REPEATABILITY OF WHOLE-BUILDING AIRTIGHTNESS MEASUREMENTS: MIDRISE RESIDENTIAL CASE STUDY

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ABSTRACT

This case study describes repeated whole-building airtightness measurements of an unoccupied ten story residential building in Madison, Wisconsin (USA). Tests were performed in two phases of testing – summer (June) and late fall (November) – over a wide range of temperatures and wind speeds in each test phase. Both multi-point regression tests (similar to ASTM-E779 and EN-13829) and repeated single point tests (similar to ASTM E-1827) were performed. Tests were performed in both pressurization and depressurization mode using portable blower door equipment. Eight separate enclosure pressures were measured – 4 at grade and 4 along the parapet wall. Throughout the tests all pressure and flow measurements were continuously recorded at one second intervals.

The short term (within-phase) results had measured standard deviations of order 1% for both single point and multi-point tests. However, between the two test phases there was a measured difference in airtightness of about 10% (with the building measuring tighter in June than in November). This difference could not be explained by any of the identified error sources. The question remains whether it may be the result of physical changes in the building.

A detailed comparison of the two test methods is given. Single point testing was more effective at precisely determining the leakage (within a given test phase) than was mutlti-point regression testing. Precision was not markedly improved by the use of both pressurization and depressurization compared with using either separately.

KEYWORDS

Airtightness, blower door, uncertainties, repeatability, pressurization, testing, large building, multiple fans, automated

1. INTRODUCTION

The airtightness of building enclosures has long been understood to have an impact on building durability, energy consumption, indoor air quality and occupant comfort. Increasingly, new buildings and buildings undergoing remedial air sealing are being tested and a significant dataset of leakage values is being developed. Even so, there is a relative lack of information on the accuracy and precision of these tests on larger buildings due, at least in part, to the difficulty and expense of conducting the appropriate experiments. This information is needed for standards development.

Buildings undergoing remedial air sealing and newly constructed buildings require measurements that are of high data quality yet are as streamlined as possible. When trying to determine compliance with a specific target airtightness, the uncertainties must be estimated and accounted for in a pass-fail determination.

This case study looks at two primary issues: The merits of single point versus multi-point testing and the benefits of conducting tests in both pressurization and depressurization modes. Many secondary issues are considered.

2. BUILDING CHARACTERISTICS AND TEST EQUIPMENT CONFIGURATION

2.1. Building Characteristics

The building is a dormitory built in 1962 with approximately 84,000 ft^2 (7800 m^2) of total enclosure area including exterior walls, roof and below grade surfaces. The interior volume is approximately 1,000,000 ft^3 (28,000 m^3). The building is situated on an isthmus, allowing direct exposure to winds coming across the lakes to the north and south. As shown in Figure 1, the building is tall and narrow. The west side of the building contains 87 windows and the east side contain 125 windows. The short ends (north and south) do not contain windows. Most floors consist of a central hallway with dorm rooms on each side. A single elevator shaft serves all residences and a ventilation air shaft also provides connections vertically. There are stairwells in the north and south running the full height of the building.

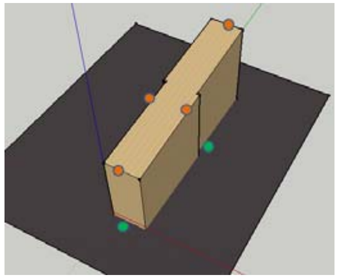

Figure 1: Building geometry and location of the 8 outside pressure taps

2.2 Preparation for testing

There are a total of 13 exterior mechanical openings which were masked for the testing, some at grade and others on the walls and roof. A detailed list was maintained so that the test setup in June could be reproduced in November. During each week of testing, the building was set up once and left in the test configuration during the overnight periods.

2.3 Equipment layout

A total of 4 blower door fans were installed, all at grade. Fans 1 and 2 were set up in a two-fan frame in the south entrance and fans 3 and 4 similarly in the west. Digital manometers with 0.1 Pa resolution were used for measuring all pressures and fan flows. All manometers were connected back to a central computer on the ground floor using cat5 cable and pressure sampling tube lengths were minimized as much as possible.

3. TEST PROTOCOL

The testing consisted of a multi-point sequence and a single point sequence. The goal for each day of testing was to alternate between the two and to complete as many repetitions as possible. Each week of testing started with setting up the building and thereafter as many tests as possible were completed. Each day started with multi-point as this was thought to be a more commonly used procedure and thus of greater interest.

3.2 Multi-point Sequence

Depressurization:
- 5 minute pre baseline
- -30 to -75 induced pressure in 5 Pa increments, each for one minute
- 5 minute post baseline

Pressurization: Repeat under positive pressure.

