AN EXPERIMENTAL STUDY AND ANALYSIS ON VENT CAP PERFORMANCE

A Thesis

by

DANIEL SANTIAGO ESCATEL

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

May 2011

Major Subject: Mechanical Engineering

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Approved by:

Chair of Committee,	Michael B. Pate
Committee Members,	Jorge L. Alvarado
	Warren Heffington
Head of Department,	Dennis O'Neal

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ABSTRACT

An Experimental Study and Analysis on Vent Cap Performance. (May 2011)

Daniel Santiago Escatel, B.S., Texas A&M University

Chair of Advisory Committee: Dr. Michael B. Pate

Air is removed from residential buildings for different reasons such as heat, odor, or moisture removal. The air is usually removed with exhaust fans connected to duct work that lead outside the building. At the interface between the ducting and the ambient, there are vent caps that are used to allow air to flow out the building but not into it. These vent caps can significantly contribute to the pressure that the exhaust fan must overcome to remove air from the building, which means the exhaust fan must consume more energy to run. Unfortunately, vent cap performances are not currently evaluated because there is no establish method to test them. For this reason the objective of this research was to develop a vent cap performance evaluation method that may be used for a variety of vent cap types, designs, and sizes. The evaluation method was then implemented to determine the variance among vent cap designs, determine the evaluation method's repeatability, and to create a method to estimate the vent cap's performance at a specific air flow rate.

An air flow chamber with an extension arm was used to test the vent caps. The extension arm is U-shaped to allow the adjustment to the three different orientations that are needed by the three vent cap types. The extension arm also has static pressure taps

to measure the pressure drop across the vent cap. The pressure drop was also used to calculate a nondimensional parameter known as a loss coefficient to facilitate performance comparison.

From this research it was concluded that the evaluation method can be implemented on the three vent cap types and a variety of designs and sizes. The repeatability of the evaluation method was confirmed by comparing two trials for two different products. The evaluation method was used to confirm that the variation in the products is significantly larger than the uncertainty in the measurements, which were 0.0077 in. w.c. for the pressure loss and 0.06 in the loss coefficient. It was also shown that the loss coefficients can be used to estimate the vent caps’ pressure drop at high air flow rates.

DEDICATION

I would like to dedicate this work to my Lord and Savior, Jesus Christ.

ACKNOWLEDGEMENTS

First of all I would like to thank my committee chair, Dr. Pate, for sparking my interesting in building energy analysis and for allowing me to work for him as an undergraduate student worker and as a graduate research assistant. A special thanks to Dr. Alvarado for allowing me to experience what it is to be a graduate student as an undergraduate and also for participating on my committee. I would also like to thank Dr. Heffington for taking the time to participate on my committee.

I would also like to thank Kathy Wadle, James Sweeney, Sankar Ravi, Sean Elliston, and Solomon for their help and friendship during my time at REEL. I would like to give a special thanks to Kelly Milligan for showing me how to air flow test, coming in on weekends to help me with my thesis research, and for being a kind and humorous manager during my time at REEL.

I would also like to thank my friends Cat, Leo, Jorge, and Joshua for their friendship during my time at Texas A&M. Last but not least, I would like to thank my sister, mother, father, and uncles for their amazing support over the years.

NOMENCLATURE

α	Alpha Ratio
C	Nozzle Discharge Coefficient
K	Loss Coefficient
μ	Dynamic Viscosity
$\overline{\mu}$	Mean
P_e	Saturated Vapor Pressure
P_p	Partial Vapor Pressure
P_b	Absolute Local Barometric Pressure
ΔP	Pressure Drop
ρ_0	Atmospheric Air Density at General Test Area
Q	Corrected Air Flow Rate
Q_5	Air Flow Rate
Re	Reynolds Number
σ	Standard Deviation
t_w	Wet-Bulb Temperature
t_d	Dry-Bulb Temperature
$\dot{V}$	Air Flow Rate
Y	Expansion Factor

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1. INTRODUCTION

Exhaust fans are used in residential buildings to remove heated air, odors, and moisture. These exhaust fans use ducting to route the air to the building's exterior. Vent caps are used at the interface of the ducting and the ambient to prevent unconditioned air and rain from entering through the ducting when the fan is off. The functional piece on a vent cap is a hinged damper that can swing open in one direction to allow exhausted air through. When there is no air pressure created by the exhaust fan, the damper remains closed under the damper's own gravitational force or a spring force.

The three vent cap types, which are soffit, wall-mounted, and roof jack, have different damper orientations due to their installation location. The three vent cap installation location can be seen in Figure 1. In Figure 1 it is important to notice that a soffit vent cap cannot be used as a wall-mounted vent cap because the damper will remain open. Therefore, each vent cap type is unique in its use and function. However, one thing that the three types have in common is that they all create a pressure loss for the exhaust fan to overcome.

This thesis follows the style of *ASHRAE Transactions.*

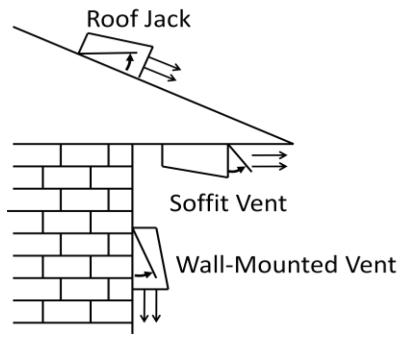

Figure 1. Vent Cap Orientation Diagram.

The pressure loss across the vent cap is important because it forces the fan blade to run at higher revolutions per minute, which consumes more energy and generates more noise, due to the higher pressure that the fan must overcome. For this reason the objective of this research was to develop a vent cap evaluation method that may be used for varied vent cap types, designs, and sizes. The evaluation method was then implemented to determine the variance among vent cap designs, the evaluation methods repeatability, and create a method to estimate the vent cap's performance at a specific air flow rate.

2. THEORY

2.1 Standard Air Density Correction for Static Pressure

The following equations are used to correct the static pressure and air flow rate for standard air density in accordance with HVI 916-2009 standard. The first equation defines the saturated vapor pressure (in. Hg), where t_{w0} is the wet-bulb temperature (°F).

(Eq. 1) $$p_e = \left(2.96x10^{-4}\right) t_{w0}^{\ 2} - \left(1.59x10^{-2}\right) t_{w0} + 0.41$$

The second equation defines the partial vapor pressure (in. Hg), where p_e is the saturated vapor pressure (in. Hg), p_b is the absolute local barometric pressure (in. Hg), and t_{d0} is the dry-bulb temperature in the general test area.

(Eq. 2) $$p_p = p_e - p_b \left(\frac{t_{d0} - t_{w0}}{2700} \right)$$

Equation 3 defines the atmospheric air density, where p_p is the saturated vapor pressure (in. Hg) and the other terms have already been defines.

(Eq. 3) $$\rho_0 = \frac{70.73\left(p_b - 0.378 p_p\right)}{R\left(t_{d0} + 459.67\right)}$$

Once the atmospheric density has been calculated equation 4 can be used to correct the measured static pressure. In equation 4, P_s (in. w.c.) is the measured static pressure and ρ_c is the standard air density, which is 0.075 lbm/ft^3.

(Eq. 4) $$P_{sc} = P_s \left(\frac{\rho_c}{\rho_0} \right)$$

2.2 Standard Air Density Correction for Air Flow Rate

The first step to make the standard air density correction to the air flow rate is to calculate the air density at the nozzle inlet chamber defined by equation 5. The only variable that has not been defined in equation 5 is t_{d5} (°F), which is the dry-bulb temperature in the inlet nozzle chamber.

(Eq. 5) $$\rho_5 = \rho_0 \left(\frac{t_{d0} + 459.67}{t_{d5} + 459.67} \right) \left(\frac{P_s + 13.63}{13.63 p_b} \right)$$

Equation 6 defines dynamic viscosity (lb_f-s/ft^2) as a function of the dry-bulb temperature (°F).

(Eq. 6) $$\mu = (11.00 + 0.018 t_d) x10^{-6}$$

In equation 7 the alpha ratio is defined, which is the ratio of absolute nozzle exit pressure to absolute approach pressure. For equation 7 the variable that has not been defines is ΔP, which is the differential pressure (in. w.c.) across the nozzle. The alpha ratio is used to define the expansion factor in equation 8. Note that the expansion factor is nondimensional.

(Eq. 7) $$\alpha = 1 - \frac{5.187 \Delta P}{53.35 \rho_5 (t_{d5} + 459.67)}$$

(Eq. 8) $$Y = 1 - 0.548(1 - \alpha)$$

The following two equations, which define the Reynolds number (Re) and the nozzle discharge coefficient (C), are interdependent. Therefore, the Reynolds number and nozzle discharge coefficient need to be solved iteratively. In equation 9 the variable that has not been defined is D_6, which is the nozzle diameter in feet.

(Eq. 9) $$\text{Re} = \frac{1096.7}{60\mu} C D_6 Y \sqrt{\Delta P \rho_5}$$

(Eq. 10) $$C = 0.9986 - \frac{7.006}{\sqrt{\text{Re}}} + \frac{134.6}{\text{Re}}$$

The final two equations define the air flow rate. In equation 11 the uncorrected air flow rate is defined, where A_6 is the nozzle cross-sectional area. If there is more than one nozzle open the products of C and A_6 must be summed. Then equation 12 produces the corrected air flow rate.

(Eq. 11) $$Q_5 = 1097 Y \sqrt{\frac{\Delta P}{\rho_5}} \Sigma(C A_6)$$

(Eq. 12) $$Q = Q_5 \left(\frac{\rho_5}{\rho_0} \right)$$

2.3 Loss Coefficient

To measure the pressure drop across the vent caps, a single pressure measurement is required since the vent cap's outlet is open to the ambient, which is at zero gauge pressure. The pressure drop and corresponding air flow rate are then used to calculate the loss coefficient seen in equation 13. The advantage to using the loss coefficient (K) is to facilitate the comparison between different sized vent caps. The specific equations used for 4-in. vent caps and 6-in. vent caps are seen in equation 14 and equation 15, respectively. The numbers preceding the equations are unit conversion factors. A detailed derivation of Equations 14 and 15 can be found in Appendix A.

(Eq.13)
$$K = \frac{\Delta P}{\frac{1}{2}\rho V^2}$$

(Eq. 14)
$$K = 122000\left(\frac{\Delta P}{\dot{V}^2}\right)$$

(Eq.15)
$$K = 617000\left(\frac{\Delta P}{\dot{V}^2}\right)$$

2.4 Kline-McClintock Uncertainty Analysis

The Kline-McClintock uncertainty analysis method is used to calculate the uncertainty in calculations made with measured parameters that also have an uncertainty. An example of the Kline-McClintock uncertainty analysis method is shown below, where w_A, w_B, w_C, and w_D are the error in variables A, B, C, and D, respectively.

(Eq. 16)
$$A = B \bullet C \bullet D$$

(Eq. 17)
$$w_A = \sqrt{\left(\frac{\partial A}{\partial B}\right)^2 (w_B)^2 + \left(\frac{\partial A}{\partial C}\right)^2 (w_C)^2 + \left(\frac{\partial A}{\partial D}\right)^2 (w_D)^2}$$

2.5 Coefficient of Variance

The coefficient of variance is a suggested measure of variability in data (D'Agostino and Schiff 1996). The coefficient of variance's definition, which can be seen in equation 18, is the standard deviation (σ) divided by the mean ($\bar{\mu}$). Therefore, the closer the coefficient of variance is to 1.0 the more variation there is in a data set.

(Eq. 18) $$CV = \frac{\sigma}{\bar{\mu}}$$

3. TEST METHODOLOGY

To create a vent cap evaluation method there were several requirements that had to be met. The first was to design an apparatus that would imitate the three different vent cap orientations required for proper function. The second requirement was to allow the uniform use of the evaluation method on all manufacturer designs and sizes. The third requirement was that the evaluation method was to facilitate the comparison between vent caps of different type, design, and size.

3.1 Apparatus

To generate the air flow an air flow chamber constructed in accordance with ASHRAE 51-2007 standard was used. A schematic of the entire setup can be seen in Figure 2. The blower creates air flow that travels through the air chamber and then through the extension arm. The extension is circular in cross-section and has a straw pack as indicated in the schematic. The straw pack is used to create fully developed flow. The straight section before the vent cap is ten diameters long to further ensure fully developed flow. In the schematic it can also be seen that the pressure reading is two diameters from the vent cap to minimize the effects of turbulence created by the vent cap.

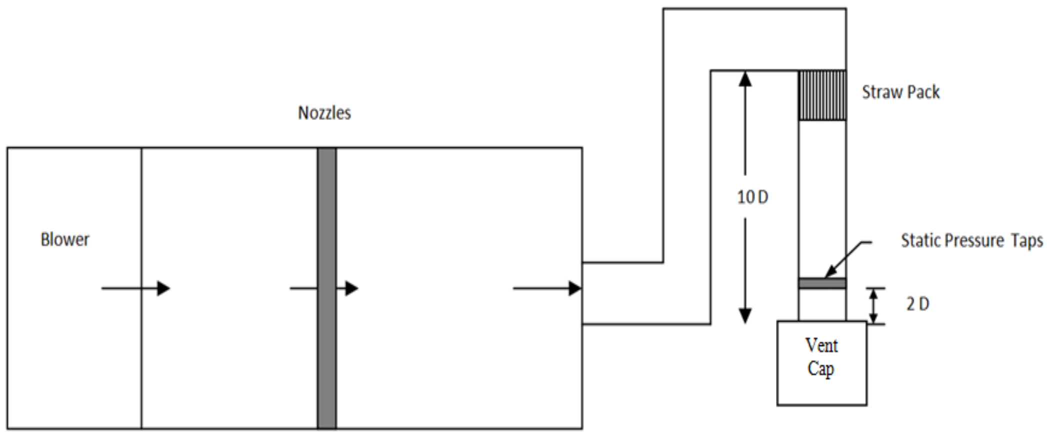

Figure 2. Test Apparatus Schematic.

