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AIRTIGHTNESS TESTING METHODS FOR ROW HOUSING

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ABSTRACT

Pressure testing is an accepted method of determining the airtightness of building envelopes, but current testing standards do not address measurement of airtightness of attached dwellings. This is a special case due to potential airflow across party walls. Airflow into the test dwelling from adjacent dwellings can be eliminated by equalizing the pressure in the test and adjacent dwellings. The significance of party wall leakage in 14 row house from five different projects was demonstrated by comparing results obtained by this procedure with those obtained by standard test methods. A proposed alternative method of correcting for party wall leakage involves computations based on measurement of indoor-outdoor pressure differentials in dwellings adjacent to the test dwelling while the latter is pressure tested. A pilot field study of this method was carried out. Results from correction by pressure equalization were compared with results from correction by computation. An average agreement within 6.5% was found.

INTRODUCTION

In row housing, infiltrating air may flow through party walls between adjacent dwellings as well as from outdoors to indoors (see Figure 1). Outdoor-indoor leakage contributes to space heating and cooling requirements. Unit-to-unit leakage does not affect heating and cooling loads to the same extent, but it may result in migration of airborne contaminants and movement of smoke in the event of fire. The gaps that permit inter-unit air leakage also increase noise transfer between dwellings.

Pressure testing has been widely accepted as a method for determining the airtightness of housing (CGSB 1984; ASTM 1981). Results of pressure testing are used to stipulate code requirements (CSA 1986) and as a criterion for certification of energy efficient dwellings. Researchers have also validated a mathematical relationship between airtightness of the *exterior* envelope as measured by pressure testing and infiltration (Grimsrud et al. 1983). However, current testing standards do not address the problem of party wall leakage in attached housing. Thus the applicability of standards, certification criteria, and formulae based on pressure testing methods described in standards is limited to detached dwellings.

When an attached dwelling is pressure tested, both indoor-outdoor and inter-unit leakage are exaggerated. In order to correctly predict infiltration, apply code provisions, and certify airtightness, it is necessary to quantify significant inter-unit airflow as well as airflow through the exterior envelopes of attached dwellings.

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METHODS FOR TESTING AIRTIGHTNESS OF ATTACHED DWELLINGS

Pressure Equalization

Party wall leakage can be eliminated during pressure testing by eliminating pressure differentials between the test unit and adjacent housing units. One additional pressure testing apparatus is required for each neighboring dwelling in which the pressure is to be equalized (see Figure 2). The equipment operators communicate by walkie-talkie and adjust indoor-outdoor pressure differentials so that they are all the same under these conditions. no airflow will occur between connected units. This is operationally easier than measuring the pressure differential between the test unit and adjacent units and maintaining it at zero. This approach will be referred to as the pressure equalization method. The amount of equipment and manpower required makes pressure equalization cumbersome, time-consuming, and expensive.

Nylund's Method

An alternative method, hereafter referred to as "Nylund's method", was proposed in 1981 (Nylund). This method involves the use of a single testing apparatus. Measurements of indoor-outdoor pressure differentials in dwellings directly adjacent to the test dwelling are used to determine party wall leakage. While validation tests have been conducted on laboratory scale modules, field tests on full-scale housing have never been attempted[*].

In Nylund's method. dwellings adjacent to the test unit (A and C in Figure 3). as well as test unit B. are prepared for testing by the sealing of all intentional openings, such as ventilation ducts and furnace flues. A fan is used to induce a range of indoor-outdoor pressure differentials and the airflow through the fan at each pressure differential is determined. An equation of the form

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

is fitted to the data.

The indoor-outdoor pressure differential is measured in dwellings A and C while the indoor-outdoor pressure differential in test unit B is maintained at 0.20 in H_2O (50 pascals), a pressure differential commonly used as a reference in airtightness testing. Walkie-talkies may be used for communication between the fan operator and the person taking measurements in the adjacent units.

Nylund's method of correction by computation is based on a couple of assumptions: .

