TIME-BASED BOUNDING VALUES FOR BLOWER DOOR INFILTRATION MEASUREMENTS IN BUILDINGS WITH COMPROMISED ENVELOPE TIGHTNESS

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Abstract

The purpose of this study was to define a strategy for determining how long to perform a depressurization test with a blower door. This paper investigates the results from a study that attempted to determine a time bounding value for depressurization of a control volume to 50 Pascals (Pa) with respect to an ambient reference pressure. The underpinning assumption was that a building envelope can be critically compromised to the point that blower door data becomes ineffective because it takes longer to depressurize a targeted space than is reasonable to wait. These ideas were evaluated by analyzing data collected from a blower door experiment performed on several control volumes with increasing infiltration rates. It was hoped that experimental results would yield a bounding time dependent only upon the size of the control volume evacuated. However, it was found that a second factor that cannot be directly measured or controlled, the infiltration permitted by the envelope of the interrogated space, also influences depressurization time. Experimental results allowed the researchers to better understand and improve their test procedures and measurements techniques.

Introduction

Blower doors are instruments used to find leaks in a building's envelope, but more often the values generated by the measurements are used to estimate infiltration for both indoor air quality and energy consumption [1]. When maintaining comfort using conditioned air in buildings, loss of air can result in significant energy consumption. Industry standard 'fan pressurization tests' using blower doors, are performed by creating a 50 – 75 Pascal (Pa) pressure difference between the analyzed control volume and ambient conditions [2]. This experiment references Texas government energy codes and standards set by American Society of Heating, Refrigerating, and Air Conditioning Engineers (ASHRAE). These references provide basis for a comprehensive testing and analysis method, but do not apply directly to the results presented herein.

> "As published in the June 4 Texas Register, the Texas State Energy Conservation Office (SECO) has officially adopted a rule (proposed March 26) to update the state's energy codes codified in 34 TAC §19.53. The rule will update the Texas Building Energy Performance Standards (currently based on the 2000 IECC with the 2001 Supplement) to:
> • For single family homes – the energy efficiency provisions (Chapter 11) of the 2009 International Residential Code (IRC), effective January 1, 2012.
> • For all other residential, commercial, and industrial buildings – the 2009 IECC, effective April 1, 2011 (this effective date was erroneously reported previously as January 1, 2011)." [3]

Buildings suffering significant air leakage may be unable to achieve a 50 – 75 Pa pressure gradient necessary to measure envelope tightness without proper industrial grade fans. In these cases, criteria other than differential pressure are required to approximate when infiltration data should be obtainable. To define these alternative parameters, a blower door is installed on sealed rooms with known volumes. The blower is allowed to evacuate each space to generate a depressurization versus time curve as a function of volume. In buildings with severe air infiltration, these measured times represent the criteria approximating when depressurization competent for infiltration measurements are achieved. The results expand the utility of the blower door infiltration measurement technique to 'legacy buildings', a term used to define buildings experiencing compromised envelope tightness and/or high air leakage rates.

Students from the University of North Texas (UNT) performed this experiment as part of their senior design project, 'Harvesting Built Environments for Global Accessible and Modular Energy Audit Training', which was sponsored by ASHRAE to develop an economical building energy auditing kit for their senior design project. The student-designed building energy audit kit was developed in consultation with collaborating faculty in Egypt and Ukraine to make the design more universally accessible both in the U.S. and abroad. ASHRAE support allowed the students to purchase professional building energy auditing equipment, which they reverse-engineered to inform their own design. With this knowledge, students designed and built an economical blower door to measure building infiltration. Students then quantitatively compared their blower door performance to the professional kit in a live building energy audit of a high-rise residential building in Dallas, TX.

This project is part of the Modular Energy Engineering Laboratory Curriculum (MEELC) being created by co-author Traum to provide turn-key energy engineering course modules for seamless insertion into high school and college Science, Technology, Engineering, and Mathematics (STEM) curricula to inspire and train a new generation of energy engineers.