The two main components that require some elaboration are the air flow chamber and the extension arm. The principle apparatus used is the air flow chamber seen in Figure 3**.** The air flow chamber is a cylindrical vessel with its circular faces perpendicular to the floor. The chamber is welded to a strut structure which raises it off the ground. At one end, the chamber is attached to a blower that creates air flow. The blower is controlled by a variable-frequency drive (VFD) to control the air flow. At the chamber's center is a plane parallel to the chamber's outer circular faces. On this center plane are five nozzles that are opened or closed depending on the desired air flow rate range. Pressure taps are placed before and after the nozzles to determine the differential pressure across the nozzles. The other end of the chamber is covered with a circular piece of plywood with a hole cut out at the center. An extension arm is attached to this end of the chamber with four bolts that are attached to the plywood plane.

Figure 3. Air Flow Chamber Picture.

The extension arm seen in Figure 4 is constructed with aluminum ducting pieces. The extension arm is in the shape of a “U” with an elbow at one end and the vent cap is attached to the other end. The elbow is attached to a plywood disk with two sets of holes drilled into it that are used to bolt the extension arm to the chamber. One set of holes are to orient the extension to test soffit and wall-mounted vent caps and the other set of holes are for the roof jack orientation. Near the vent cap is a pressure tap that is two diameters from the vent cap. This pressure tap measures the static pressure that is used to determine the pressure drop across the vent cap.

Figure 4. Extension Arm Picture.

3.2 Instrumentation

The instrumentation that was utilized to measure the necessary parameters can be seen in Table 1. It is important to note that the Dwyer 616-00 and Dwyer 616-1 pressure transmitters are responsible for the static pressure measurements in the extension arm. The Dwyer 616-00 pressure range is 0-1.0 inches of water and the Dwyer 616-1 pressure range is 0-3.0 inches of water.

Table 1. Instrumentation List.

Quantity	Descriptions	Manufacturer Model	Accuracy
1	Barometric Pressure Transducer	Setra 278	± 0.3 mb
1	Differential Pressure Transmitter	Dwyer 616-00	± 0.0025 in. w.c.
3	Differential Pressure Transmitter	Dwyer 616-1	± 0.0075 in. w.c.
3	Temperature Transmitter	Dwyer 650-2	± 0.34 °F

3.3 Test Procedure

1. Place the plywood plane on the air flow chamber. There is a separate plywood plane for the 4-in. and 6-in. vent caps. Ensure that the plywood plane is properly clamped and taped to eliminate air leaks.
2. Determine the extension arm orientation required by the vent cap to be tested. Wall-mounted vent caps require the extension arm to be parallel to the floor. Roof Jacks require that the extension arm be approximately 25° from vertical. Soffit vent caps require that the extension arm to be vertical. Figure 5 illustrates the extension arm orientation for each vent cap type.

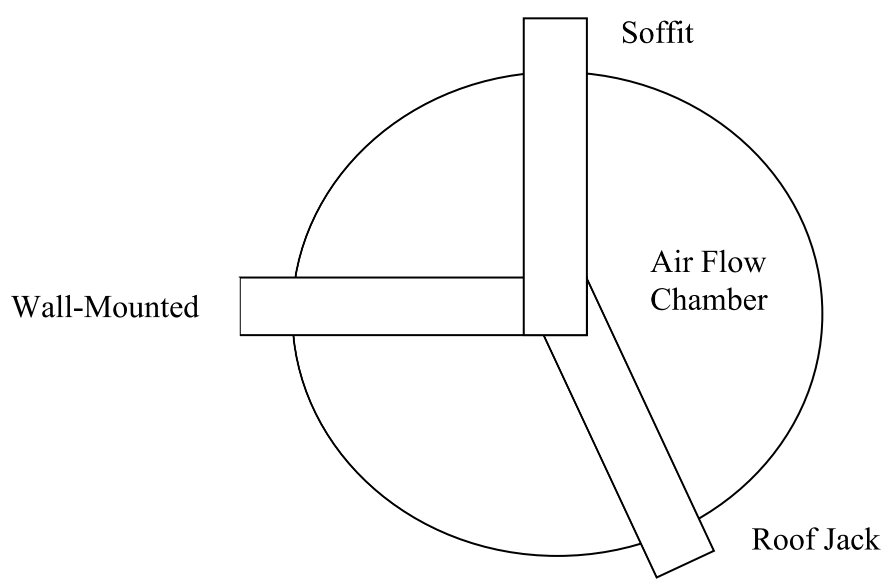

Figure 5. Extension Arm Orientation Schematic.

3. Bolt the extension arm in the proper orientation to the air flow chamber.

4. Attach and tape the vent cap to the extension arm with the damper perpendicular to the floor.
5. Open the appropriate nozzle. Nozzle #1 is used for air flow rates under 30 CFM. Nozzle #2 is used for air flow rates between 30 CFM and 300 CFM. Nozzle #3 is used for air flow rates between 300 CFM and 600 CFM.
6. Turn on psychometric station used to measure wet-bulb and dry-bulb temperature.
7. Zero pressure transducers to atmospheric pressure.
8. Start up data collection program (DCP) and input vent cap information requested by the program.
9. Collect a static pressure reading every 20 CFM for 4-inch vent caps and every 40 CFM for 6-inch vent caps.
10. Calculate the loss coefficient for each point using equation 14 or equation 15.

4. VENT CAP CHARACTERSTICS

The distinguishing characteristics for each vent cap can be seen in Table 2. The product letter, type, size, and the material the vent cap is constructed from can be seen in the table. Table 2 also indicates with an "X" if the vent cap has a damper, spring-loaded damper, or grill. The vent cap pictures can be seen in Appendix B.

Table 2. Vent Cap Characteristics.

Product	Size	Type	Material	Damper	Spring-Loaded Damper	Grill
A	4-in.	Soffit	Plastic	X		
B	4-in.	Soffit	Plastic	X		
C	4-in.	Soffit	Plastic	X		
E	4-in.	Wall-Mount	Steel			X
F	4-in.	Wall-Mount	Aluminum			X
G	4-in.	Wall-Mount	Galvanized	X		
H	4-in.	Wall-Mount	Plastic	(Louvers)		
I	4-in.	Wall-Mount	Plastic	X		X
J	4-in.	Wall-Mount	Plastic			X
K	4-in.	Wall-Mount	Aluminum			X
L	4-in.	Roof Jack	Plastic	X		X
M	4-in.	Roof Jack	Aluminum	X		X
N	4-in.	Roof Jack	Aluminum	X		
O	4-in.	Roof Jack	Aluminum	X		X
P	6-in.	Soffit	Plastic	X		X
Q	6-in.	Wall-Mount	Copper	X	X	
R	6-in.	Wall-Mount	Plastic			
S	6-in.	Wall-Mount	Aluminum	X	X	
T	6-in.	Wall-Mount	Aluminum	X	X	X
U	6-in.	Wall-Mount	Plastic	X	X	X
V	6-in.	Wall-Mount	Aluminum	X		
W	6-in.	Roof Jack	Plastic	X		X
X	6-in.	Roof Jack	Plastic	X		X

5. UNCERTAINTY ANALYSIS

The Kline-McClintock uncertainty analysis method was used to determine the uncertainty in the corrected pressure drop, corrected air flow rate, and the loss coefficient. To determine the uncertainty in these three parameters it was necessary to perform an uncertainty analysis on every variable defined in section 2.1. The uncertainty in the variables required to calculate the corrected static pressure can be seen in Table 3. The uncertainty in the static pressure was determined to be 0.0077 inches of water. By observing Table 1 it can observed that the majority of the uncertainty in the static pressure reading comes from the pressure transducer, which has an uncertainty of 0.0075 in. w.c.

Table 3. Corrected Static Pressure Uncertainty.

	P_e	P_p	ρ_0	P_{sc}
Error	0.01057 in. Hg	0.012 in. w.c.	2.5E-5 lbm/ft^3	0.0077 in. w.c.

To determine the uncertainty in the corrected air flow rate there were several variables whose uncertainty also needed to be calculated. The uncertainty in the variables used to calculate the corrected air flow rate can be seen in Table 4. It was determined that the uncertainty in the corrected air flow rate is 2.7 CFM.

Using the uncertainty in the corrected static pressure and corrected air flow rate it was also determine that the uncertainty in the loss coefficient was 0.06. It should be noted that that uncertainties mention in this section can be considered maximum uncertainties. The reason the uncertainties can be considered maximum uncertainties due to the fact that the uncertainty was analyzed for a 6-inch vent cap at the highest flow rate (400 CFM). For higher flow rates the Dwyer 616-1 pressure transducer is used, which has a larger uncertainty. Also, a larger nozzle is used for higher flow rates, which also adds to the uncertainty in the nozzle discharge coefficient and Reynolds number.

Table 4. Corrected Air Flow Rate Uncertainty.

	ρ_5	μ	α	Y	Re	C	Q5	Q
Error	6.9E-5 lbm/ft^3	6.12E-09 lb$_f$-s/ft^2	1.80E-05	1.00E-05	842	6.26E-05	2.68 CFM	2.70 CFM

6. RESULTS

The test methodology was implemented to produce the figures found in this section. The figures in the section are categorized in the follow groups: pressure drop with respect to air flow rate graphs, average pressure drop with respect to average air flow rate graphs, loss coefficient with respect to air flow rate graphs, and the average loss coefficient with respect to average air flow rate graphs.

6.1 Pressure Drop versus Air Flow Rate Graphs

The graphs in this subsection display the pressure drop versus the air flow rate. The pressure drops are displayed in the units of inches of water and the air flow rates are in cubic feet per minute (CFM). Each graph has the same scale for the pressure drop and air flow to allow comparison. The pressure drop has a scale that starts at zero and ends at 1.2 inches of water with tick marks at every 0.2 inches of water. The air flow rate scale starts at zero and end at 250 CFM in intervals of 50 CFM. There are a total of six graphs in this subsection representing 4-inch and 6-inch soffit, wall-mounted, and roof jack vent caps. Each product is represented by 11 points in evenly spaced intervals of 20 CFM or 40 CFM that start at zero and end at 200 CFM or 400 CFM. Each figure also has a legend that indicates the product letter. The product letter can be used to find the product's raw data table in Appendix C.

The first graph that will be described is Figure 6, which represents the 4-inch soffit vent caps. In this figure there are three products shows along. Each product has a steady increase in pressure drop as the air flow rate increases. At 20 CFM, product A shows a significantly lower pressure drop from the other two products. Product A and product B have a pressure difference that starts at 0.05 inches of water and ends at 0.6 inches of water. Product A and B experience the same pressure drop up to 100 CFM. After 100 CFM, product B starts to show a lower pressure drop by about 0.1 inches of water. At 200 CFM, there is a spread in pressure drop of 0.7 inches of water between the three products. Product A has the lowest pressure drop with 0.4 inches of water and product C has the highest pressure drop with 1.1 inches of water at 200 CFM.

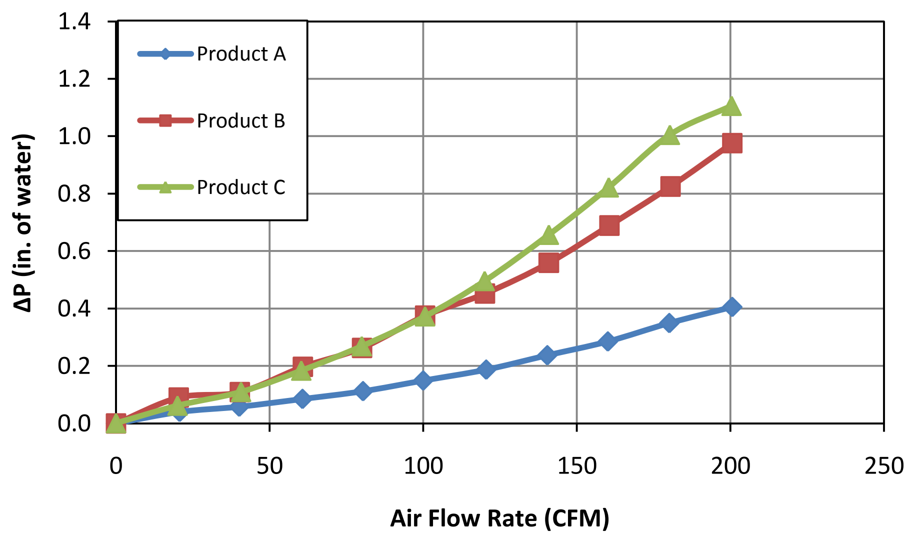

Figure 6. Pressure Drop versus Flow Rate for 4-inch Soffit Vent Caps.