1. The airtightness characteristics of the dwellings in the cluster under study are all the same (i.e. C and n are the same for all dwellings). so that the airflow rates under pressure in dwellings A through B will be equal for a given pressure differential, ΔP_i. Thus

$$Q_A = Q_B = Q_C = Q_D = Q_E = C \Delta P_i{}^n \tag{2}$$

2. The flow through party walls is much smaller than the flow through the exterior envelope of any dwelling.

If a fan is used to depressurize unit B, airflows will be induced as shown in Figure 4 (flows would be reversed in the case of positive pressurization). According to the assumptions stated above, there are three parallel flows so that

$$Q_B = Q_{AB} + Q_{B'} + Q_{BC} = C (\Delta P_A{}^n + \Delta P_B{}^n + \Delta P_C{}^n) \tag{3}$$

It is assumed that airflow from dwellings D and E is small enough to be ignored.

If unit B is pressure tested with 0.20 in H_2O (50 pascals) as the reference pressure differential. then values are known or can be measured for $\Delta P_B{}^n$, Q_{B50}, $\Delta P_A{}^n$, and $\Delta P_C{}^n$. Then

$$Q_{B50} = C (\Delta P_A{}^n + 50^n + \Delta P_C{}^n) \tag{4}$$

which may be revised to

$$C = \frac{Q_{B50}}{50^n + \Delta P_A{}^n + \Delta P_C{}^n} \tag{5}$$

If Equation 5 is substituted for C in Equation 1, the flow at 0.20 in H_2O (50 pascals) with party wall leakage eliminated will be given by

$$Q_{B50\,cor} = \frac{Q_{B50} \quad 50^n}{50^n + \Delta P_A{}^n + \Delta P_C{}^n} \tag{6}$$

Nylund[*] suggests that a factor R may be defined

$$R = (Q_A{}' + Q_C{}') [Q_{B50} - (Q_A{}' + Q_C{}')^2 - 1] \tag{7}$$

so that $Q_{B50\,cor}$ may also be expressed as

$$Q_{B50\,cor} = Q_{B50} - Q_A{}' - Q_C{}' + R \tag{8}$$

In cases where party walls are very airtight, R would approach zero. $Q_A{}'$ and $Q_C{}'$ could then be obtained graphically from the uncorrected leakage curve for B, given the measured values for $\Delta P_A{}^n$ and $\Delta P_C{}^n$ (see Figure 5).

RELATIVE SIGNIFICANCE OF PARTY WALL LEAKAGE

The first experimental task that was undertaken was determination of the relative significance of party wall leakage. If party wall leakage was found to be very small relative to exterior wall leakage, then it would not be important to differentiate party wall leakage. Data from standard pressure testing and from the pressure equalization method were compared to quantify total and exterior envelope leakage; party wall leakage was then taken as the difference between the two. The Canadian standard for pressure testing was followed insofar as was possible (CGSB 1984). Results for 14 row housing units are shown in Table 1. Descriptive information on the units tested is provided in Appendix A.

The average reduction in airflow with pressure equalization was 29% for end units and 38% for interior units; reductions ranged from 17% to 52%. The data show that party wall leakage is substantial relative to leakage through the exterior envelope and may vary considerably from unit to unit, even within the same row housing complex. The airtightness of dwellings within the same cluster also varied significantly. This indicated that party wall leakage must be differentiated from exterior envelope leakage to obtain useful results when quantifying airtightness of attached dwellings by pressure testing. It also raised the possibility that violation of the assumptions on which Nylund's theory was based would introduce enough error to make the method impractical.

The data generated from the above tests were used to determine the magnitudes of the pressure differentials that would exist if Nylund's method were valid. Manipulating Equation 6 and substituting Q_{B50eq} for Q_{B50cor} the following expression was obtained

$$\Delta P_A{}^n + \Delta P_C{}^n = 50^n \left| \frac{Q_{B50}}{Q_{B50\,eq}} - 1 \right| \tag{9}$$

If it is assumed that the adjacent units are equally leaky and have equal volumes, then

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[*] Nylund, P.O., Tyrens AB, Sundbyberg, Sweden, June 1986, personal communication.

$$\Delta P_A{}^n = \Delta P_C{}^n - \frac{50^n}{2} \left| \frac{Q_{B50}}{Q_{B50\ eq}} - 1 \right|$$

(10)

For end units, which have only one party wall, the expression would be

$$\Delta P_C{}^n - 50^n \left| \frac{Q_{B50}}{Q_{B50\ eq}} - 1 \right|$$

(11)

The calculated indoor-outdoor pressure differentials ranged from 0.010 to 0.080 in H_2O (2.5 to 20 pascals) (see Table 2), averaging 0.036 in H_2O (9 pascals).

