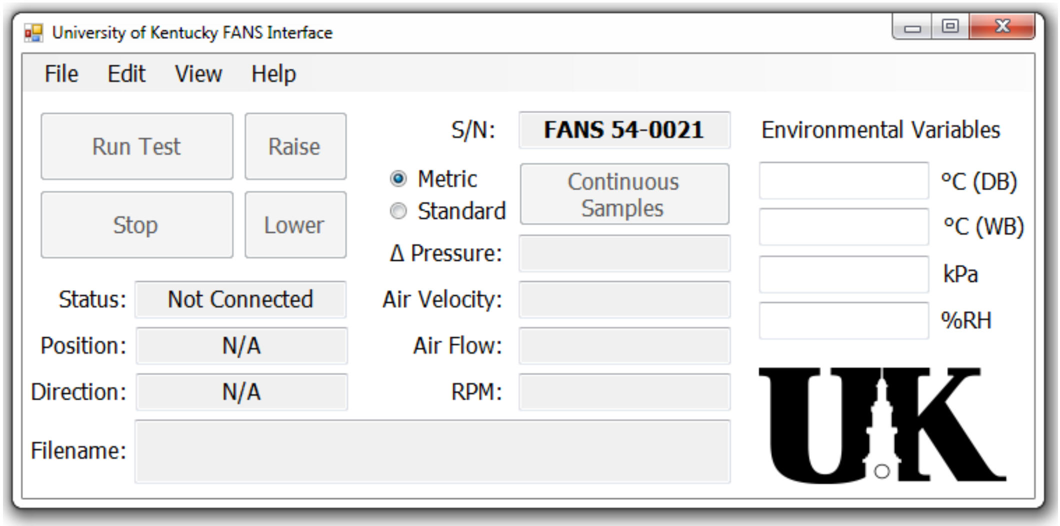


Figure 2-2 – FANS interface software (version 1.4.0.0)

The FANS interface software allows controlling the device with a personal computer. The connection can be made with a common serial cable or by using wireless Bluetooth technology (Bluetooth adaptor has to be connected to FANS).

The software use includes the selection of a default folder for data storage and automatic filename (date and time of the test) or a filename override. It is prepared to operate any FANS unit (selection of FANS serial number necessary). Results may be recorded and given in metric or standard English units. The version used also includes the option of manually inputting the environmental variables so they are saved within the same data collection file.

The FANS interface software features large control buttons that allow the free operation of the FANS (when test is not running) and control the test (start and if necessary canceling the procedure before it is over). Information on the current array position, connection status and direction of array are also given to facilitate operation and control by the user.

2.1.3.3 FANS test procedure.

The FANS test standard procedure consists of positioning the FANS against the wall on the intake side of the fan. The current procedure requires the tested fan to be centered within the FANS unit. In order to ease the height adjustment a hydraulic lift table has been used. After the FANS unit is positioned, the gaps between the device and the wall must be sealed to improve test results.

The airflow data is obtained and combined with a static pressure reading (both given by the FANS) and saved as a data pair. In order to obtain a full description of the fan performance curve, static pressure must be varied between tests so a fan performance curve can be generated. Morello (2011) found statistically significant fan performance curves using eight values of static pressure. Lopes et al. (2010) also obtained statistically strong fan performance curves using five static pressure values. The static pressure range depends on the study to be conducted, however, one should not exceed 60 Pa, since the FANS pressure transducer has an operational range of 0 to 62Pa (0 to 0.25 inH_2O). To a static pressure average of 60 Pa, it is expected that pressure values will be higher at a given point maxing out the pressure transducer if so.

2.1.4 FANS effects on airflow measurement studies.

Various studies on different FANS test setup and effects have been conducted in order to develop a better understanding of the device and factors that may cause differences in results. Such studies provide information that allows researchers to avoid test conditions that may cause unreliable results. A better understanding of the operation and test setups help researchers to adopt a standard test methodology, making comparison between research work results more applicable.

Wheeler et al. (2002) used a hydraulic lift cart in an attempt to refine the protocol and speed data collection. Taping all gaps between FANS and the fan housing, improved airflow measurements by about 6% versus not taping. The use of a 1.22m long duct to transition from the 1.22m FANS down to a 0.91m fan resulted on an airflow improvement of 2.5% versus not using a duct.

Casey et al. (2007) investigated the FANS unit use and its impacts on results. The FANS unit was found to be very repeatable with variation between tests to be less than the estimated measurement imprecision of the device itself. It was suggested that static pressure measurements should be taken throughout the test duration and averaged to reduce errors. Sama et al. (2008) described the addition of a static pressure sensor to the FANS that performs such measurement. FANS induced penalties were not encountered for 0.91m and 1.22m fans (with airflow lower than 34,000m^3s^{-1}). A 2% difference was found in 1.22m high flow fans. A 0.4m long expanded polystyrene and duct-tape transition was also tested between the 1.22m FANS and a 0.415m diameter fan and the difference averaged lower than the device measurement accuracy. Further study into the effects when testing fans bigger than 1.22m was suggested.

The FANS unit was originally designed to be positioned on the intake of the tested fan. However, Li et al. (2009) described the necessity of positioning the device on the discharge side of the fan when the original placing was impractical due to field conditions. The use of the FANS on the discharge side of the fan was considered to be possible given that the study revealed 0.6%±0.4% to 4.0%±0.9% (mean±SE) higher airflow rates versus the original designed placement (intake of fan). It was suggested that the discharge side placement of the FANS unit should be studied for smaller or bigger fans than the ones tested by that study. Morello (2011) found that the use of the FANS on the discharge side of the fan was not considered significantly different from the intake side position. Morello also studied the effect of adjacent fans operation when testing with the FANS unit. The use of the FANS unit on the discharge side of the fan was also studied. Results indicated up to 12.6%±4.4% difference in airflow measurements depending on adjacent fans operation. The difference was considered to be caused mainly by the FANS frame airflow obstruction on such test conditions.

Several studies were conducted to better understand the effects of different FANS testing setup and conditions, however, further studies with other common test variations must be conducted to achieve a standard test procedure. The study of transitions between FANS and fan housing and the positioning of the FANS on the discharge side of fan can be identified as common procedures when the original designed use is impractical. Most studies were conducted *in situ*. Further laboratory evaluation is also necessary to reduce errors caused by variation in field conditions which may generally be characterized by more uncontrollable sources of variation and errors than laboratory conditions.

Copyright© Igor Moreira Lopes 2012

Chapter 3. Material and methods.

3.1 FANS unit calibration.

All fan performance tests were conducted with two FANS units that were previously calibrated. The 1.22 m (48") FANS unit (serial number 48-0023) and the 1.37 m (54") FANS unit (serial number 54-0021) were calibrated at the BioEnvironmental Structural Systems Laboratory (BESS Lab) at the Agricultural and Biological Engineering Department, University of Illinois, Urbana-Champaign, IL.

The 1.22 m FANS unit calibration was also described by Morello (2011). The 1.37 m FANS unit calibration was performed with the same procedure. The calibration was performed by positioning the FANS unit on the outlet wall of the chamber at the BESS laboratory (Figure 3-1). The gaps between FANS unit and the wall chamber were closed with expanded polystyrene boards. Ten pressure points across the unit, in the 0 to 62Pa (0 to 0.25 inH2O) range, were set and the airflow was measured with the FANS unit and recorded for each pressure point. Airflow was also calculated based on the pressure drop through calibrated nozzles installed at the BESS chamber given the ambient conditions, temperature, humidity and barometric pressure. Morello (2011), stated the chamber airflow calculation was based on the ANSI/AMCA Standard 210-07 ANSI/ASHRAE 51-07, Laboratory Methods of Testing Fans for Certified Aerodynamic Performance Rating.

The FANS unit airflow reading was regressed as a linear function of the BESS chamber values (Equation 3-1). Intercept and slope of the regression were inserted into the FANS unit software in order to have the FANS unit readings calibrated.

$$FANS = a_1 BESS + a_0 \qquad \textit{Equation 3-1}$$

where,

$FANS$ =FANS airflow reading,

$BESS$ =BESS reference airflow reading,

a_0 = intercept, and

a_1 = slope.

The equation is inverted after it is regressed and used to obtain true airflow from the FANS reading. The calculation to obtain true airflow out of the FANS reading is performed by the FANS software.

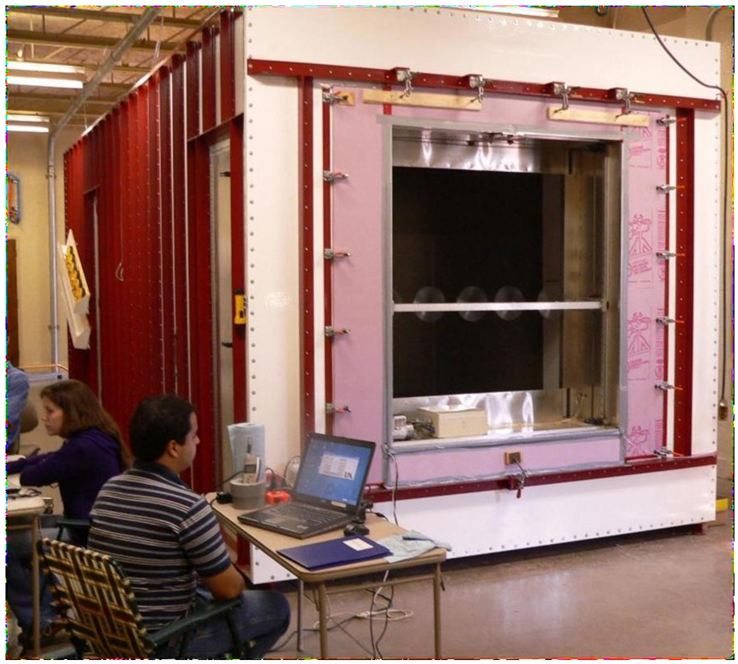


Figure 3-1 – FANS calibration at BESS lab (Morello, 2011)

3.2 Analytical evaluation of the wind tunnel specifications.

The maximum pressure drop caused by the wind tunnel chamber occurs when the highest airflow fan is installed and operating. The test procedure requires the development of a fan performance curve which should, at least, present a static pressure range in which the fan normally operates in field condition (optimal range 10 to 50 Pa). The critical (maximum) static pressure drop was evaluated by the analytical method (Idelchik, 1986), considering the worst test condition related to pressure drop.

3.2.1 Selection of fan airflow for calculation.

The airflow chosen for the analysis was based on the BESS lab calibration information (BESS, 2012) for a 1.37m (54”) axial fan (commonly used in animal production facilities). Figure 3-2 shows a fan curve performance obtained from the BESS lab calibration data website. The fan chosen is a high flow fan (critical airflow condition).

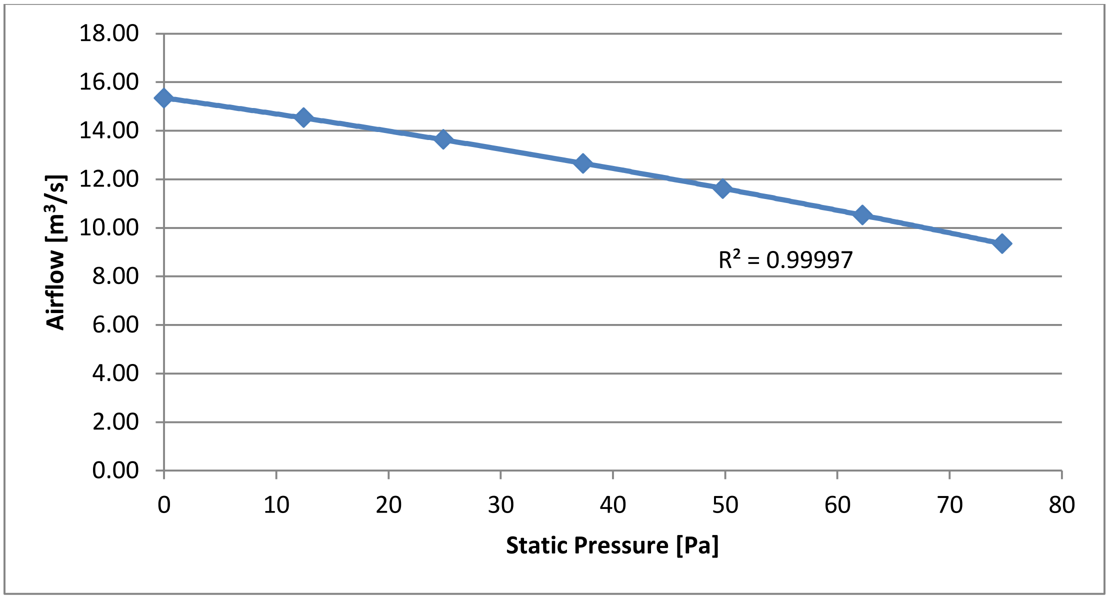


Figure 3-2 – High flow fan performance curve (BESS, 2012)

Normal fan operation condition for a tunnel ventilation system (animal facilities) produces static pressures within the range of 20 to 30 Pa. Based on Figure 3-2 the airflow moved under these conditions may be as high as 14 m^3s^{-1} (30,000 cfm). The airflow considered for the calculation was 16 m^3s^{-1}, which adds 2 m^3s^{-1} to the basic airflow obtained from the fan performance curve.

3.2.2 Analytical method.

An airflow straightener wall is necessary before the test chamber in order to guarantee laminar airflow inside the wind tunnel. The addition of a perforated plate on the airflow path causes pressure drop and must considered when estimating total pressure drop as the air moves through the tunnel.

An uniformly perforated plate, positioned in a cross section of channel (Figure 3-3), generates a resistance to the fluid flow. Losses occur by the movement of the fluid in the channel and also at the fluid passage through the orifices of the plate, associated with entry in the orifices and sudden expansion at the orifices exits (Idelchik, 1986). The total pressure loss of a fluid flowing in a channel with a perforated plate can be defined by Equation 3-2:

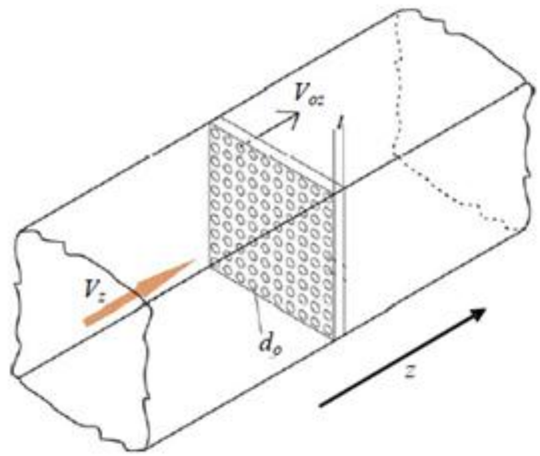


Figure 3-3 - Scheme of a channel with perforated plate (Santos, 2008)

$$\Delta p_{total} = \Delta p_{plate} + \Delta p_{channel} \qquad \textit{Equation 3-2}$$

where,

Δp_{plate} = pressure loss due to the perforated plate,

$\Delta p_{channel}$ = pressure loss due to friction at the channel surfaces.

The frictional losses along a straight tube can be calculated from the modified Darcy-Weisbach equation (Equation 3-3).

$$\Delta p_{channel} = \left[\left(\frac{\lambda\, \mathrm{L}}{D_h}\right)\left(\frac{\rho V_z^2}{2}\right)\right] \qquad \textit{Equation 3-3}$$

where,

λ = friction factor for the channel surface,

L = length of the channel [m],

D_h = Hydraulic diameter of the channel [m],

ρ = specific mass of the fluid [kg m^{-3}], and

V_z = average velocity in the channel [m s^{-1}].

The use of D_h is only possible when the thickness (δ) of the boundary layer is very small over the entire perimeter of the cross section compared with the dimensions of the channel cross section ($\delta << D_h$), (Idelchik, 1986).

The friction factor for the channel surface can be calculated by the Colebrook's equation (Equation 3-4)(ASHRAE, 2009a).

$$\frac{1}{\sqrt{\lambda}} = -2log_{10}\left[\left(\frac{\varepsilon}{3.7D_h}\right) + \left(\frac{2.51}{Re\sqrt{\lambda}}\right)\right]$$ *Equation 3-4*

where,

$\varepsilon =$ absolute roughness factor, [mm],

Re is the Reynolds number given by

$$Re = \frac{V_z D_h}{\upsilon}$$ *Equation 3-5*

where υ is the kinematic viscosity of the fluid, [m^{2}s^{-1}].

The Colebrook's formula (Equation 3-4) cannot be easily solved since it is in an implicit format. Ashtul's approximate formula (Equation 3-6) can be used for engineering calculations (Idelchik, 1986):

$$\lambda = 0.11\left(\overline{\Delta} + \frac{68}{\mathrm{Re}}\right)^{0.25}$$ *Equation 3-6*

where, $\overline{\Delta}$ is the relative roughness given by

$$\overline{\Delta} = \varepsilon/D_h$$ *Equation 3-7*

The pressure losses at the perforated plate can be calculated by:

$$\Delta p_{plate} = \frac{K\rho V_{z0}^2}{2} \qquad \textit{Equation 3-8}$$

where V_{z0} is the average velocity at the orifice and K is the resistance coefficient of the flow passage, which can be determined by Equation 3-9 (Idelchik, 1986):

$$K = \left(0.707\sqrt{1-\overline{f}} + 1 - \overline{f}\right)^2 \frac{1}{\overline{f}^2} \qquad \textit{Equation 3-9}$$

where, $\overline{f}$ is the ratio of the total orifice area and the total section area of the plate.

3.2.3 Perforated plate versus chamber section evaluation

The analytical method presented in section 3.2.2 was used to evaluate different wind tunnel scenarios. The evaluation considered different chamber sections (square sections of height 1.8, 2.1, 2.4, 2.7, 3.0 and 3.3m or 6, 7, 8, 9, 10, and 11ft approximately) and different perforated plate characteristics (Table 3-1).

Table 3-1 – Perforated plate characteristics

Plate	Orifice diameter [m]	Plate thickness [m]	Opening percentage [%]
Plate 1	0.003	0.00131	40
Plate 2	0.002	0.0009	46
Plate 3	0.013	0.00131	48
Plate 4	0.005	0.00131	50
Plate 5	0.004	0.0009	51
Plate 6	0.006	0.0009	58
Plate 7	0.004	0.00085	63
Plate 8	0.004	0.00131	63
Honeycomb	0.00635	0.0508	90

A pressure loss curve versus chamber height was developed for each perforated plate using the equations above. The curves are presented in Figure 3-4.

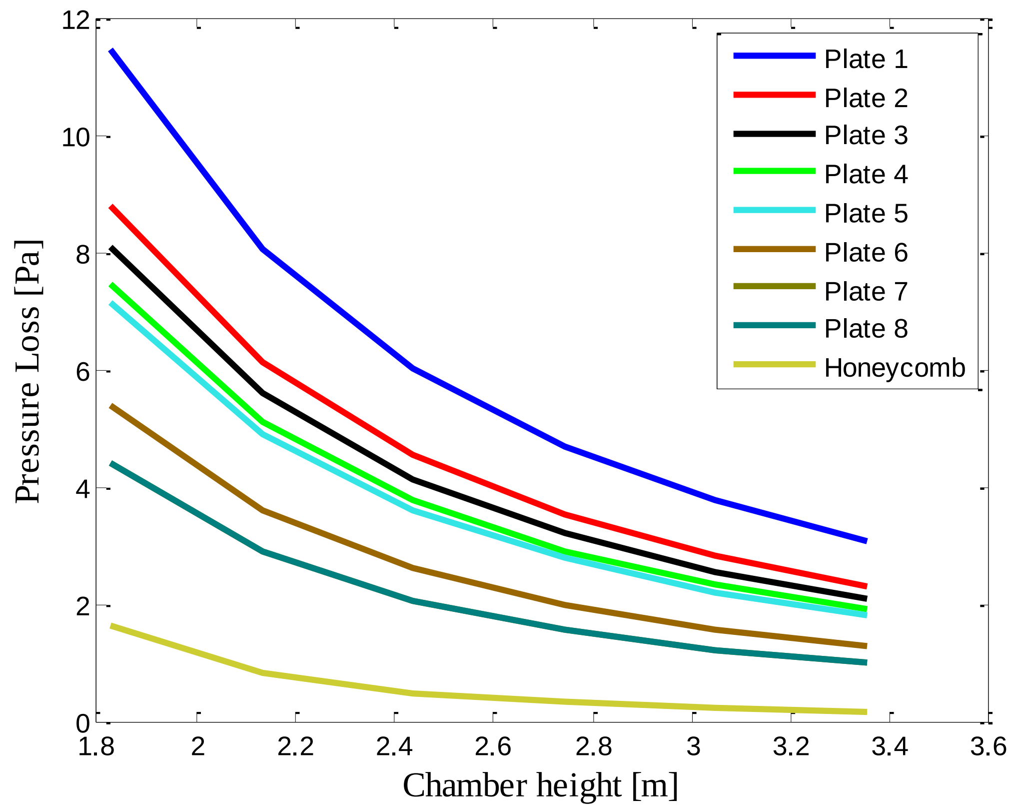


Figure 3-4 - Pressure loss curves for plates described in Table 3-1.

The curves indicate that no wind tunnel characteristics that were simulated resulted in pressure losses over 12 Pa. The desired static pressure test range was 10 to 50 Pa which requires the chamber not to cause total pressure loss over 10 Pa, otherwise the lowest pressure value within the desired range would be possible. Only the chamber with 1.83m (6ft) and plate 1 was not adequate when considering the pressure loss range desired, all other plate/section combination resulted on total pressure losses under 10 Pa.

3.2.4 Chamber section selection

The critical pressure loss analysis resulted in chamber heights as low as 1.83m (6ft), but, another design constraint had to be considered. The biggest FANS unit to be used has as its longest dimension, exactly 1.83m (6ft) of height. The test procedure used requires this measurement device to be mounted not only outside but also inside the test chamber. Therefore, in order to allow enough space for the mounting of the device inside the chamber and also some space to facilitate the moving and mounting of the equipment the 3m (10ft) square section was chosen.