The next graph is Figure 7, which displays the 4-inch wall-mounted vent caps. In this figure there are seven different products that are represented. In Figure 7 it can be seen that five of the products create a pack with a maximum range of 0.25 inches of water. In the pack, Product I has the highest pressure drop and begins to show a separation from the pack after 50 CFM. Product E and product I remain indistinguishable throughout the entire graphs domain. Product F distinguishes itself from product G after 120 CFM. At 200 CFM, product F has a difference of about 0.025 inches of water between itself and products E, G, and I. Product G experiences the lowest pressure drop between the five products packed together. The products that greatly distinguish themselves from the rest of the products are products J and H. Product J shows that it will have a much larger pressure drop than the rest after 40 CFM. Product J's separation from the pack ranges between 0.025 and 0.4 inches of water. The other product that showed some unique behavior is product H. The most unique characteristic that product H possesses is that its pressure drop does not vary significantly after 20 CFM. After 20 CFM it maintains around 0.025 inches of water in pressure drop. The uniqueness of Product H's pressure drop could be due to the fact that this is the only vent cap that uses louvers instead of a damper.

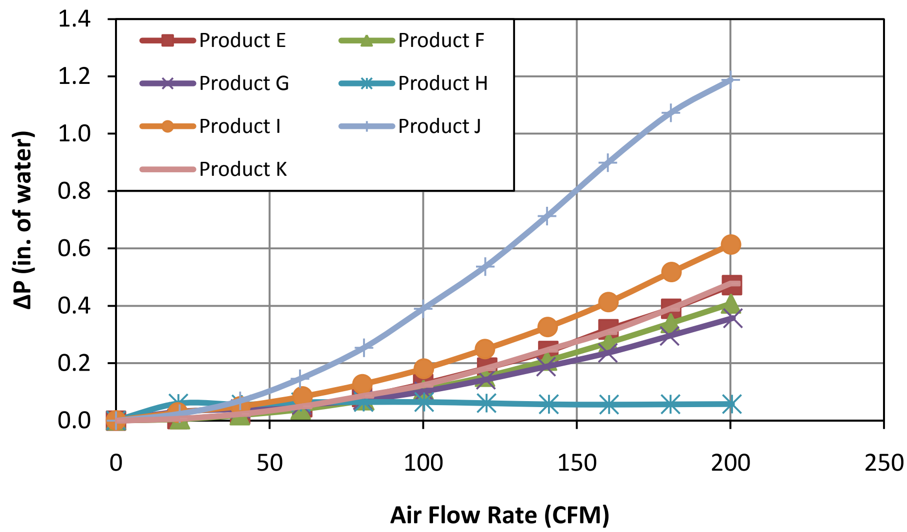

Figure 7. Pressure Drop versus Flow Rate for 4-inch Wall-Mounted Vent Caps.

The results for the 4-inch roof jack vent caps can be seen in Figure 8. There were four 4-inch roof jacks that were tested in total. From Figure 8 it can be seen that the four products' pressure drop remains within 0.1 inches of water. Below 50 CFM product L has the highest pressure drop but then there is a transition that takes place at around 75 CFM in which product N gains the highest pressure drop. Another behavior that takes place at around 75 CFM is that product L and product M converge to the same pressure drop. The product with the lowest pressure drop throughout the entire domain is product O with a little under 0.6 inches of water at 200 CFM. The highest pressure drop at 200 CFM was produced by product N with 0.8 inches of water.

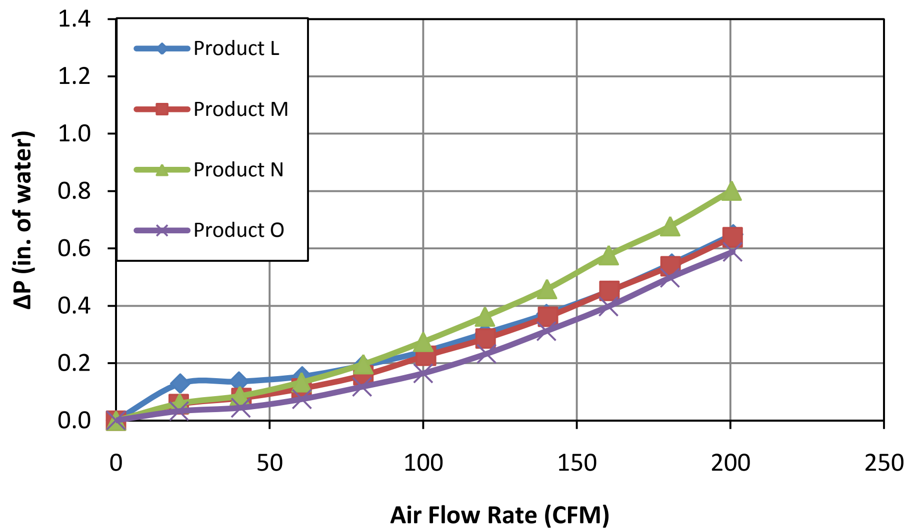

Figure 8. Pressure Drop versus Flow Rate for 4-inch Roof Jack Vent Caps.

The only 6-inch soffit vent cap available for testing, which is labeled product P can be seen in Figure 9. From Figure 9 it can be seen that product P's pressure drop increases linearly with an increase in air flow. The maximum pressure occurs at 400 CFM with a little under 0.5 inches of water.

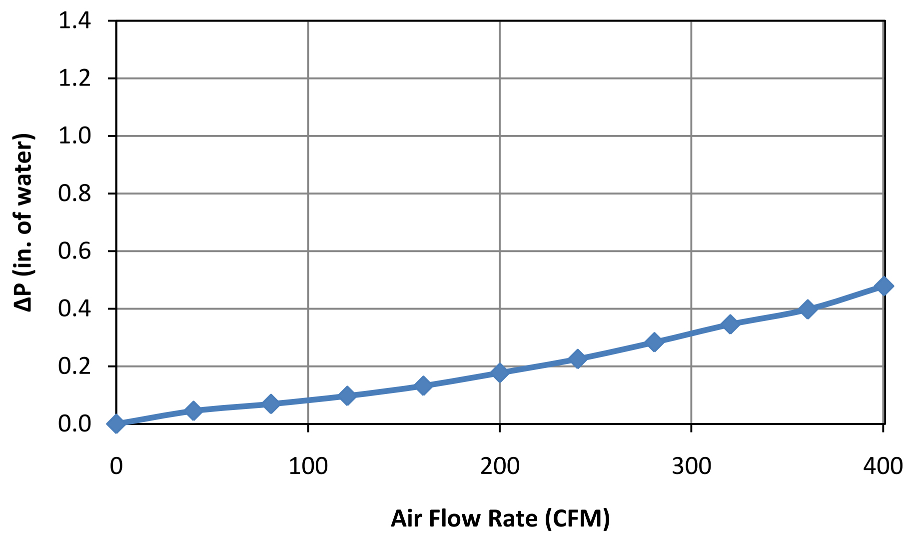

Figure 9. Pressure Drop versus Flow Rate for 6-inch Soffit Vent Caps.

The 6-inch wall-mounted vent caps can be seen in Figure 10. There were a total of six 6-inch wall-mounted vent caps that were tested. From Figure 10 it can be seen that the six vent caps had results that were grouped together. The product with the highest pressure drop throughout the entire domain was product U. At 320 CFM product U is matched by product V in pressure drop. Product V displays an interesting behavior in that it has the lowest pressure drop below 100 CFM but then gradually becomes the product with the highest pressure drop as the air flow rate increases. The final range in pressure drop between the six products was about 0.3 inches of water.

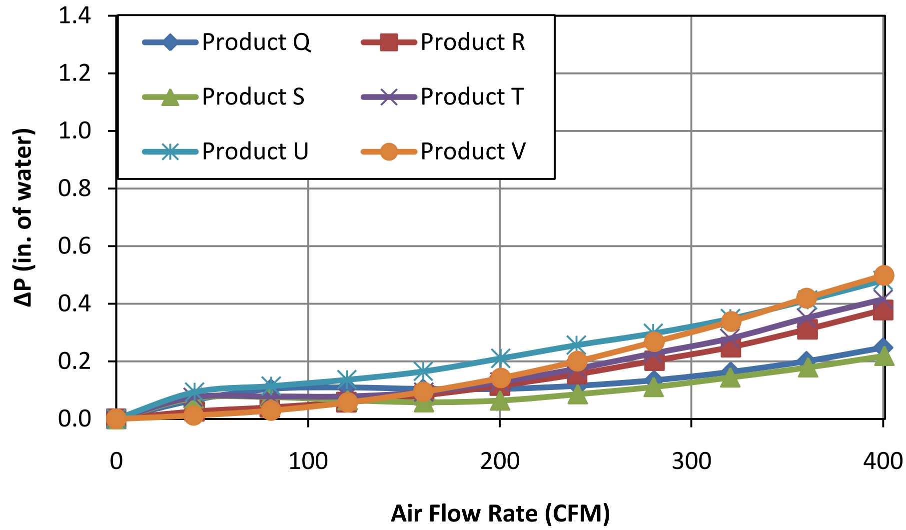

Figure 10. Pressure Drop versus Flow Rate for 6-inch Wall-Mounted Vent Caps.

The next products represented in Figure 11 are the 6-inch soffit vent caps. Product W and product X maintain a separation in pressure drop throughout the entire domain that is around 0.1 inches of water. Through the entire domain, product W maintains the highest pressure drop. At 400 CFM, product W has a pressure drop of around 1.3 inches of water and Product X has a pressure drop a little over 1.1 inches of water.

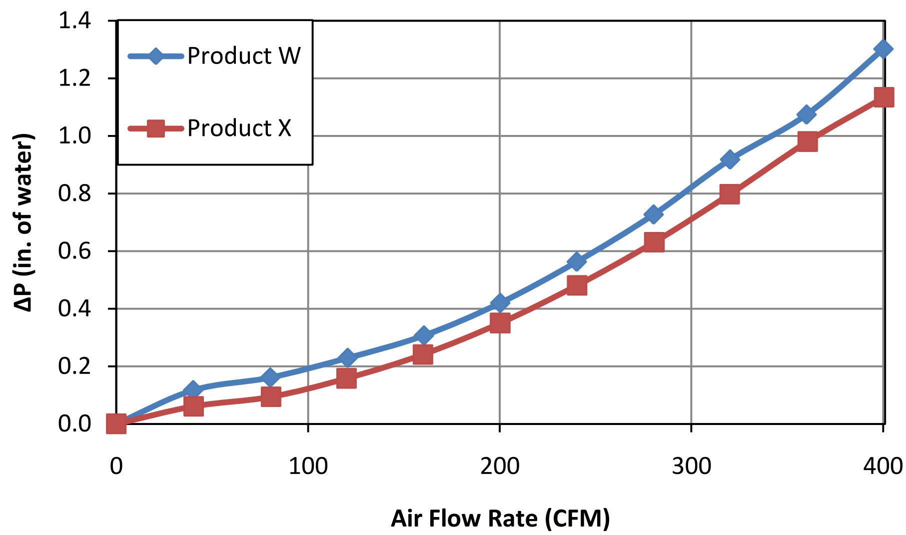

Figure 11. Pressure Drop versus Flow Rate for 6-inch Roof Jack Vent Caps.

6.2 Loss Coefficient versus Air Flow Rate Graphs

The graphs in this subsection show the loss coefficient with respect to air flow in cubic feet per minute. The bottom x-axis displays the air flow rate with 50 CFM tick marks and grid lines. The top x-axis displays the Reynolds number that corresponds to the air flow rate. The y-axis displays the loss coefficient with tick marks in intervals of four. For each product there are ten points displayed that each correspond to a loss coefficient and air flow rate, which can be found in Appendix C. To allow the comparison of loss coefficients at higher flow rates the scale for the y-axis was set to 16. Any loss coefficients that are not seen in the figure can be found in the tables in Appendix C.

Before analyzing the figures it is important to note that the transition zone from laminar to turbulent flow for 4-in. vent caps occurs between 50 CFM and 100 CFM. For

6-in. vent caps the transition zone is between 76 CFM and 152 CFM. In the loss coefficient figures it is seen that the loss coefficient rapidly decreases in the transition zone. The transition zones were determined by calculating the air flow rates that produce a Reynolds number of 5,000 and 10,000 for each size.

Now that the transition zones have been defined, the first loss coefficients that will be examined are those for the soffit vent caps that can be seen in Figure 12. From Figure 12 it can be seen that product B has the highest loss coefficients at air flow rates below 50 CFM. Product B also seems to converge with product C between 40 and 120 CFM. After 120 CFM there is some separation between products B and C but converge once again at 200 CFM. The product that maintains separation throughout the entire domain is product A. Product A also maintains the lowest loss coefficient throughout the entire domain. The behavior that is common to these three products and all the others to follow is that the loss coefficient seems to remain constant after a certain air flow rate is reach. From Figure 12 it can be seen that the 4-inch soffit vent caps' loss coefficient remain nearly constant after 150 CFM.

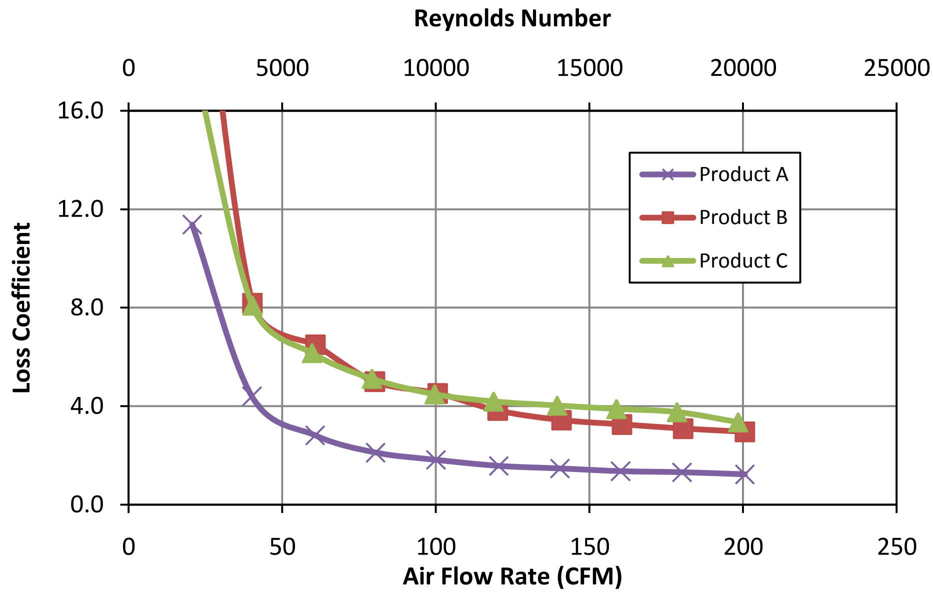

Figure 12. Loss Coefficient versus Flow Rate for 4-inch Soffit Vent Caps.