3.3 Single point Sequence

Depressurization (repeat x 10):
- 1 minute baseline
- 1 minute induced -75

Pressurization: Repeat under positive pressure.

4. RESULTS

Table 1 contains the data for all multi-point tests and Table 2 contains all single point tests. The first character in the Test name represents the Test Phase where a=June, b=November.

Table 1: Multi-point Tests

Test	T in (F)	T out (F)	Wind mi/hr.	CFM75(d)	+/- 95%	CFM75 (p)	+/- 95%
amp1	78	77	15	14913	236	16255	229
amp2	78	85	23	14479	458	16097	512
amp3	78	57	14	14552	203	16008	192
amp4	78	54	16	14402	140	15868	310
amp5	78	56	9	14567	85	16040	224
amp6	78	53	7	14767	51	16102	229
bmp1	66	35	23	16153	915	18177	483
bmp2	73	32	7	16049	68	17266	70
bmp3	67	45	9	15851	131	17327	207
bmp4	65	41	11	16035	184	17617	160
bmp5	75	38	3	15977	122	17542	210
bmp6	70	41	7	16186	112	17272	190
bmp7	68	40	19	16362	262	17248	549
bmp8	77	27	2	16309	146	17852	266

Table 2: Single Point Tests

Test	T in (F)	T out (F)	Wind mi/hr.	CFM75(d)	+/- 95%	CFM75 (p)	+/- 95%
asp1	78	82	18	14757	400	15883	448
asp2	78	55	11	14548	75	16353	157
asp3	78	56	12	14515	82	16408	161
asp4	78	55	4	14498	56	16189	97
bsp1	69	37	4	15856	24	17673	56
bsp2	67	45	9	15929	156	17905	164
bsp3	69	41	4	15849	85	17576	143
bsp4	68	42	7	15892	77	17985	196
bsp5	69	37	6	15994	71	17913	95

The CFM75 values for Multi-point and Single-point tests are shown below in Figures 1 and 2, respectively. Note that the reference lines for each test phase are the weighted mean of the given test mode (pressurization or depressurization) within the given test phase (June or November). The weights are the inverse of the calculated variance of the test.

Pressurization produced consistently higher leakage than depressurization, and there was a clear shift between June and November which was about equal for pressurization and depressurization. No cause for this shift has been identified.

The noticeable positive deviation of the pressurization value for test index 7 in Table 1 is the result of a loose panel on an air handler cabinet being blown open. This was discovered not by looking at the data but by a pre-planned inspection of all seals, underscoring the importance of such inspections. The errant value does not significantly change the conclusions of this work and is therefore being included in the analysis.

The error bars in Figure 2 are the predicted 95% confidence intervals directly from the regression statistics. Visual inspection shows that they are not adequate to explain the deviations from the weighted mean, even within test phase. By calculating the standardized errors (from the weighted means within test phase) it can be shown that the error bars are roughly 3 times too small.

The error bars in Figure 3 are based on standard statistics applied to the 10 repeats which represent each data point. These errors are approximately the right size to explain the deviations from the weighted means, and it appears that the standard statistical techniques are adequately explaining the precision errors. This is not the same procedure as in ASTM E-1827 but is applied here as it is thought to be a simpler and more appropriate statistical technique for this experiment.

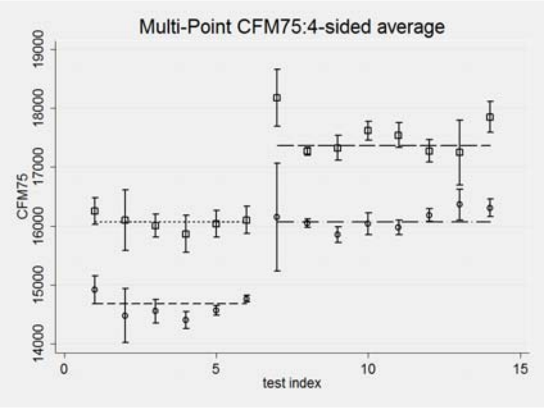

Figure 2: Multipoint CFM75 versus test index using 4 outside pressure taps

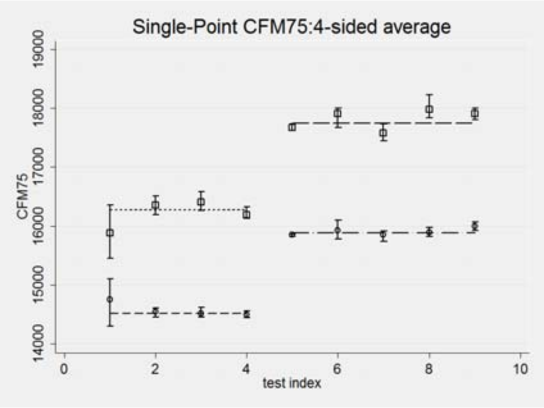

Figure 3: Single point CFM75 versus test index using 4 outside pressure taps

Figures 4 and 5 show the estimated precision errors versus average wind speed of each test. The wind speeds used in this analysis come from a nearby weather station on top of a tall building approximately 1 mile from the site. It is expected that wind speeds experienced by the test building are somewhat lower than those of the weather station.