PILOT FIELD TEST OF NYLUND'S METHOD

A field test was arranged to conduct a pilot test of Nylund's method by comparing results obtained by that method with results obtained by the pressure equalization method . Flow coefficients and exponents for the test dwellings are shown in Table 3, while indoor-outdoor pressure differentials in the adjacent dwellings are shown in Table 4.

Table 5 provides a comparison of results obtained by the pressure equalization method and Nylund's simplified method (Equation 7 with R taken as zero). It is evident that application of Nylund's simplified method introduces a substantial error in calculating airflow with party wall leakage eliminated.

Q_{50cor} was recomputed using Equation 6 (see Table 6). These results showed that an accurate estimate of the airflow with party wall leakage eliminated could be obtained for the test row houses. The maximum discrepancy between results for the pressure equalization method and Nylund's method was 10%, and the average discrepancy was 6.5%.

USE OF CORRECTED AIRFLOW INFORMATION

Given that an acceptably accurate estimate of corrected airflow at 0.20 in H_2O (50 pascals) indoor-outdoor pressure differential can be obtained, the problem remains of applying this information in calculating common criteria for rating airtightness. One such criterion is the number of air changes per hour with a pressure differential of 0.20 in H_2O (50 pascals) induced across the building envelope. Since this parameter is obtained by dividing the volume of the dwelling by the induced airflow at 0.20 in H_2O (50 pascals) pressure differential, it is easily derived given Q_{50cor}.

Other parameters cannot be obtained so directly. For instance, the effective leakage area, a parameter used in the LBL infiltration model (Grimsrud et al. 1983), is determined by

$$L_0 = Q_4 \left| \frac{2\,\Delta P}{p} \right|^{0.5}$$

(12)

Q_4 is normally obtained using Equation 1, the fitted leakage curve for the dwelling in question, which requires values for C and n. Nylund's method provides only one point on the corrected leakage curve, which is insufficient to determine the slope of the curve (given by n). An approximate corrected flow coefficient (C_{cor}) may be obtained by using n in Equation 5; values of C_{cor} computed this way are shown in Table 7. In three out of five cases, the discrepancies are on the order of 20% to 30%, which is unacceptably large.

Kiel, Wilson, and Sherman (1985) suggest that C and n are not independent metrics, but are related as follows

$$K = C \left| \frac{n - 1.0}{0.5 - n} \right|$$

(13)

In this case, deviations in C might be compensated by corresponding deviations in n. Values of Q_4 calculated using metrics generated by Nylund's method are compared with values generated by the pressure equalization method in Table 8. In all cases where the error in the estimate for C_{cor} was large, the in the estimate for Q_4 was substantially less. In other cases the error did not change markedly.

CONCLUSION

In pilot field tests, Nylund's method offered acceptably accurate estimates of airflow through the exterior envelopes of row houses with party wall leakage eliminated. Since only a single testing apparatus is required to obtain corrected information, it offers a much more economical means of assessing the airtightness of attached dwellings than the pressure equalization method. Further testing is warranted to provide more information on the range of error that would be introduced where larger variations occur in leakage characteristics of neighboring dwellings.

NOMENCLATURE

C = empirical flow coefficient, no correction for party wall leakage ($ft^3/min\cdot(in\ H_2O)^n$ [$L/s\cdot Pa^n$])

C_{cor} = estimated flow coefficient with party wall leakage eliminated computed by Nylund's method ($ft^3/min\cdot(in\ H_2O)^n$ [$L/s\cdot Pa^n$])

C_{eq} = empirical flow coefficient determined with party wall leakage eliminated by pressure equalization ($ft^3/min\cdot(in\ H_2O)^n$ [$L/s\cdot Pa^n$])