The loss coefficients for the 4-inch wall-mounted vent caps can be seen in Figure 13. The most unique behavior that can be seen in Figure 13 is produce by product H. At low flow rates product H has a high loss coefficient that goes pass the scales maximum. However, past 80 CFM product H becomes the wall-mounted vent cap with the smallest loss coefficient. Some more unique behavior that is seen in Figure 13 is that products E, F, J, and K maintain almost constant loss coefficients through the entire air flow domain. The product that has the highest loss coefficient throughout the majority of the domain is product I.

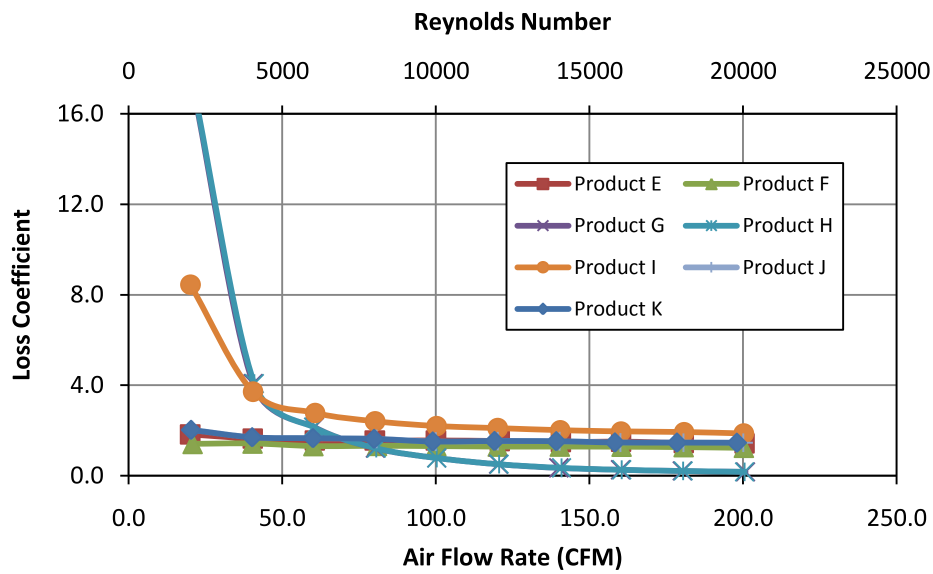

Figure 13. Loss Coefficient versus Flow Rate for 4-inch Wall-Mounted Vent Caps.

The loss coefficients for the 4-inch roof jacks can be seen in Figure 14. The first thing that is observed in Figure 14 is that products N, M, and L have high loss coefficients at flow rates below 50 CFM. Another behavior that can be seen in Figure 14 is that products O, M, and L converge at flow rates greater than 150 CFM. At the higher flow rates the only roof jack to slightly distinguish itself is product N, which maintains the highest loss coefficients throughout the entire air flow domain.

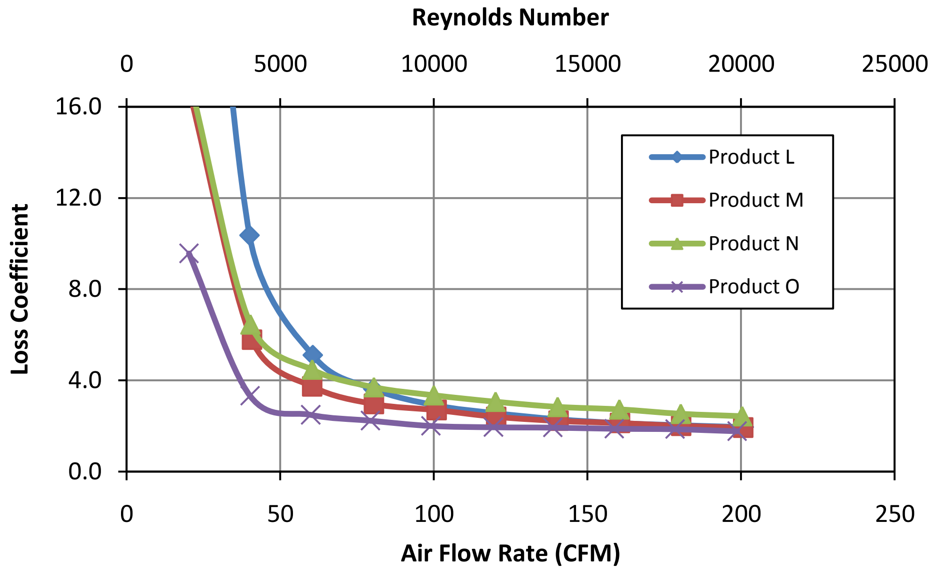

Figure 14. Loss Coefficient versus Flow Rate for 4-inch Roof Jack Vent Caps.

The loss coefficients for product P, which is the only 6-inch soffit vent cap tested, can be seen in Figure 15. Like other vent caps already discussed, product P also has high loss coefficients at low flow rates that then level off at higher air flow rates. At the higher flow rates the loss coefficient for product P levels off to a value around two.

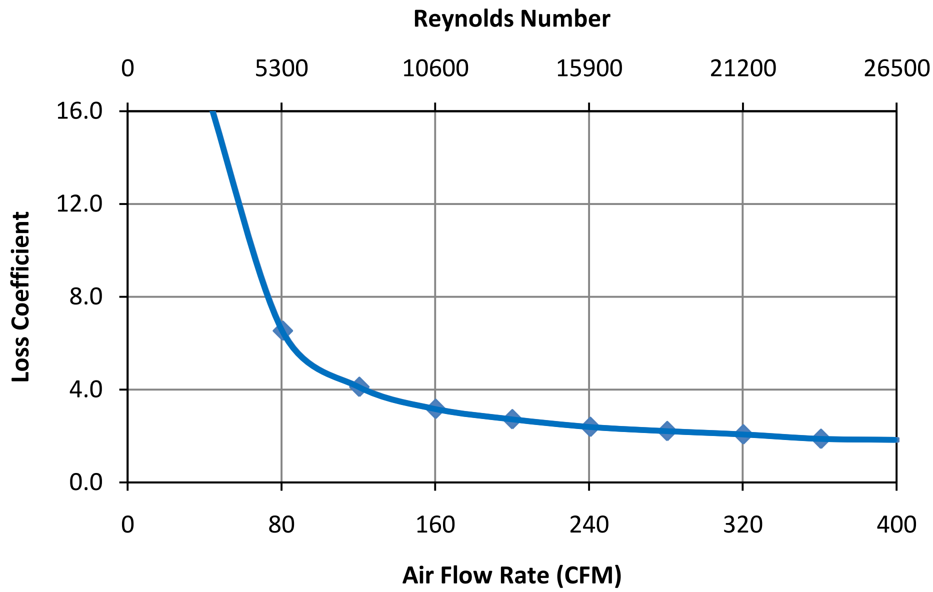

Figure 15. Loss Coefficient versus Flow Rate for 6-inch Soffit Vent Caps.

The loss coefficients for the six 6-inch wall-mounted vent caps can be seen in Figure 16. In Figure 16 it can be seen that products R and V are the only products to have loss coefficients small enough to be seen on the graph. However, product V has one of the largest loss coefficients at the higher air flow rates. Most of the products in Figure 16 seem to level off to a constant loss coefficient after 200 CFM except product U. Product U levels off after 300 CFM. At air flow rates higher than 300 CFM all the products fall within a range that spans from 1 .0 to 2.0.

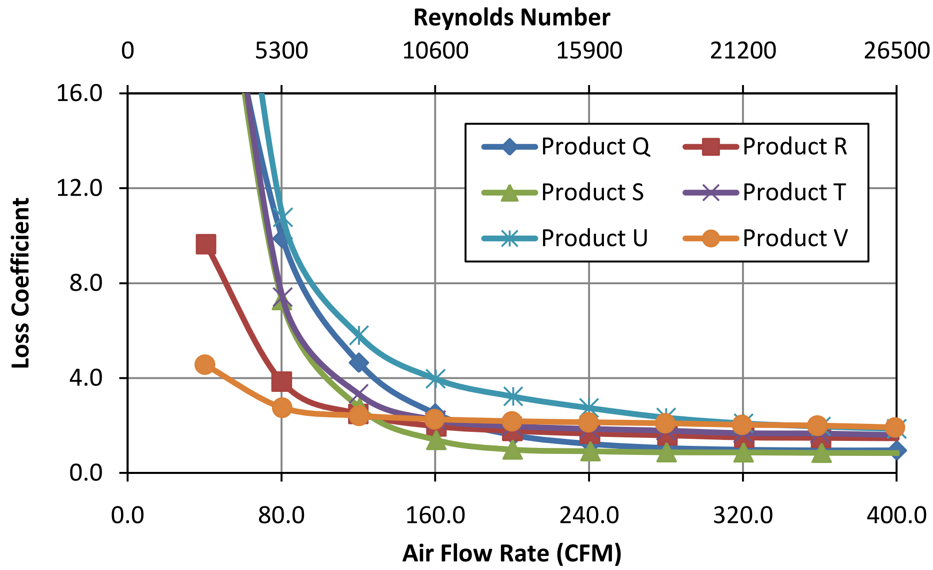

Figure 16. Loss Coefficient versus Flow Rate for 6-inch Wall-Mounted Vent Caps.

The final loss coefficients that are presented are those for the 6-inch roof jack vent caps, which can be seen in Figure 17. Product W and product X both have similar behaviors but product X maintains the lower loss coefficients throughout the entire air flow domain. At flow rates higher than 300 CFM both products come within 1.0 for their loss coefficient. At 400 CFM product W has a loss coefficient around 5.0 and product X has a loss coefficient slightly higher than 4.0.

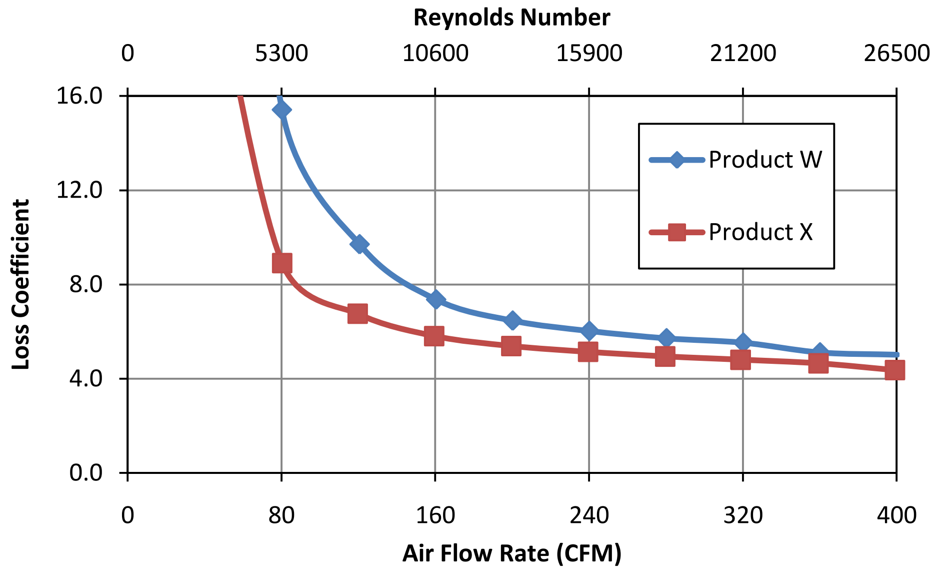

Figure 17. Loss Coefficient versus Flow Rate for 6-inch Roof Jack Vent Caps.

7. COMPARISON OF RESULTS

In the previous section, products of different designs were compared among vent caps of the same type and size. A comparison that is also of interest is a comparison between the three types and the two sizes. To compare among type and size, averages were calculated at every point for the air flow rate, pressure drop, and loss coefficient. One thing that needs to be mentioned is that the 6-inch soffit vent cap data for the figures in this section do not represent an average since there was only one 6-inch soffit vent cap that was tested. The 6-inch soffit vent data set was included in the figures for the purpose of comparison.

7.1 An Average Pressure Drop Comparison among Type and Size

The average pressure drop versus average air flow can be seen in Figure 18. The average pressure drop is in inches of water and the average air flow is in cubic feet per minute. Since it is difficult to distinguish lines below 100 CFM an addition figure has been created that will be discussed next. The portion of Figure 18 that is above 100 CFM will be discussed first. The first thing that can be seen in Figure 18 is that the 4-inch vent caps produce a much higher pressure drop above 100 CFM. If the 4-inch vent cap trend lines continue in the same linear fashion they would produce a much greater pressure drop than the 6-inch vent caps at the higher air flow rates.