Note that the estimated errors seem to be roughly the same (at a given wind speed) for single point tests and multi-point tests. However, recall that the multi-point errors were being underestimated by a factor of about 3. Therefore single point tests provide a more precise result at a given wind speed for this building under the conditions in which these tests were performed.

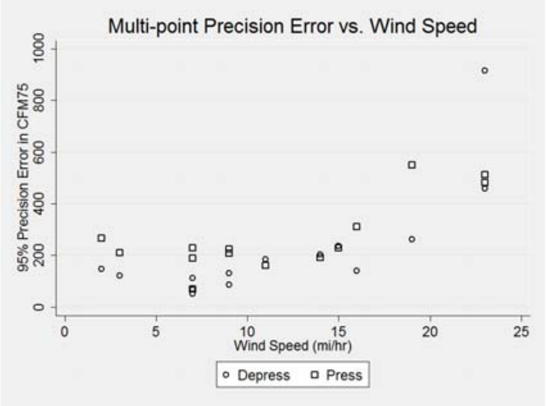

Figure 4: Multi-point precision errors versus wind speed

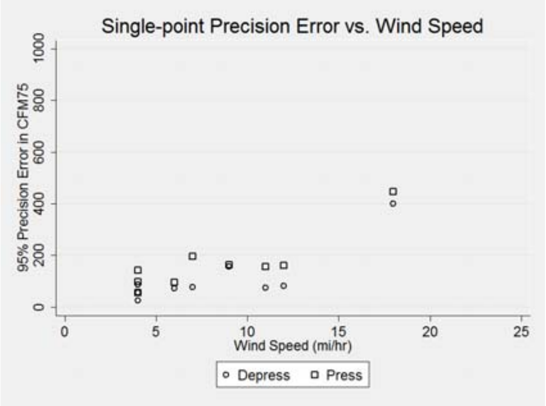

Figure 5: Single point precision errors versus wind speed

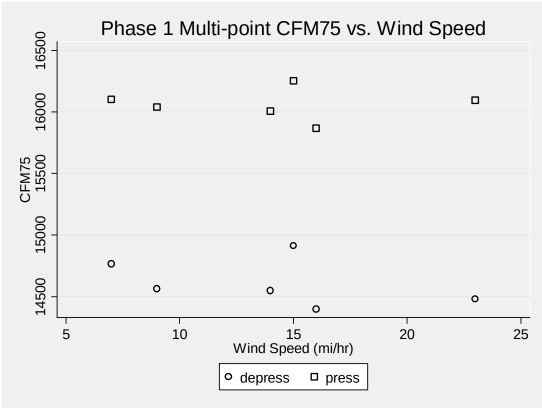

Figure 6: Phase 1 Multi-point CFM75 versus wind speed

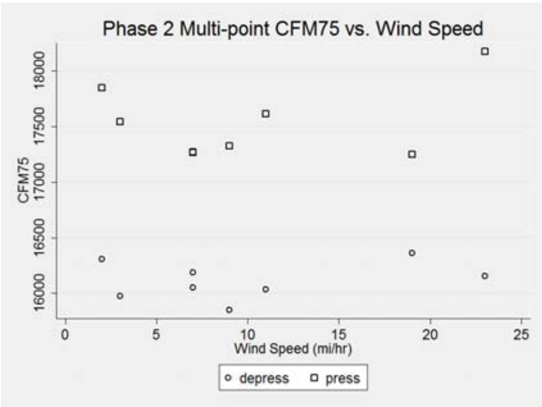

Figure 7: Phase 2 Multi-point CFM75 versus wind speed

Below are some representative graphs of individual tests. Figure 8 shows the combined pressurization and depressurization results of the first multi-point sequence (MP1). Figure 9 shows the first depressurization run in single point test (SP1).