The purpose of the study reported here was to define a strategy for determining how long to perform a depressurization test with a blower door. The student researchers attempted to determine a time bounding value for depressurization of a control volume to 50 Pascals (Pa) with respect to an ambient reference pressure. The underpinning assumption was that a building envelope can be critically compromised to the point that blower door data becomes ineffective because it takes longer to depressurize a targeted space than is reasonable to wait. These ideas were evaluated by analyzing data collected from a blower door experiment performed on several control volumes with increasing infiltration rates. It was hoped that experimental results would yield a bounding time dependent only upon the size of the control volume evacuated. However, it was found that a second factor also influences depressurization time: the infiltration permitted by the envelope of the interrogated space. This second factor cannot be directly measured or controlled, complicating interpretation of the test results.

Methods

The test procedure for this experiment stems from 'Test Procedure 2' in the ASHRAE Journal article, *Controlling Air Leakage in Tall Buildings.* 'Test Procedure 2' specifies achieving a 50 Pa pressure difference between the volume of interest (in this case, a small closet or isolated room) and the ambient (the remainder of the house) [2]. Furthermore, ASHRAE standards commonly recognize the metric ACH_{50} (translated as air changes per hour when depressurized to 50 Pa) as an acceptable way of quantifying the leakiness of a test volume envelope; hence the decision to use 50 Pa as an experimental standard here. ASHRAE recommends that a residence experiences a minimum of 0.35 ACH to maintain adequate human health and comfort [4].

The procedure followed in this experiment consists of applying the blower door to each control volume in order to create a pressure difference. After obtaining critical control volume dimensional measurements; the volumetric flow rate, in cubic feet/minute (CFM), was recorded for increments of 5 Pa up to a 60 Pa pressure difference across the fan. Measuring the difference up to the 60 Pa difference ensured that the equipment operated consistently above and below the optimum range of gage pressure measurements. Due to high envelope tightness in some of the tested control volumes, a specialized low flow plate was attached to the blower door fan to allow for low CFM flow readings.

The next step in the experimental procedure was to measure the amount of power supplied to the fan at gage pressure differences of 50 Pa and 60 Pa to provide comparable and controllable measurement settings between each control volume. A theoretical 'standard' was calculated by measuring the power required to achieve pressure differences of 50 Pa and 60 Pa for each control volume. Time measurements were then taken at the standardized settings as the pressure difference increased in increments of 5 Pa until a 50 Pa pressure difference was created across the blower fan. This measurement was repeated eleven times for each control volume and averaged to generate a series of mean value depressurization versus time curves.

A total of 5 distinct control volumes (CV) were used for this experiment. CV 1, a small residential pantry located in Corinth, TX with no compromised envelope or form of ventilation, was used to simulate a volume with theoretically maximum air tightness. CV 2 was a closet space of a residence located in Lewisville, TX. CV 2 had no ventilation ducts and was assumed to be directly comparable to the air tightness of CV 1. CV 3 and CV 4 were two distinct CVs within a team member's apartment located in Denton, TX. These two control volumes provided a comparable reference to how a residence normally behaves using a fan pressurization blower door test. CV 5 was an empty lab room located at the University of North Texas Discovery Park Engineering Campus. CV 5 consisted of an open room with a dropped ceiling using a floating frame to supports ceiling tiles. This CV simulated an envelope with minimal air tightness.

Table 1: Infiltec E3-A-MAG-110 Fan Specifications

Feature	Specification
Fan Motor	3/4 hp @ 110 vac/60 Hz
Maximum flow @ 50 Pa	5450 cfm (9265 m^3/h)
Minimum calibrated flow	42 cfm (71 m^3/h)
Maximum current	8.7 amps
Motor speed ranges	2

All blower door measurements were taken using an Infiltec E3-A-MAG-110 blower door system. Specifications for the blower door system, per Infiltec's Website, are listed in Table 1 [5]. Time measurements were taken using a laboratory stopwatch, relying on human reaction time to produce an expected and systematic source of error similar to the uncertainty that would occur in real blower door tests. Data were recorded and analyzed using Microsoft Excel.