Another characteristic that can be observed is that above 100 CFM there is significant separation between each vent cap type and size. Above 100 CFM the separation between each data set is around 0.1 inches of water, which is a magnitude greater than the error in the pressure drop. This separation allows us to see that for the 4-inch vent caps the order of the types from highest to lowest pressure drop was soffit, roof jack, and wall-mounted. The order of types for the 6-inch vent caps from highest to lowest pressure drop was roof jack, soffit, and wall-mounted. Since there was only one 6-inch soffit vent cap and only two 6-inch roof jack vent caps, it is unlikely that the averages for 6-inch soffit and roof jack vent caps are reliable. A larger sample of 6-inch soffit and roof jack vent caps is needed to provide conclusive averages. However, there were six 6-inch wall-mounted vent caps, which is a sufficient number for an average. Therefore, it can be stated that above 100 CFM the wall-mounted vent cap is the type with the best performance. It can also be stated that above 100 CFM the 4-inch vent cap type with the second best performance was the roof jack and soffit vent caps had the worst performance.

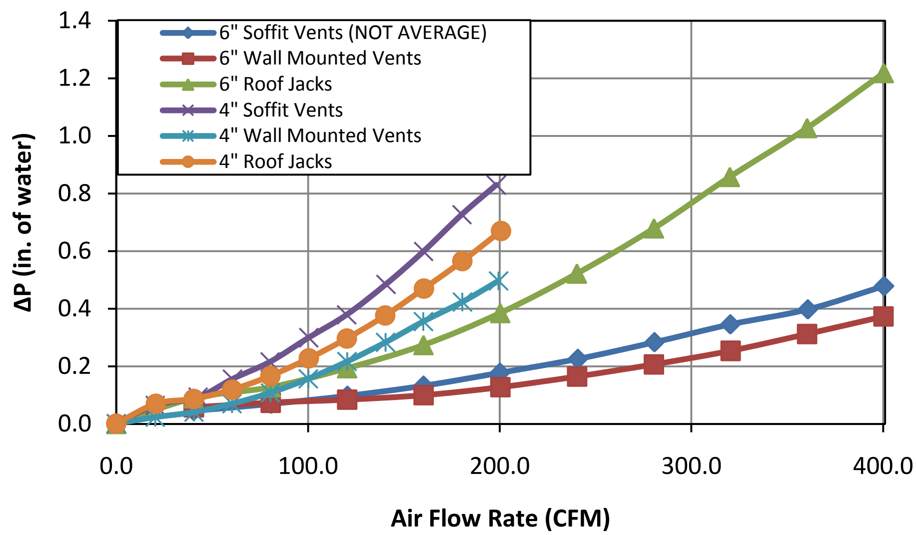

Figure 18. Average Pressure Drop versus Average Flow Rate.

A close look at the portion of Figure 18 below 100 CFM can be seen in Figure 19. The first noticeable behavior in Figure 19 is that there is no clear separation between types and sizes as there was in Figure 18 above 100 CFM. Therefore, it is inconclusive which size performance better under 100 CFM. However, the performance for each type can be determined. The order of type from highest pressure drop to lowest pressure drop for the 4-inch vent caps was soffit, roof, then wall-mounted. The order of type for the 6-inch vent caps from highest pressure drop to lowest pressure drop was roof, wall-mounted, then soffit. For the 4-inch vent caps the performance order was the same above and below 100 CFM. Therefore, it can be concluded that among 4-inch vent caps wall-mounted vent caps have the best performance followed by roof jacks and also that soffit vent caps have the worst performance. For the 6-inch vent cap types, the order from highest pressure drop to lowest pressure drop is roof, wall-mounted, the soffit. Since the order of the 6-inch vent cap types does not coincide with the 4-inch vent caps and there are insufficient 6-inch soffit and roof jack vent caps, there are no conclusions that can be made for the pressure drop among 6-inch vent cap types.

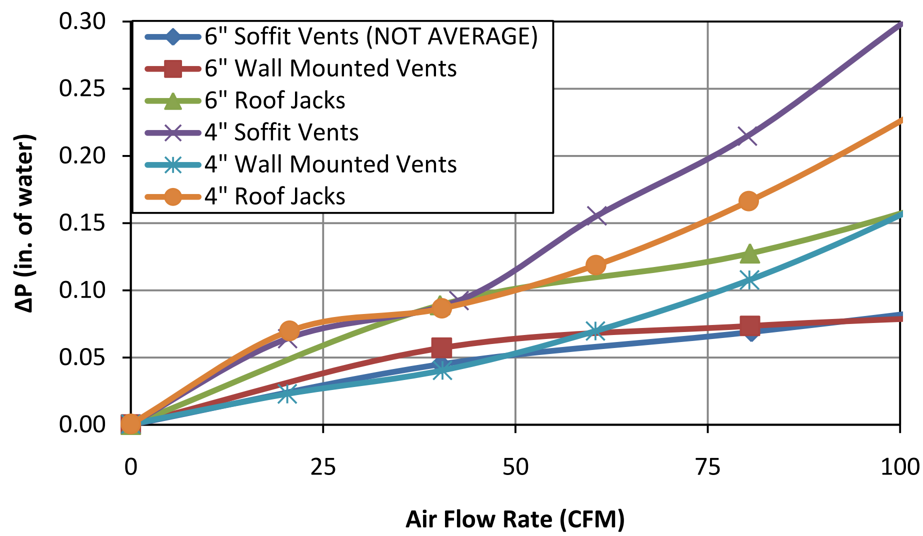

Figure 19. Zoomed in Figure 18.

7.2 An Average Loss Coefficient Comparison among Type and Size

In addition to analyzing the average pressure drop, which was done in section 7.1, it is also important to analyze the average loss coefficient for each type and size. Since the loss coefficient is proportional to the pressure drop it is expect that examining the average loss coefficients with produce the same conclusions.

The average loss coefficients with respect to air flow rate can be seen in Figure 20. Similar to what was done in subsection 7.1, the loss coefficients will be analyzed in two sections: below 100 CFM and above 100 CFM. Figure 20 will be used to analyze the loss coefficients below 100 CFM.

The more prominent characteristic that can be observed in Figure 20 is that below 100 CFM the 6-inch vent caps have the higher loss coefficients. The 6-inch vent cap order in descending average loss coefficient is roof, wall-mounted, then soffit. The 4-inch vent caps order in descending average loss coefficient is soffit, roof jack, then wall-mounted. Therefore, it is seen that the 6-inch and 4-inch vent caps do not show the same results for type performance. However, as it was already mention previously there was only one 6-inch soffit vent cap and two 6-inch roof jack vent caps that were tested. Therefore, the performance based on loss coefficients by type is inconclusive for 6-inch vent caps. On the other hand, the 4-inch vent cap performance based on loss coefficients can be accepted because there was a larger sample size for each vent cap type. Therefore, it can be concluded that for flow rates under 100 CFM the vent cap type order from worst to best performance based on loss coefficient is soffit, roof jack, and then wall-mounted.

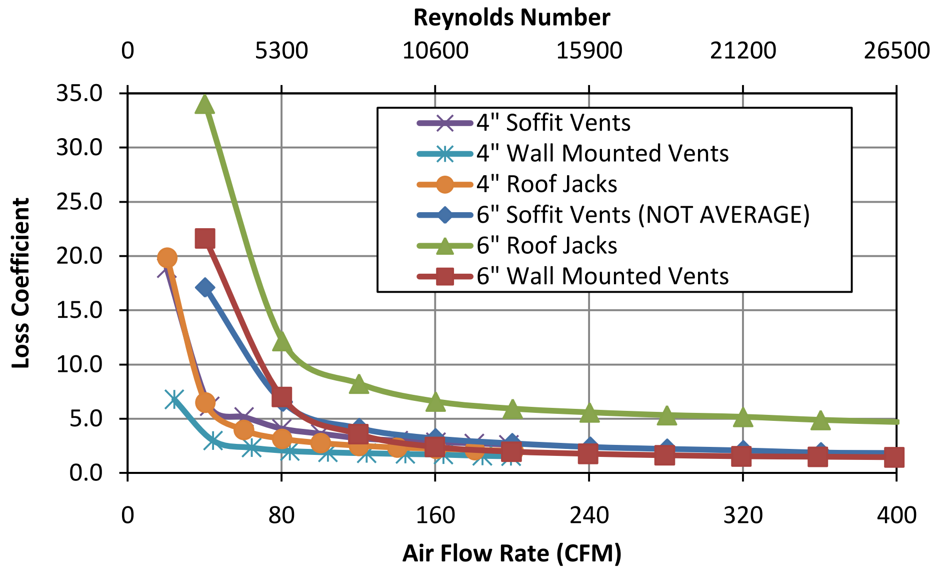

Figure 20. Average Loss Coefficient versus Flow Rate.

To compare the average loss coefficients above 100 CFM, Figure 20 was scaled down to the area of interest to product Figure 21. The first comparison that can be made is between the two sizes. From Figure 21 it can be seen that for each type the 4-inch vent caps have the smaller average loss coefficient up to 200 CFM. After 200 CFM it cannot be determined which size has the smaller average loss coefficient since there was no data collected for the 4-inch vent caps above 200 CFM. Another comparison that was made is the performance order based on average loss coefficient for each type. The order for the 6-inch vent caps in descending order of average loss coefficients is roof jack, soffit, and then wall-mounted. The order for the 4-inch vent caps in descending order of average loss coefficients is soffit, roof, and wall-mounted. Since the wall-mounted vents produced the smallest loss coefficients for both the 4-inch and 6-inch vent caps, it can be concluded that the wall-mounted vent caps have the best performance above 100 CFM. Other conclusions that can be drawn are that the 4-inch soffit vent caps had the worst performance and the 4-inch roof jack vent caps performed between soffit vent caps but worse than wall-mounted vent caps.

It is important to note that the conclusions that were drawn based on the average pressure drops are the same based on the average loss coefficients, which is expected as mentioned earlier.

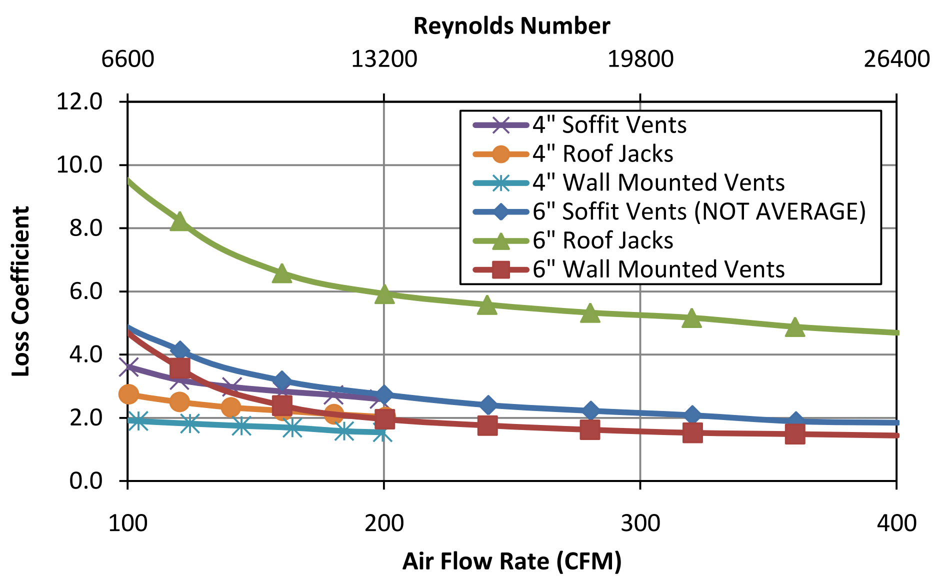

Figure 21. Zoomed in Figure 20.

8. VARIANCE ANALYSIS

A variance analysis was also performed on each vent cap type and size. A variance analysis is important to verify that there is significant variance among designs. If no significant variances exist then there is no reason to evaluate the performance of vent caps. A significant variance will be defined as a variation in performance that is larger than the uncertainty in the pressure drop and loss coefficient. To determine the variation in the designs, the averages and standard deviation were determine for the pressure drop and loss coefficient at every data point. The coefficients of variance were then calculated using the average and standard deviation at every data point.

In Table 5 the averages, standard deviations, and coefficients of variance can be seen for the 4-in. soffit vent caps. In Table 5 it can be observed that the lowest standard deviation for the pressure drop is 0.025 in. w.c., which occurs at 20.4 CFM. The lowest standard deviation for the loss coefficient is 1.3, which occurs at 200.5 CFM. Also, the lowest coefficient of variance is 0.32, which occurs at 40.4 CFM. Since all the standard deviations and the loss coefficient are larger than the uncertainty for each parameter it is clear that there is significant variance among 4-in. soffit vent cap designs.

Table 5. Statistical Indicators for 4-inch Soffit Vent Caps.

Average Air Flow Rate (CFM)	20.4	40.4	60.6	80.2	100.4	120.2	140.7	160.4	180.3	200.5
Average Pressure Drop (in. w.c.)	0.064	0.092	0.155	0.215	0.299	0.378	0.484	0.599	0.726	0.829
Average Loss Coefficient	18.87	6.89	5.16	4.08	3.61	3.20	2.98	2.83	2.72	2.51
St. Dev. Pressure Drop (in. w.c.)	0.025	0.030	0.061	0.089	0.130	0.167	0.220	0.280	0.339	0.373
St. Dev. Loss Coefficient	7.49	2.16	2.04	1.70	1.55	1.42	1.34	1.32	1.27	1.13
Coefficient of Variance	0.39	0.32	0.39	0.41	0.43	0.44	0.45	0.47	0.47	0.45

The statistical indicators for 4-in. wall-mounted vent caps can be seen in Table 6. In Table 6 it can be seen that the lowest standard deviation for the pressure drops and loss coefficients are 0.018 and 0.98, respectively. Also, the lowest coefficient of variance is 0.80. Therefore, it can be concluded that there is significant variance among 4-in. wall-mounted vent caps.

