Implementing the Results of Ventilation Research
16th AIVC Conference, Palm Springs, USA
19-22 September, 1995

Fan Pressurization Measurements by Four Protocols

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FAN PRESSURIZATION MEASUREMENTS BY FOUR PROTOCOLS

SYNOPSIS

Thirty-one independent fan pressurization measurement series were performed on seven apartments in three family housing buildings at Fort Riley, Kansas, using four protocols (Table 2). The tests followed procedures in new or revised fan pressurization standards by the International Standards Organization (ISO), American Society for Testing and Materials (ASTM) and Canadian General Standards Board (CGSB). In addition, the effect of interzonal flow was considered.

The three standards gave similar results. The tests during windy and calm conditions demonstrated that basic uncertainty calculations give a comparative indication of the quality of the results. The tests addressing interzonal flow did not show a strong influence on airtightness results, based on whether the adjacent units were open, closed, or pressurized at the same level.

LIST OF SYMBOLS

Table 1 Explanation of symbols.

Symbol	Explanation
ACH_{50}	Air flow rate at P_{ref} = 50 Pa per unit of zone volume(1/h)
C	Flow coefficient ($m^3/s\ Pa^n$)
L	Leakage area (m^2)
n	Flow exponent (dimensionless)
P	Pressure difference across the building envelope (Pa)
P_{ref}	Reference pressure difference across the building envelope (Pa)
Q	Air flow rate (m^3/s)
Q_{ref}	Air flow rate at P_{ref} (m^3/s)
Q_4	Air flow rate at P_{ref} = 4 Pa (m^3/s)
Q_{10}	Air flow rate at P_{ref} = 10 Pa (m^3/s)
Q_{30}	Air flow rate at P_{ref} = 30 Pa (m^3/s)
ρ_e	Air density passing through the leaks in the building envelope (kg/m^3)

1.0 INTRODUCTION

1.1 Fan Pressurization Standards

Fan pressurization measurements of building air leakage have long been in use. ASTM [1] first published E-779 in 1981. Canada published CAN/CGSB-149.10 [2] in 1986. Now there are proposed revisions or supplements to each. Recently ISO adopted the soon-to-be-published ISO 9972 [3].

This paper investigates new protocols proposed for CAN/CGSB-149.10 [4] and a proposed blower-door-based standard that supplements E-779, here designated ASTM E-X [5]. These are compared with ISO 9972. In addition this paper touches on protocols for multizone tests.

1.2 Goals of the Experiment

The experiment reported in this paper had two goals: to compare test protocols and to ascertain the airtightness of the buildings tested. The comparison of test protocols was to determine differences in measured values and their statistical uncertainties, as calculated by each protocol. The question of airtightness of the buildings tested is of importance to the Corps of Engineers [6], which specified that they should have no greater than seven air changes per hour, when tested at a 50-Pa pressure difference.

2.0 PROCEDURES

2.1 Fan Pressurization Protocols

Fan pressurization measurements of airtightness may have a variety of different goals. Testing the airtightness of the building envelope requires that all intentional openings be closed. Testing to characterize a building's probable behavior under natural forces influencing air exchange requires that intentional openings be set to their normal positions.

Each of the protocols tested uses fan-induced air pressure differences across the building envelope to cause a measurable air leakage rate through the envelope. With the information on pressures and air flows, each offers a number of measures of airtightness. ISO 9972 permits pressurization and depressurization; ASTM E-X allows both but encourages depressurization; CGSB requires depressurization.

2.1.1 *Measured Quantities* – All three standards require measurement of air pressure and air flow. All require adjustment of the measured air flow with a density correction to become the corrected air flow at the fan, and a dynamic viscosity correction in the case of ASTM E-X, to adjust the envelope flow to a reference condition. ISO 9972 corrects for dynamic viscosity and density in the airtightness calculation.

ISO and CGSB require a series of pressure-flow measurements at differences in pressure that range between 10 and 60 Pa (ISO) or 15 and 50 Pa (CGSB). CGSB also offers a single-point measurement at 30 Pa. ASTM E-X offers two options, a single-point measurement at 50 Pa or a two-point measurement with 50 and 12.5-Pa pressure stations.