Results and Discussion

Figure 1 displays the depressurization versus time date for the tested control volumes. The time values found show the time required for the control volumes to reach a 50 Pa gage pressure between the tested volumes and ambient pressure.

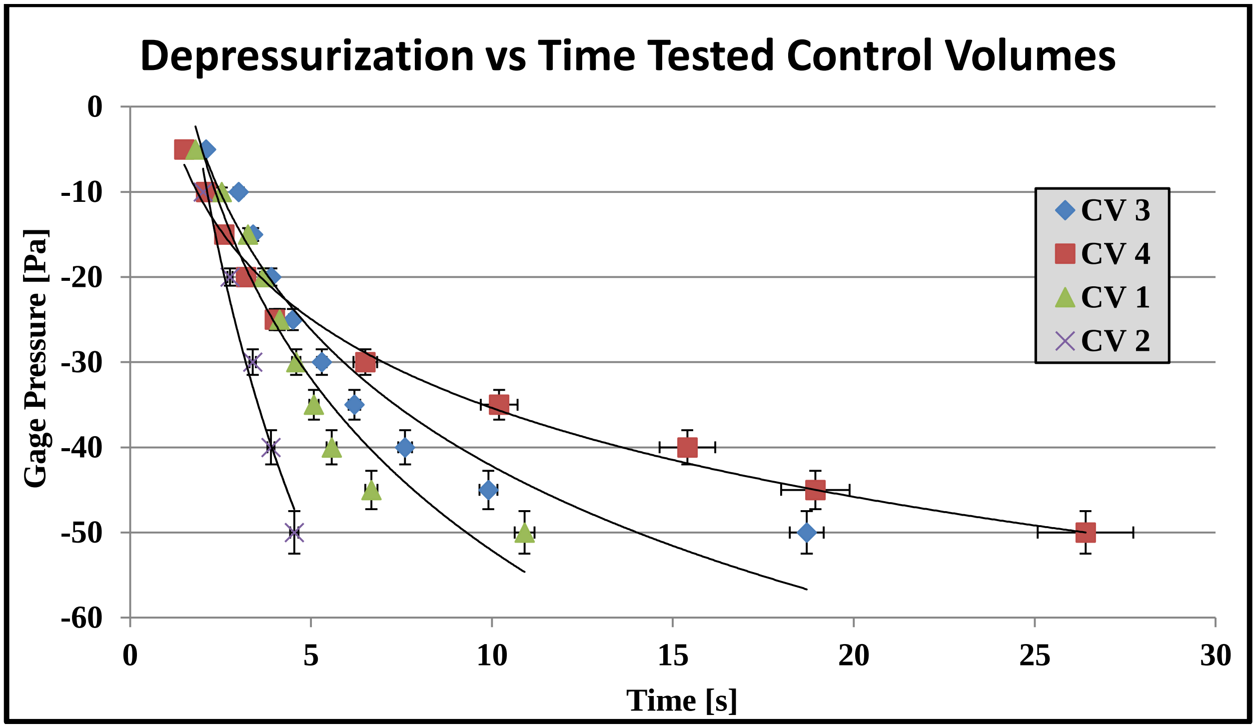

Figure 1: Time-Bound Depressurization Curves for Tested Control Volumes

As expected, CV 5 never completely depressurized due to excessive infiltration, and this null data set was therefore not included in Figure 1. CV 3 and 4 required the longer amounts of time to reach a 50 Pa gage pressure differential, which was in agreement with the size and perceived leakiness of each control volume tested. It makes sense that larger volumes permitting more infiltration (CV 3 and CV 4) would require more time to depressurize than smaller, better sealed volumes (CV 1 and CV 2).

The HVAC ductwork connecting CV 3 and CV 4 to the outside contributed to the higher volume flow rates and longer times required to reach 50 Pa pressure differential because outdoor air was constantly being drawn into the volumes by the ductwork. It was hypothesized that the low but measurable air volume flow rates from CV 1 and CV 2, shown in Table 2 below, were primarily due to air leakage through the blower door frame. Since no air conditioning ductwork or any visible leakage factors contributed to the CV 1 and CV 2 volume flow rate value, the principle place air could be drawn into the otherwise sealed volumes was the gap between the blower door and the door frame. These values were therefore highly dependent on proper installation of the blower door.