Table 6. Statistical Indicators for 4-inch Wall-Mounted Vent Caps.

Average Air Flow Rate (CFM)	20.3	40.5	60.4	80.4	100.2	120.4	140.5	160.2	180.6	200.4
Average Pressure Drop (in. w.c.)	0.023	0.040	0.070	0.108	0.156	0.216	0.283	0.355	0.423	0.496
Average Loss Coefficient	6.78	2.99	2.33	2.03	1.90	1.82	1.75	1.69	1.58	1.51
St. Dev. Pressure Drop (in. w.c.)	0.018	0.018	0.034	0.063	0.101	0.141	0.191	0.243	0.293	0.321
St. Dev. Loss Coefficient	5.41	1.33	1.16	1.17	1.23	1.19	1.18	1.16	1.09	0.98
Coefficient of Variance	0.80	0.45	0.49	0.58	0.64	0.65	0.68	0.68	0.69	0.65

In Table 7 the 4-in. roof jack vent cap averages and standard deviations can be seen. For the 4-in. roof jack vent caps the smallest standard deviation occurred at 60.5 CFM with a pressure drop of 0.034 in. w.c. The smallest standard deviation for the loss coefficients are 0.28, which occur at 200.7 CFM. The smallest coefficient of variance is

0.14. Evaluating the lowest standard deviations and coefficient of variance it can be concluded that there is significant variance in the 4-in. roof jack vent caps.

There was no statistical analysis done on the 6-in. soffit vent since there was only one sample.

Table 7. Statistical Indicators for 4-inch Roof Jack Vent Caps.

Average Air Flow Rate (CFM)	20.6	40.4	60.5	80.4	100.4	120.3	140.3	160.5	180.5	200.7
Average Pressure Drop (in. w.c.)	0.070	0.087	0.119	0.166	0.227	0.297	0.376	0.470	0.565	0.670
Average Loss Coefficient	19.83	6.48	3.96	3.14	2.74	2.50	2.33	2.22	2.11	2.03
St. Dev. Pressure Drop (in. w.c.)	0.041	0.038	0.034	0.037	0.046	0.054	0.061	0.076	0.078	0.092
St. Dev. Loss Coefficient	11.31	2.91	1.12	0.68	0.56	0.46	0.38	0.36	0.29	0.28
Coefficient of Variance	0.59	0.43	0.28	0.22	0.20	0.18	0.16	0.16	0.14	0.14

The 6-in. wall-mounted vent cap averages and standard deviations can be seen in Table 8. The smallest standard deviations were 0.031 in. w.c. for the pressure drop and 0.45 for the loss coefficient. The smallest coefficient of variance was 0.31. The two standard deviations and the loss coefficients indicate that there is significant variation in the 6-in. wall-mounted vent caps.

Table 8. Statistical Indicators for 6-inch Soffit Vent Caps.

Average Air Flow Rate (CFM)	40.4	80.5	120.4	160.3	200.4	240.4	280.4	320.5	360.4	400.3
Average Pressure Drop (in. w.c.)	0.057	0.074	0.084	0.099	0.127	0.164	0.206	0.254	0.312	0.373
Average Loss Coefficient	21.61	6.99	3.57	2.39	1.95	1.76	1.62	1.52	1.48	1.44
St. Dev. Pressure Drop (in. w.c.)	0.031	0.034	0.032	0.036	0.048	0.061	0.073	0.086	0.103	0.117
St. Dev. Loss Coefficient	11.80	3.19	1.37	0.86	0.74	0.65	0.57	0.52	0.49	0.45
Coefficient of Variance	0.55	0.46	0.38	0.36	0.38	0.37	0.35	0.34	0.33	0.31

The standard deviations for the 6-in. roof jack vent caps can be seen in Table 9. However, it should be noted as a reminder that there were only two 6-in. roof jacks, which is too small a sample size for a statistical analysis. Despite the small sample size the data is still represented in Table 9. The smallest standard deviations were 0.04 in w.c. and 0.33 for the loss coefficient. The smallest coefficient of variance was 0.06, which is larger than the error in the coefficient of variance. Therefore, there is significant variation in the 6-in. roof jacks.

Table 9. Statistical Indicators for 6-inch Wall-Mounted Vent Caps.

Average Air Flow Rate (CFM)	40.2	80.5	120.4	160.3	200.3	240.3	280.5	320.1	360.4	400.4
Average Pressure Drop (in. w.c.)	0.089	0.128	0.194	0.274	0.385	0.522	0.679	0.858	1.027	1.218
Average Loss Coefficient	34.05	12.16	8.23	6.58	5.92	5.58	5.33	5.17	4.88	4.69
St. Dev. Pressure Drop (in. w.c.)	0.040	0.047	0.050	0.047	0.049	0.058	0.068	0.086	0.066	0.119
St. Dev. Loss Coefficient	15.36	4.60	2.08	1.09	0.76	0.63	0.54	0.51	0.33	0.46
Coefficient of Variance	0.44	0.37	0.26	0.17	0.13	0.11	0.10	0.10	0.06	0.10

9. REPEATABILITY

To determine the experiment's repeatability two vent caps were chosen at random and two trials were compared for each vent cap. The two products that were chosen were Product R (6-inch wall-mounted) and Product X (6-in roof jack). This comparison can be seen in Figure 22. The first trial for each vent cap was a preliminary trial, which was done before the test procedure was fully established. For this reason it can be observed that the first trial for each vent cap is not spaced out in intervals of 40 CFM and the trial is not carried out to 400 CFM. However, when the first trials were taken the apparatus and instrumentation had been fully established, the only steps that had not been fully developed were the data collection method.

By observing Figure 22, it can be seen that the two trials for each vent cap are identical. It can also be observed that the first trials would have produced the same pressure drops for the higher air flow rates. Therefore, it can be concluded that the experiments for this research are highly repeatable.

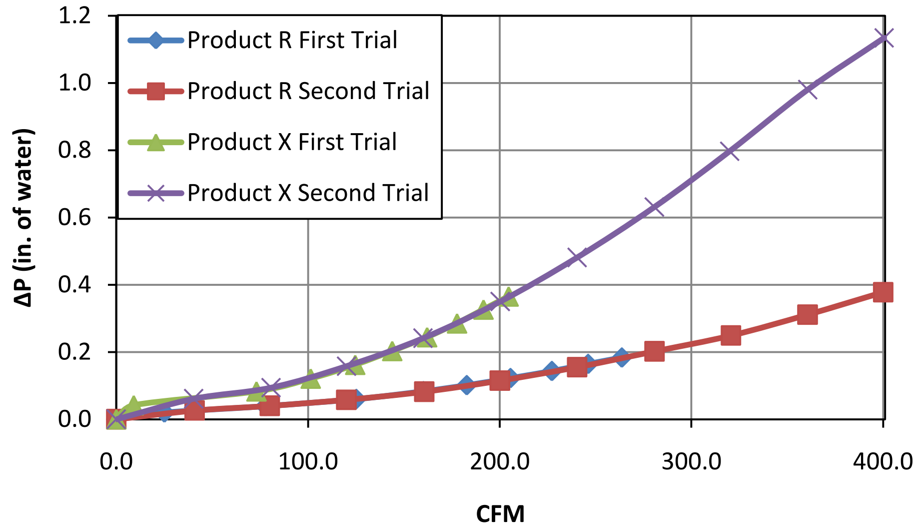

Figure 22. Repeatability Comparison.

10. LOSS COEFFICIENTS AT HIGH AIR FLOW RATES

The loss coefficients for vent caps were shown to become almost constant at the higher air flow rates in section 4.2. This behavior can be used to estimate a pressure drop at flow rates higher than 100 CFM for 4-in vent caps and higher than 300 CFM for 6-in. vent caps. The equations used to estimate the pressure drop are equation 19 and equation 20, which are forms of equations 14 and 15. As defined previously ΔP is the pressure drop in inches of water, $\dot{V}$ is the air flow rate in cubic feet per minute, and K is the loss coefficient, which is dimensionless.

(Eq. 19) $$\Delta P = 8.21x10^{-6} K\dot{V}^2$$

(Eq. 20) $$\Delta P = 1.62x10^{-6} K\dot{V}^2$$

The loss coefficients for the average of the last three data points can be seen in Tables 10 and 11 for the 4-in. and 6-in. vent caps, respectively.

Table 10. Loss Coefficients for 4-inch Vent Caps.

Soffit			Wall-Mounted							Roof Jack			
A	B	C	E	F	G	H	I	J	K	L	M	N	O
1.30	3.10	3.67	1.46	1.27	1.10	0.22	1.92	3.97	1.46	2.04	2.03	2.57	1.84

Table 11. Loss Coefficients for 6-inch Vent Caps.

Soffit	Wall-Mounted						Roof Jack	
P	Q	R	S	T	U	V	W	X
1.93	0.96	1.48	0.85	1.65	1.97	1.98	5.22	4.60

A comparison can be seen in Figure 23 between the actual pressure drop and the calculated pressure drop using equations 19 and 20. Product A is a 4-in. soffit vent and Product V is a 6-in. wall-mounted vent cap. In Figure 23 product A and product V both experience a difference of 10% between measured and estimated pressure drop at 100 CFM and 200 CFM, respectively. The difference between measured and estimated diminishes as the air flow rate is increase for both products.

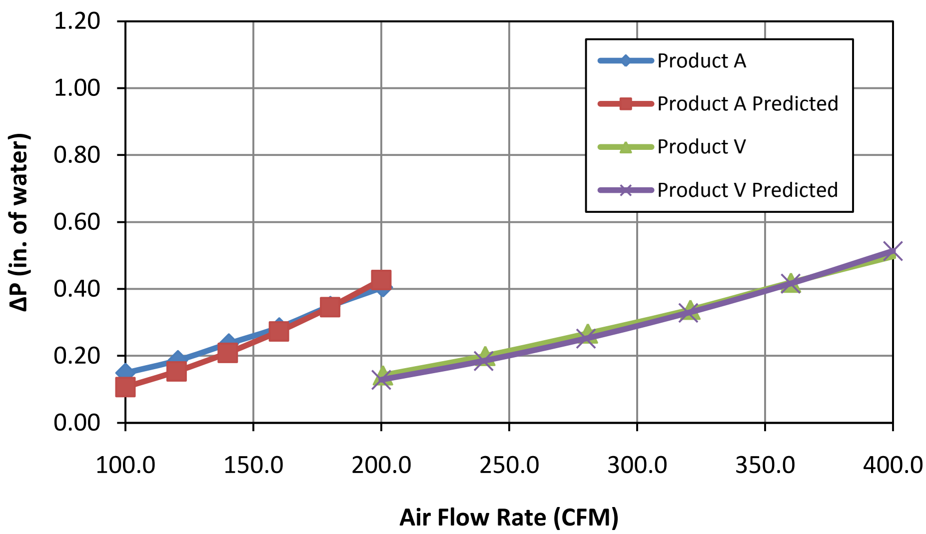

Figure 23. Estimated Pressure Drop Comparison.

An analysis of the predicted pressure drop was also done for every vent cap at a specific air flow rate. This information can be seen in Tables 12 and 13. In Table 12 the percent error in the predicted pressure drop at an air flow rate of 140 CFM can be seen for the 4-in. vent caps. The measured and predicted pressure drop can also be seen in Table 12. From Table 12 it can be determine that the 4-in. vent cap with the greatest error was product H. Product H had a 38.5% error, which is almost four times the error of any other 4-in. vent cap. Product H's high error can be explained by its unique design. Remember that product H has louvers and not a damper like the other vent caps. The other vent caps have a maximum error of 11.9%.

Table 13 shows the predicted pressure drop error for the 6-in. vent caps at 280 CFM. The maximum error seen in Table 13 is 15.8%, which is still a reasonable number for rough calculations.

By observing Figure 23, Table 12, and Table 13 it can be concluded that the average loss coefficient can be used to predict the pressure drop at high air flow rates. For a predicted pressure drop error around 10% a high air flow rate is greater than 140 CFM for 4-in. vent caps and 280 CFM for 6-in. vent caps.

Table 12. Predicted Pressure Drop Error for 4-inch Vent Caps.

Product	Measured (in. w.c.)	Predicted (in. w.c.)	Error (%)
A	0.237	0.209	11.9
B	0.559	0.498	10.8
C	0.657	0.591	10.1
E	0.242	0.236	2.6
F	0.209	0.204	2.5
G	0.188	0.177	5.7
H	0.057	0.035	38.5
I	0.326	0.309	5.3
J	0.713	0.638	10.5
K	0.247	0.235	4.8
L	0.371	0.329	11.4
M	0.362	0.326	9.9
N	0.459	0.413	10.0
O	0.312	0.297	4.9

Table 13. Predicted Pressure Drop Error for 6-inch Vent Caps.

Product	Measured (in. w.c.)	Predicted (in. w.c.)	Error (%)
P	0.283	0.246	13.2
Q	0.134	0.122	8.8
R	0.202	0.187	7.2
S	0.111	0.108	2.5
T	0.227	0.209	7.7
U	0.297	0.250	15.8
V	0.267	0.251	5.9
W	0.727	0.663	8.8
X	0.631	0.585	7.3

11. CONCLUSIONS

The objective of this research was to develop a vent cap evaluation method that may be used for a variety of vent cap types, designs, and sizes. The evaluation method was then implemented to determine the variance among vent cap designs, the evaluation methods repeatability, and create a method to estimate the vent cap's performance at a specific air flow rate. From this research it can be concluded that the evaluation method can be implemented on the three vent cap types and a variety of designs and sizes. The repeatability of the evaluation method was confirmed by comparing two trials for two different products. The evaluation method was used to confirm that the variation in the products is significantly larger than the uncertainty in the measurements. It was also show that the loss coefficients calculated through the evaluation method can be used to estimate the vent caps pressure drop at high air flow rates.