3.3 WINTAC: Wind Tunnel Assessment Chamber.

3.3.1 WINTAC dimensions.

The Wind Tunnel Assessment Chamber (WINTAC) was designed based on the analysis and considerations described on item 3.1. The WINTAC has a 3 m high by 3 m wide by 8.7 m long (10 x 10 x 29 ft) chamber with two internal chambers separated by an airflow straightener wall (Figure 3-5)

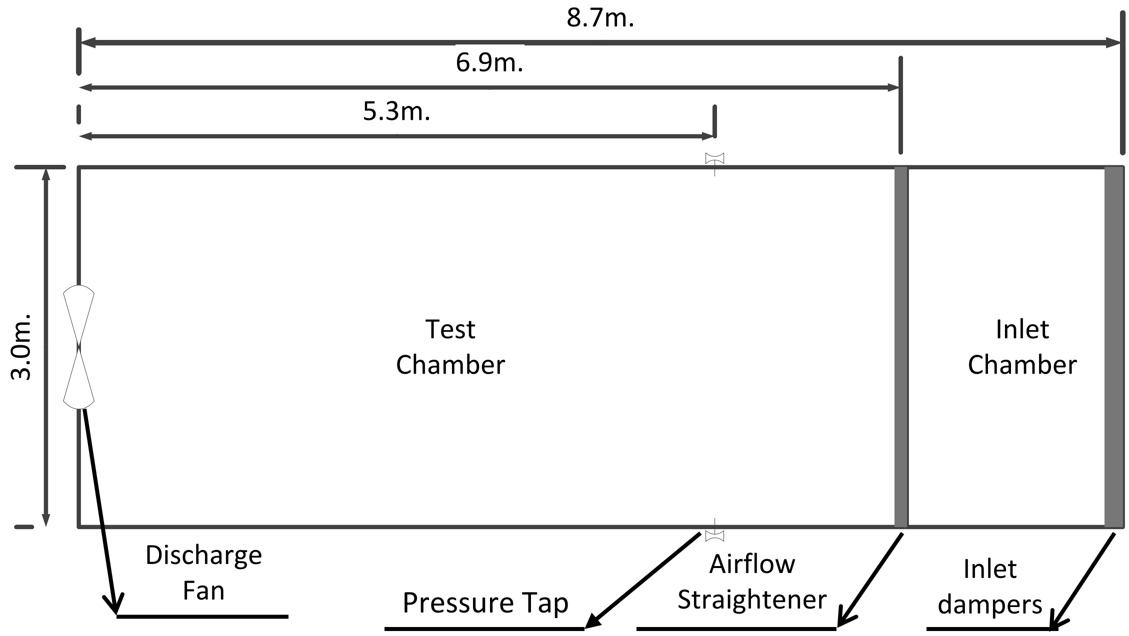


Figure 3-5 – WINTAC: top view

The inlet chamber is 1.8m (6ft) long and the test chamber is 6.9 m (22ft and 8in) long.

3.3.2 WINTAC features.

3.3.2.1 Airflow straightener wall.

The airflow straightener wall is located 1.8 m (approximately 6ft) from the inlet wall separating the tunnel chamber into two sections. The first section, located between the straightener wall and the inlet, is the air inlet section. The air inlet section allows the air to enter the chamber before it is conditioned by the airflow straightener wall. The second chamber is the test chamber, where the equipment is placed for testing.

The airflow straightener wall is a honeycomb wall (Figure 3-6) built so the air turbulence is reduced in order to simulate tunnel ventilation conditions. The honeycomb material used had a 0.635 cm (¼ in) cell and was 5.08 cm (2 in) thick. The ratio between the thickness and cell size is 8:1. Honeycombs reduce the turbulence in the test section, have small pressure drops and thus less effect on axial velocity, but owing to their length, they reduce lateral velocities. The minimum length of a honeycomb should be 6-8 times the cell size (Rae Jr. and Pope, 1984). The air flow straighteners were supported in the chamber by u-shaped aluminum bars held together with rivets.

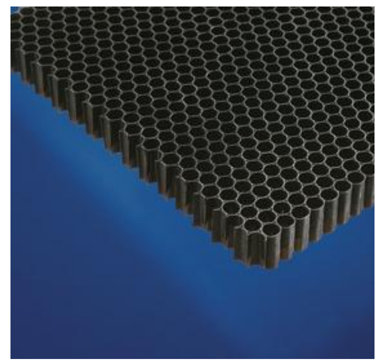


Figure 3-6 – WINTAC: Airflow Straightener and honeycomb detail (Plascore, 2012)

3.3.2.2 Doors.

The WINTAC has two 213cm by 91.5cm (84 x 36 in) metal doors flush to the inside wall with custom made handle (Figure 3-7) in order to keep the roughness of the wall as low as possible. Each door allows access to one of the sections of the WINTAC.

Figure 3-7 – WINTAC: Door and inside knob detail

3.3.2.3 Windows.

The WINTAC has two acrylic windows (1.22 x 2.44m and 1.22 x 1.22m)(Figure 3-8) that allow researchers to observe the inside of the chamber as the tests are performed. Both windows are located so airflow observation tests can be performed with the use of smoke. They also allow the researcher to observe the inside of the chamber in case any problem occurs such as undesired movement of a test object inside the chamber or malfunction of equipment/sensors during the tests.

The first window is located so the test chamber can be easily observed from the middle of the chamber. It is 2.44 by 1.22 m (8 x 4 ft) in size (Figure 3-8). Each light direction can be adjusted and each light bulb can operated individually as necessary in order to achieve the best flow/test visualization possible.

The second window is located on the last part of chamber. It allows close observation of the end wall and the fan operation. It is 1.22 by 1.22 m (4 x 4 ft) in size.

Figure 3-8 – WINTAC: Windows (Inside and outside view)

3.3.2.4 Automated opposed blade inlets.

The inlet wall was constructed with four 1.5 x 1.5 m (5 x 5 ft) opposed blade dampers (Figure 3-9). Each damper presented an extended axis that allows the attachment of either manual or automatic controls.

Figure 3-9 – WINTAC: Inlet wall (closed and opened)

Each damper had one proportional damper actuator installed (Figure 3-10). The actuator can be separately controlled by a 2 to 10 V input signal and gives a 2 to 10 V position feedback. The control box used to control the actuators is described in item 3.3.2.8.

Figure 3-10 – Proportional Damper Actuator

3.3.2.5 Detachable end section.

The end section of the tunnel was designed so it can be moved away from the main tunnel structure. The end section is moved so that bigger equipment that would not pass through the doors can be moved into the tunnel. The end section was mounted on a cart with four heavy duty casters (Figure 3-11).

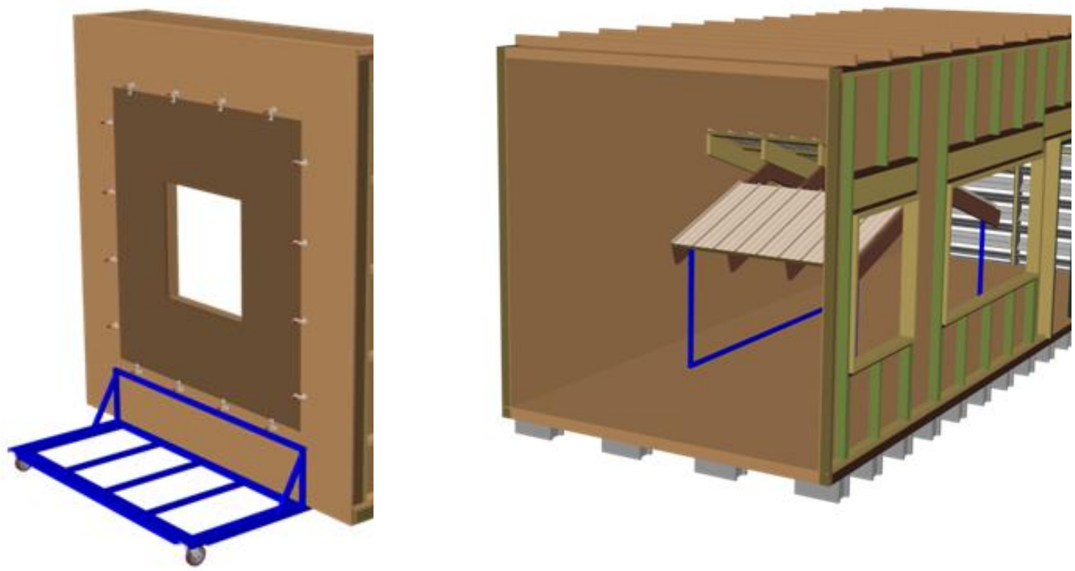
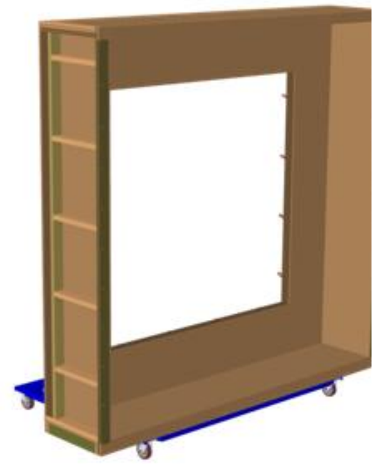


Figure 3-11 – WINTAC: End section detail

3.3.2.6 End wall opening.

The end wall has a 2.1m by 2.1m (7ft x 7ft) opening in order to accommodate different sizes of fans. It also features hold-down toggle clamps that hold the additional structure with the fan to be used (Figure 3-12).



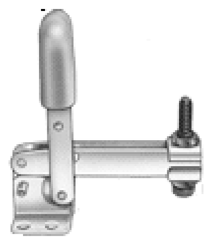


Figure 3-12 – WINTAC: End wall end Hold-down clamp detail (McMaster Carr, 2011)

3.3.2.7 Differential static pressure reading.

The WINTAC has six pressure taps located inside the test chamber (two on the top and two on each side wall) so the differential static pressure (difference in pressure between the outside and inside of the chamber) can be assessed (Figure 3-13). All six pressure taps are located at 1.65m (65”) from the air straightener wall.

Figure 3-13 – WINTAC: pressure tap

3.3.2.8 Automated inlet control.

The WINTAC has a control box to operate the inlet dampers. The control box was built to be operated manually through the control panel or by computer with a Bluetooth connection (Figure 3-14).

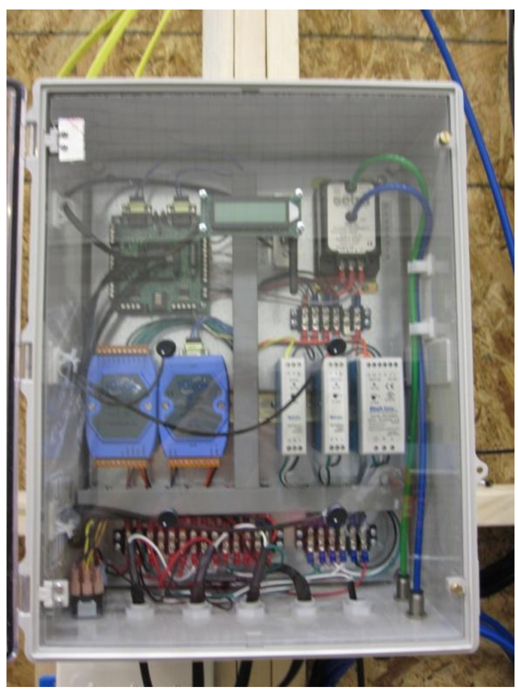


Figure 3-14 – WINTAC: Inlet control box

The chamber inlet, as described in item 3.3.2.4, is divided in four separate opposed blade dampers. The control box has four potentiometer knobs that allow the control of each damper separately. The control box also features a screen in which the current set position of each damper and its current true position is given as a percentage value (0 to 100%). This interface also provides the possibility of continuous, real time pressure control via feedback through the pressure sensors.

3.4 Fans tested.

Three different fans were tested in three different experiments. The fans were three different sizes: 0.91 (36), 1.22 (48) and 1.37 (54) m (in). The fan sizes were chosen based on common fan sizes used in Kentucky animal houses.

3.4.1 Fans description.

3.4.1.1 Experiment 1 - 0.91m Fan (36”).

Experiment 1 tests were conducted on a 0.91m (36”) fan. (Figure 3-15). The model number and description of the fan are given in Table 3-2.

Figure 3-15 – 0.91m (36”) fan

Table 3-2– 0.91m (36”) fan description.

GlassPac Canada 0.91m (36”) fan	
Housing	Glass fiber
Blades	3
Cone	No
Power	373W (½ hp)
Voltage	230 V
Shutter	Plastic louver on intake
Drive	Direct driven
Model #	GPSW 3655
Serial #	Y09M06

3.4.1.2 Experiment 2 - 1.22 m Fan (48”).

Experiment 2 tests were conducted on a 1.22m (48”) fan (Figure 3-16). The model number and description of the fan is given in Table 3-3.

Figure 3-16 – 1.22m (48”) fan

Table 3-3 – 1.22m (48”) fan description.

GlassPac Canada 1.22m (48”) fan	
Housing	Glass fiber
Blades	3
Cone	No
Power	746W (1 hp)
Voltage	230 V
Shutter	Plastic louver on intake
Drive	Belt Driven
Model #	GPSW48100
Serial #	030811

3.4.1.3 Experiment 3 - 1.37m Fan (54”).

Experiment 3 tests were conducted on a 1.37m (54”) fan (Figure 3-17). The model number and description of the fan is given in Table 3-4.

Figure 3-17 – 1.37m (54”) fan

Table 3-4 – 1.37m (54”) fan description.

Hired Hand 1.37m (54”) fan	
Housing	Metal
Blades	3
Cone	Yes
Power	1119W (1.5 hp)
Voltage	230 V
Shutter	Metal Butterfly Damper on discharge
Drive	Belt Driven
Part #	6603-1533
Model #	MF-54ED-B-3G-HF-1.5S-246S-0-1
Serial #	146191

3.5 Transition and Extension Design.

The best transition design should minimize pressure loss resulting in an airflow measurement closest to the airflow that would occur without the transition in place. Design of converging transitions is a complex procedure in which the increase in length results in the decrease of angle. An increase in the length of converging transition pieces leads to an increase in friction losses, while a decrease in their length causes an increase in the resistance due to flow separation from diverging walls (Idelchik, 1986).

3.5.1 Complete (or divergence) angle between.

Complete (or divergence) angle (α) is the angle obtained by extending the transition diverging wall planes and measuring the angle between them (Idelchik, 1986) (Figure 3-18). This is valid for both intake and discharge placement (converging and diverging transition respectively). The angle α/2 is the angle between the transition wall and the center line of the transition. All transitions used were square to square sections.

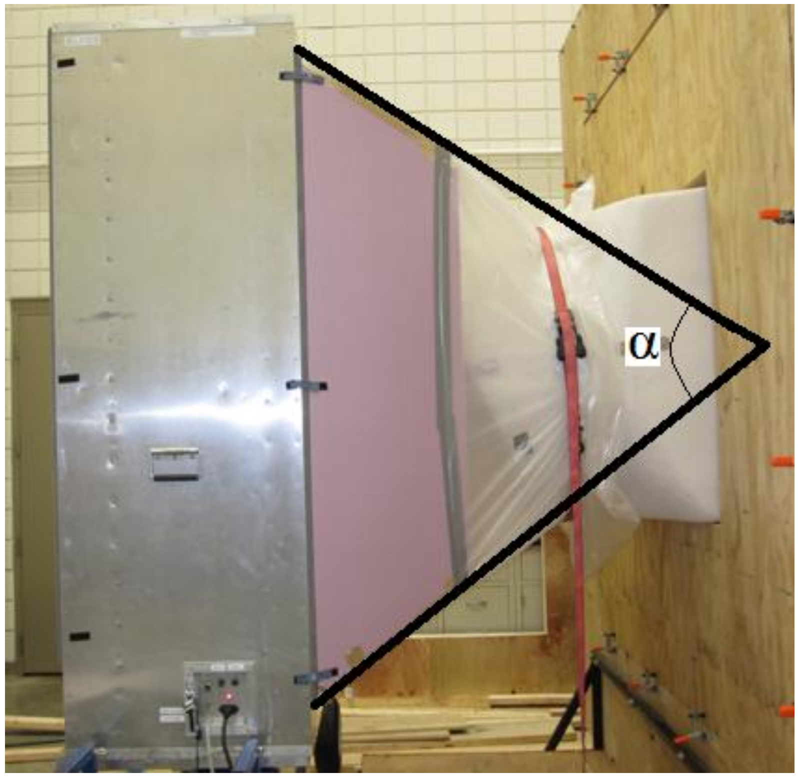


Figure 3-18 – Transition complete(or divergence) angle

3.5.2 Pressure loss coefficient (K).

Transition from a larger section to a smaller section through a smoothly converging section is accompanied by irreversible losses of total pressure (Idelchik, 1986). The losses can be separated into local losses (due to flow separation of the walls directly after the contraction) and friction losses at the transition. A general resistance coefficient for converging transitions can be obtained by

$$K = \frac{\Delta p}{\rho {\omega_0}^2/2} = K_{loc} + K_{fr} \qquad \textit{Equation 3-10}$$

where,

$\omega_0 =$ average velocity at smaller section,

$K_{loc} =$ coefficient of local fluid resistance, and

$K_{fr} =$ coefficient of friction resistance of the segment of length *l.*

The local friction coefficient is a function of the area ratio (smaller section / larger section) and the complete angle α. The friction resistance coefficient is a function of the relative roughness off the walls, the area ratio and the complete angle of the transition.

3.5.3 Transition details.

The complete angles (α) used on experiments 1 and 2 were 30, 45 and 60 degrees. The lowest angle chosen was 30 degrees so the transition length would not exceed 3.05m (10’). The 3.05m threshold was chosen considering that transitions over 10’ long are likely to cause more problems in field test conditions. Big transitions are more difficult to transport and position for testing. The maximum angle considered was 60 degrees since angles over 60 degrees are expected to result in pressure losses close to the ones obtained with the 60 degree angle (Figure 3-19). The conditions under which this work was conducted are related to the top left group of curves in the Figure 3-21.

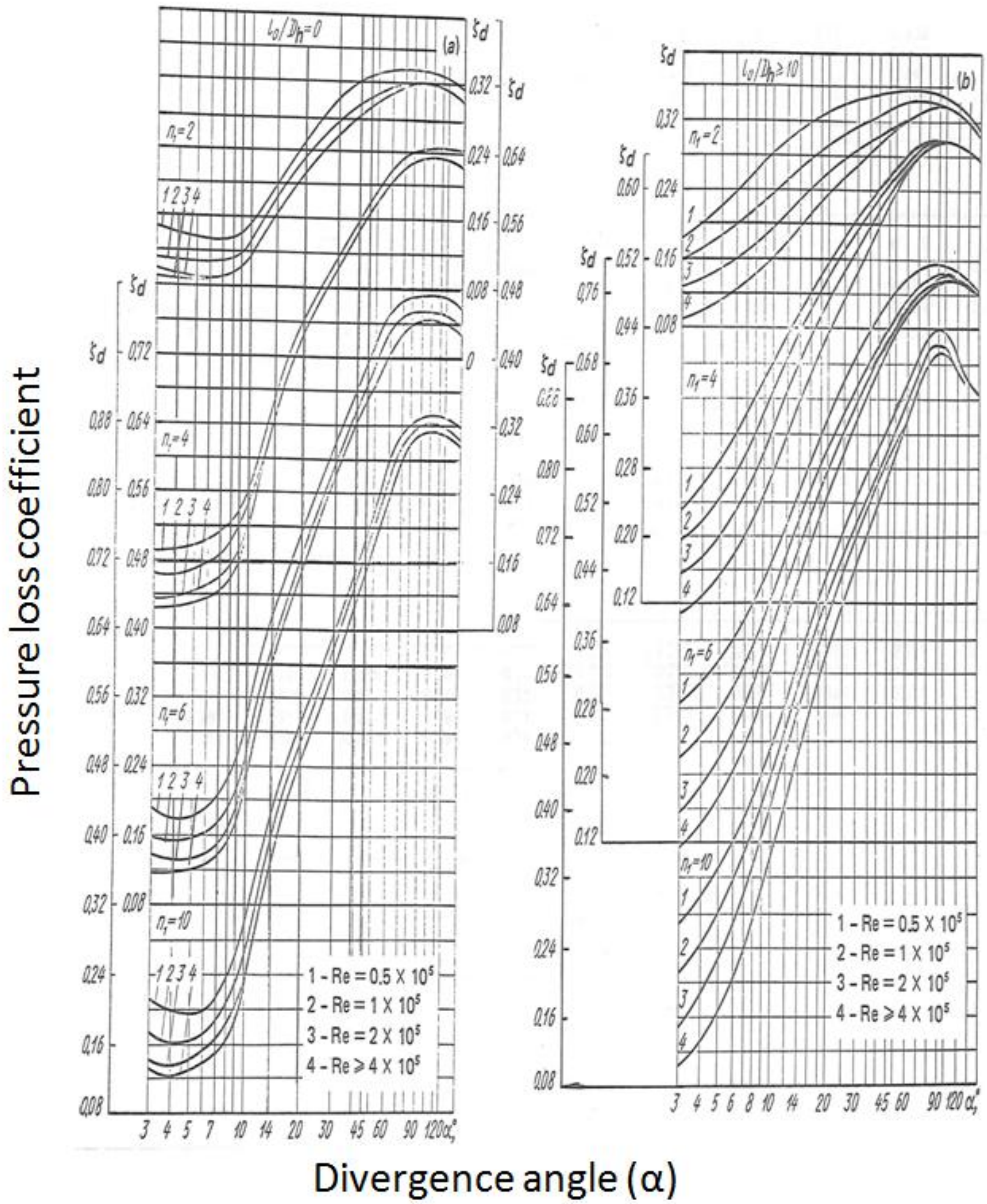


Figure 3-19 – Total resistance coefficient for rectangular section transition (Idelchik, 1986)

Both experiments 1 and 2 used transitions for some of the test treatments (described in item 4.1.2). Experiment one used transitions from a 54” FANS unit to a 36”fan. Experiment 2 used transitions from a 54” FANS unit to a 48”fan. Experiments one and two used three different transition angles: 30, 45 and 60 degrees. Other treatments with no transition were also used.

The transitions in experiments 1 and 2 were built with 1.27 and 2.54cm (½" and 1") expanded polystyrene boards and HVAC foil tape. The transition contact surface between wind tunnel walls and also between FANS unit were sealed with foam weather strip (Figure 3-20).

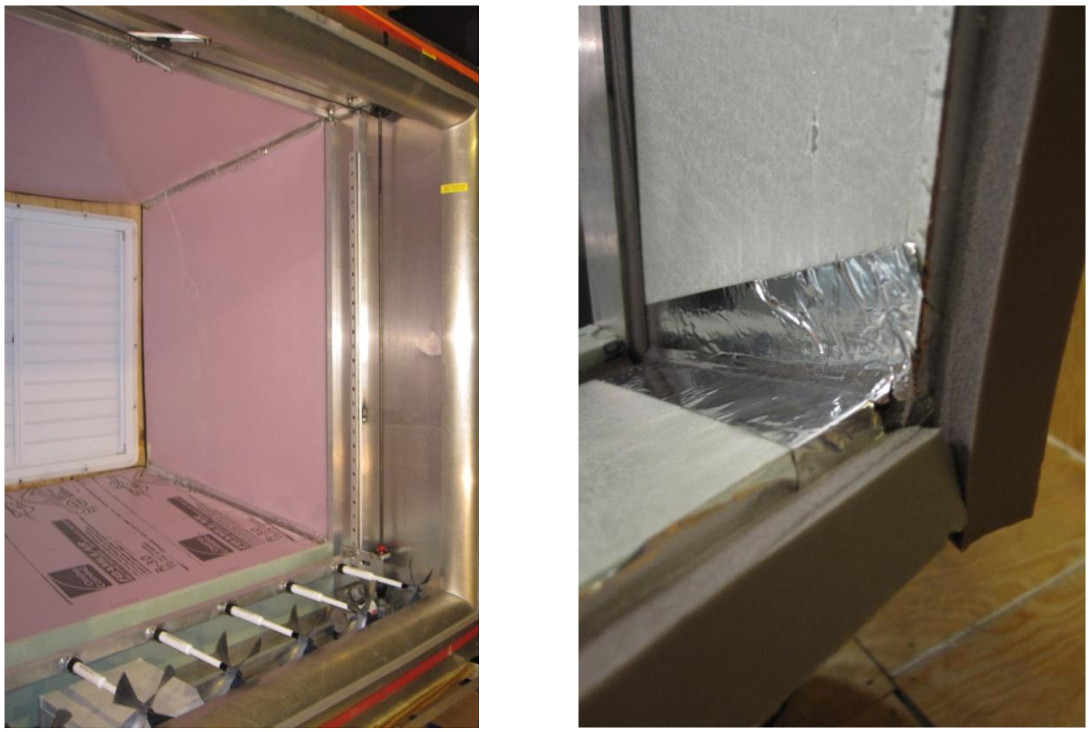


Figure 3-20 – Transition detail

Experiment three used a 25 cm (10") expanded polystyrene extension (Figure 3-21). The extension was built with construction adhesive and weather strip to guarantee it was air tight.