K = correlation constant ($ft^3/(ft^{2n+1}\ s\ (in\ H_2O)^n$)[$cm^3/(m^{2n+1}\ s\ Pa^n)$]

L_0 = the effective leakage area (ft^2 [m^2])

n = empirical flow exponent, no correction for party wall leakage

n_{eq} = empirical flow exponent with party wall leakage eliminated by pressure equalization

ΔP = pressure differential ((in H_2O) [Pa])

p = the density of air (0.075 lb/ft^3 [1.2 kg/m^3])

Q = airflow rate across the building envelope (ft^3/min [L/s])

Q_B = the airflow through the envelope of test dwelling B (including party wall leakage) (ft^3/min [L/s])

Q_B' = the airflow through the exterior envelope of test dwelling B (exclusive of party wall leakage) (ft^3/min [L/s])

Q_A' = the airflow through the exterior envelope of dwelling A due to pressure drop across the party wall between dwellings A and B when B is under test (ft^3/min [L/s])

Q_C' = the airflow through the exterior envelope of dwelling C due to pressure drop across the party wall between dwellings C and B when B is under test (ft^3/min [L/s])

Q_{B50} = flow rate through test dwelling B with a 50 pascal pressure differential across the envelope (ft^3/min [L/s])

Q_{B50cor} = flow rate through test dwelling B with a 50 pascal pressure differential across the envelope with party wall leakage eliminated by calculation (ft^3/min [L/s])

Q_{B50eq} = flow rate through test dwelling B with a 50 pascal pressure differential across the envelope; party wall leakage eliminated by pressure equalization $(ft^3/min [L/s])[L/s]$

Q_4 = the airflow at a 4 Pa pressure differential (m^3/s)

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APPENDIX A: FEATURES OF DWELLING CONSTRUCTION FOR HOUSING TESTED

Sample 1

Project 1: built about 1970; 99 m^2 floor area; 376 m^3 volume; 2 story units; wood frame on concrete basement

Project 2: built about 1970; 83 m^2 floor area; 324 m^3 volume; 2 story units; wood frame on concrete foundation; flat roof

Project 3: built about 1978, 102 m^2 floor area; 300 m^3 volume; 3 story units; carport under at grade; wood frame on concrete lower floor

Project 4: built about 1982; 94 m^2 floor area; 354 m^3 volume; 2 story units; wood frame on concrete basement

Project 5: built about 1982; 100 m^2 floor area; 372 m^3 volume; 3 story units; wood frame on concrete lower floor

Sample 2

Project 6: built about 1982; 94 m^2 floor area; 354 m^3 volume; 2 story units; wood frame on concrete basement

TABLE 1

Comparison of Airflow through 14 Row Houses (Sample 1) with 0.20 in H_2O (50 pascals) Indoor-Outdoor Pressure Differential and with Pressure Differentials between Adjacent Units Unequalized and Equalized

	Unit Code	Q_{50} unequalized airflow		Q_{50eq} equalized airflow		$Q_{50} - Q_{50eq}$		$(Q_{50} - Q_{50eq})$ as percentage of Q_{50}
		ft^3/min	(L/s)	ft^3/min	(L/s)	ft^3/min	(L/s)	for SI
end units	1a	950	450	740	350	210	100	22
	2a	640	300	530	250	100	50	17
	3a	1550	730	1040	490	510	240	33
	4a	1100	530	680	320	440	210	42
	5a	1250	590	830	390	420	200	34
	5b	1170	550	890	420	280	130	24
	Average	1100	520	780	370	340	160	29
interior units	2b	660	310	470	220	190	90	29
	3b	1420	670	910	430	510	240	36
	3c	1840	870	1080	510	760	360	41
	5c	1140	540	850	400	300	140	26
	5d	1020	480	490	230	530	250	52
	5e	1400	660	850	400	550	260	39
	5f	1460	690	950	450	510	240	33
	5g	950	450	530	250	420	200	44
	Average	1230	580	760	360	470	220	38

TABLE 2
Estimated Pressure Differentials in Dwelling Units Adjacent to Test Dwelling Units (Based on Equations 9 and 10 Applied to Housing Sample 1).

