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Converting Velocity Pressure into Cubic Feet per Minute (CFM)

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Abstract

Almost every building in the United States has a HVAC (Heating, ventilation, and air conditioning) system that relies on balancing Velocity Pressure and calculated CFM to properly control the atmosphere in a building. This is ensured and tested by Field Engineers whose job it is to maintain the efficiency and proper output of these HVAC systems. These systems are used to improve indoor air quality, control moisture and condensation, and contaminants while satisfying comfort needs of occupants. Just with any mechanical system, HVAC systems function efficiently with multiple formulas derived from calculus and physics. Every building is equipped with a system that needs to meet a certain threshold of air movement, measured in Cubic Feet per Minute (CFM), that creates a stable and comfortable indoor atmosphere by testing and balancing these systems with Velocity Pressure. Velocity Pressure is the base reading it takes to understand and adjust air movement within a HVAC system to guarantee the overall best quality of an indoor air environment. Once a measurement of Velocity Pressure, measured in inches of water column (in-WC) using a tool called a Flow Hood or Straight Pitot Tube, is taken then you can start to calculate flow readings and test if a fan is producing the correct amount of CFM that the system was built to produce and support. This testing is done by using a series of calculus and algebraic equations that takes area and velocity into consideration. When solving these formulas, it can then be determined if a HVAC system and its fans are producing the ideal amount of airflow and air quality to accurately produce the precise environment for any building.

Keywords

Velocity Pressure, HVAC (Heating, ventilation, and air conditioning) system, CFM

PROBLEM STATEMENT

Calculating the CFM in FPM of a 20” by 20” vent and balancing the system for a commercial or industrial HVAC system.

MOTIVATION

This specific occurrence in engineering is very important because of how much the average company and person depends on a HVAC system for everyday comfort and living, especially in the United States. The testing and balancing of these systems solely depend on the mathematical skills of engineers to build and maintain an artificial environment indoors. This job and skillset are relied on severely from millions of businesses and homes across the world to enhance the comfort of living. When incorporating calculus and physics on an everyday basis it takes precision of problem-solving and formula manipulation to either find or evaluate a problem that can affect thousands of people a day. Velocity Pressure and atmospheric pressure surrounds every single person every day, so a Field Engineers job is very important of accurately sustaining these pressures for those millions of businesses and homes. By calculating velocity of air within a given area and ensuring the balance of these systems, people can go about their normal lives in a comfortable environment without even noticing.

MATHEMATICAL DESCRIPTION AND SOLUTION APPROACH

Converting velocity pressure into CFM. Every AC unit has a CFM that it is rated for optimal performance. This is a large part of test and balance to ensure units are always running close to their design CFM. This helps to ensure the discharge air temperatures are close to 55F and assists in controlling humidity (pulling enough moisture from the air as it passes through the evaporator coil). Typically, they use a tool called a Flow Hood to read the actual CFM of a unit, but this is not always possible due to the location of the air diffusers and/or their shape (our flow hood is 24"X24" so any diffuser not that size does not read correctly). So, we will use what is known as a duct traverse (a duct traverse is executed by drilling several equal-distant holes in a supply air duct). These traverse readings are read via a Straight Pitot Tube connected to a digital manometer. This manometer outputs the readings in velocity pressure (unit – inWC) and in Feet per Minute (FPM). This conversion is done by hand using the following Bernoulli formula:

$$V_{(\text{ std air})} = 4005 \times \sqrt{VP}$$

So, with a reading of 0.0141"WC on the manometer, you effectively have 476 FPM of air. Now we need CFM. FPM is turned into CFM by multiplying the average FPM in the duct by its area. Depending on the duct shape one of the following can be used:

$$\text{Area}_{\text{Round}} = \frac{\pi \times \left(\frac{d}{2}\right)^2}{144} = \frac{(\pi \times r^2)}{144}$$

$$\text{Area}_{(\text{square/rectangular})} = \frac{(HT \times WD)}{144}$$

$$\text{Area}_{\text{Oval}} = \frac{\left((HT \text{ x } WD) + (\pi \times \left(\frac{HT}{2}\right)^2)\right)}{144}$$

Using square area for simplicity. Measuring the duct is 20"x20", this will get an area of 2.78. Take the 2.78 and multiply it by our previous FPM reading of 476 and get 1,322CFM. This CFM can then be compared to the design CFM of the unit, and it can be determined if the unit needs to be sped up or slowed down. Engineers do this by adjusting the motor pulleys inside the units in most scenarios.