Figure 3-21 – Extension positioned on 54”FANS unit

Copyright© Igor Moreira Lopes 2012

Chapter 4. Experimental design and procedure.

4.1 Experiment Protocol.

4.1.1 Test setup and procedure.

4.1.1.1 Intake test setup.

The intake test setup consisted of positioning the FANS unit on the intake side of the fan. The FANS unit was positioned on a height adjustable cart and held against the wall with straps. A foam gasket was used between the FANS unit and wall so the FANS/wall interface was airtight (Figure 4-1).

Figure 4-1 – Intake test setup

Transitions were held in position with hook and loop fasteners and then pressed between the FANS unit and wall by the straps. Foam weather strip was used on both sides of the transitions to guarantee air tightness (Figure 4-2 and Figure 4-3).

Figure 4-2 – Intake test setup(hook and loop fastener and foam strip detail)

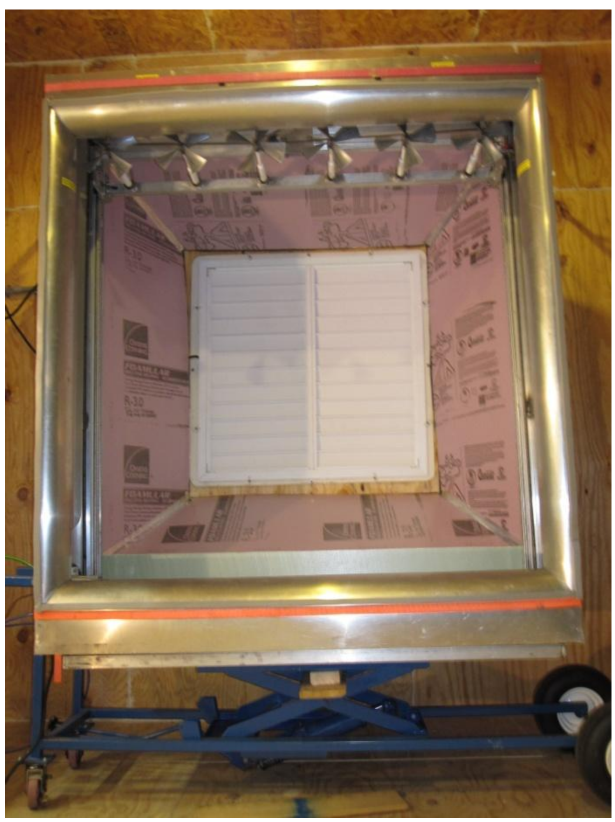


Figure 4-3 – Intake setup (with transition)

4.1.1.2 Discharge test setup.

The discharge test setup consisted of positioning the FANS on the discharge side of the fan. The FANS unit was positioned on the height adjustable cart. The gap between FANS unit and fan was closed with plastic. The plastic was attached to the FANS unit with adhesive tape and with a strap to the fan housing (Figure 4-4 and Figure 4-5).

Figure 4-4 – Discharge test setup

Figure 4-5 – Discharge test setup (strap detail)

4.1.1.3 Fan test procedure.

Tests were conducted by setting static pressure values around target values and running airflow and differential static pressure measurements. Pressure target values were chosen in order to obtain fan performance curves that include common farm operation static pressure values within their range. The static pressure range used was 10 to 50 Pa (0.04 to 0.2 inH_2O). Five static pressure target values were selected equally distanced within the range: 10, 20, 30, 40 and 50 Pa (0.04, 0.08, 0.12, 0.16, and 0.20 inH_2O). Three measurements per target pressure were performed resulting in 15 data points (airflow x static pressure). Further description of treatment versus static pressure use are described in section 0.

4.1.2 Treatments.

The treatment coding is given in the format "XX_YY_T", where XX is the fan size, YY is the FANS unit size and T is type of transition and position of FANS unit. XX can be

36, 48 or 54 (possible fan diameter sizes in inches). YY can be 48 or 54 (FANS unit sizes used) and possible C codes are described in Table 4-1.

Table 4-1 – Treatment coding (T codes).

Treatment Code T	Description
ND	No transition or sealed connection to fan
D	Outside position (discharge of the fan)
30D	Outside 30^{o} angle (α) transition
45D	Outside 45^{o} angle (α) transition
60D	Outside 60^{o} angle (α) transition
I	Inside position (intake of the fan)
30I	Inside 30^{o} angle (α) transition
45I	Inside 45^{o} angle (α) transition
60I	Inside 60^{o} angle (α) transition
EI	Inside with extension

4.1.2.1 Control treatment.

The control treatment was chosen based on the most common test setup for the fan tested in each experiment. All experiments control treatments used the FANS unit positioned on the intake against the wall. FANS sizes for each experiment were:

- Experiment 1 and 2: 1.22m (48”) FANS unit;
- Experiment 3: 1.37m (54”) FANS unit

4.1.2.2 Treatments – Experiment 1 – 0.91m Fan (36”).

All experiment 1 treatments have the number “36” at the beginning of their code indicating that experiment 1 tested the 0.91m (36”) fan. Experiment 1 was designed to satisfy objective 1. The treatments are described below.

- Treatment 36_48_I; 48”FANS unit on the intake side of the fan directly against the wall (Figure 4-6). This is considered the control treatment because it is the setup in accordance with the FANS unit original designed use.

Figure 4-6 – Fan testing setup; Treatment 36_48_I

- Treatment 36_54_I; 54” FANS unit on the intake side of the fan directly against the wall. 180 degree transition (Figure 4-7).

Figure 4-7 – Fan testing setup; Treatment 36_54_I

- Treatment 36_54_30I; 54” FANS unit on the intake side of the fan with a 30 degree transition between FANS unit and wall (Figure 4-8).

Figure 4-8 – Fan testing setup; treatment 36_54_30I

- Treatment 36_54_45I; 54” FANS unit on the intake side of the fan with a 45 degree transition between FANS unit and wall (Figure 4-9).

Figure 4-9 – Fan testing setup; treatment 36_54_45I

- Treatment 36_54_60I; 54" FANS unit on the intake side of the fan with a 60 degree transition between FANS unit and wall (Figure 4-10).

Figure 4-10 – Fan testing setup; treatment 36_54_60I

- Treatment 36_54_D; 54" FANS unit on the discharge (outside) side of the fan with the FANS unit positioned right after fan housing and the use of plastic for sealing (Figure 4-11).

Figure 4-11 – Fan Testing setup; Treatment 36_54_D

- Treatment 36_54_30D; 54" FANS unit on the discharge (outside) side of the fan with 30 degree angle transition and the use of plastic for sealing (Figure 4-12).

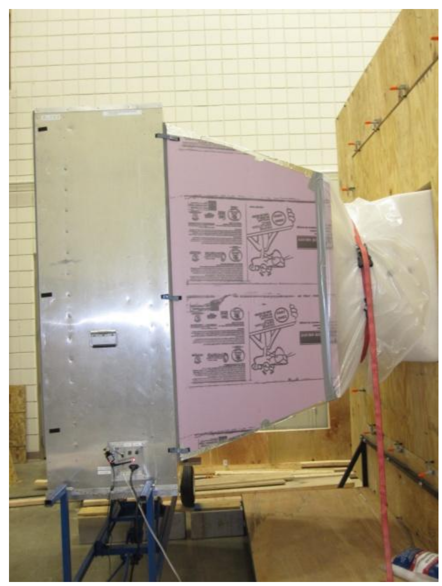


Figure 4-12 – Fan testing setup; treatment 36_54_30D

- Treatment 36_54_45D; 54" FANS unit on the discharge (outside) side of the fan with 45 degree angle transition and the use of plastic for sealing (Figure 4-13).

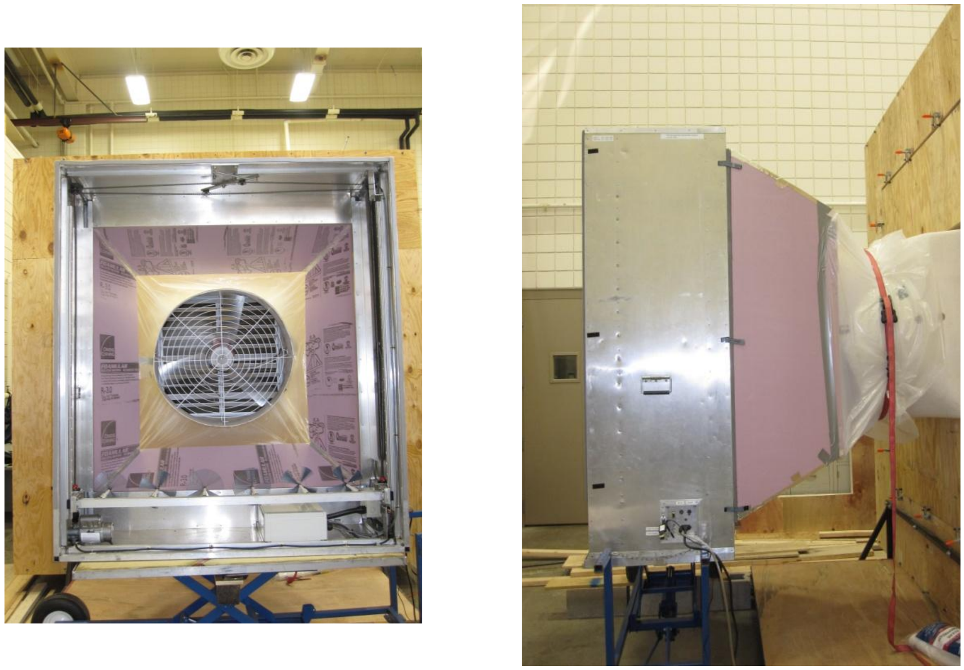


Figure 4-13 – Fan testing setup; treatment 36_54_45D

- Treatment 36_54_60D; 54" FANS unit on the discharge (outside) side of the fan with 60 degree angle transition and the use of plastic for sealing (Figure 4-14).

Figure 4-14 – Fan testing setup; treatment 36_54_60D

- Treatment 36_54_ND; 54" FANS unit on the discharge (outside) side of the fan with no method of sealing the gap between fan and FANS unit (Figure 4-15).

Figure 4-15 – Fan Testing setup; treatment 36_54_ND

4.1.2.3 Treatments – Experiment 2 – 1.22m Fan (48”).

All experiment 2 treatments have the number “48” at the beginning of their code indicating that experiment 2 tested the 1.22 m (48”) fan. Experiment 2 was designed to satisfy objective 2. The treatments are described below.

- Treatment 48_48_I; 48” FANS unit on the intake side of the fan directly against the wall. This is considered the control treatment for this experiment.
- Treatment 48_54_I; 54” FANS unit on the intake side of the fan with a 30 degree transition between FANS unit and wall. 180 degree transition (Figure 4-16).

Figure 4-16 – Fan testing setup; treatment 48_54_I

- Treatment 48_54_30I; 54" FANS unit on the intake side of the fan with a 30 degree transition between FANS unit and wall (Figure 4-17).

Figure 4-17 – Fan testing setup; 48_54_30I

- Treatment 48_54_45I; 54" FANS unit on the intake side of the fan with a 45 degree transition between FANS unit and wall (Figure 4-18).

Figure 4-18 – Fan testing setup; treatment 48_54_45I

- Treatment 48_54_60I; 54” FANS unit on the intake side of the fan with a 60 degree transition between FANS unit and wall (Figure 4-19).

Figure 4-19 – Fan testing setup; 48_54_60I

- Treatment 48_54_D; 54” FANS unit on the discharge (outside) side of the fan with the FANS unit positioned right after fan housing and the use of plastic for sealing (Figure 4-20).

Figure 4-20 – Fan testing; 48_54_D

- Treatment 48_54_30D; 54" FANS unit on the discharge (outside) side of the fan with 30 degree angle transition and the use of plastic for sealing (Figure 4-21).

Figure 4-21 _ Fan testing; Treatment 48_54_30D

-

- Treatment 48_54_45D; 54" FANS unit on the discharge (outside) side of the fan with 45 degree angle transition and the use of plastic for sealing (Figure 4-22).

Figure 4-22 – Fan testing setup; treatment 48_54_45D

- Treatment 48_54_60D; 54" FANS unit on the discharge (outside) side of the fan with 60 degree angle transition and the use of plastic for sealing (Figure 4-23).

Figure 4-23 – Fan testing setup; treatment 48_54_60D

- Treatment 48_54_ND; 54” FANS unit on the discharge (outside) side of the fan with no method of sealing the gap between fan and FANS unit (Figure 4-24).

Figure 4-24 – Fan testing setup; treatment 48_54_ND

4.1.2.4 Treatments – Experiment 3 – 1.37m Fan (54”).

All experiment 3 treatments have the number “54” at the beginning of their code indicating that experiment 3 tested the 1.37 m (54”) fan. Experiment 3 was designed to satisfy objective 3. The treatments are described below.

- Treatment 54_54_I; 54” FANS unit on the intake side of the fan directly against the wall. This is considered the control treatment for this experiment (Figure 4-25).

Figure 4-25 – Fan testing setup; treatment 54_54_I

- Treatment 54_54_EI; 54” FANS unit on the intake side of the fan with 10 inch long between FANS unit and wall (Figure 4-26).

Figure 4-26 – Fan testing setup; treatment 54_54_EI

- Treatment 54_54_D; 54”FANS unit on the discharge (outside) side of the fan with the FANS unit positioned right after fan housing and the use of plastic for sealing (Figure 4-27).

Figure 4-27 – Fan testing setup; treatment 54_54_D

- Treatment 54_54_ND; 54” FANS unit on the discharge (outside) side of the fan with no method of sealing the gap between fan and FANS unit (Figure 4-28).

Figure 4-28 – Fan testing setup; treatment 54_54_ND

4.2 Experimental design.

Experiment 1 2 and 3 were designed to test one fan size and its transitions. The experimental treatments (described in section 4.1.2) were applied to each of three fans as separate experiments. Each experiment was treated in a completely randomized design. The static pressure was treated as a covariate; therefore, it was not necessary to achieve exactly the pressure target values (airflow measurement was performed after static pressure achieved values close to target values, ±2Pa). The experimental unit of all three experiments is defined as the combination of fan at each static pressure.

However, due to constraints (limited time, excessive assembly and disassembly and difficulty of moving test setup from intake to discharge), actual complete randomization was not achieved and some limitations were defined:

- Treatment randomization was performed separately for intake and discharge treatments due to the difficulty of moving the test setup from one position to the other.
- After each treatment was applied, five data points were obtained. All five static pressure target values were randomized and applied in order to obtain the five data points.
- After five data points were obtained the next treatment was randomly selected.
- Each treatment was set three times, totaling 15 data points per treatment.

4.3 Statistical analysis.

Analysis of variance (ANOVA) was used to verify if different treatments resulted in different airflow readings. The statistical model used is given in Equation 4-1.

$$AF_{(ij)k} = \mu + Trt_i + \Delta P_j + \Delta PSquared_j + E_{(ij)k} \qquad \textit{Equation 4-1}$$

where,

$\mu =$ overall mean considered common to all observation [m^3hr^{-1}],

$Trt_i =$ fixed effect of the i-th treatment, i = {1 to z}, z = 10, 9 and 4 for experiments 1, 2 and 3 respectively,

$\Delta P_j =$ fixed effect of the j-th level of static pressure reading, j = {1 through 5}, [Pa],

$\Delta PSquared_j =$ fixed effect of the j-th level of static pressure squared, [Pa^2],

$E_{(ij)k}$= random component, which explains the random variation or experimental error to the experimental unit, k= {1, 2, 3}, and

$AF_{(ij)k} =$ airflow observation from the effect of the i-th treatment, the j-th covariate (P) and its squared value effects of the k-th replicate.

In each experiment, comparisons between the control treatment and other treatments were performed using the Dunnett's test. Proc GLM of SAS® (9.2, SAS Institute Inc., 2002-2008 Cary, NC, U.S.A) was used.

The Dunnett's procedure is used when the objective of multisample experiments, or treatments, is to determine whether the mean of one treatment, designated as a "control", differs significantly from each of the means of the other treatments. Based on the number of treatments and error degrees of freedom from the analysis of variance, one obtains critical values for the test statistic (q), in a manner similar to that of the Tukey test procedure (Zar 1999). The standard error for Dunnett's test is

$$SE = \sqrt{\frac{2s^2}{n}} \qquad \textit{Equation 4-2}$$

where,

$SE =$ Standard error for Dunnett's test,

$s^2 =$ error mean square from the analysis of variance, and

$n =$ number ot data in each of the treatments.

The test statistic q (test statistic for Dunnett's procedure) is distributed according to the normal distribution and 95% confidence level was considered.

$$q = \frac{\overline{X_{control}} - \overline{X_A}}{SE} \qquad \textit{Equation 4-3}$$

where,

$\overline{X_{control}}$ = mean of control treatment, and

$\overline{X_A}$ = mean of treatment "A", A being the treatment compared to control treatment.

The difference between airflows for each treatment versus the control treatment in m3s-1 and in percentage of the control treatment airflow was obtained. Second order polynomial regressions (Equation 4-4) were obtained for each treatment with 15 data points each.

$$Q = B_2X^2 + B_1X + B_0 \qquad \textit{Equation 4-4}$$

where,

Q =Response variable (airflow), [m^3hr^{-1}],

X =independent variable (static pressure), [Pa],

B_2 = second order coefficient,

B_1 = first order coefficient, and

B_0 = intercept.

Eight (Experiment 1) to nine (Experiments 2 and 3) values of static pressure, varying from 10 to 45 (Exp. 1) or 50 Pa (Exp.2 and 3) (in 5Pa increments), were used to calculate airflow values based on the regression curves (Equation 4-4) for each treatment. The mean difference between each treatment and the control treatment was obtained by calculating the average difference in airflow for each static pressure value (Figure 4-29 and Equation 4-5). The mean difference given as a percentage over the control treatment airflow was also calculated (Equation 4-6).

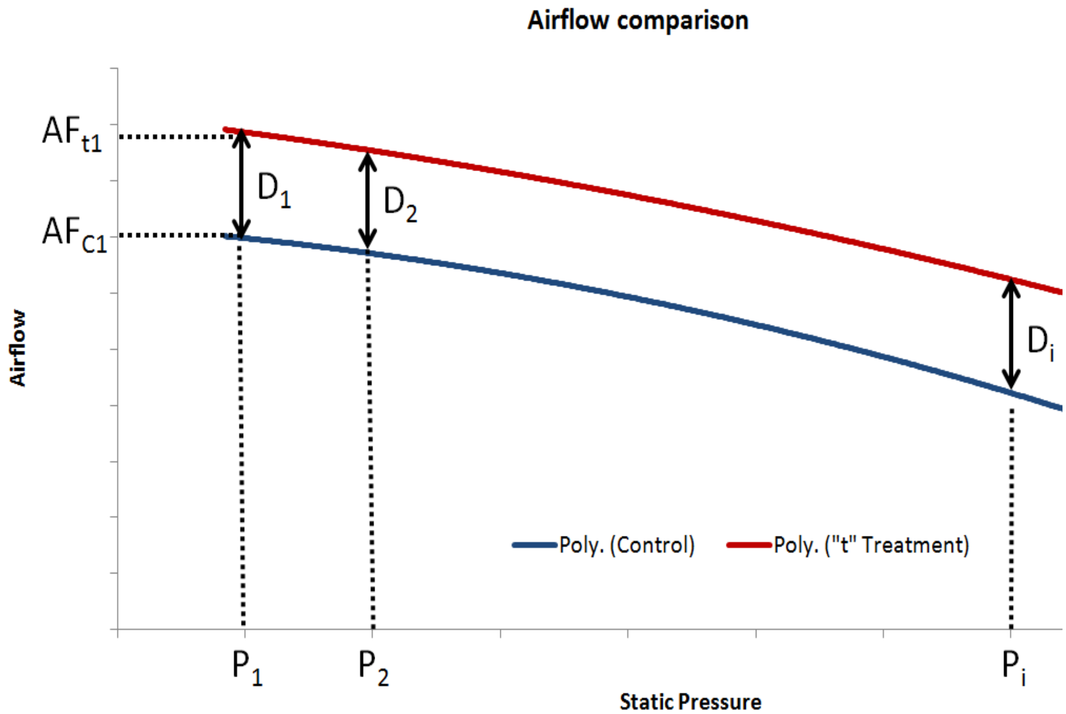


Figure 4-29 – Airflow comparison example

$$Diff_{tC} = \frac{\sum_1^i (AF_{ti} - AF_{Ci})}{i}$$ *Equation 4-5*

$$Diff\%_{tC} = 100 \frac{\sum \left({(AF_{ti} - AF_{Ci})}/{(AF_{Ci})} \right)}{i}$$ *Equation 4-6*

Plots of the pair-wise comparisons with the polynomial regressions and confidence intervals were also used to illustrate the comparisons and facilitate the analysis and discussion of the results.

Copyright© Igor Moreira Lopes 2012

Chapter 5. Results and Discussion

5.1 FANS calibration.

5.1.1 1.22 m (48”) FANS calibration (serial 48-0023).

The 1.22 m FANS calibration regression resulted in the following values:

Intercept = -0.097 ± 0.039 m^3s^{-1} and Slope = 0.979 ± 0.004; R^2 = 0.9999.