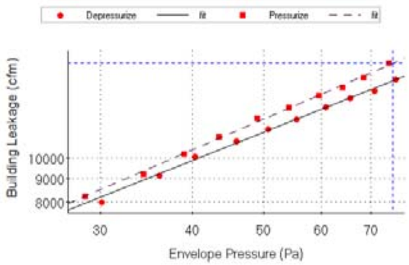

Figure 8: Multi-point sequence MP1, pressurization and depressurization

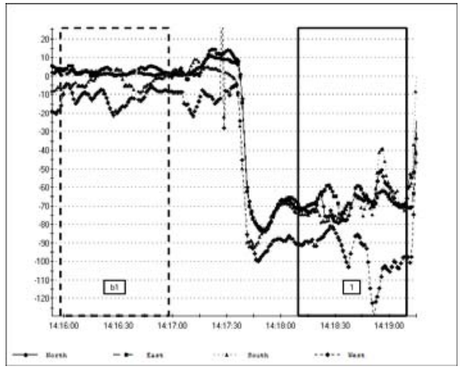

Figure 9: First of 10 repeats for SP1 (depressurization), pressure versus time

4. ANALYSIS

The multi-point confidence intervals are clearly too small. This most likely means that some underlying statistical assumption is not being met. One important contributor may be the baseline fluctuations, which are not being accounted for properly. Baseline readings clearly contain an error component, yet when these readings are simply subtracted from the fan-on pressure readings there is not proper accounting for their uncertainty. These errors may cause nonlinearity in the log-log data, resulting in a slight increase in estimated uncertainty, but the effect is too small.

If we perform the simple calculation of how much difference it makes to use the post baseline (alone) versus the pre-baseline (alone) it should give an idea how large the effects can be. Table 3 shows the change in CFM75 caused by using the post-test baseline versus the pre-test baseline for both depressurization and pressurization. It is noteworthy that there appears to be a systematic shift towards tighter results using the post-baseline in depressurization mode. There is not such as obvious trend with the pressurization data. These changes are also expressed as a fraction of the 95% confidence interval. It is seen that in some cases the change in measured leakage can be several times the estimated 95% precision error. This suggests that the baseline errors can be important contributors to the overall precision errors and need to be accounted for in the analysis. It is beyond the scope of this paper to develop such a model but this will be an area of on-going work.

Table 3: Impact of using just post-test baseline versus just pre-test baseline

Change in CFM75(D)	Fraction of 95% error	Change in CFM75(P)	Fraction of 95% error
-106	-0.45	56	0.25
-46	-0.10	-128	-0.25
24	0.12	36	0.19
67	0.49	59	0.19
-9	-0.11	65	0.29
-103	-1.94	111	0.49
-585	-0.62	-68	-0.14

-338	-5.45	118	1.66
-213	-1.59	60	0.29
-124	-0.66	20	0.13
-247	-2.09	-43	-0.21
-391	-3.62	61	0.33
-725	-2.51	-20	-0.04
-244	-1.69	87	0.33

5. CONCLUSIONS

Short term (within-phase) repeatability was excellent for both multi-point and single point tests over a range of wind speeds and temperatures. Single point repeated tests had better precision than multipoint tests and, importantly, the precision errors could be adequately estimated using standard statistical techniques. The multi-point precision errors seemed to be underestimated by about a factor of 3 when using standard regression statistics. Averaging all four sides of the building improved the precision as compared with randomly selecting a single outside pressure tap. For any given test, a carefully selected pressure tap on the leeward side of the building often had better precision than the average of the four.

One reason often cited for specifying both pressurization and depressurization tests is that there are cancellations of errors due to wind, stack and other sources such that there is an improvement in precision and accuracy. That does not seem to be the case with these results. There was no obvious precision benefit from testing in both pressurization and depressurization modes. If the goal were to make a measurement as precise as possible, in the least amount of time, these data suggest it would be better to test one mode twice than to test both modes. The time spent reversing the fans was not rewarded in an improvement. There was, however, about a 10% leakage difference between the two test modes and in some cases that would be important to consider. But if, for example, you want to measure a change in building tightness from remedial air-sealing it may be more efficient to specify just one test mode.

For the range of wind speeds encountered, there was no clear bias due to wind. There was an increase in the *estimated* precision errors but not enough data to observe an actual increase in errors due to wind. Studies of short term repeatability should be conducted for various building geometries in even higher wind speeds in order to bracket the conditions under which testing can occur.

There was an inexplicable shift in airtightness of about 10% (tighter in June than in November). Despite careful effort, it could be that there was a failure to replicate the test conditions between phases, or some other cause of a large concentrated leak which was different between test phases. It could also be that many leaks changed - effectively an overall change in permeability. Additional Studies should be conducted on other buildings of various construction types to look for seasonal changes in airtightness.

5. ACKNOWLEDGEMENTS

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6. REFERENCES

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