2.1.2 *Airtightness Calculations* – All three standards offer a calculation of a leakage area (L in m^2) which corresponds to the area of an orifice that would result in a corresponding flow at a reference pressure. ISO 9972 cites 4 Pa as a conventional reference pressure, but allows other values. ASTM E-X makes no requirement, but cites 4 Pa as one advocated by ASHRAE [7]. The CGSB calculates Equivalent Leakage Area (*ELA* in cm^2) which is L times 11.57, taken at a reference pressure of 30 Pa.

The leakage area is based on a fit of data for induced pressure differences across the envelope, P in Pa, to measured airflows through the building envelope, Q in m^3/s, to a power law, as follows:

$$Q = C \cdot P^n \tag{1}$$

where C and n are constants determined by performing a linear regression on Eq 1, in the natural logarithm domain. ASTM E-X is designed to diminish the uncertainty of estimating L at P_{ref}=4 Pa. It focuses on a high and a low point that are each the means of multiple data. Under either protocol the leakage area (m^2) is:

$$L = C \cdot P_{ref}^{(n-0.5)} \cdot \left(\frac{\rho_e}{2}\right)^{0.5} \tag{2}$$

where ρ_e is the density of the air coming through the leaks in the building envelope.

Only ASTM E-X offers an index based directly on flow, ACH_{50}, in air changes per hour (1/h), calculated as the corrected flow at 50 Pa divided by the volume of the zone. This is the criterion cited by the Corps of Engineers in its specifications for airtightness.

2.1.3 *Uncertainty Calculations* – The CGSB and ISO documents rely on standard calculations of variance and confidence intervals about a regression. These calculations do not incorporate estimates of bias. Bias is difficult to estimate in field measurements in the absence of independent standards. ASTM E-X uses uncertainty[1] calculations based on estimates of precision and bias, expressed in quadrature, adapted from Sherman and Palmiter [8]

2.1.4 *Multiple Zones* – ISO 9972 and the CGSB document pertain strictly to a single zone. They allow for the opening of interior doors and other impediments to uniform pressure within the zone to create a single zone. Flanders [9] has tried testing interzonal airtightness by a protocol that measured the change in air flow in a zone that maintained a constant pressure while the pressure was varied in the adjacent zone. Such a technique potentially has high uncertainty due to the small flow values obtained and the bias inherent from not being able to assure that all the observed flow passes between the two zones.

Moffat [10] suggested that closing doors and other operable connections between zones, and at the same time opening doors and windows to the outdoors in the adjacent zones, would create a practical measurement of building envelope airtightness in buildings with multiple zones. Such a technique does not by itself account for interzonal flow. In most buildings interzonal flow is as undesirable as air leakage across the envelope's exterior, because it represents paths for fire, sound, and indoor air pollution. ASTM E-X defines the test zone to be "a building or a portion of a building that is configured as a single zone for the purpose of this test method." This is consistent with Moffat's suggestion.

2.2 Test Sites

The fan pressurization tests were performed on three buildings at Fort Riley, Kansas that were under construction, but near completion, as family housing. The tests were conducted in cooperation with the design and contracting agency, the Missouri River Division

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[1] Defined as the estimate of error from precision and bias errors.

of the U.S. Army Corps of Engineers. Similar buildings were tested previously and found to have ACH_{50} values of less than seven, with an unknown treatment of ventilation openings.

2.2.1 *Building Descriptions* – Each building was of light metal-frame construction with adjacent two-story residential units. There were three types of unit, end units of 276 m^3, middle units of 304 m^3, and a handicap-accessible unit of 287 m^3. Building 44671 was a triplex with one unit of each type. Building 44673 was a duplex with two end units. Building 44675 (Figure 1) was a four-plex with two end units and two middle units.

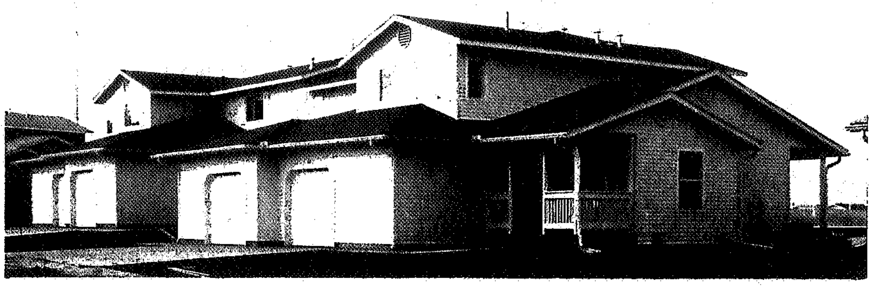

Figure 1. Four-plex family housing unit, Building 44675.