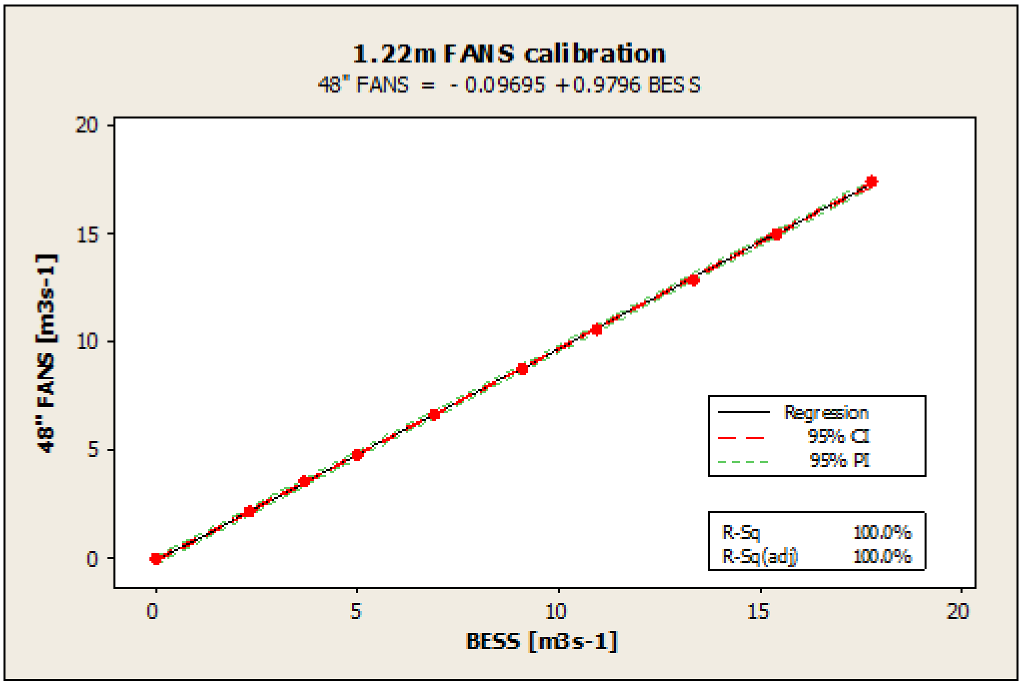


Figure 5-1 – 1.22m (48”) FANS calibration

5.1.2 1.37 m (54”) FANS calibration (serial 54-0021).

The 1.37 m FANS calibration regression resulted in the following values:

Intercept = - 0.439 ± 0.094 m^3s^{-1} and Slope = 1.036 ± 0.007; R^2 = 0.9996.

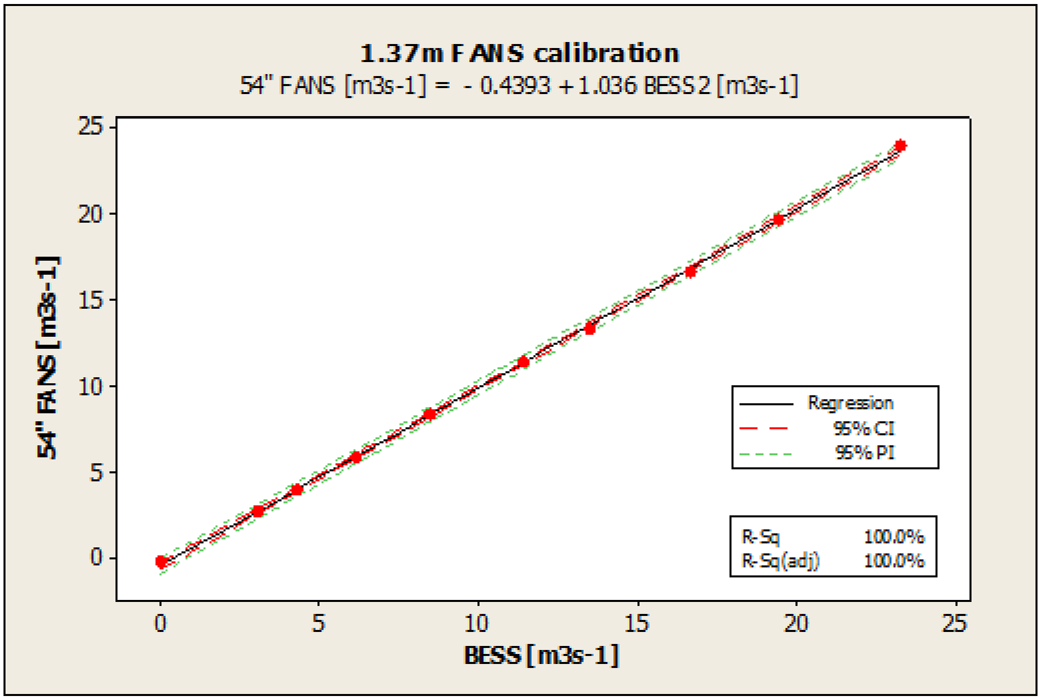


Figure 5-2 – 1.37 m (54”) FANS calibration

5.2 Experiment 1: 0.91m (36”) Fan.

The ANOVA analysis based on the statistical model described in section 4.3 shows that mean airflow rates were significantly different as different treatments were applied to the 0.91m fan ($p<0.0001$) (Appendix A). Given that there were significant differences between treatments, a pair wise comparison of each treatment to the control treatment was performed. Table 5-1 presents all comparisons to the control (36_48_I) treatment. The simultaneous 95% confidence limits are obtained considering the minimum significant difference (at 95% confidence level) obtained for the Dunnett’s procedure (one for all comparisons) and the difference between means for each comparison.

Table 5-1 – Experiment. 1 Comparisons with control treatment (Dunnett's procedure).

Trt Compared to Control	Difference between means [m3hr-1]	Simultaneous 95% Confidence Limits [m3hr-1]		
36_54_ND	3786.6	3380.1	4193.1	*
36_54_D	1590.5	1184.0	1997.0	*
36_54_30D	1323.3	916.9	1729.8	*
36_54_45D	1730.1	1323.6	2136.5	*
36_54_60D	1352.2	945.7	1758.7	*
36_54_I	532.2	125.7	938.7	*
36_54_30I	-142.8	-549.2	263.7	
36_54_45I	154.5	-251.9	561.0	
36_54_60I	182.6	-223.9	589.1	

Comparisons significant at the 0.05 level are indicated by *

Airflow measurements performed using the 1.37m (54") FANS unit with transitions on the intake side of the fan were the same as those obtained with the control (1.22m FANS on intake) treatment. Thus when using the 1.37m (54") FANS unit, any of the different angle transitions can be used to perform the airflow measurement and a reading similar to that with the 1.22m (48") FANS unit. More importantly, results indicate that if a 0.91m (36") fan is to be tested with the 1.37m (54") FANS unit on the intake side of the fan, a transition should be used since the airflow obtained with no transition (treatment 36_54_I) was statistically different to the control treatment.

All treatments that had the FANS unit positioned on the discharge side of the tested fan produced statistically different airflow measurements to the control results. Treatment 36_54_ND presented the biggest difference between means (3787 m^3hr^{-1}) among the comparisons to the control treatment. Other discharge side treatments caused differences between 1300 and 1800 m^3hr^{-1}. The 30 degree angle transition resulted in the smallest difference among the outside treatments. All treatments that were statistically different from the control treatment caused higher airflow rates than the control.

In order to calculate the average airflow difference between each treatment and control treatment, as described in section 4.3 by Equation 4-4, second order polynomial regressions for each treatment were obtained. These values are presented in Table 5-2. The calculated average airflow differences for the control treatment versus each of the other treatments are given in Table 5-3.

Table 5-2 – Experiment. 1, second order polynomial regressions (Equation 4-4) .

Trt	Intercept [$m^3 hr^{-1}$]	1st order coeff. [$m^5N^{-1}hr^{-1}$]	2nd order coeff. [$m^7N^{-2}hr^{-1}$]	R-squared	P-value
36_48_I	14600.89	-35.38	-2.97	0.98	<0.0001
36_54_ND	18793.42	-89.4	-1.71	0.997	<0.0001
36_54_D	16565.09	-41.04	-2.99	0.994	<0.0001
36_54_30D	15448.29	59.36	-5.12	0.943	<0.0001
36_54_45D	17094.88	-72.94	-2.55	0.982	<0.0001
36_54_60D	16956.85	-92.27	-2.27	0.993	<0.0001
36_54_I	15208.71	-45.49	-2.55	0.983	<0.0001
36_54_30I	14928.68	-60.65	-2.63	0.986	<0.0001
36_54_45I	15423.59	-93.76	-1.8	0.99	<0.0001
36_54_60I	15101.95	-56.08	-2.58	0.98	<0.0001

Table 5-3 – Experiment.1, airflow difference to control treatment

Trt	Aiflow Difference [m3hr-1]		Airflow Difference %	
	Mean	Std. Deviation	Mean	Std. Deviation
36_54_ND	3825	242.6	37.1	12.24
36_54_D	1791	82.8	17.0	3.55
36_54_30D	1545	390.2	14.0	2.04
36_54_45D	1834	184.4	17.2	3.04
36_54_60D	1413	241.0	13.1	1.93
36_54_I	703	167.2	7.1	3.66
36_54_30I	-65	90.6	-0.8	0.91
36_54_45I	256	160.9	2.7	2.45
36_54_60I	278	48.6	2.7	1.11

The inside treatments with transitions, which were not statistically different from the control treatment, presented average airflow differences lower than 3%. Discharge treatments with sealed gaps resulted in average differences of 14.02 to 17.23%. The discharge treatment with no method of sealing the gaps between FANS and fan housing, resulted in an average difference of 37.10%.

Graphs with fan performance curves were plotted (Figure 5-3 through Figure 5-11) in order to further understand and visualize the differences between treatments and the control. Each graph shows performance curves for one experimental treatment and the 36_48_I (control) treatment. The colored band around the curves indicates the 95% confidence interval of each polynomial regression. The point shown are actual data obtained during the tests Treatments 36_54_30I, 36_54_45I and 36_54_60I confidence bands overlay on the 36_48_I (control) confidence band in accordance with the results from the Dunnett's test.

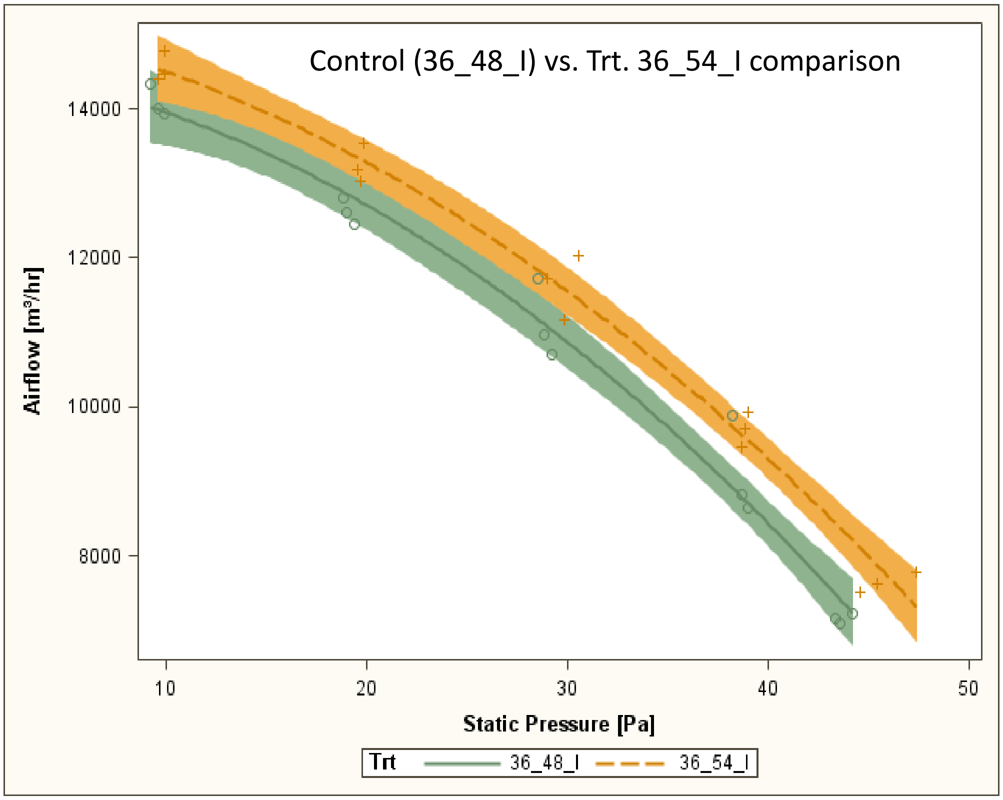


Figure 5-3 – Experiment 1(a). Fan performance curves with 95% confidence intervals.

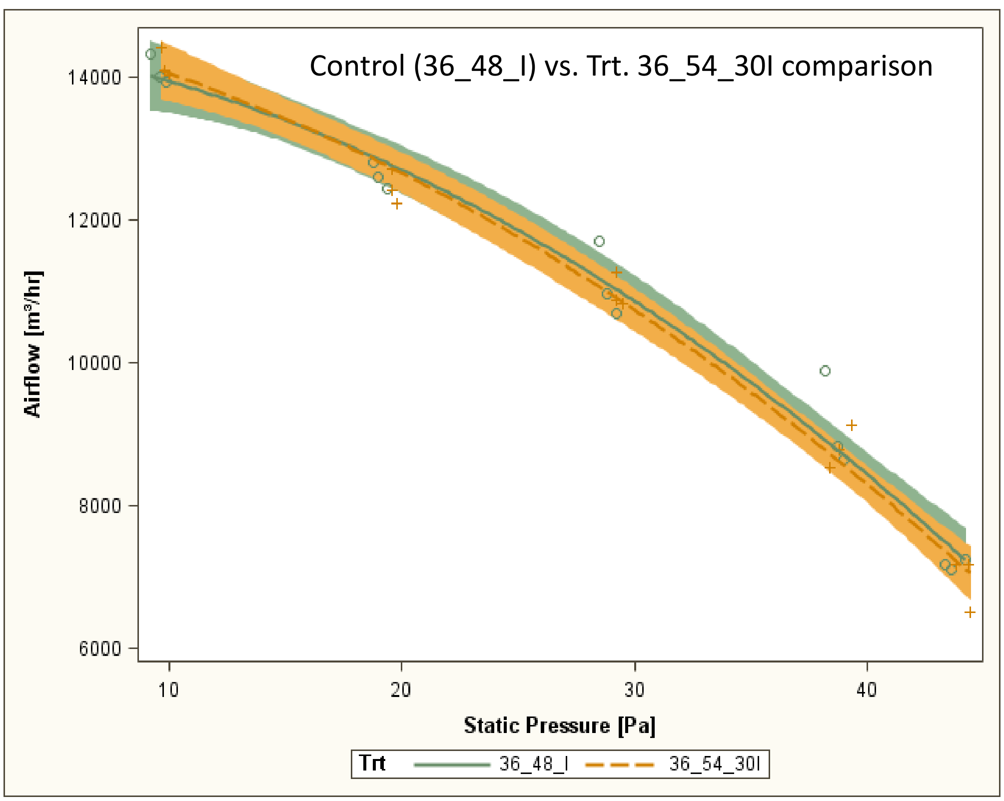


Figure 5-4 – Experiment 1(b). Fan performance curves with 95% confidence intervals.

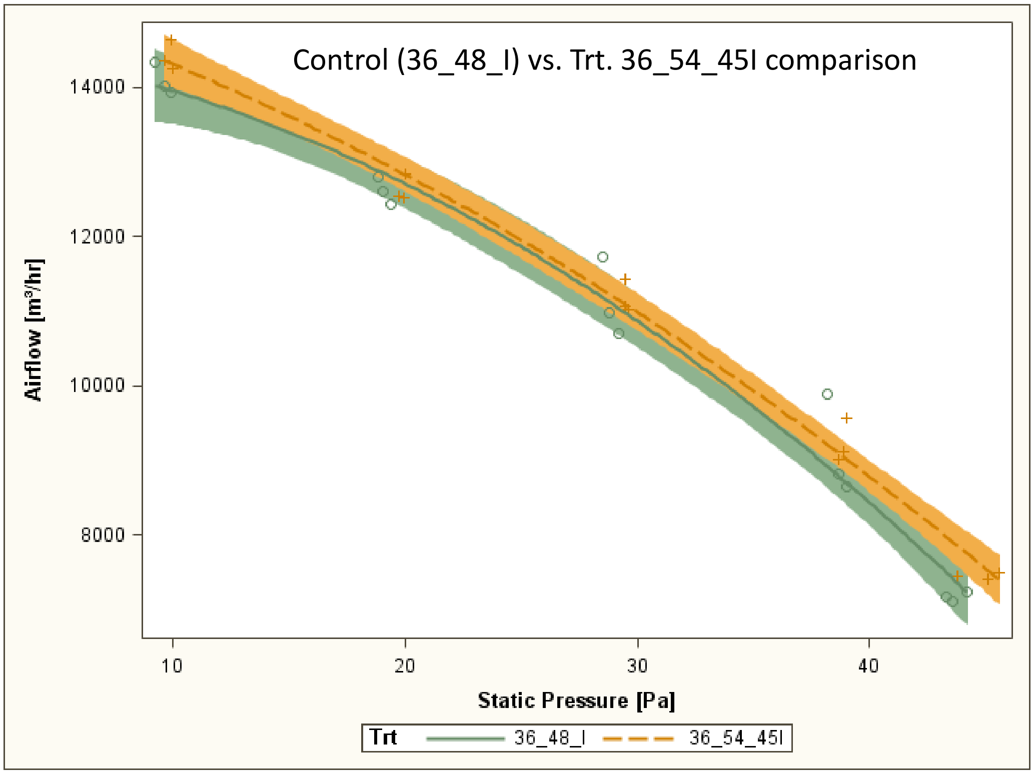


Figure 5-5 – Experiment 1(c). Fan performance curves with 95% confidence intervals.

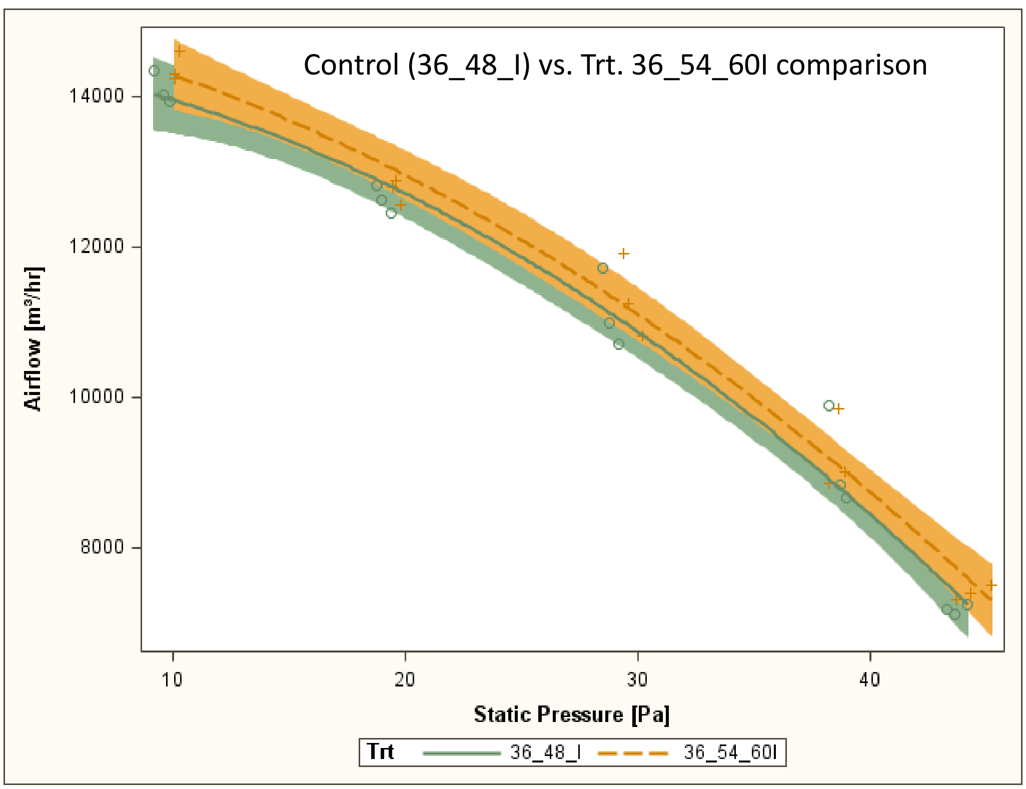


Figure 5-6 – Experiment 1(d). Fan performance curves with 95% confidence intervals.

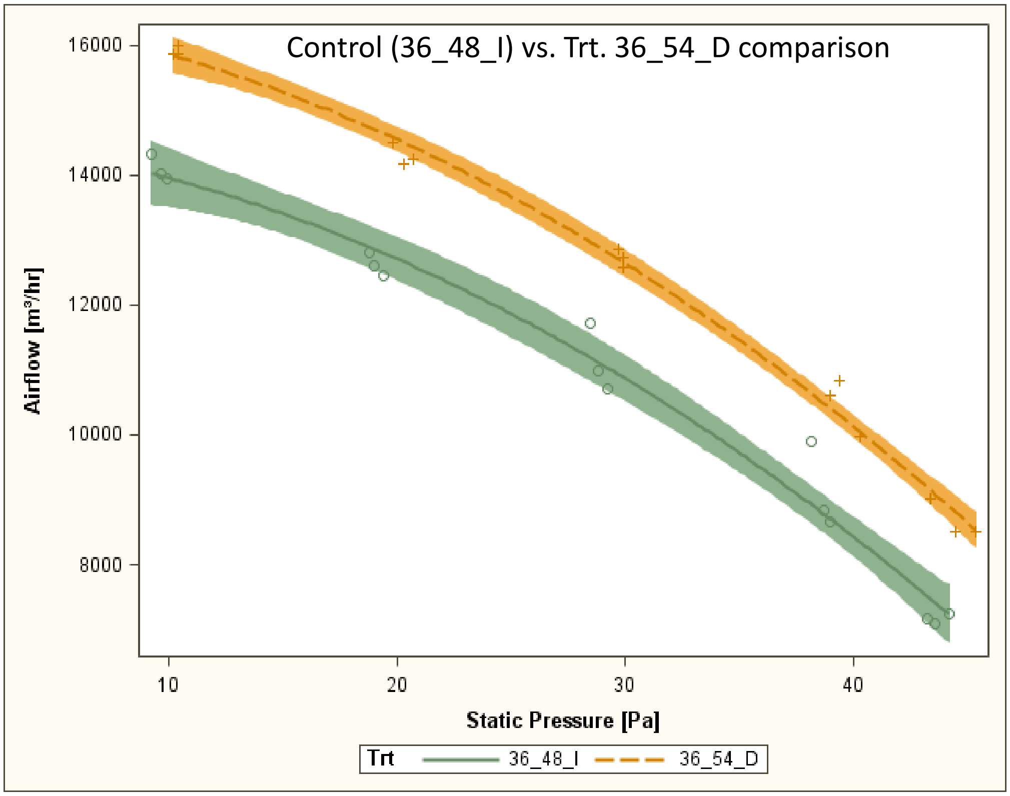


Figure 5-7 – Experiment 1(e). Fan performance curves with 95% confidence intervals.