Table 2: Blower Door Data from Tested Control Volumes

Control Volume #	Infiltration Volume Flow Rate @ 50 Pa Depressurization (CFM)	Approximate Volume Evacuated (ft^3)
1	62.5	234
2	110	614
3	727	2150
4	978	5000

Table 3 shows the relationship between infiltration volume flow rate and blower door fan power at a 50 Pa gage pressure depressurization. As expected, larger rooms with more compromised envelopes required a greater power draw to achieve a 50 Pa pressure depressurization.

Table 3: Fan Power Consumption Versus Infiltration Flow Rate at 50 Pa Depressurization

Control Volume #	Infiltration Volume Flow Rate @ 50 Pa Depressurization (CFM)	Fan Power Draw at 50 Pa Depressurization (W)
1	62.5	990
2	110	1220
3	727	1250
4	978	1300

While the nameplate power rating of the Infiltec E3-A-MAG-110 fan motor was 0.75 hp (~ 560 watts), the motor was capable of absorbing up to 1657 watts considering the 8.7 amp maximum current rating at 110 VAC [$\sqrt{3}$ X 8.7 amps X 110 volts ≈ 1657 watts]. Thus, the limit on the ability of the blower door to depressurize a space by 50 Pa was expected to occur at a fan power draw 1657 watts. Unfortunately, the 50 Pa depressurization CV 4 power draw was 1300 watts, and 50 Pa depressurization of CV 5 was not achieved even at maximum fan power. Thus, the bounding time for a blower door field test using the Infiltec E3-A-MAG-110 is longer than the depressurization time measured for CV 4, 26.4 seconds. However, it is not precisely known.

Conclusion

This experiment examined air evacuation rates of existing well-sealed and poorly-sealed residential spaces using a fan pressurization blower door. The original goal of this work was to establish a depressurization versus time curve for a leaky space at the limit of the evacuation ability of the blower door. This curve would have provided a bounding time value for fan pressurization tests. If a test in the field reached this bounding time without depressurizing by 50 Pa below ambient, the space would be deemed too leaky for competent testing using this technique.

Before running these experiments, it was assumed that achieving a pressure drop of 50 Pa across the blower fan would require substantial time. However, collected experimental data showed this pressure drop to occur very rapidly, on the order of 30 seconds. Moreover, this pressure drop was dependent upon at least three experimental factors: 1) the power supplied to the fan, 2) the volume of the space being evacuated, and 3) the leakiness of the envelope being tested. While the volume of a space being depressurized did impact depressurization time, it could not be concluded that CV's of similar volume have similar depressurization times. The envelope infiltration rates (e.g., the leakiness of air through the room's walls) might be different. This second factor introduced an element of complexity not considered in the initial hypothesis of the student experimenters.

Time intervals to depressurize five increasingly leaky control volumes by 50 Pa were recorded. However, the fifth control volume (CV 5) did not depressurize by 50 Pa, even at maximum fan power over several minutes, because the infiltration rate of the space was too high. Thus, the desired time bound for blower door field tests lays somewhere beyond the depressurization time of CV 4, 26.4 seconds, but it was not directly measured. As such, further experiments are needed to directly measure a bounding time for infiltration tests with the Infiltec E3-A-MAG-110 blower door.

References

[1] Sherman, Max, "The Use of Blower Door Data," (1998), http://www.engext.ksu.edu/ventilation.asp

[2] Genge, Colin, "Controlling Air Leakage in Tall Buildings," *ASHRAE Journal*, April (2009)

[3] "Texas Energy Office Officially Adopts 2009 IECC and 2009 IRC", http://bcap-ocean.org/news/2010/june/04/texas-energy-office-officially-adopts-2009-iecc-and-2009-irc

[4] http://www.infiltec.com/inf-e3-s.htm

[5] http://www.engext.ksu.edu/ventilation.asp