It was also concluded that from the three different types of vent caps that were tested the wall-mounted vent caps performed the best. Also, for the 4-inch vent caps tested it was determined that the performance order in descending order was wall-mounted, roof jack, then soffit. With respect to size, it was concluded that the 4-inch vent caps that were tested produce a higher pressure drop than the 6-inch vent caps that were tested.

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APPENDIX A

Detailed Loss Coefficient Calculation for Four Inch Vent Caps

$$K = \frac{\Delta P}{\frac{1}{2}\rho V^2}$$

$$A = 0.087266\,ft^2 \quad \text{(4" ducting)}$$

$$\rho = 0.075\frac{lbm}{ft^3} \quad \text{(standard air density)}$$

$$\frac{\Delta P}{\frac{1}{2}\left(0.075\frac{lbm}{ft^3}\right)\left(\frac{\dot{V}}{.087266\,ft^2}\right)^2} = 0.203\frac{ft^7}{lbm}\frac{\Delta P}{\dot{V}^2}$$

Put in conversion factors

$$\left(0.036\frac{psi}{in.H_2O}\right)\left(0.203\frac{ft^7}{lbm}\right)\left(\frac{in.H_2O}{\frac{ft^6}{\min^2}}\right)\left(\frac{32.17lbm\frac{ft}{s^2}}{1lbf}\right)\left(\frac{144in^2}{1\,ft^2}\right)\left(\frac{3600s^2}{1\min^2}\right) = 121875$$

Final Equation

$$K = 122000\left(\frac{\Delta P}{\dot{V}^2}\right)$$

ΔP is in inches of water

$\dot{V}$ is in cubic feet per minute

Detailed Loss Coefficient Calculation for Six Inch Vent Caps

$$K = \frac{\Delta P}{\frac{1}{2}\rho V^2}$$

$$A = 0.19635\,ft^2 \text{ (6" ducting)}$$

$$\rho = 0.75\frac{lbm}{ft^3} \text{ (standard air density)}$$

$$\frac{\Delta P}{\frac{1}{2}\left(0.075\frac{lbm}{ft^3}\right)\left(\frac{\dot{V}}{.19635\,ft^2}\right)^2} = 1.02809\frac{ft^7}{lbm}\frac{\Delta P}{\dot{V}^2}$$

Put in conversion factors

$$\left(0.036\frac{psi}{in.H_2O}\right)\left(1.02809\frac{ft^7}{lbm}\right)\left(\frac{in.H_2O}{\frac{ft^6}{\min^2}}\right)\left(\frac{32.17lbm\frac{ft}{s^2}}{1lbf}\right)\left(\frac{144in^2}{1\,ft^2}\right)\left(\frac{3600s^2}{1\min^2}\right) = 617234$$

Final Equation

$$K = 617000\left(\frac{\Delta P}{\dot{V}^2}\right)$$

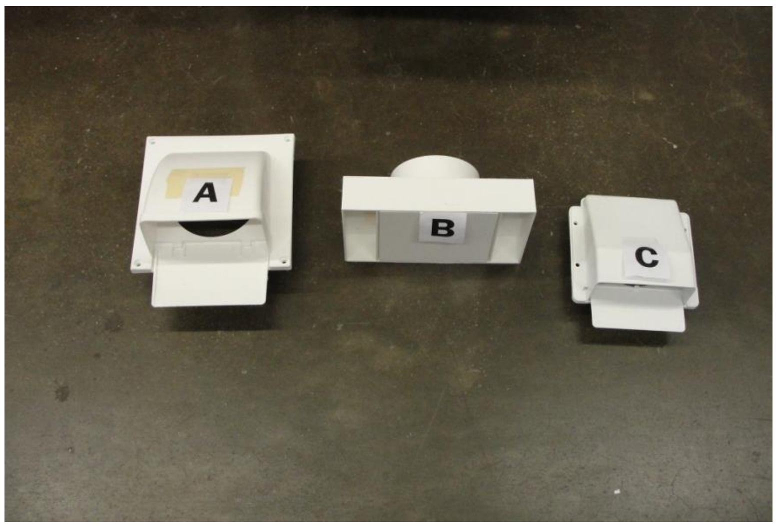
ΔP is in inches of water

$\dot{V}$ is in cubic feet per minute

APPENDIX B

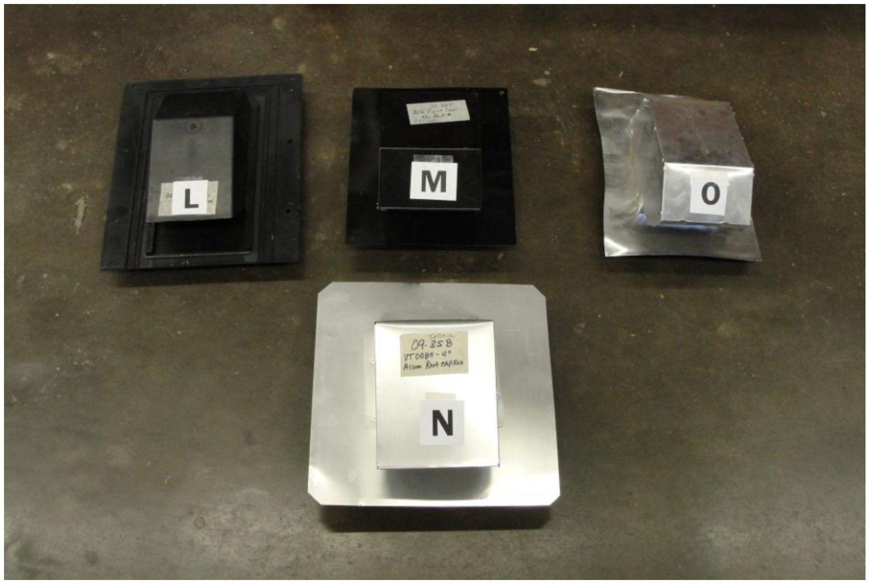
Vent Cap Pictures

4-in. Soffit Vent Caps

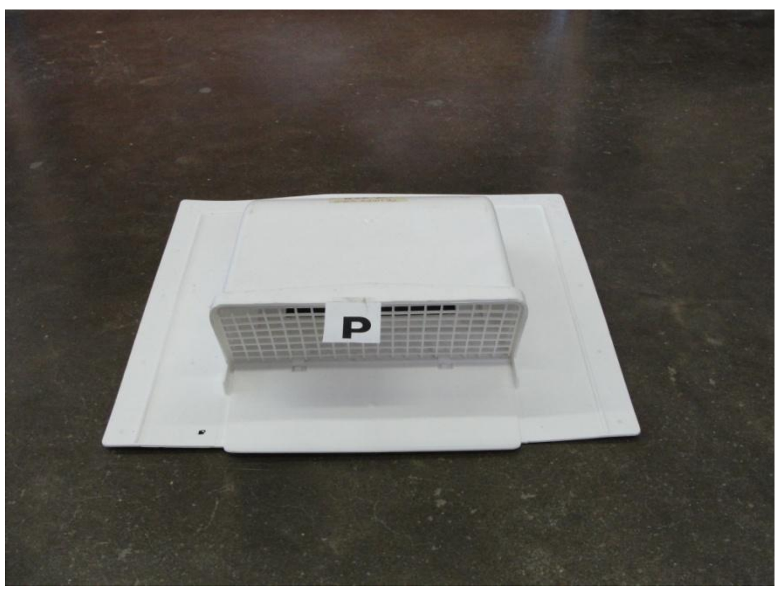


4-in. Wall-Mounted Vent Caps

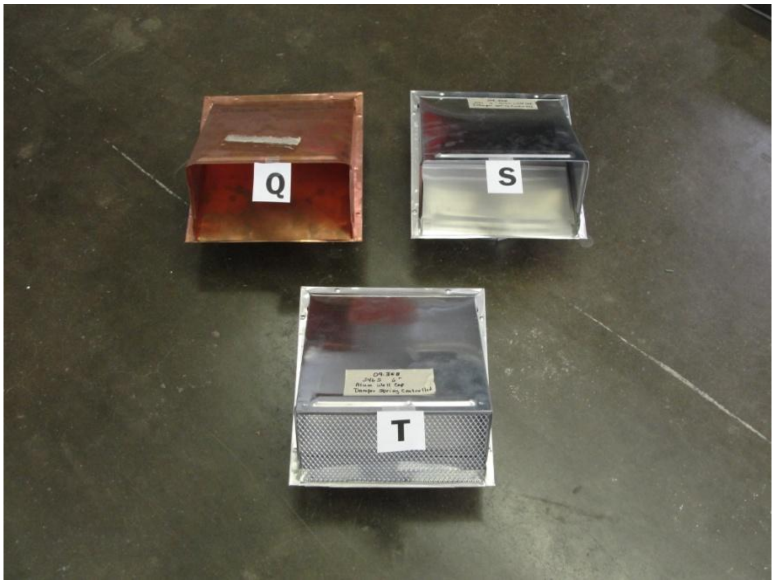
4-in. Roof Jack Vent Caps



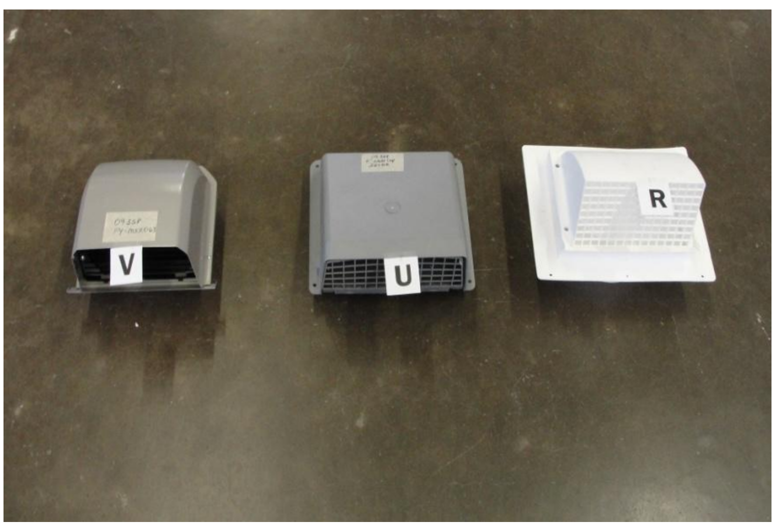
6-in. Soffit Vent Cap



6-in. Wall-Mounted Vent Cap



6-in. Wall-Mounted Vent Caps



6-in. Roof Jack Vent Cap

APPENDIX C

Raw Data Tables for 4 Inch Soffit Vent Caps

Product A

	1	2	3	4	5	6	7	8	9	10
CFM at Nozzle Inlet	20.7	40.1	60.7	80.4	100.0	120.5	140.4	160.1	180.1	200.6
Static Pressure	0.040	0.058	0.085	0.112	0.149	0.187	0.237	0.285	0.349	0.405
Velocity Pressure	0.004	0.013	0.030	0.053	0.083	0.120	0.163	0.212	0.269	0.335
Total Pressure of Fan	0.043	0.071	0.116	0.166	0.231	0.308	0.400	0.497	0.618	0.74
Loss Coefficient	11.38	4.40	2.81	2.11	1.82	1.57	1.47	1.36	1.31	1.23

Product B

	1	2	3	4	5	6	7	8	9	10
CFM at Nozzle Inlet	20.4	40.3	60.8	80.1	100.6	120.1	140.9	160.6	180.5	200.6
Static Pressure	0.090	0.109	0.197	0.263	0.375	0.452	0.559	0.689	0.825	0.976
Velocity Pressure	0.003	0.018	0.031	0.053	0.084	0.119	0.164	0.214	0.27	0.334
Total Pressure of Fan	0.094	0.128	0.228	0.316	0.459	0.571	0.723	0.902	1.095	1.311
Loss Coefficient	26.36	8.18	6.49	5.00	4.52	3.82	3.43	3.26	3.09	2.96

Product C

	1	2	3	4	5	6	7	8	9	10
CFM at Nozzle Inlet	20.0	40.7	60.3	80.0	100.6	120.0	140.9	160.4	180.3	200.4
Static Pressure	0.062	0.110	0.184	0.269	0.373	0.496	0.657	0.822	1.005	1.106
Velocity Pressure	0.003	0.014	0.030	0.053	0.084	0.119	0.165	0.213	0.27	0.311
Total Pressure of Fan	0.066	0.124	0.214	0.322	0.457	0.615	0.822	1.035	1.275	1.417
Loss Coefficient	18.89	8.09	6.17	5.12	4.49	4.20	4.03	3.89	3.77	3.36

Raw Data Table for 4 Inch Wall-Mounted Vent Caps

Product E

	1	2	3	4	5	6	7	8	9	10
CFM at Nozzle Inlet	20.0	40.4	60.6	80.1	100.0	120.8	140.7	160.3	180.7	200.5
Static Pressure	0.006	0.022	0.047	0.082	0.128	0.184	0.242	0.318	0.39	0.472
Velocity Pressure	0.003	0.013	0.030	0.053	0.083	0.121	0.164	0.213	0.271	0.334
Total Pressure of Fan	0.010	0.035	0.078	0.135	0.211	0.305	0.406	0.531	0.661	0.806
Loss Coefficient	1.83	1.64	1.56	1.56	1.56	1.54	1.49	1.51	1.46	1.43