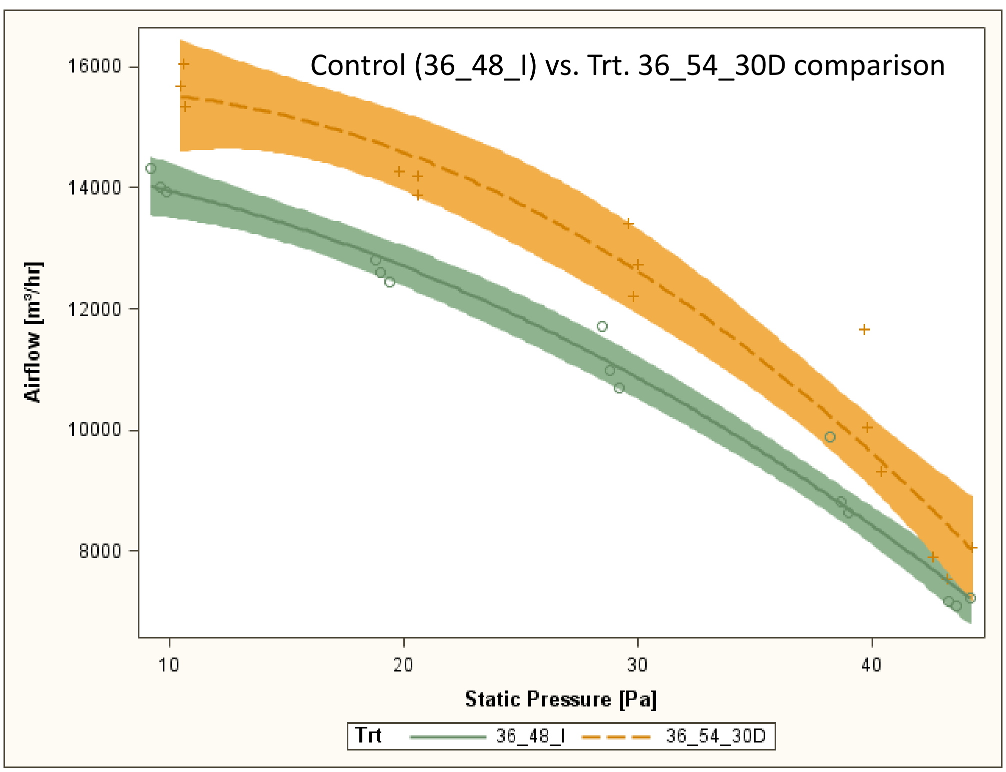


Figure 5-8 – Experiment 1(f). Fan performance curves with 95% confidence intervals

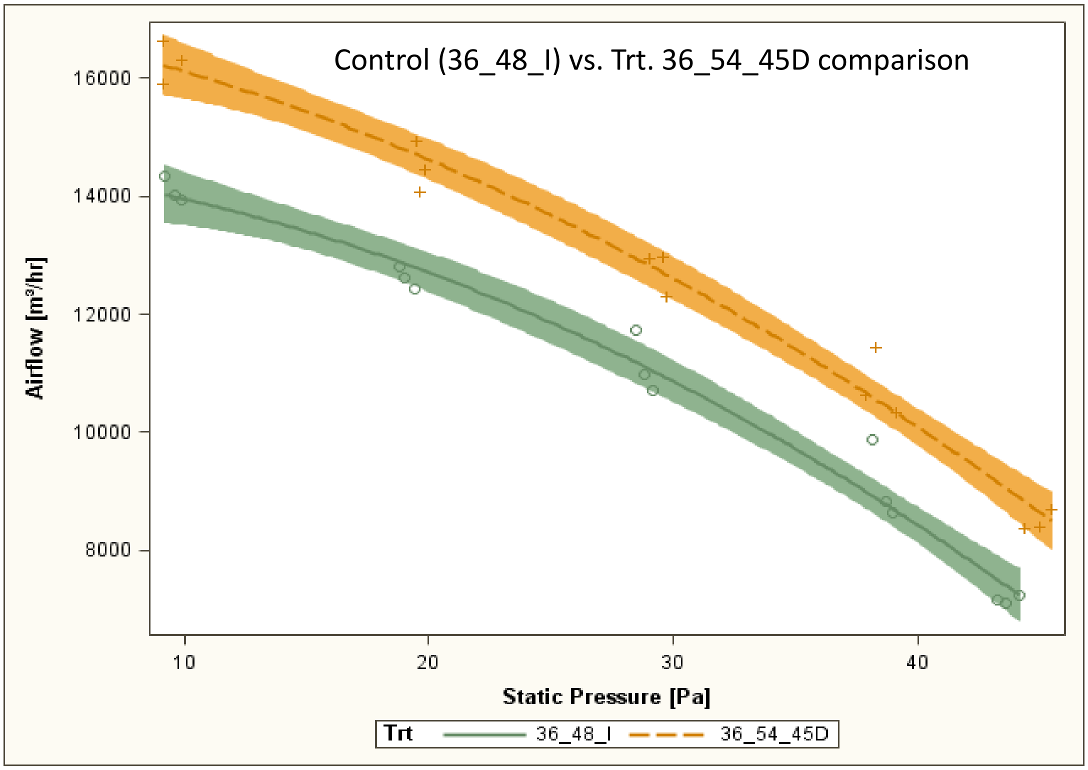


Figure 5-9 – Experiment 1(g). Fan performance curves with 95% confidence intervals.

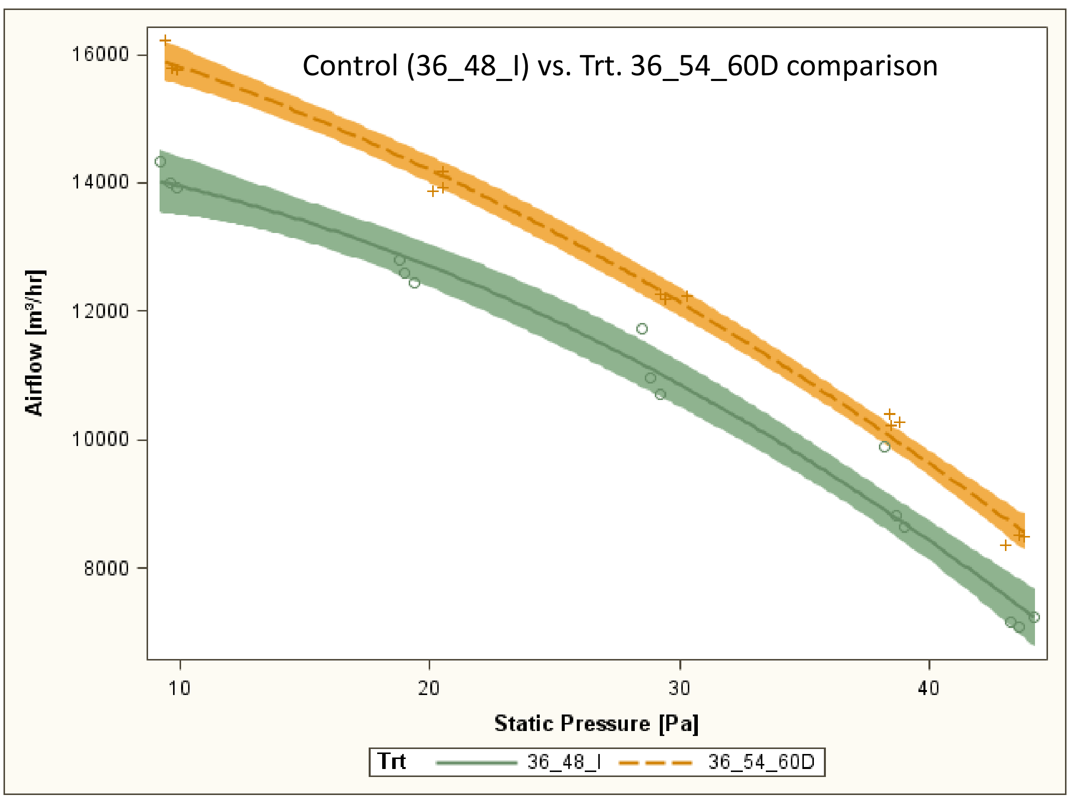


Figure 5-10 – Experiment 1(h). Fan performance curves with 95% confidence intervals.

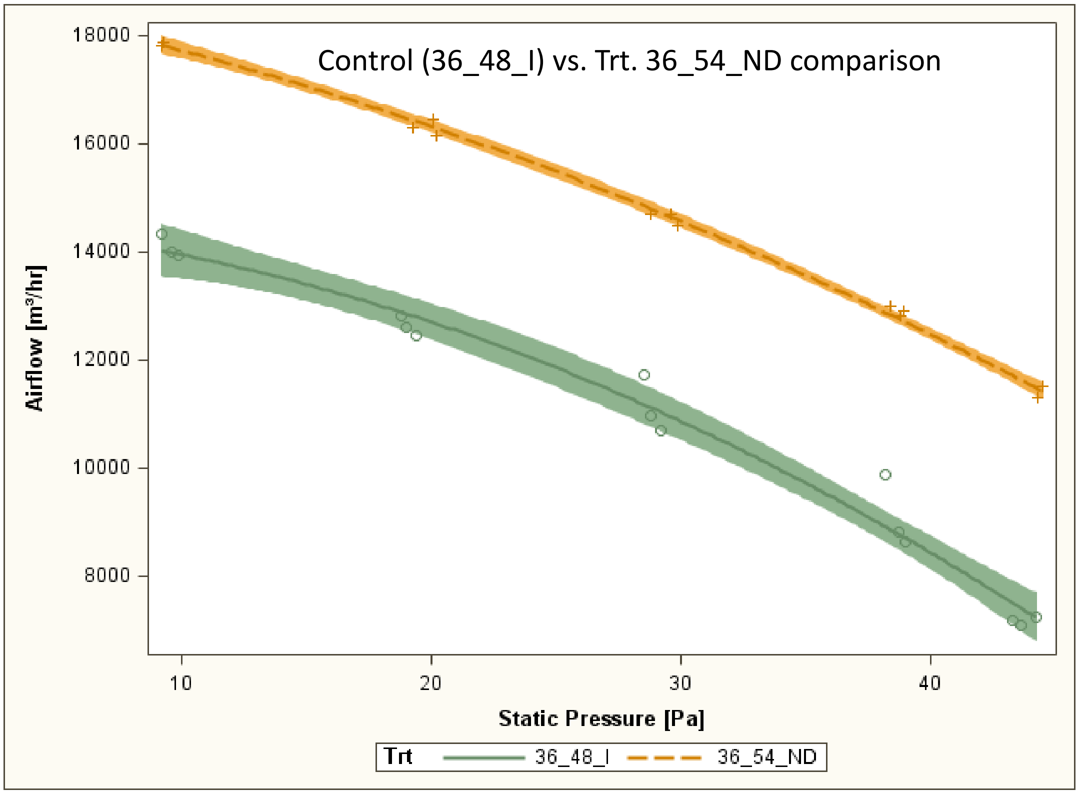


Figure 5-11 – Experiment 1(i). Fan performance curves with 95% confidence intervals.

5.3 Experiment 2: 1.22m (48") Fan.

The ANOVA analysis based on the statistical model described in section 4.3 shows that airflow readings were significantly different as different treatments were applied to the 1.22m fan ($p<0.0001$) (Appendix C). Given that there was significant difference between treatments a pair wise comparison of each treatment to the control treatment was performed. The Dunnett's procedure was used to perform the comparisons. Table 5-4 presents all comparisons to the control (48_48_I) treatment.

Table 5-4 – Experiment. 2, comparisons with control treatment (Dunnett's procedure).

Trt Compared to Control	**Difference between means [m^3hr^{-1}]**	**Simultaneous 95% Confidence Limits**		
48_54_ND	5137.7	4741.4	5534.0	*
48_54_D	2489.6	2093.2	2885.9	*
48_54_30D	2584.4	2188.1	2980.7	*
48_54_45D	2370.0	1973.7	2766.3	*
48_54_60D	2438.3	2042.0	2834.7	*
48_54_I	1006.1	609.7	1402.4	*
48_54_30I	1025.0	628.7	1421.4	*
48_54_45I	1053.5	657.2	1449.8	*
48_54_60I	1041.3	645.0	1437.6	*

Comparisons significant at the 0.05 level are indicated by *

All treatment comparisons were significantly different from the control treatment at the 0.05 level. All treatments that had the FANS unit positioned on the intake side of the fan produced smaller differences compared to the control than the discharge (outside) treatments.

All intake treatments resulted in approximately 1000 m^3hr^{-1} difference from the 48_48 (control) treatment. Differently from experiment 1, the treatment that uses the 1.37m (54") FANS unit and no transition (48_54_I) resulted in the smallest difference.

Outside treatments produced differences over twice as big as the intake treatments differences. Differences between means of the outside treatments and the control treatment were over 2000 m^3hr^{-1} for treatments with sealed gaps and over 5000 m^3hr^{-1} for the treatment with opened gap.

The average airflow difference between each treatment and control treatment, as described in section 4.3 was calculated. Second order polynomial regressions for each treatment were obtained so the average differences could be calculated. The coefficients for these analyses are presented in Table 5-5. The calculated average airflow differences for the control treatment versus each of the other treatments are given in Table 5-6.

Table 5-5 - Experiment. 2, second order polynomial regressions.

Trt	**Intercept [m^3hr^{-1}]**	**1st order coeff. [$m^5N^{-1}hr^{-1}$]**	**2nd order coeff. [$m^7N^{-2}hr^{-1}$]**	**R-squared**	**P-value**
48_48_I	27649.77	-152.76	-2.76	0.996	<0.0001
48_54_ND	33390	-222.53	-1.56	0.994	<0.0001
48_54_D	30408.91	-134.2	-3.6	0.998	<0.0001
48_54_30D	31594.14	-182.37	-3.21	0.999	<0.0001
48_54_45D	31347.83	-210.32	-2.51	0.999	<0.0001
48_54_60D	30874.06	-161.12	-3.34	0.998	<0.0001
48_54_I	28796.03	-166.94	-2.61	0.999	<0.0001
48_54_30I	28419.14	-134.79	-3.1	0.998	<0.0001
48_54_45I	28291.46	-120.84	-3.3	0.999	<0.0001
48_54_60I	28701.72	-153.38	-2.77	0.998	<0.0001

Table 5-6 – Experiment 2, airflow difference to control treatment

Trt	Aiflow Difference [m^3hr^{-1}]		Airflow Difference %	
	Mean	Std. Deviation	Mean	Std. Deviation
48_54_ND	4927	188.6	25.8	6.94
48_54_D	2420	455.0	12.1	0.52
48_54_30D	2576	778.3	12.6	1.25
48_54_45D	2238	584.1	11.0	0.58
48_54_60D	2355	597.8	11.6	0.58
48_54_I	881	74.6	4.5	0.79
48_54_30I	946	62.4	4.9	0.91
48_54_45I	1023	84.0	5.3	1.12
48_54_60I	1023	16.8	5.3	1.20

Results for experiment 2 showed that, similar to experiment 1, intake treatments produced smaller average differences with the control treatment than the discharge treatments. Intake treatments produced differences from 4.5%±0.79% to 5.3%±1.20% to the control treatment. Discharge treatments, however, produced higher differences (11.0%±0.58% to 12.6%±1.25% for closed gap treatments and 25.8%±6.94% for opened gap treatment). All treatments caused higher airflow rates than the control treatment.

In order to further understand and visualize the differences between treatments and the control, graphs with fan performance curves were plotted (Figure 5-12 through Figure 5-20). Each graph shows one treatment and the 48_48_I (control) treatment performance curves. The colored band around the curves indicates the 95% confidence interval of each polynomial regression. As indicated by the Dunnett's procedure and average airflow differences to the control treatment, treatments 48_54_30I, 48_54_45I, 48_54_60I and 48_54_I curves were closer to the control curve than the outside treatments were.

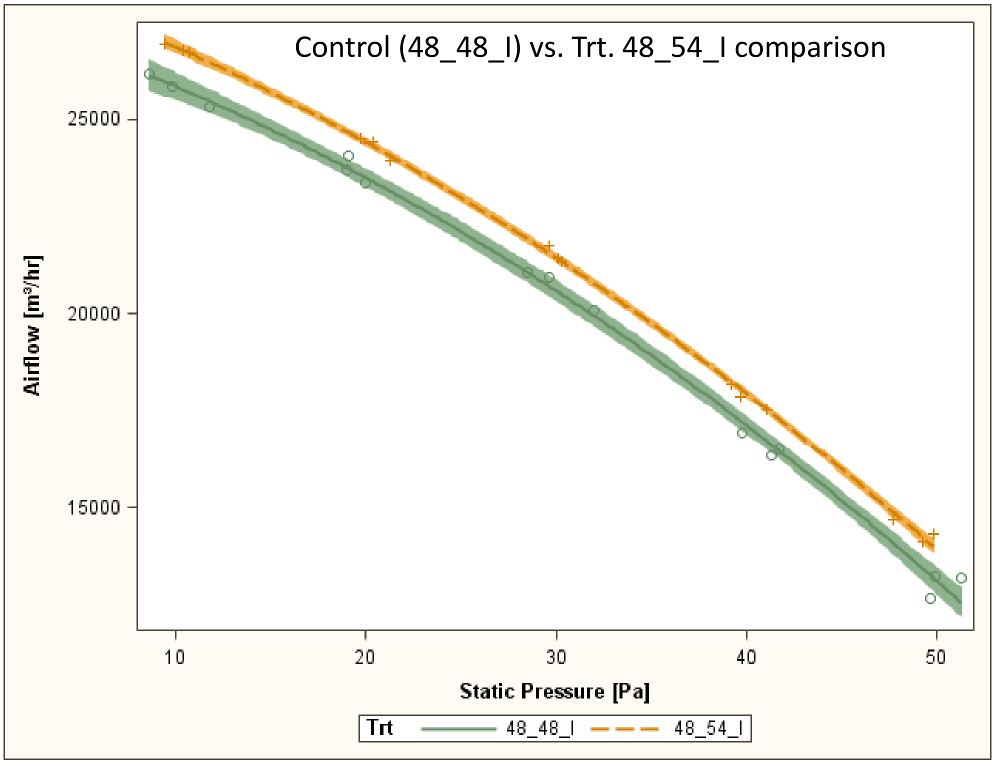


Figure 5-12 – Experiment 2(a). Fan performance curves with 95% confidence intervals.

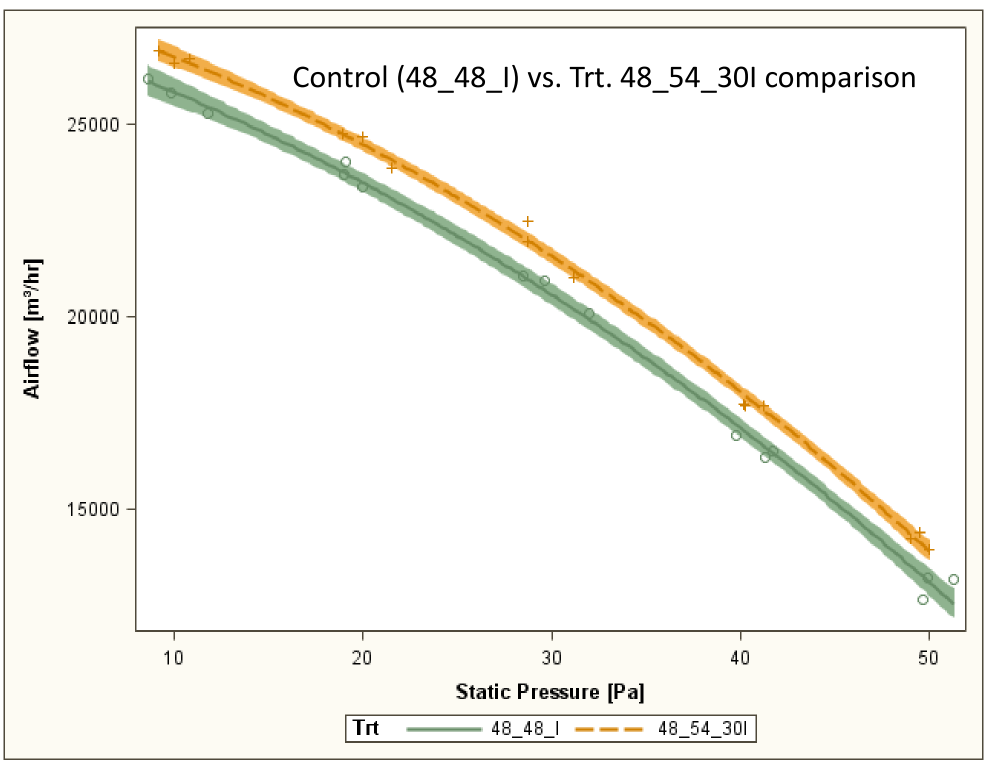


Figure 5-13 – Experiment 2(b). Fan performance curves with 95% confidence intervals.

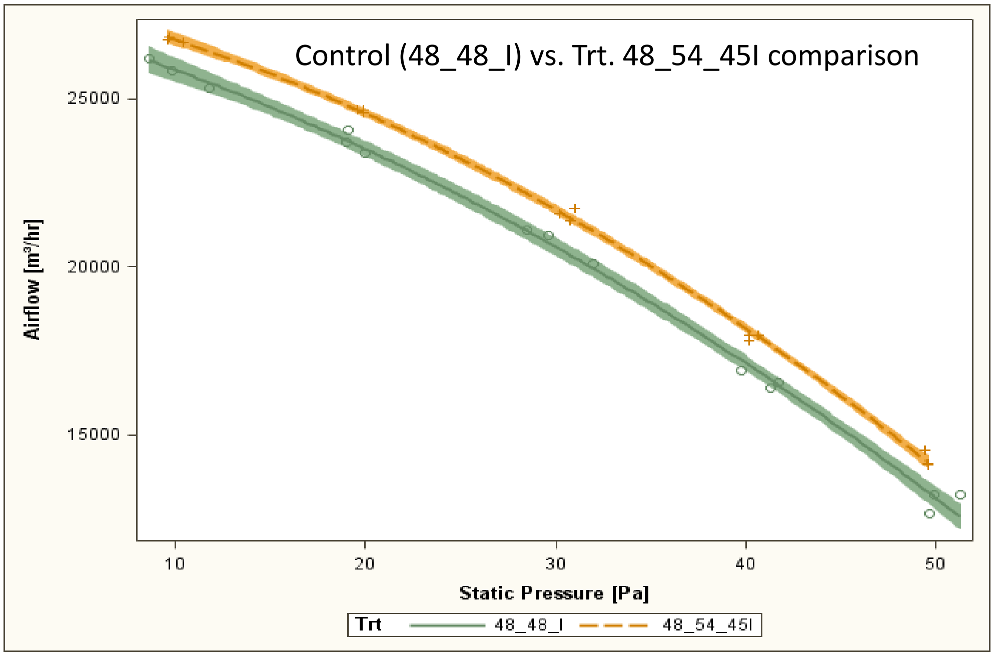


Figure 5-14 – Experiment 2(c). Fan performance curves with 95% confidence intervals.