2.2.2 *Test Configuration of the Buildings* – Because of constraints placed on us by the building owner, the dryer vent was taped closed (no dryer was installed) for the tests, but the bathroom and kitchen vent fans were uncovered. This represents the building configured for use, but not a measure of construction airtightness. All doors and windows were latched closed. There was no fireplace. The gas-fired hot water heater was left in operation.

2.3 The Test Cases

The primary factors considered in the study were the differences between protocols, the differences between and within building types, and the effects of wind on precision and bias.

2.3.1 *The Protocols Tested* – In this study the following protocols were tried (Table 2):

Table 2. Summary of protocols use in this study.

Source	Protocol
ISO 9972, CGSB	Regression of P and Q data to calculate L.
ASTM E-X	Two-point measurements of P and Q to calculate L.
CGSB, ASTM E-X	Single-point measurements at 50 or 30 Pa.
ASTM E-X	Adjacent zone open, closed or at equal pressure.

This paper compares the values and uncertainties of L calculated for traditional reference pressure values of P_{ref} = 4, 10, and 30 Pa, using both regression and two-point techniques. For the single-point techniques, the comparison is of ACH_{50} values for different wind and building conditions. For interzonal flow, a comparison is made among ACH_{50} values when the adjacent zone was pressurized at an equal level, when its doors and windows were simply closed, and when its doors and windows were open.

2.3.2 *End or Middle Units* – Testing multiple examples of similar building types allows characterization how consistently the units were built. Comparing different types of units of similar construction allows comparing effects of the different configurations. Only one handicap-accessible unit was tested, so most comparisons were between and among the end and middle units.

2.3.3 *Calm or Windy Conditions* – The tests occurred on two consecutive days. On the first day the wind was at 4.5 m/s with gusts of 6.7 m/s. On the second day the wind was light and variable. Wind has potential to cause bias by shifting the neutral plane caused by wind across the building in such a way that it changes the relative roles of leakage sites during the fan pressurization tests. Wind has the potential to increase measurement imprecision due to the effects of gusts and eddies during the test.

2.4 The Apparatus

The fan pressurization apparatuses were two blower door units. The plug filling the door opening was a steel frame with a urethane-coated membrane sealed against the door jamb with an inflatable tube. The fans mounted facing in or out to conduct pressurization or depressurization. The control units were digital and offered the following level of imprecision in monitoring air pressure and air flow (Table 3), as stated by the manufacturer:

Table 3. Imprecision of instruments.

Measurement	Imprecision
Air flow – Percentage of flow at the test pressure	±3
Pressure difference – Percentage of the mean value of at least five samples.	±1

3.0 RESULTS

3.1 Tests Performed

The following tests were performed, as shown in Table 4. All but four were under depressurization.

Table 4. Number of tests performed by test condition.

	End Units		Middle Units	
Test Condition	Calm	Windy	Calm	Windy
Multipoint, open-adjacent (O)	9	4	2	3
Multipoint, guarded-adjacent (G)	2	—	2	—
Single-point, closed-adjacent (C)	3	2	1	3

In addition, two tests were performed under calm conditions in the handicap-accessible unit.

To obtain data for use in all four protocols, we performed fan depressurization tests with multiple readings at 10, 30, and 50 Pa. Those single-point tests with the adjacent apartment closed were at 50 Pa only.

3.1 Calculated Airtightness

This paper uses ACH_{50} as a means to compare airtightness values as flows at 50 Pa normalized to the volume of the zone tested. This is one means of normalization. Another means, to normalize by unit of exterior envelope area, was not tried. This paper uses L as a means to compare the two-point protocol of ASTM E-X and the traditional multipoint regression protocols of ISO 9972 and CGSB.