Product F

	1	2	3	4	5	6	7	8	9	10
CFM at Nozzle Inlet	20.8	40.3	60.1	80.8	100.1	120.1	140.3	160.4	180.6	200.2
Static Pressure	0.005	0.019	0.039	0.071	0.108	0.153	0.209	0.272	0.34	0.408
Velocity Pressure	0.004	0.013	0.030	0.054	0.083	0.119	0.163	0.213	0.271	0.333
Total Pressure of Fan	0.009	0.032	0.069	0.125	0.191	0.272	0.372	0.485	0.611	0.741
Loss Coefficient	1.41	1.43	1.32	1.33	1.31	1.29	1.29	1.29	1.27	1.24

Product G

	1	2	3	4	5	6	7	8	9	10
CFM at Nozzle Inlet	20.2	40.5	60.5	80.3	100.3	120.4	140.0	160.1	180.2	200.8
Static Pressure	0.031	0.041	0.055	0.071	0.102	0.143	0.188	0.236	0.295	0.357
Velocity Pressure	0.003	0.014	0.030	0.053	0.083	0.120	0.162	0.213	0.27	0.335
Total Pressure of Fan	0.035	0.055	0.085	0.124	0.185	0.263	0.350	0.449	0.564	0.692
Loss Coefficient	9.26	3.05	1.83	1.34	1.24	1.20	1.17	1.12	1.11	1.08

Product H

	1	2	3	4	5	6	7	8	9	10
CFM at Nozzle Inlet	20.3	40.9	60.2	80.6	100.3	120.6	140.9	160.5	180.5	200.5
Static Pressure	0.060	0.056	0.064	0.065	0.065	0.061	0.057	0.056	0.057	0.058
Velocity Pressure	0.003	0.014	0.030	0.054	0.083	0.120	0.164	0.214	0.271	0.334
Total Pressure of Fan	0.063	0.070	0.094	0.119	0.148	0.182	0.222	0.269	0.327	0.393
Loss Coefficient	17.74	4.08	2.15	1.22	0.79	0.51	0.35	0.26	0.21	0.18

Product I

	1	2	3	4	5	6	7	8	9	10
CFM at Nozzle Inlet	20.1	40.5	60.7	80.2	100.2	120.1	140.5	160.3	180.8	200.2
Static Pressure	0.028	0.050	0.084	0.127	0.181	0.249	0.326	0.413	0.518	0.614
Velocity Pressure	0.003	0.014	0.030	0.053	0.083	0.119	0.164	0.213	0.271	0.333
Total Pressure of Fan	0.032	0.064	0.115	0.180	0.264	0.368	0.489	0.627	0.789	0.948
Loss Coefficient	8.45	3.72	2.78	2.41	2.20	2.10	2.01	1.96	1.93	1.87

Product J

	1	2	3	4	5	6	7	8	9	10
CFM at Nozzle Inlet	20.7	40.4	59.9	80.7	100.0	120.2	140.3	160.1	180.6	200.1
Static Pressure	0.024	0.069	0.146	0.254	0.390	0.537	0.713	0.899	1.073	1.188
Velocity Pressure	0.004	0.013	0.030	0.054	0.083	0.119	0.163	0.213	0.271	0.308
Total Pressure of Fan	0.027	0.082	0.175	0.307	0.473	0.656	0.876	1.111	1.343	1.496
Loss Coefficient	6.83	5.15	4.96	4.75	4.75	4.53	4.41	4.27	4.01	3.62

Product K

	1	2	3	4	5	6	7	8	9	10
CFM at Nozzle Inlet	20.5	40.6	60.6	80.7	100.0	120.3	140.6	159.9	180.3	200
Static Pressure	0.007	0.023	0.050	0.087	0.124	0.182	0.247	0.308	0.39	0.478
Velocity Pressure	0.003	0.014	0.030	0.054	0.083	0.120	0.164	0.212	0.27	0.333
Total Pressure of Fan	0.011	0.037	0.081	0.141	0.206	0.302	0.411	0.520	0.66	0.811
Loss Coefficient	2.03	1.70	1.66	1.63	1.51	1.53	1.52	1.47	1.46	1.46

Raw Data Tables for 4 Inch Roof Jack Vent Caps

Product L

	1	2	3	4	5	6	7	8	9	10
CFM at Nozzle Inlet	20.9	40.0	60.6	80.3	100.7	120.1	140.1	160.7	180.9	200.9
Static Pressure	0.129	0.136	0.154	0.192	0.242	0.304	0.371	0.452	0.547	0.649
Velocity Pressure	0.004	0.013	0.030	0.053	0.084	0.119	0.162	0.214	0.271	0.335
Total Pressure of Fan	0.133	0.149	0.184	0.245	0.326	0.424	0.534	0.666	0.819	0.985
Loss Coefficient	35.99	10.36	5.11	3.63	2.91	2.57	2.30	2.13	2.04	1.96

Product M

	1	2	3	4	5	6	7	8	9	10
CFM at Nozzle Inlet	20.4	40.8	60.4	80.5	100.9	120.3	140.6	160.6	180.5	200.7
Static Pressure	0.057	0.079	0.112	0.158	0.226	0.286	0.362	0.452	0.538	0.639
Velocity Pressure	0.003	0.014	0.030	0.054	0.084	0.120	0.164	0.214	0.27	0.335
Total Pressure of Fan	0.060	0.093	0.142	0.211	0.310	0.406	0.525	0.666	0.808	0.974
Loss Coefficient	16.69	5.78	3.74	2.97	2.71	2.41	2.23	2.14	2.01	1.93

Product N

	1	2	3	4	5	6	7	8	9	10
CFM at Nozzle Inlet	20.7	40.3	60.4	80.5	100.0	120.1	140.3	160.4	180.4	200.4
Static Pressure	0.060	0.086	0.134	0.197	0.275	0.363	0.459	0.577	0.678	0.802
Velocity Pressure	0.004	0.013	0.030	0.054	0.083	0.119	0.163	0.213	0.27	0.334
Total Pressure of Fan	0.063	0.100	0.164	0.251	0.357	0.483	0.622	0.790	0.948	1.135
Loss Coefficient	17.07	6.45	4.48	3.71	3.35	3.07	2.84	2.73	2.54	2.43

Product O

	1	2	3	4	5	6	7	8	9	10
CFM at Nozzle Inlet	20.5	40.6	60.5	80.1	100.0	120.6	140.1	160.3	180.3	200.7
Static Pressure	0.033	0.045	0.075	0.118	0.165	0.233	0.312	0.398	0.498	0.588
Velocity Pressure	0.003	0.014	0.030	0.053	0.083	0.120	0.163	0.213	0.27	0.335
Total Pressure of Fan	0.036	0.058	0.105	0.171	0.248	0.353	0.474	0.611	0.768	0.922
Loss Coefficient	9.57	3.33	2.50	2.24	2.01	1.95	1.94	1.89	1.87	1.78

Raw Data Tables for 6 Inch Soffit Vent Caps

Product P

	1	2	3	4	5	6	7	8	9	10
CFM at Nozzle Inlet	40.3	80.7	120.5	160.2	200.1	240.7	280.7	320.3	360.7	400.5
Static Pressure	0.045	0.069	0.097	0.132	0.177	0.225	0.283	0.345	0.397	0.478
Velocity Pressure	0.003	0.011	0.024	0.042	0.065	0.094	0.129	0.168	0.213	0.262
Total Pressure of Fan	0.048	0.079	0.120	0.174	0.242	0.320	0.412	0.512	0.609	0.741
Loss Coefficient	17.10	6.54	4.12	3.17	2.73	2.40	2.22	2.08	1.88	1.84

Raw Data Tables for 6 Inch Wall-Mounted Vent Caps

Product Q

	1	2	3	4	5	6	7	8	9	10
CFM at Nozzle Inlet	40.3	80.6	120.3	160.0	200.7	240.8	280.5	320.5	360	400
Static Pressure	0.065	0.104	0.109	0.104	0.104	0.115	0.134	0.163	0.2	0.247
Velocity Pressure	0.003	0.011	0.024	0.042	0.066	0.094	0.128	0.168	0.212	0.262
Total Pressure of Fan	0.067	0.114	0.132	0.146	0.170	0.210	0.262	0.330	0.412	0.509
Loss Coefficient	24.70	9.88	4.65	2.51	1.59	1.22	1.05	0.98	0.95	0.95

Product R

	1	2	3	4	5	6	7	8	9	10
CFM at Nozzle Inlet	40.8	80.1	120.0	160.6	200.1	240.4	280.8	320.7	360.6	400.1
Static Pressure	0.026	0.040	0.058	0.082	0.115	0.155	0.202	0.249	0.311	0.378
Velocity Pressure	0.003	0.010	0.023	0.042	0.065	0.094	0.129	0.168	0.213	0.262
Total Pressure of Fan	0.029	0.050	0.082	0.124	0.180	0.249	0.330	0.416	0.524	0.641
Loss Coefficient	9.64	3.85	2.49	1.96	1.77	1.66	1.58	1.49	1.48	1.46

Product S

	1	2	3	4	5	6	7	8	9	10
CFM at Nozzle Inlet	40.3	80.2	120.7	160.5	200.2	240.7	280.3	320.3	360.9	400.7
Static Pressure	0.072	0.076	0.065	0.058	0.064	0.086	0.111	0.144	0.179	0.219
Velocity Pressure	0.003	0.010	0.024	0.042	0.065	0.094	0.128	0.168	0.213	0.263
Total Pressure of Fan	0.075	0.087	0.089	0.100	0.130	0.180	0.239	0.311	0.392	0.481
Loss Coefficient	27.36	7.29	2.75	1.39	0.99	0.92	0.87	0.87	0.85	0.84

Product T

	1	2	3	4	5	6	7	8	9	10
CFM at Nozzle Inlet	40.0	80.6	120.2	160.4	200.0	240.1	280.0	320.1	360	400.1
Static Pressure	0.075	0.078	0.078	0.093	0.128	0.174	0.227	0.279	0.35	0.415
Velocity Pressure	0.003	0.011	0.023	0.042	0.065	0.094	0.128	0.167	0.212	0.262
Total Pressure of Fan	0.077	0.088	0.102	0.135	0.194	0.268	0.355	0.446	0.562	0.677
Loss Coefficient	28.93	7.41	3.33	2.23	1.98	1.86	1.79	1.68	1.67	1.60

Product U

	1	2	3	4	5	6	7	8	9	10
CFM at Nozzle Inlet	40.8	80.8	120.3	160.2	200.5	240.0	280.1	320.4	360.7	400
Static Pressure	0.093	0.114	0.136	0.165	0.210	0.256	0.297	0.348	0.413	0.481
Velocity Pressure	0.003	0.011	0.024	0.042	0.065	0.094	0.128	0.168	0.213	0.262
Total Pressure of Fan	0.096	0.125	0.159	0.207	0.276	0.350	0.425	0.516	0.626	0.743
Loss Coefficient	34.48	10.78	5.80	3.97	3.22	2.74	2.34	2.09	1.96	1.86

Product V

	1	2	3	4	5	6	7	8	9	10
CFM at Nozzle Inlet	40.3	80.7	120.8	160.2	200.6	240.6	280.7	320.8	360.1	400.6
Static Pressure	0.012	0.029	0.057	0.094	0.142	0.200	0.267	0.338	0.419	0.498
Velocity Pressure	0.003	0.011	0.024	0.042	0.066	0.094	0.128	0.168	0.212	0.263
Total Pressure of Fan	0.015	0.040	0.081	0.135	0.208	0.294	0.396	0.506	0.631	0.76
Loss Coefficient	4.56	2.75	2.41	2.26	2.18	2.13	2.09	2.03	1.99	1.92

Raw Data Tables for 6 Inch Roof Jack Vent Caps

Product W

	1	2	3	4	5	6	7	8	9	10
CFM at Nozzle Inlet	40.1	80.3	120.7	160.5	200.3	240.2	280.3	320.2	360.1	400.2
Static Pressure	0.117	0.161	0.229	0.307	0.420	0.563	0.727	0.918	1.074	1.302
Velocity Pressure	0.003	0.010	0.024	0.042	0.065	0.094	0.128	0.167	0.212	0.262
Total Pressure of Fan	0.120	0.171	0.253	0.349	0.485	0.657	0.855	1.086	1.286	1.564
Loss Coefficient	44.91	15.41	9.70	7.36	6.46	6.02	5.71	5.53	5.11	5.02

Product X

	1	2	3	4	5	6	7	8	9	10
CFM at Nozzle Inlet	40.3	80.7	120.1	160.0	200.3	240.4	280.7	320.0	360.7	400.6
Static Pressure	0.061	0.094	0.158	0.241	0.350	0.481	0.631	0.797	0.98	1.134
Velocity Pressure	0.003	0.011	0.023	0.042	0.065	0.094	0.128	0.167	0.213	0.263
Total Pressure of Fan	0.064	0.104	0.182	0.283	0.416	0.576	0.760	0.964	1.193	1.397
Loss Coefficient	23.18	8.91	6.76	5.81	5.38	5.14	4.94	4.80	4.65	4.36

VITA

Daniel Santiago Escatel received his Bachelor of Science in mechanical engineering from Texas A&M University in 2009. He entered the mechanical engineering graduate program at Texas A&M University in August 2009 and received his Master of Science in mechanical engineering in May 2011.

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