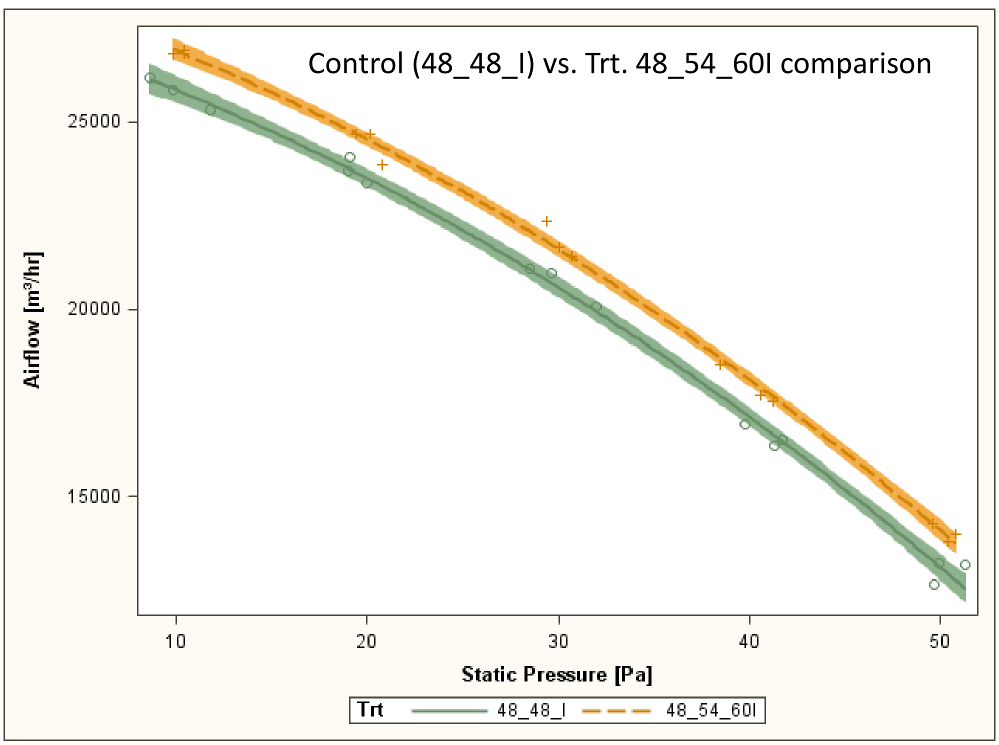


Figure 5-15 – Experiment 2(d). Fan performance curves with 95% confidence intervals.

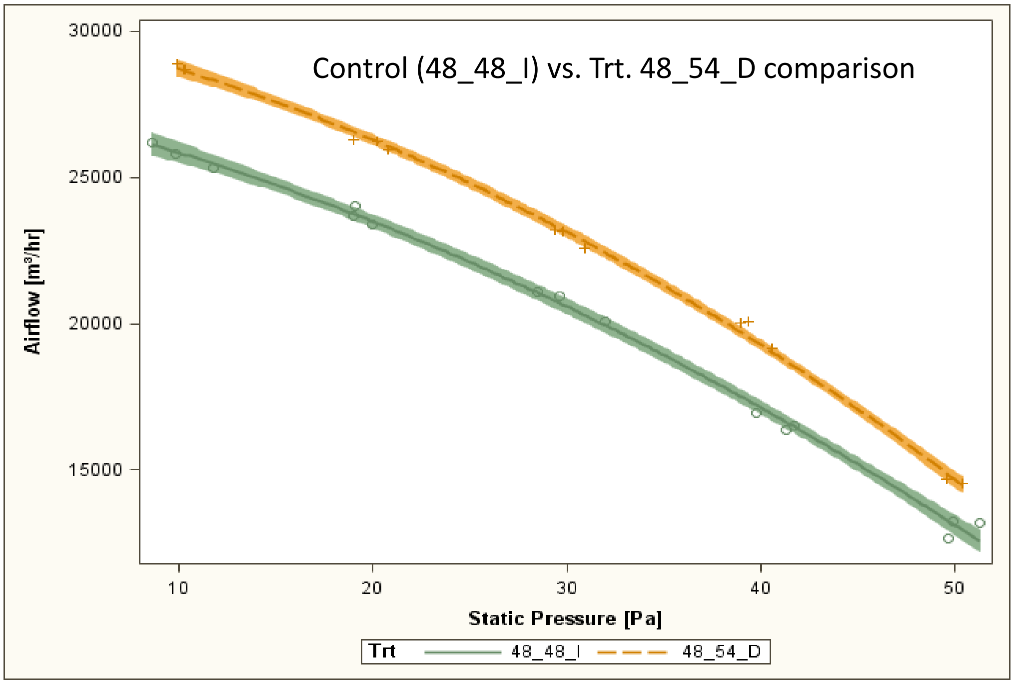


Figure 5-16 – Experiment 2(e). Fan performance curves with 95% confidence intervals.

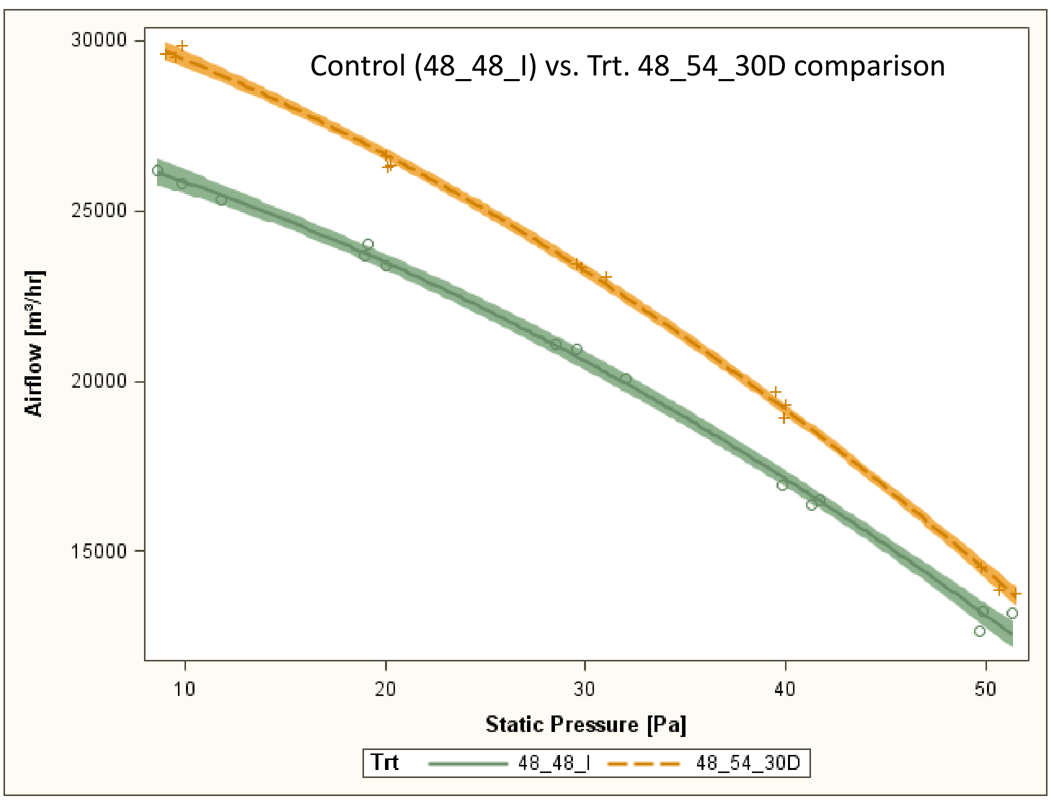


Figure 5-17 – Experiment 2(f). Fan performance curves with 95% confidence intervals.

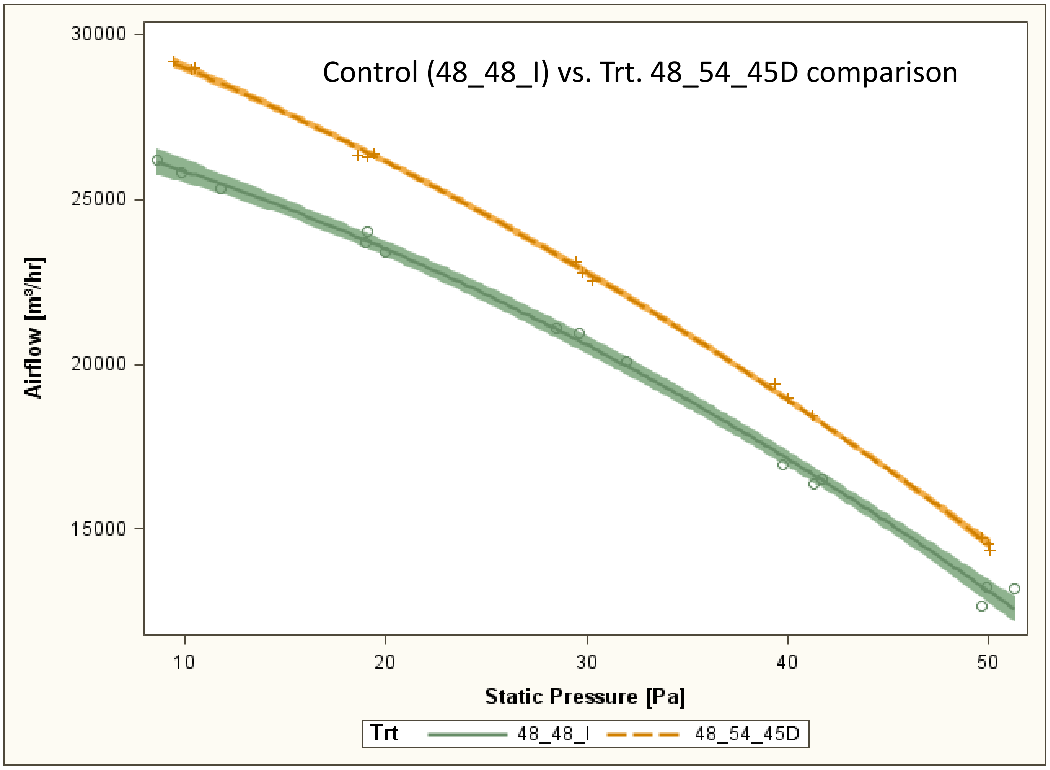


Figure 5-18 – Experiment 2(g). Fan performance curves with 95% confidence intervals.

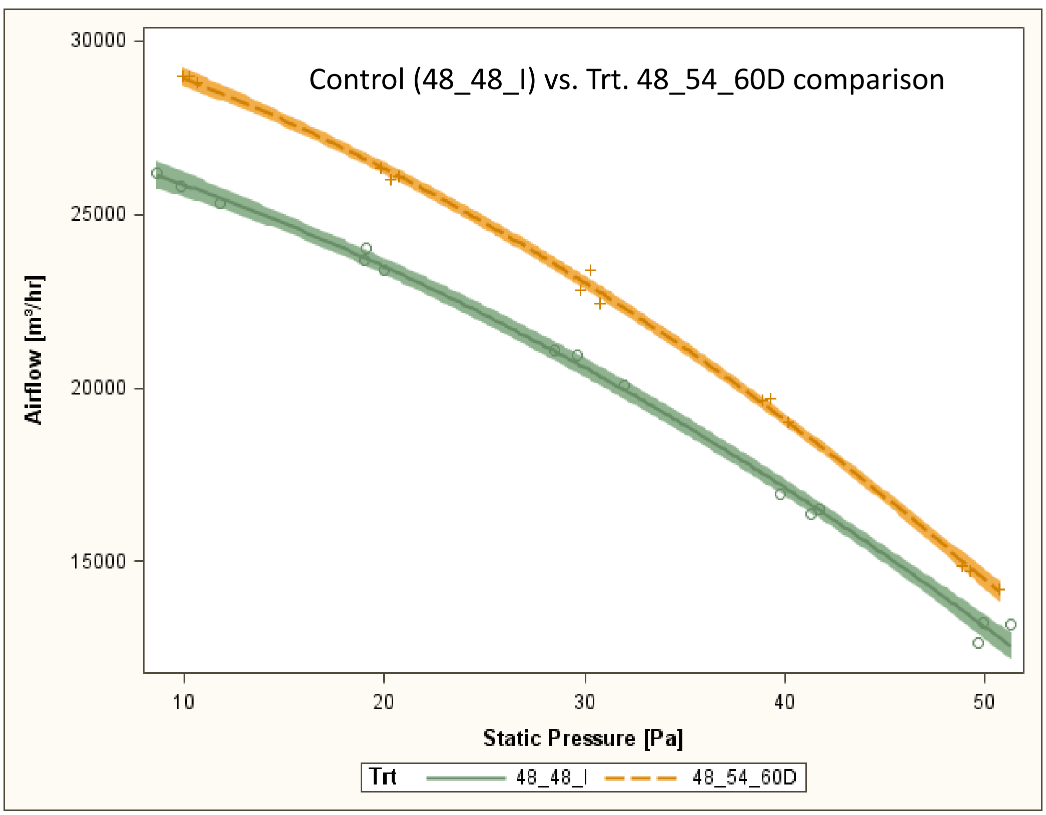


Figure 5-19 – Experiment 2(h). Fan performance curves with 95% confidence intervals.

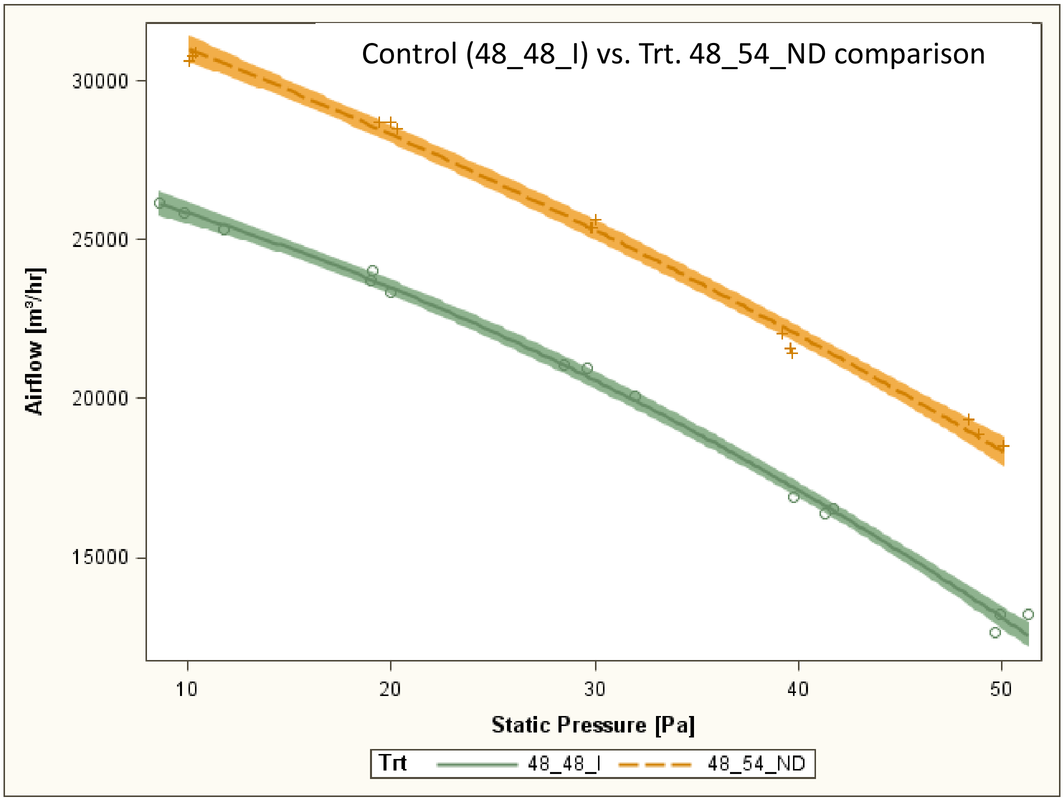


Figure 5-20 - Experiment 2(i). Fan performance curves with 95% confidence intervals.

5.4 Experiment 3: 1.37m (54") Fan.

The ANOVA analysis based on the statistical model described in section 4.3 shows that airflow readings were significantly different as different treatments were applied to the 1.37m fan ($p<0.0001$) (Appendix D).

Given that there was significant difference between treatments a pair wise comparison of each treatment to the control treatment was performed. The Dunnett's procedure was used to perform the comparisons. Table 5-7 presents all comparisons to the control (54_54_I) treatment.

Table 5-7 – Experiment 3, comparisons with control treatment (Dunnett's procedure).

Trt Compared to Control	Difference between means [m^3hr^{-1}]	Simultaneous 95% Confidence Limits		
54_54_ND	-3141.7	-3395.3	-2888.1	*
54_54_D	-1398.3	-1651.9	-1144.7	*
54_54_EI	-411.0	-664.6	-157.4	
Comparisons significant at the 0.05 level are indicated by *				

All treatment means comparisons were significantly different from zero at the 0.05 level. The Dunnett's procedure indicated that the difference between each treatment mean and the control treatment mean was smaller for the inside treatment than the outside (discharge) treatments. The treatment with no method of closing the gap between FANS unit and fan housing (54_54_ND) resulted in the biggest difference between means.

In order to calculate the average airflow difference between each treatment and control treatment, as described in section 4.3, second order polynomial regressions for each treatment were obtained. The results are presented in Table 5-8. The calculated average airflow differences for the control treatment versus each of the other treatments are given in Table 5-9

Table 5-8 - Experiment. 3, second order polynomial regressions.

Trt	Intercept [m^3s^{-1}]	1st order coeff. [$m^5N^{-1}s^{-1}$]	2nd order coeff. [$m^7N^{-2}s^{-1}$]	R-squared	P-value
54_54_I	55355.29	-179.79	-0.76	0.998	<0.0001
54_54_ND	51765.85	-154.05	-0.97	0.995	<0.0001
54_54_D	52708.55	-124.14	-1.16	0.996	<0.0001
54_54_EI	54931.53	-170.46	-1.03	0.997	<0.0001

Table 5-9 – Experiment. 3, airflow difference to control treatment.

Trt	Aiflow Difference [m^3hr^{-1}]		Airflow Difference %	
	Mean	Std. Deviation	Mean	Std. Deviation
54_54_ND	-3041.24	182.85	-6.19	0.09
54_54_D	-1403.91	437.80	-2.82	0.71
54_54_EI	-431.86	102.97	-0.89	0.27

Although the Dunnett's procedure indicated significant difference from all three treatments to the control treatment average airflow, the average airflow for the treatment with the 25.4cm (10") extension on the intake position was only 0.89%±0.27% lower than the control treatment. The use of the extension when necessary is, therefore, recommended. The discharge treatment with plastic sealing the gap between FANS and fan housing produced average airflow difference of 2.82%±0.71% lower to the control treatment. Tests conducted on with method of sealing the gap between FANS and fan housing resulted in higher average airflow differences to the control treatment (6.19%±0.09% lower)

In order to better visualize the differences between treatments and the control, graphs with fan performance curves were plotted (Figure 5-21 through Figure 5-23). Each graph shows one treatment and the 54_54_I (control) treatment performance curves. The colored band around the curves indicates the 95% confidence interval of each polynomial regression. As the first graph in Figure 5-22 shows, although treatment 54_54_EI (10" long extension) was considered statistically different, the mean difference between the 54_54_EI and the control treatment was not large (curves close to each other).

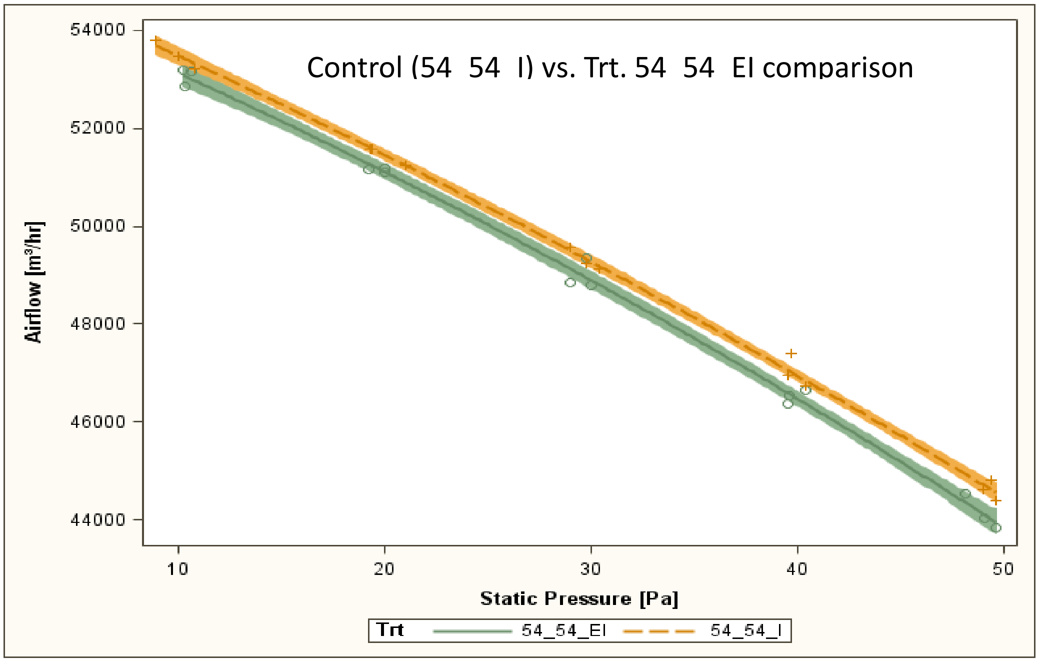


Figure 5-21 – Experiment 3(a). Fan performance curves with 95% confidence intervals.

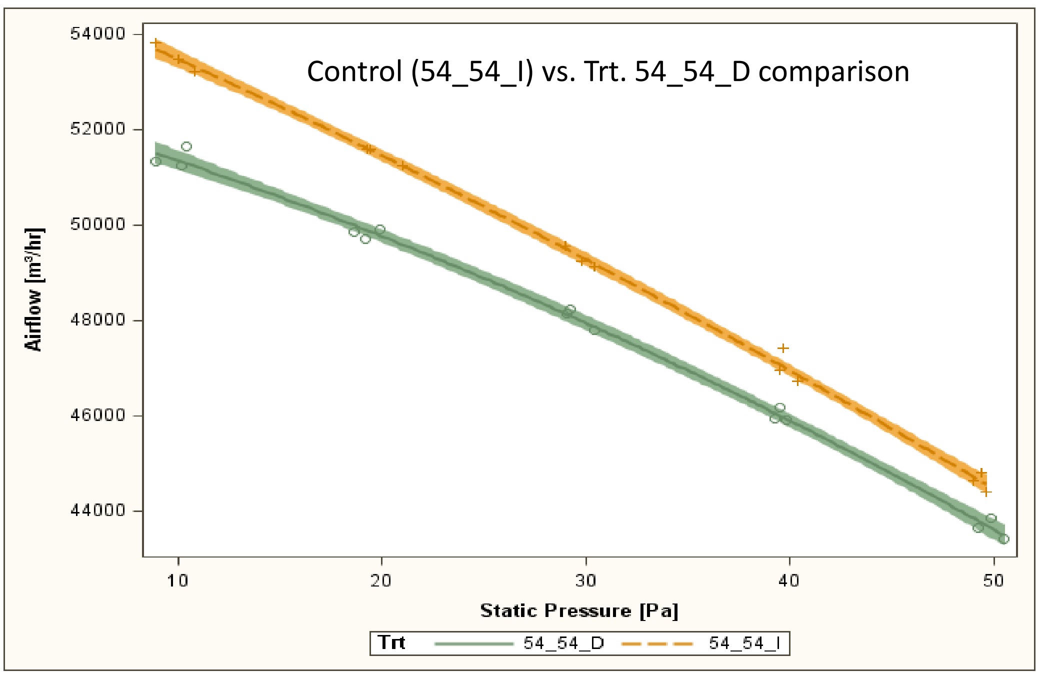


Figure 5-22 – Experiment 3(b). Fan performance curves with 95% confidence intervals.