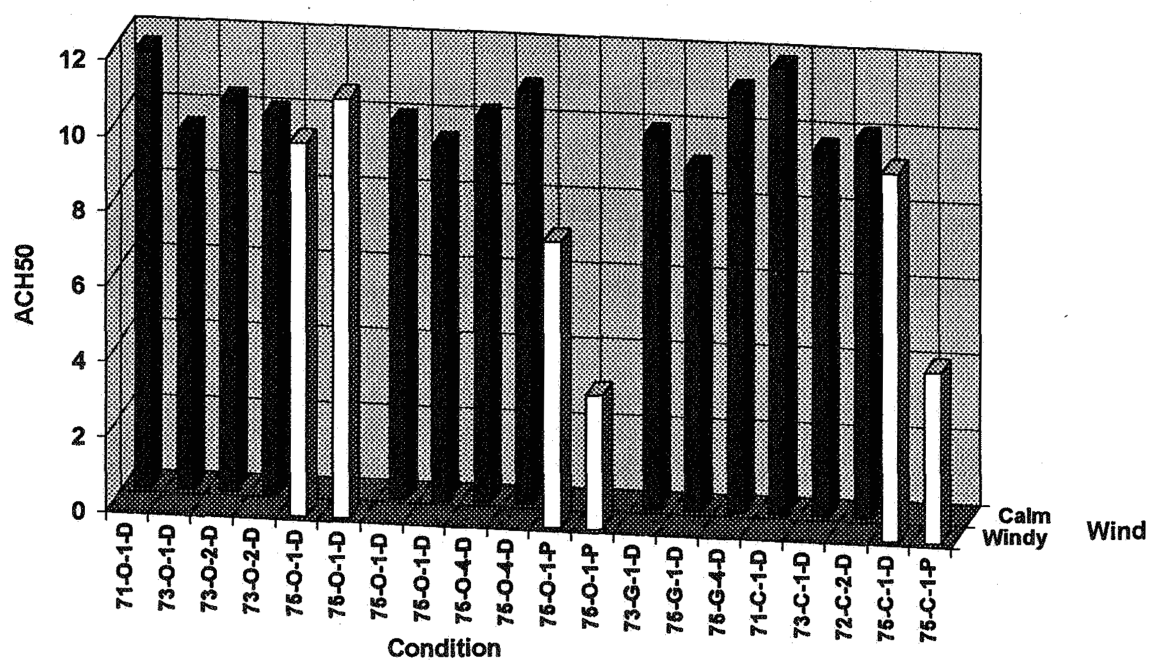

Figure 2. ACH_{50} for all end units measured and all test conditions.

Key: ##-(O, C, G)-#-(D, P) = Building 446##-(Condition)-Apartment #-(Depressurize, Pressurize), where Condition is: **O** = multipoint, **open**-adjacent, **C** = single-point, **closed**-adjacent, **G** = multipoint, **guarded**-adjacent.

3.1.1 *ACH_{50} Comparisons* – The greatest bulk of data pertains to the end units tested. Figure 2 illustrates the consistency of the ACH_{50} values obtained in each of the test conditions described in Table 4. These had a coefficient of variation[2] of 18% for the open-adjacent conditions across all units, including replicates. For the closed-adjacent conditions, the coefficient of variation was 10%. Those obtained under windy conditions were the least consistent. The data for the middle apartments show similar consistencies.

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[2] Standard deviation divided by the mean, expressed as a percentage.

The median ACH_{50} values for depressurization and ratios between the closed-adjacent and the open-adjacent conditions (C/O) and between the guarded-adjacent and the open-adjacent conditions (G/O) are summarized in Table 5.

Table 5. ACH_{50} median values (1/hr).

	Values			**Ratios**	
Test Condition	O	C	G	C/O	G/O
End apartment	**10.4**	**10.0**	**10.5**	**1.0**	**1.0**
Middle apartment	**13.8**	**10.1**	**12.5**	**0.73**	**0.95**
Handicap-access	**12.8**	**12.7**	—	**0.99**	—

3.1.2 *Leakage Area* – In calculating the values of n and C from Eq 1 by the two methods, using two points or a multipoint regression analysis and then computing L from Eq 2 for each method, the values for each were in agreement by one digit in the second significant digit. In summary, the median of the ASTM two-point L-values were 99% of the ISO 9972 values for end apartments and 102% for middle apartments.