The following formula can be used to see how your change in FAN rpm changes the CFM output of the unit (make adjustment on the motor, read the difference on the fan):

US Units (IP)
$\frac{CFM_2}{CFM_1} = \frac{RPM_2}{RPM_1}$

Once you change your RPM to get the CFM you want, the unit total is balanced.

DISCUSSION

Resulting from the testing and balancing, the analysis of the fan was up to specifications on how the unit should be performing. Given the mathematical approach, there is a range of 1,200 to 1,400 CFM that the tested unit needed to be performing within. As tested, 1,322 CFM is within the threshold that the system was designed to operate within. The objective of the overall project is to analyze a HVAC system's unit making sure it was operating within the threshold listed previously. The calculations that I concluded support the observation of the unit was producing enough CFM to maintain the proper Velocity Pressure as assessed via manometer. Overall, in the field these systems are evaluate by Field Engineers day in and day out using applied algebra, calculus, and physics to draw conclusions if the system and its many units are running at peak performance and accomplishing the standards they are set to.

CONCLUSIONS AND RECOMMENDATIONS

In hindsight, a Field Engineer has a particularly important role with commercial and industrial HVAC systems ensuring the quality of these vents, ducts, and fans. Flowrates vary in every individual instance with Velocity Pressure, CFM, and area that these are dependent upon. Dependent on the Field Engineer's knowledge of accuracy of placement of the sensors of the Straight Pitot Tube giving readings to the manometer, the area of the ducting, the understanding of Velocity Pressure, and the applied algebra and calculus simply to evaluate these systems plays a particularly key role. But then the Engineer's knowledge to take the applied calculations of balancing these units and test repeatedly until the desired setting is achieved makes rehearsal of applied calculus and understand the physics of airflow and pressure especially critical. When comparing results of testing to the design of unit it is the Field Engineer's job to certify CFM, Velocity Pressure, and FPM that his calculations reflect what the specifications of the system was set to do.

Reflecting, the calculations concluded in this project the results shown must be executed by the Engineer with precision of understanding how one small reading of Velocity Pressure solely influences the how to control and certify CFM. As evaluated, a 20" by 20" duct requires 1,200 to 1,400 CFM to function appropriately. By measuring Velocity Pressure then applying Bernoulli formula I can then calculate the FPM. From there, I then transfer the FBM into CFM by calculating the area of the square duct. Once completed, I then analyzed my results to compare them to the tolerance of the unit which is given as 1,200 to 1,400 CFM from the Field Engineer. Of course, with today's technology there is a machine that calculates this with ease that is called a Flow Hood. Think of a Flow Hood as a calculator that evaluates air flow and pressure instead of basic arithmetic. If one were to recreate this project it would be a much easier to simply use a Flow Hood; however as stated, it will not always fit or even be available to use. If such tools as a manometer is not available to measure Velocity Pressure, it can be calculated by determining velocity using Q (air flow rate) = A (area of duct) multiplied by V (air velocity).

NOMENCLATURE

- inWC = Inches Water Column
- CFM = Cubic Feet per Minute
- FPM = Feet per Minute
- RPM = Revolutions per Minute
- V Velocity FPM
- VP Velocity Pressure inWC
- HT Height inches
- WD Width inches

REFERENCES

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APPENDIXES

a.) Bernoulli's Formula:

$$V_{(\text{ std air})} = 4005 \times \sqrt{VP}$$

b.) Square footage of round, square/rectangle, and oval:

$$\text{Area}_{\text{Round}} = \frac{\pi \times \left(\frac{d}{2}\right)^2}{144} = \frac{(\pi \times r^2)}{144}$$

$$\text{Area}_{(\text{square/rectangular})} = \frac{(HT \times WD)}{144}$$

$$\text{Area}_{\text{Oval}} = \frac{\left((HT \text{ x } WD) + \left(\pi \times \left(\frac{HT}{2}\right)^2\right)\right)}{144}$$

c.) RPM to CFM:

US Units (IP)
$\frac{CFM_2}{CFM_1} = \frac{RPM_2}{RPM_1}$