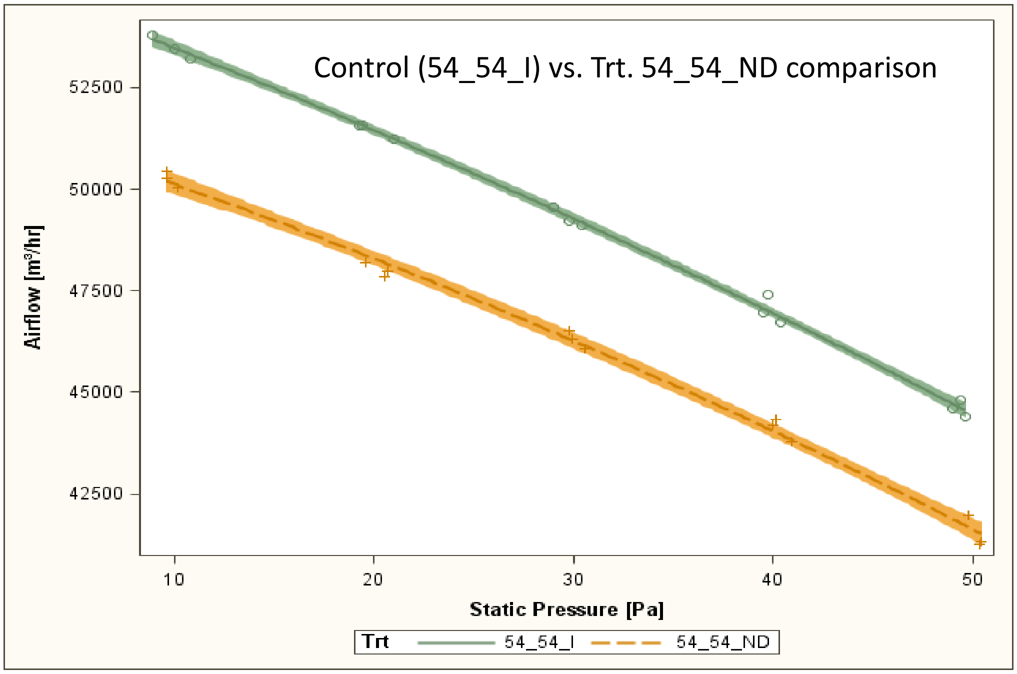


Figure 5-23 – Experiment 3(c). Fan performance curves with 95% confidence intervals.

Copyright© Igor Moreira Lopes 2012

Chapter 6. Summary and conclusion.

6.1 Summary

6.1.1 Experiment 1, 0.91m fan.

Airflow readings for the 0.91m fan were significantly influenced by treatments ($p < 0.0001$). The Dunnett's procedure used to compare treatments to the control treatment showed that intake treatments with a transition resulted in airflow measurements statistically equal to the control results (differences were less than or equal to 2.7%±1.11%). The intake positioning of the 54"FANS directly against the wall (no transition) produced an airflow test result that was significantly higher (7.1±3.66%) than the result from the control treatment (48"FANS directly against the wall).

Discharge (FANS positioned on the discharge side of the fan) treatments with sealed gaps between FANS and fan housing resulted in airflow readings 13.1%±1.93% to 17.2%±3.04% higher than the control treatment. The discharge treatment with open gaps produced an airflow measurement that was 37.1%±12.24% higher than results from the control treatment. All treatments statistically different from the control treatment had higher airflow rates than the control treatment

6.1.2 Experiment 2, 1.22m fan.

Airflow readings for the 1.22m fan were significantly influenced by treatments ($p < 0.0001$). The Dunnett's procedure results indicated that all treatments were significantly different from the control treatment.

Further investigation showed that, although all treatments were significantly different from the control treatment, differences between control results and intake treatment airflow measurements (4.5%±0.79 to 5.3%±1.20%) were lower than differences observed in the discharge treatments (11.0%±0.58% to 12.6%±1.25% for closed gap treatments and 25.8%±6.94% for opened gap treatment). All treatments resulted in higher airflow rates than the control treatment.

6.1.3 Experiment 3, 1.37m fan.

Airflow readings for the 1.37m fan were significantly influenced by treatments ($p < 0.0001$). The Dunnett's procedure result showed all treatments to be significantly different from the control treatment.

The use of an extension between FANS and fan housing, although significantly different from the control, resulted in differences of -0.9%±0.27% in airflow measurements compared to the control. The comparison between the intake treatment with the extension versus the control treatment, although statistically significant at 0.05 level, resulted in a mean difference that was near the FANS unit calibration absolute error (170 m^3hr^{-1})

The FANS unit, positioned on the discharge side of the fan with sealed gaps, produced airflow readings 2.8%±0.71 lower than the control results. The use of the FANS on the discharge side of the fan and with open gaps presented airflow measurements 6.19%±0.09% lower than the control. All treatments resulted in lower airflow rates than the control treatment

6.2 General conclusions.

All three experiments showed that the use of a transition or extension may cause a difference in the airflow reading compared to the generally accepted standard test condition (matching FANS unit size positioned on the intake side of the fan).

Airflow measurements performed with the 1.37m (54") FANS unit positioned on the intake side of the fans were closer to results from the control treatment than measurements obtained when the FANS was positioned on the discharge side of a test fan. In all treatments with statistically significant differences from the control, airflow measurements for the treatments were higher than results from the control treatment. Previous researchers reported that using a FANS unit on the discharge side of tested fan was possible and did not result in significant differences from the intake results. Li et al. (2009) reported no significant difference between intake and discharge tests performed on 1.32 and 1.22m fans. The fans tested had exhaust cones and were tested in the field. Li's results showed that the discharge treatment measurements were 0.6% ±0.4% to 4.0% ±0.9% higher than intake treatments results. Morello (2011) tested 1.22m fans with the 1.22m FANS unit in the field and reported no significant differences between discharge and intake treatments. Morello's discharge treatments produced average airflow rates 1.78%±5.26% higher than intake treatments for fan with no exhaust cone and airflow rates 1.56%±2.47% lower than intake treatment rates for fans with exhaust cone.

Results for this work, however, showed all discharge treatments resulted in significant differences in airflow compared to the control for all three fan sizes. Average airflow differences between the discharge treatment and the control treatment varied from 11.0%±0.58% to 17.2%±3.04% in experiments 1 and 2. In experiment 3 discharge treatments produced airflow rates 2.8%±0.71% lower than intake treatments. The higher airflow rates encountered in experiment 1 and 2 for the discharge treatments may be related to the FANS unit placed on the discharge acting as an exhaust cone, which tends to improve fan performance (Casey et al. 2008). Experiment 3, in which the fan tested had a cone resulted in discharge treatment rates lower than the intake treatment rates The fan discharge cone in this experiment had dimensions slightly larger than the width of the FANS unit. Morello (2011) also found airflow rates lower with FANS on the discharge side than with FANS on the intake side for fans with discharge cones. Her results were reversed for fans without discharge cones.

Wheeler et al. (2002) used a 1.22m FANS to measure airflow of a 0.91m fan and reported 2.5% difference between tests with a 1.22m long expanded polystyrene duct transition (α = approximately 14 degree) and no transition in field conditions. Casey et al. (2007), however, did not find benefits from using a transition when testing a smaller 0.415m fan. Results for this work showed that, for the 0.91m fan, the use of a transition resulted in lower average airflow rate differences to the control than tests with no transition (2.71%±1.11% and 7.08%±3.66% respectively).

Wheeler et al. (2002) suggested taping all gaps between FANS and fan housing and reported a 6% airflow measurement improvement versus not taping (FANS on the intake placement). Both, 0.91m and 1.37m fans were tested with opened gaps between FANS and fan housing (FANS on the discharge placement). Results showed the practice of sealing the gap should be used. Not sealing the gap resulted in an average airflow rate difference of 37.10%±12.24% for the 0.91m fan and 6.19%±0.09% for the 1.37m fan.

Transitions with angles varying from 30 to 60 divergence angle caused differences in airflow compared to the control that were similar in magnitude. Different transition angles did not appear to cause significant differences within the 30 to 60 degree range tested.

The fact that results from the Dunnett's procedure indicated significant differences even for small average airflow rate differences indicate the repeatability of the tests was good. It is important to remember that some of the small average airflow rate differences were on the order of the standard error of the calibration regressions and, although statistically significant, they should be interpreted with some caution. Fan performance curves with narrow confidence interval also indicate good repeatability of the tests.

6.3 Future work recommendations.

Based on the outcomes of this work, some recommendations for future work can be made:

- The discharge positioning of the FANS should be further investigated to better assess its effects. It is reasonable to expect different effects when testing fans with and without discharge cones. Different fan designs should also be considered.
- Although the transitions differed in angles, no significant difference in airflow measurement was encountered. However, a standard

transition design development is suggested so the variability between test results and setup from different research works is reduced.

- The full inlet automatic control capability of the WINTAC should be used. The development of a control software for the inlets will allow remote control of the inlets as well as automatic control to achieve and maintain specific static pressures inside the chamber.
- The use of the Bluetooth technology to connect the FANS to the computer made test setup and control easier, as well as allowed flexibility in the positioning of the FANS (no restrictions due to communication cord length). Use of the Bluetooth technology in the field should be considered

Copyright© Igor Moreira Lopes 2012

Appendix

Appendix A. SAS code for all 3 experiments (Dunnett's procedure)

```
   options ps=54 ls=80
 FORMDLIM='-';
    proc print data=WORK.Lopes_MS_1;
       title 'Exp 1 data';
 run;
proc GLM data=WORK.Lopes_MS_1;
 class Trt;
 model AF=Trt SP SP*SP/SS1;
 means Trt/ dunnett;
    title '0.91m Fan Performance Comparison';
   run;
   proc print data=WORK.Lopes_MS_2;
       title 'Exp 2 data';
 run;
proc GLM data=WORK.Lopes_MS_2;
 class Trt;
 model AF=Trt SP SP*SP/SS1;
 means Trt/ dunnett;
    title '1.22m Fan Performance Comparison';
   run;
   proc print data=WORK.Lopes_MS_3;
       title 'Exp 3 data';
 run;
proc GLM data=WORK.Lopes_MS_3;
 class Trt;
 model AF=Trt SP SP*SP/SS1;
 means Trt/ dunnett;
    title '1.37m Fan Performance Comparison';
   run;
```

Appendix B. Experiment 1 SAS output

Obs	Trt	AF	SP
1	36_48_I	11719.6	28.5
2	36_48_I	9884.9	38.2
3	36_48_I	12804.1	18.8
4	36_48_I	14331.5	9.2
5	36_48_I	7238.6	44.2
6	36_48_I	10973.2	28.8
7	36_48_I	8828.3	38.7
8	36_48_I	12609.9	19
9	36_48_I	14009.3	9.6
10	36_48_I	7102.2	43.6
11	36_48_I	8650.6	39
12	36_48_I	12443.3	19.4
13	36_48_I	10705.7	29.2
14	36_48_I	7171.6	43.3
15	36_48_I	13931.2	9.9
16	36_54_I	12032.6	30.5
17	36_54_I	13533.4	19.8
18	36_54_I	14779.7	9.9
19	36_54_I	7787.7	47.4
20	36_54_I	9932.2	39
21	36_54_I	11712.4	29
22	36_54_I	13174.9	19.5
23	36_54_I	14474.6	9.9
24	36_54_I	9715.4	38.8
25	36_54_I	7637	45.4
26	36_54_I	13038.9	19.7
27	36_54_I	14395.1	9.6
28	36_54_I	11180	29.8
29	36_54_I	9472.6	38.7
30	36_54_I	7520.3	44.6
31	36_54_30I	11278.8	29.2
32	36_54_30I	9142.1	39.3
33	36_54_30I	14431.7	9.7
34	36_54_30I	7166	44.3
35	36_54_30I	12721.2	19.6
36	36_54_30I	7181.2	43.8
37	36_54_30I	10882	29.2
38	36_54_30I	8794.2	38.8
39	36_54_30I	12422.9	19.6
40	36_54_30I	14092.9	9.8

41	36_54_30I	10843	29.5
42	36_54_30I	6505.9	44.4
43	36_54_30I	12248.1	19.8
44	36_54_30I	8531.4	38.4
45	36_54_30I	14021.1	10
46	36_54_30D	13409.3	29.6
47	36_54_30D	11651.9	39.7
48	36_54_30D	16039.9	10.6
49	36_54_30D	14193.1	20.6
50	36_54_30D	8067.1	44.3
51	36_54_30D	14261.7	19.8
52	36_54_30D	10034.5	39.8
53	36_54_30D	15668.3	10.5
54	36_54_30D	12723.9	30
55	36_54_30D	7541	43.2
56	36_54_30D	9312.3	40.4
57	36_54_30D	13890	20.6
58	36_54_30D	15335.3	10.7
59	36_54_30D	12221.2	29.8
60	36_54_30D	7904.5	42.6
61	36_54_45I	11435.2	29.5
62	36_54_45I	9571.4	39
63	36_54_45I	14629.8	9.9
64	36_54_45I	7486.6	45.6
65	36_54_45I	12842.3	20
66	36_54_45I	7416.8	45.1
67	36_54_45I	11072.4	29.5
68	36_54_45I	9107.1	38.9
69	36_54_45I	12543.1	19.7
70	36_54_45I	14244.3	10
71	36_54_45I	11024.4	29.6
72	36_54_45I	9012.6	38.7
73	36_54_45I	14367.3	9.6
74	36_54_45I	7448.9	43.8
75	36_54_45I	12520	19.9
76	36_54_45D	11424.8	38.3
77	36_54_45D	16632	9.1
78	36_54_45D	14922.7	19.5
79	36_54_45D	12981	29.6
80	36_54_45D	8688.5	45.5
81	36_54_45D	16301.1	9.9
82	36_54_45D	14456.9	19.8
83	36_54_45D	8396.2	45

84	36_54_45D	12947.8	29
85	36_54_45D	10333.5	39.1
86	36_54_45D	8370	44.4
87	36_54_45D	14076.9	19.6
88	36_54_45D	15893.9	9.1
89	36_54_45D	10636.7	37.9
90	36_54_45D	12292.8	29.7
91	36_54_60I	11906.1	29.4
92	36_54_60I	14586.1	10.3
93	36_54_60I	9842.5	38.6
94	36_54_60I	7497.5	45.2
95	36_54_60I	12874.7	19.6
96	36_54_60I	11234	29.6
97	36_54_60I	14302.6	10.1
98	36_54_60I	7378.6	44.3
99	36_54_60I	12784.6	19.5
100	36_54_60I	9002.1	38.9
101	36_54_60I	10815.5	30.2
102	36_54_60I	12541.4	19.8
103	36_54_60I	7299	43.7
104	36_54_60I	14225.4	10.1
105	36_54_60I	8852.6	38.2
106	36_54_60D	10238.8	38.5
107	36_54_60D	14171.4	20.5
108	36_54_60D	16217.3	9.4
109	36_54_60D	8496.7	43.8
110	36_54_60D	12184.6	29.4
111	36_54_60D	15789.7	9.7
112	36_54_60D	12234.7	30.3
113	36_54_60D	8510.4	43.6
114	36_54_60D	13915.7	20.5
115	36_54_60D	10274.2	38.8
116	36_54_60D	12274.3	29.2
117	36_54_60D	8356.6	43.1
118	36_54_60D	13864.3	20.1
119	36_54_60D	10410.5	38.4
120	36_54_60D	15747.8	9.9
121	36_54_ND	11298.5	44.3
122	36_54_ND	12921.9	38.9
123	36_54_ND	16290.1	19.3
124	36_54_ND	14484.2	29.9
125	36_54_ND	17831.9	9.2
126	36_54_ND	14708.5	29.6

127	36_54_ND	17826.3	9.2
128	36_54_ND	16458.3	20.1
129	36_54_ND	13005	38.4
130	36_54_ND	11518.6	44.5
131	36_54_ND	11291.6	44.3
132	36_54_ND	17886.4	9.3
133	36_54_ND	12829	38.8
134	36_54_ND	14704.9	28.8
135	36_54_ND	16148	20.2
136	36_54_D	10834.9	39.4
137	36_54_D	12860.7	29.7
138	36_54_D	8506.5	45.4
139	36_54_D	14258.6	20.7
140	36_54_D	15979.9	10.4
141	36_54_D	10610.8	39
142	36_54_D	12579.3	29.9
143	36_54_D	8504.7	44.5
144	36_54_D	14504.6	19.8
145	36_54_D	15867	10.4
146	36_54_D	12728.6	29.9
147	36_54_D	9011.5	43.4
148	36_54_D	9972.9	40.3
149	36_54_D	15857.9	10.2
150	36_54_D	14183.6	20.3

Class Level Information		
Class	Levels	Values
Trt	10	36_48_I 36_54_30D 36_54_30I 36_54_45D 36_54_45I 36_54_60D 36_54_60I 36_54_D 36_54_I 36_54_ND

Number of Observations Read	150
Number of Observations Used	150

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	11	1154902306	104991119	627.63	<.0001
Error	138	23084924	167282		
Corrected Total	149	1177987230			

R-Square	Coeff Var	Root MSE	AF Mean
0.980403	3.443393	409.0013	11877.86

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Trt	9	191359047.3	21262116.4	127.10	<.0001
SP	1	947917317.0	947917317.0	5666.58	<.0001
SP*SP	1	15625942.0	15625942.0	93.41	<.0001

Note: This test controls the Type I experiment wise error for comparisons of all treatments against a control.

Alpha	0.05
Error Degrees of Freedom	138
Error Mean Square	167282.1
Critical Value of Dunnett's t	2.72171
Minimum Significant Difference	406.48

Comparisons significant at the 0.05 level are indicated by ***.				
Trt Comparison	Difference Between Means	Simultaneous 95% Confidence Limits		
36_54_ND - 36_48_I	3786.6	3380.1	4193.1	***
36_54_45D - 36_48_I	1730.1	1323.6	2136.5	***
36_54_D - 36_48_I	1590.5	1184.0	1997.0	***
36_54_60D - 36_48_I	1352.2	945.7	1758.7	***
36_54_30D - 36_48_I	1323.3	916.9	1729.8	***
36_54_I - 36_48_I	532.2	125.7	938.7	***
36_54_60I - 36_48_I	182.6	-223.9	589.1	
36_54_45I - 36_48_I	154.5	-251.9	561.0	
36_54_30I - 36_48_I	-142.8	-549.2	263.7	

Appendix C. Experiment 2 SAS output

Obs	Trt	AF	SP
1	48_54_30D	29850	9.8
2	48_54_30D	26627.9	20
3	48_54_30D	23338.3	29.8
4	48_54_30D	19699.5	39.5
5	48_54_30D	13750.5	51.5
6	48_54_30D	19282.9	40
7	48_54_30D	29536.2	9.5
8	48_54_30D	26298.2	20.1
9	48_54_30D	14548.9	49.8
10	48_54_30D	23426	29.6
11	48_54_30D	29619.5	9
12	48_54_30D	26348.8	20.3
13	48_54_30D	18929.8	39.9
14	48_54_30D	13877.7	50.7
15	48_54_30D	23074.4	31
16	48_54_45D	18969	40
17	48_54_45D	28976.5	10.5
18	48_54_45D	23103.7	29.5
19	48_54_45D	14745.7	49.7
20	48_54_45D	26335.8	18.6
21	48_54_45D	19397.5	39.4
22	48_54_45D	14541.3	50
23	48_54_45D	22787.2	29.8
24	48_54_45D	26294.1	19.1
25	48_54_45D	29169.4	9.4
26	48_54_45D	14344.9	50.1
27	48_54_45D	22545.3	30.3
28	48_54_45D	18442	41.2
29	48_54_45D	26392.8	19.4
30	48_54_45D	28947.7	10.3
31	48_54_60D	28994.4	10.2
32	48_54_60D	26341.8	19.8
33	48_54_60D	19011.1	40.2
34	48_54_60D	14202.8	50.7
35	48_54_60D	23411.7	30.3
36	48_54_60D	26100.3	20.7
37	48_54_60D	28773.5	10.6
38	48_54_60D	19693.8	39.3
39	48_54_60D	14706.4	49.3
40	48_54_60D	22833.9	29.8

Obs	Trt	AF	SP
41	48_54_60D	28997.5	9.9
42	48_54_60D	14852.7	48.9
43	48_54_60D	19652.1	38.9
44	48_54_60D	22440.4	30.8
45	48_54_60D	26005.1	20.3
46	48_54_D	20073.5	39.4
47	48_54_D	14517.7	50.4
48	48_54_D	26226.9	20.2
49	48_54_D	23184.6	29.4
50	48_54_D	28700.2	10.2
51	48_54_D	19152	40.6
52	48_54_D	25935.1	20.8
53	48_54_D	14675.9	49.6
54	48_54_D	22568.2	30.9
55	48_54_D	28894.6	9.9
56	48_54_D	26303.7	19
57	48_54_D	23151.2	29.8
58	48_54_D	28709.7	10.3
59	48_54_D	20013.2	39
60	48_54_D	14679.2	49.6
61	48_48_I	16930	39.8
62	48_48_I	23375.7	20
63	48_48_I	12659.5	49.7
64	48_48_I	25829.5	9.8
65	48_48_I	21069	28.5
66	48_48_I	24041.8	19.1
67	48_48_I	20941.3	29.6
68	48_48_I	13202.8	51.3
69	48_48_I	16371.1	41.3
70	48_48_I	26171.2	8.6
71	48_48_I	23704.7	19
72	48_48_I	20085.2	32
73	48_48_I	25305.4	11.8
74	48_48_I	16532.8	41.7
75	48_48_I	13222.4	49.9
76	48_54_I	14336.3	49.8
77	48_54_I	24410.3	20.4
78	48_54_I	18171.8	39.2
79	48_54_I	26736.7	10.7
80	48_54_I	21355.9	30.3
81	48_54_I	14125	49.3
82	48_54_I	24516.1	19.7

Obs	Trt	AF	SP
83	48_54_I	26773.2	10.4
84	48_54_I	21417.7	30.1
85	48_54_I	17543.6	41.1
86	48_54_I	23929.3	21.3
87	48_54_I	14683.7	47.7
88	48_54_I	26929.1	9.4
89	48_54_I	21745.2	29.6
90	48_54_I	17859.4	39.7
91	48_54_30I	22508.9	28.7
92	48_54_30I	24671.3	20
93	48_54_30I	26709.8	10.8
94	48_54_30I	17716.8	41.2
95	48_54_30I	14390.7	49.5
96	48_54_30I	21963.8	28.7
97	48_54_30I	23871.2	21.5
98	48_54_30I	17745.7	40.2
99	48_54_30I	13972.7	50
100	48_54_30I	26901.8	9.2
101	48_54_30I	21037.2	31.2
102	48_54_30I	24775.2	18.9
103	48_54_30I	17694	40.3
104	48_54_30I	14262.5	49
105	48_54_30I	26596.5	10
106	48_54_45I	21718.6	31
107	48_54_45I	14526	49.4
108	48_54_45I	24646.2	19.9
109	48_54_45I	17953	40.7
110	48_54_45I	26822.9	9.7
111	48_54_45I	24670.9	19.6
112	48_54_45I	14148.2	49.6
113	48_54_45I	21587.2	30.2
114	48_54_45I	26755.1	9.6
115	48_54_45I	17946.9	40.2
116	48_54_45I	24568.3	19.9
117	48_54_45I	14090.5	49.6
118	48_54_45I	21361.4	30.8
119	48_54_45I	26666.3	10.4
120	48_54_45I	17783.9	40.2
121	48_54_60I	22344.8	29.4
122	48_54_60I	24667.7	20.1
123	48_54_60I	26907.8	10.4
124	48_54_60I	18522.2	38.5

Obs	Trt	AF	SP
125	48_54_60I	13998.6	50.8
126	48_54_60I	21640.5	30
127	48_54_60I	26835.1	9.8
128	48_54_60I	17708	40.6
129	48_54_60I	13814.3	50.4
130	48_54_60I	24667.6	19.4
131	48_54_60I	14300	49.6
132	48_54_60I	23865.6	20.8
133	48_54_60I	26830.2	10.4
134	48_54_60I	21406.6	30.7
135	48_54_60I	17553.1	41.2
136	48_54_ND	19359.1	48.4
137	48_54_ND	22043.2	39.2
138	48_54_ND	25661.4	30
139	48_54_ND	30907.5	10.4
140	48_54_ND	28733.8	20
141	48_54_ND	30782.2	10.2
142	48_54_ND	18902.4	48.9
143	48_54_ND	25374.4	29.8
144	48_54_ND	28730.6	19.4
145	48_54_ND	21594.2	39.6
146	48_54_ND	18501.6	50.1
147	48_54_ND	28481.9	20.3
148	48_54_ND	25364.1	29.9
149	48_54_ND	30645.1	10.1
150	48_54_ND	21426.6	39.7

Class Level Information		
Class	Levels	Values
Trt	10	48_48_I 48_54_30D 48_54_30I 48_54_45D 48_54_45I 48_54_60D 48_54_60I 48_54_D 48_54_I 48_54_ND

Number of Observations Read	150
Number of Observations Used	150

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	11	3686205065	335109551	2107.32	<.0001
Error	138	21945018	159022		
Corrected Total	149	3708150083			

R-Square	Coeff Var	Root MSE	AF Mean
0.994082	1.822771	398.7755	21877.43

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Trt	9	276538688	30726521	193.22	<.0001
SP	1	3374897330	3374897330	21222.8	<.0001
SP*SP	1	34769046	34769046	218.64	<.0001

Note: This test controls the Type I experimentwise error for comparisons of all treatments against a control.