The median values for the flow exponent n was 0.59±0.00 for the end apartments, as calculated by either ASTM E-X or by ISO 9972. For the middle apartments, the median value for the flow exponent n was 0.56±0.01 for the end apartments, as calculated by either method.

3.2 Uncertainties

Wind was an important factor in the uncertainty calculations of Q_{ref}, C, and n, as illustrated in Table 6. The uncertainties, recommended by Sherman and Palmiter [8], are based on the individual uncertainties of the high and low measurements of P and Q; they are applicable both to the two-point and multipoint protocols. The predicted air flow rates Q_4, Q_{10}, and Q_{30} at $P_{ref} = 4$, 10, and 30 Pa have much higher uncertainties under the windy conditions observed than under the calm conditions observed.

Table 6. Median uncertainties of Q_{ref}, C, and n for end apartments.

	Uncertainty (%)	
Calculation	Calm	Windy
Q_4	**29**	**110**
Q_{10}	**18**	**72**
Q_{30}	**6**	**26**
C	**28**	**129**
n	**18**	**26**

The coefficient of variation for ACH_{50} in end units was 38% on the windy day and 5%, or less, on the calm day.

3.3 Discussion of Results

3.3.1 *Calculated Airtightness* – The end apartments were studied in statistically significant numbers. The resulting airtightness measurements, whether ACH_{50} or L, were more consistent than would have been predicted for all protocols and wind conditions. Clearly, one would have to take many more independent measurements under windy conditions than under calm in order to achieve reasonable certainty of the result.

Calculations based on data about a single P and an assumed value of $n = 0.65$ would have been wide of the mark, since the actual values varied between $0.59 \geq n \geq 0.55$.

On the windy days the ACH_{50} and flow exponent values were markedly different between pressurization and depressurization for two tests. Furthermore, the regression fit was poor for pressurization tests.

3.3.2 *Uncertainties* – The two-point protocol of ASTM E-X and the traditional multipoint regression protocols of ISO 9972 and CGSB closely agreed about the values of C and n, on which Eqs 1 and 2 are based. Even when the wind conditions were calm, the uncertainty of Q_4 was almost 30%, based on the median percentage values of measurement uncertainties for P and Q in all end apartments tested. This suggests that modeled flows, based on values of P_{ref} in the 4-Pa range, will be approximate. Measurements of ACH_{50} require calm conditions when coefficients of variation of 5% or better can be expected.

3.3.3 *Interzonal Flow* – One expects to see the largest ACH_{50} when the adjacent apartment is open (O), the next largest ACH_{50} when the adjacent apartment is closed (C), and the lowest ACH_{50} when the adjacent apartment has the same pressure (G). The summary in Table 5 does not agree with this hypothesis, nor do individual measurements of the same apartment. However, there are too few data, spanning both windy and calm conditions, to clearly demonstrate meaningful differences among the test conditions.

3.3.4 *ACH_{50} Criterion* – The criterion value of $ACH_{50} = 7$ or less, as specified by the Corps of Engineers [6], was not observed. The specified testing protocol was not specific enough to assure consistent results from different testers. In these tests the openings for the kitchen and bathroom vent fans were not sealed. Under depressurization, back-draft dampers should have minimized the effects of kitchen and bathroom vent openings. Tests of unintentional leakage sites in the construction should occur with such openings sealed.

4.0 CONCLUSIONS

- Protocols from all three standards give similar C and n results. The results are reliable when the data are obtained under calm conditions.
- Tests of similar apartments gave similar ACH_{50} results.
- Tests of multifamily apartment units should be made with adjacent units open to the outdoors to demonstrate the integrity of the construction between units.
- Calculated uncertainties may be optimistic due to autocorrelation of data obtained by current standard protocols.
- Calculations based on extrapolations to 4 Pa will be sketchy even with good data.
- Standards should include an airtightness index like ACH_{50}.

ACKNOWLEDGMENTS

The author thanks Steven Rumbaugh of the Missouri River Division of the U.S. Army Corps of Engineers who helped arrange for the test. He further thanks Greg Krajeski and Erika Peterson who performed the tests.

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