Alpha	0.05
Error Degrees of Freedom	138
Error Mean Square	159021.9
Critical Value of Dunnett's t	2.72171
Minimum Significant Difference	396.31

Comparisons significant at the 0.05 level are indicated by ***.				
Trt Comparison	Difference Between Means	Simultaneous 95% Confidence Limits		
48_54_ND - 48_48_I	5137.7	4741.4	5534.0	***
48_54_30D - 48_48_I	2584.4	2188.1	2980.7	***
48_54_D - 48_48_I	2489.6	2093.2	2885.9	***
48_54_60D - 48_48_I	2438.3	2042.0	2834.7	***
48_54_45D - 48_48_I	2370.0	1973.7	2766.3	***
48_54_45I - 48_48_I	1053.5	657.2	1449.8	***
48_54_60I - 48_48_I	1041.3	645.0	1437.6	***
48_54_30I - 48_48_I	1025.0	628.7	1421.4	***
48_54_I - 48_48_I	1006.1	609.7	1402.4	***

Appendix D. Experiment 3 SAS output

Obs	Trt	AF	SP
1	54_54_ND	50446.9	9.6
2	54_54_ND	44347.3	40.1
3	54_54_ND	46532.7	29.8
4	54_54_ND	48200.8	19.6
5	54_54_ND	41964.6	49.8
6	54_54_ND	44194.5	40
7	54_54_ND	47999.9	20.7
8	54_54_ND	50041.9	10.2
9	54_54_ND	46080.2	30.6
10	54_54_ND	41262.7	50.3
11	54_54_ND	41310.2	50.4
12	54_54_ND	50283.5	9.6
13	54_54_ND	46316.7	29.9
14	54_54_ND	47862.4	20.5
15	54_54_ND	43775.6	40.9
16	54_54_D	43848.4	49.9
17	54_54_D	49918.8	19.9
18	54_54_D	51658.4	10.4
19	54_54_D	46165.4	39.5
20	54_54_D	48227.4	29.2
21	54_54_D	43648.4	49.2
22	54_54_D	48148.4	29.1
23	54_54_D	45905.9	39.8
24	54_54_D	49852.4	18.6
25	54_54_D	51333.8	8.9
26	54_54_D	45924.3	39.3
27	54_54_D	49706.9	19.2
28	54_54_D	47788.3	30.4
29	54_54_D	51248.3	10.2
30	54_54_D	43395.8	50.5
31	54_54_I	47414.8	39.7
32	54_54_I	44812.7	49.4
33	54_54_I	53812.9	8.9
34	54_54_I	49565.6	29
35	54_54_I	51582.9	19.4
36	54_54_I	46720.1	40.4
37	54_54_I	44618.2	49
38	54_54_I	51587.1	19.3
39	54_54_I	53472.5	10
40	54_54_I	49116.4	30.4

Obs	Trt	AF	SP
41	54_54_I	53220.6	10.8
42	54_54_I	51244.3	21
43	54_54_I	46950.8	39.5
44	54_54_I	49231.5	29.8
45	54_54_I	44395.5	49.6
46	54_54_EI	49340.9	29.8
47	54_54_EI	46649.7	40.4
48	54_54_EI	44542.4	48.1
49	54_54_EI	53183.1	10.2
50	54_54_EI	51093.4	20
51	54_54_EI	46524.7	39.6
52	54_54_EI	44019.4	49.1
53	54_54_EI	51200	20
54	54_54_EI	53154.9	10.6
55	54_54_EI	48794.5	30
56	54_54_EI	46375.5	39.5
57	54_54_EI	43836.5	49.6
58	54_54_EI	51159.2	19.2
59	54_54_EI	48842.5	29
60	54_54_EI	52864.1	10.3

Class Level Information		
Class	Levels	Values
Trt	4	54_54_D 54_54_EI 54_54_I 54_54_ND

Number of Observations Read	60
Number of Observations Used	60

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	638234627.4	127646925.5	1545.80	<.0001
Error	54	4459136.2	82576.6		
Corrected Total	59	642693763.6			

R-Square	Coeff Var	Root MSE	AF Mean
0.993062	0.599353	287.3614	47945.29

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Trt	3	87997037.1	29332345.7	355.21	<.0001
SP	1	548737208.9	548737208.9	6645.19	<.0001
SP*SP	1	1500381.4	1500381.4	18.17	<.0001

Note: This test controls the Type I experimentwise error for comparisons of all treatments against a control.

Alpha	0.05
Error Degrees of Freedom	54
Error Mean Square	82576.6
Critical Value of Dunnett's t	2.41689
Minimum Significant Difference	253.6

Comparisons significant at the 0.05 level are indicated by ***.				
Trt Comparison	Difference Between Means	Simultaneous 95% Confidence Limits		
54_54_I - 54_54_D	1398.3	1144.7	1651.9	***
54_54_EI - 54_54_D	987.3	733.7	1240.9	***
54_54_ND - 54_54_D	-1743.4	-1997.0	-1489.8	***

Copyright© Igor Moreira Lopes 2012

References

ASHRAE, 2009a. Chapter 16 - ventilation and infiltration, in: Handbook of Fundamentals. ASHRAE, Atlanta.

ASHRAE, 2009b. Chapter 14 - measurement and instruments, in: Handbook of Fundamentals. ASHRAE, Atlanta.

BESS, 2012. bess.illinois.edu/. University of Illinois.

Bottcher, R.W., Baughman, G.R., Magura, J.T., 1996. Field Measurements of Fan Speed and Power Use in Poultry Houses. Applied Poultry Science. 5, 56-62.

Burns, R., Li, H., Moody, L., Xin, H., Gates, R., Overhults, D., Earnest, J., 2008a. Quantification of Particulate Emissions from Broiler Houses in the Southeastern United States. Livestock Environment VIII. ASABE, Iguassu Falls, Brazil, pp. 101-109.

Burns, R.T., Li, H., Xin, H., Gates, R.S., Overhults, D.G., Earnest, J., Moody, L., 2008b. Greenhouse Gas (GHG) Emissions from Broiler Houses in the Southeastern United States. ASABE Annual International Meeting. ASABE, Providence, Rhode Island.

Calvet, S., Cambra-López, M., Blanes-Vidal, V., Estellés, F., Torres, a. G., 2010. Ventilation rates in mechanically-ventilated commercial poultry buildings in Southern Europe: Measurement system development and uncertainty analysis. Biosystems Engineering. 106, 423-432.

Casey, K.D., Bicudo, J.R., Schmidt, D.R., Singh, A., Gay, S.W., Gates, R.S., Jacobson, L.D., Hoff, S.J., 2006. AIR QUALITY AND EMISSIONS FROM LIVESTOCK AND POULTRY PRODUCTION / WASTE MANAGEMENT SYSTEMS. M. Rice, D. F. Caldwell, F.J.H. (Ed.), Animal Agriculture and the Environment: National Center for Manure and Animal Waste Managemente White Papers. ASABE, St. Joseph, Michigan, pp. 1-40.

Casey, K.D., Ford, S.E., Mcclure, J.W., Zhang, Y., Gates, R.S., 2007. DETERMINING FAN PERFORMANCE USING FANS: AN INVESTIGATION OF PERFORMANCE IMPACTS. Applied Engineering in Agriculture. 23, 333-338.

Casey, K.D., Gates, R.S., Shores, R.C., Thoma, E.D., Harris, D.B., 2010. Ammonia Emissions from a U.S. Broiler House—Comparison of Concurrent Measurements Using Three Different Technologies. Journal of the Air & Waste Management Association. 60, 939-948.

Casey, K.D., Gates, R.S., Wheeler, E.F., Xin, H., Liang, Y., Pescatore, a. J., Ford, M.J., 2008. On-Farm Ventilation Fan Performance Evaluations and Implications. The Journal of Applied Poultry Research. 17, 283-295.

Demmers, T.G.M., Burgess, L.R., Short, J.L., Phillips, V.R., Clark, J. a., Wathes, C.M., 1999. Ammonia emissions from two mechanically ventilated UK livestock buildings. Atmospheric Environment. 33, 217-227.

Gates, R.S., Casey, K.D., Xin, H., Burns, R.T., 2009. Building emissions uncertainty estimates. Transactions Of The Asabe. 52, 1345-1351.

Gates, R.S., Casey, K.D., Xin, H., Wheeler, E.F., Simmons, J.D., 2004. Fan assessment numeration system (FANS) design and calibration specifications. TRANSACTIONS-. 47, 1709-1715.

Groot Koerkamp, P; Metz, J. H. M.; Uenk, G. H.; Phillips, V. R.; Holden, M. R., Sneath, R. W.; Short, J. L.; White, R. P.; Hartung, J.; Seedorf, J.; Schroder, M.; Linkert, K. H.; Pedersen, S.; Takai, H.; Johnsen, J. O.; Wathes, C.M., 1998. Concentrations and Emissions of Ammonia in Livestock Buildings in Northern Europe. Journal of Agricultural Engineering Research. 70, 79-95.

Idelchik, I.E., 1986. Handbook of hydraulic resistance, in: Handbook of Hydraulic Resistance. Hemisphere Publishing Corporation.

Janni, K.A., Jacobson, L.D., Nicolai, R.E., Hetchler, B., Johnson, V.J., 2005. AIRFLOW EDUCTION OF LARGE BELT -DRIVEN EXHAUST VENTILATION FANS WITH SHUTTERS AND LOOSE BELTS. Brown-Brandl, T. (Ed.), Livestock Environment VIII, Proceedings of the Seventh International Symposium, May 2005, Beijing, China. ASAE, St. Joseph, Michigan.

Li, H., Xin, H., Li, S., Burns, R.T., 2009. UPSTREAM VS. DOWNSTREAM PLACEMENT OF FANS DEVICE TO DETERMINE VENTILATION FAN PERFORMANCE IN SITU. Transactions Of The Asabe. 52, 2087-2090.

Li, H., Xin, H., Liang, Y., Gates, R.S., Wheeler, E.F., Heber, A.J., 2005. COMPARISON OF DIRECT VS. INDIRECT VENTILATION RATE DETERMINATIONS IN LAYER BARNS USING MANURE BELTS. Transactions of the ASAE. 48, 367-372.

Lim, T.-T., Ni, J.-Q., Heber, A.J., Jin. Y., 2010. Applications and Calibrations of the FANS and Traverse Methods for Barn Airflow Rate Measurement. International Symposium on Air Quality and Manure Management for Agriculture. ASABE.

Lopes, I.M., Overhults, D.G., Morello, G.M., Earnest Jr, J., Gates, R.S., Pescatore, A., Jacob, J., Miller, M., 2010. Assessing Air Leakage in Commercial Broiler Houses. 2010 ASABE Annual International Meeting. Pittsburg, PA. Technical.

McMasterCarr, 2011. http://www.mcmaster.com.

Morello, G.M., 2011. INFLUENCE OF FAN OPERATION ON FAN ASSESSMENT NUMERATION SYSTEM (FANS) TEST RESULTS. University of Kentucky.

Pedersen, S., Takai, H., Johnsen, J.O., Metz, J.H.M., Groot Koerkamp, P.W.G., Uenk, G.H., Philips, V.R., Holden, M.R., Sneath, R.W., Short, J.L., White, R.P., Hartung, J., Seedorf, J., Schroder, M., Linkert, K.H., Wathes, C.M., 1998. A Comparison of Three Balance Methods for Calculating Ventilation Rates in Livestock Buildings. Journal of Agricultural Engineering Research. 70, 25-37.

Pescatore, A.J., Casey, K.D., Gates, R.S., 2005. Ammonia Emissions from Broiler Houses. Applied Poultry Science. 14, 635-637.

Plascore, 2012. www.plascore.com.

Rae Jr., W.H., Pope, A., 1984. Low-Speed Wind Tunnel Testing, Second edi. John wiley & sons.

Sama, M.P., Gates, R.S., Adams, W.C., Day, G.B., King, C.L., 2008. Fan Assessment Numeration System (FANS) Scaling and Upgrades. ASABE Annual International Meeting. Providemce, Rhode Island.

Santos, A.A.C., 2008. MODELAGEM NUMÉRICA COM VALIDAÇÃO EXPERIMENTAL DE ESCOAMENTO ATRAVÉS DO BOCAL INFERIOR DE UM ELEMENTO COMBUSTÍVEL NUCLEAR. Federal University of Minas Gerais.

Simmons, J.D., Hannigan, T.E., Lott, B.D., 1998a. A PORTABLEANEMOMETER TO DETERMINE THE OUTPUT OF LARGE IN-PLACE VENTILATION FANS. Applied Engineering in Agriculture. 14, 649-653.

Simmons, J.D., Lott, B.D., Hannigan, T.E., 1998b. MINIMUM DISTANCE BETWEEN VENTILATION FANS INADJACENT WALLS OF TUNNELVENTILATED BROILER HOUSES. Applied Engineering in Agriculture. 14, 533-535.

Topper, P.A., Wheeler, E.F., Zajaczkowski, J.S., Gates, R.S., Xin, H., Liang, Y., Casey, K.D., 2008. AMMONIA EMISSIONS FROM TWO EMPTY BROILER HOUSES WITH BUILT-UP LITTER. Transactions of The ASABE. 51, 219-225.

Wheeler, E.F., Casey, K.D., Gates, R.S., Xin, H., Topper, P.A., Liang, Y., 2008. Ammonia Emissions from USA Broiler Chicken Barns Managed with New Bedding , Built-up Litter , or Acid-Treated Litter. ASABE Annual International Meeting. ASABE, Iguassu Falls, Brazil, pp. 25-31.

Wheeler, E.F., Casey, K.D., Gates, R.S., Xin, H., Zajaczkowski, J.L., Topper, P.A., Liang, Y., Pescatore, A.J., 2006. AMMONIA EMISSIONS FROM TWELVE U.S. BROILER CHICKEN HOUSES. Transactions Of The Asabe. 49, 1495-1512.

Wheeler, E.F., Gates, R.S., Xin, H., Zajaczkowski, J.S., Topper, P.A., Casey, K.D., 2002. Field Estimation of Ventilation Capacity Using FANS. ASAE Annual International Meeting / CIGR XVth World Congress. Chicago, Illinois, USA.

Xin, H., Li, H., Burns, R.T., Gates, R.S., Overhults, D.G., Earnest, J.W., 2009. USE OF CO2 CONCENTRATION DIFFERENCE OR CO2 BALANCE TO ASSESS VENTILATION RATE OF BROILER HOUSES. Transactions Of The Asabe. 52, 1353-1361.

Zar, J.H., 1999. Biostatistical Analysis, Fourth Edi. Prentice Hall, Upper Saddle River, New Jersey, pp. 217-219.

Copyright© Igor Moreira Lopes 2012

VITA

Igor Moreira Lopes

Date and Place of Birth: 07/13/1985,

Timóteo, MG, Brazil.

Education:

01/2010 – Present

Graduate research assisstant in the Biosystems and Agricultural Engineering dpt., University of Kentucky, under supervision of Dr. Douglas G. Overhults. Project title:

“Evaluation of transitions for testing agricultural ventilation fans with the Fan Assessment Numeration System (FANS)”.

03/2003 – 12/2008

03/2003 – 08/2008 - B.S. in Agricultural Engineering , State University of Campinas (UNICAMP), Campinas, SP, Brazil.

2005-2006 One year as part of the Student Branch committee. Integration between new students and the campus community.

08/2006 – 08/2007 - One Scientific Initiation project (one year research program) in post harvesting, under supervision of Dr. Inácio Maria Dal Fabbro. Project title:

- “Aplicação da técnica de moiré no estudo da geometria de corpos vegetais” (“Application ot the moiré technique to study the geometry of vegetables”).

08/2007 – 08/2008 - One Scientific Initiation project (one year research program) in non-destructive test of construction materials, under supervision of Dr. Raquel Gonçalves. Project title:

- “Caracterização do concreto por teste de ultrasom” (“Concrete characterization with ultrasound testing”).

Work Experience:

January – December 2009

Research Assistant at the Research and Education Center, University of Kentucky. Worked on the project “Poultry House Evaluation Service (PHES)”, Princeton, KY.

July – December 2008

Research Assistant at the Laboratory for Non-Destructive tests and took two graduate level courses related to non-destructive test and experimental design. Worked with ultra-sound in wood and concrete materials. Took part in the research and development project “Projeto de Pesquisa e Desenvolvimento – P&D 133 – Classificação e monitoramento de postes das linhas aéreas” (Classification and inspection of poles used in electric distribution).of UNICAMP/CPFL

Awards and Achievements:

- Outstanding Project Award, in recognition of Kentucky Poultry Energy Efficiency Project – Kentucky Association of State Extension Professionals (March/2011).
- Member of Golden Key International Honor Society, University of Kentucky Chapter (May/2011).
- Member of Alpha Epsilon Honor Society of Agricultural, Food and Biological Engineering (2012)

Publication:

Journals:

GONCALVES, Raquel; GIACON JUNIOR, Milton and LOPES, Igor M. Determining the concrete stiffness matrix through ultrasonic testing. *Eng. Agric.* 2011, vol.31, n.3, pp. 427-437

Conferences:

Lopes, I.M., D.G. Overhults, and G.B. Day V. (2011). WINTAC: A Wind tunnel-based Transition Assessment Chamber wind tunnel chamber for evaluating methods of interfacing a FANS unit with exhaust ventilation fans for *in situ* performance testing. Presented at ASABE International Meeting August 7-10, 2011, Louisville, KY. St. Joseph MI: ASABE.

Morello, G.M., D.G. Overhults, R.S. Gates, G.B. Day V, and I.M. Lopes. (2011). Effect of Operating Nearby Fans on Test Results from a Fans Assessment Numeration System (FANS). Presented at ASABE International Meeting August 7-10, 2011, Louisville, KY. St. Joseph MI: ASABE.

Overhults, D.G., A. Pescatore, I.M. Lopes, G.M. Morello, J.P. Jacob, M. Miller, J.W. Earnest, Jr., and R.S. Gates. 2010. Air velocities in poultry houses raising large broilers. *2010 Poultry Science Association Annual Meeting*. Poultry Science 89 (Supp. 1).

Overhults, D.G., A. Pescatore, I.M. Lopes, G.M. Morello, J.P. Jacob, J.W. Earnest, Jr., M. Miller, and R.S. Gates. 2010. Overview of lighting in Kentucky broiler houses. *2010 Poultry Science Association Annual Meeting*. Poultry Science 89(Supp. 1).

Overhults, D.G., A. Pescatore, I.M. Lopes, G.M. Morello, J.W. Earnest, Jr., M. Miller, J.P. Jacob, and R.S. Gates. 2010. Using thermal imaging for poultry house energy assessments. *International Poultry Scientific Forum, Southern Poultry Science Society Meeting Abstracts*, p. 49.

Lopes, I. M., D. G. Overhults, G. M. Morello, J. Earnest Jr., R. S. Gates, A. Pescatore, J. Jacob and M. Miller. 2010. Assessing Air Leakage in Commercial Broiler Houses. *In 2010 ASABE Annual International Meeting*, Pittsburgh, Pennsylvania. Technical paper number: 1009236.

Morello G. M., D. G. Overhults, I. L. Lopes, J. Earnest Jr., R. S. Gates, A. Pescatore, J. Jacob, M. Miller. 2010. Influence of Fan Operations on FANS (Fan Assessment Numeration System) Test Results. *In: 2010 ASABE Annual International Meeting,* Pittsburgh, Pennsylvania. Technical paper number: 1009235.

GIACON JR., M. ; LOPES, I. M. ; GONÇALVES, R. . Grading and inspection of concrete poles using ultrasound - influence of the diameter and internal hole. In: International Conference of Agricultural Engineering, 2008, Foz do Iguaçu. Proceedings of CIGR International Conference of Agricultural Engineering, 2008. v. 1.

Lopes, I.M., Gonçalves R., CLASSIFICAÇÃO DE POSTES TUBULARES DE CONCRETO. PIBIC-XVI Congresso Interno de Iniciação Científica. UNICAMP, Campinas, SP. Brazil, 2008. T0967

Lopes, I.M., Dal Fabbro I. M. ,APLICAÇÃO DA TÉCNICA DE MOIRÉ NO ESTUDO DA GEOMETRIA DE CORPOS VEGETAIS. PIBIC- XV Congresso Interno de Iniciação Científica. UNICAMP, Campinas, SP. Brazil, 2007. T0814.

07/04/2012