	Unit Code	Estimated Pressure Differential in H_2O	(Pa)
end units	1a	0.027	6.8
	2a	0.010	2.5
	3a	-	-
	4a	-	-
	5a	0.080	20.0
	5b	0.040	10.0
	Average	0.039	9.8
interior units	2b	0.020	5.1
	3b	0.028	7.1
	3c	0.042	10.5
	5c	0.018	4.4
	5d	0.078	19.5
	5e	0.031	7.9
	5f	0.029	7.3
	5g	0.044	11.0
	Average	0.036	9.1

TABLE 3
Flow Coefficients and Exponents for Unequalized and Equalized Pressure Test Conditions

	Unit Code	Flow Coefficients				Flow Exponents	
		C (unequalized)		C_{eq} (equalized)		n	n_{eq}
		$ft^3/min \cdot (in\ H_2O)^n$	$L/s \cdot Pa^n$	$ft^3/min \cdot (in\ H_2O)^n$	$L/s \cdot Pa^n$		
end units	6a	2600	32	2200	27	0.66	0.68
interior units	6b	3600	30	2400	22	0.73	0.71
	6c	3300	39	2000	33	0.68	0.61
	6d	2500	35	1600	31	0.64	0.58
	6e	2700	45	1900	38	0.61	0.58

TABLE 4
Pressure Differentials between Dwellings Tested and Adjacent Dwellings as Determined by Nylund's Method

	Unit Code	ΔP_A in H$_2$O	(Pa)	ΔP_B in H$_2$O	(Pa)
end unit	6a	-	-	0.028	7.1
interior units	6b	0.023	5.7	0.026	6.6
	6c	0.024	6.1	0.020	5.1
	6d	0.024	6.0	0.027	6.8
	6e	0.024	6.0	0.012	3.1

TABLE 5
Comparison of Airflow through Test Row Houses with Party Wall Airflow Eliminated by Pressure Equalization and by Nylund's Simplified Method (Equation 7)

	Unit Code	Q_{50} unequalized airflow ft^3/min	(L/s)	Q_{50eq} equalized airflow ft^3/min	(L/s)	Q_{50cor} Q_{50} corrected by Nylund's simpli-fied method ft^3/min	(L/s)	Percent Discrepancy Between Q_{50eq} and Q_{50cor} for SI
end unit	6a	890	420	740	350	640	300	16
interior units	6b	1100	530	760	360	640	300	20
	6c	1100	540	760	360	640	300	20
	6d	890	420	640	300	380	180	40
	6e	1000	490	760	360	550	260	28
						Average		33

TABLE 6
Comparison of Airflow Through Test Row Houses with Party Wall Airflow Eliminated by Pressure Equalization and by Nylund's Method (Equation 6)

	Unit Code	Q_{50} unequalized airflow ft^3/min (L/s)		Q_{50eq} equalized airflow ft^3/min (L/s)		Q_{50cor} Q_{50} corrected by Nylund's method ft^3/min (L/s)		Percent Discrepancy Between Q_{50eq} and Q_{50cor} for SI
end unit	6a	890	420	740	350	700	330	5.7
interior units	6b	1100	530	760	360	780	370	2.8
	6c	1100	540	760	360	800	380	5.5
	6d	890	420	640	300	570	270	10.0
	6e	1040	490	740	360	700	330	8.3
						Average		6.5

TABLE 7
Comparison of C_{eq} and C_{cor}

	Unit Code	C (flow coefficient)				
		C_{eq} determined using pressure equalization $ft^3/min \cdot (in\ H_2O)^n$	$L/s \cdot Pa^n$	C_{cor} calculated using equation (5) $ft^3/min \cdot (in\ H_2O)^n$	$L/s \cdot Pa^n$	percent discrepancy for SI
end unit	6a	2200	27	2100	25	7.4
interior units	6b	2400	22	2500	21	4.5
	6c	2000	33	2300	27	18.0
	6d	1600	31	1700	22	29.0
	6e	1900	38	1900	30	21.0
				Average		11.3

TABLE 8
Comparison of Airflows at 4 pascals Pressure Differential Calculated Using C Corrected by Pressure Equalization and n_{eq}, and C Corrected by Nylund's Method and n

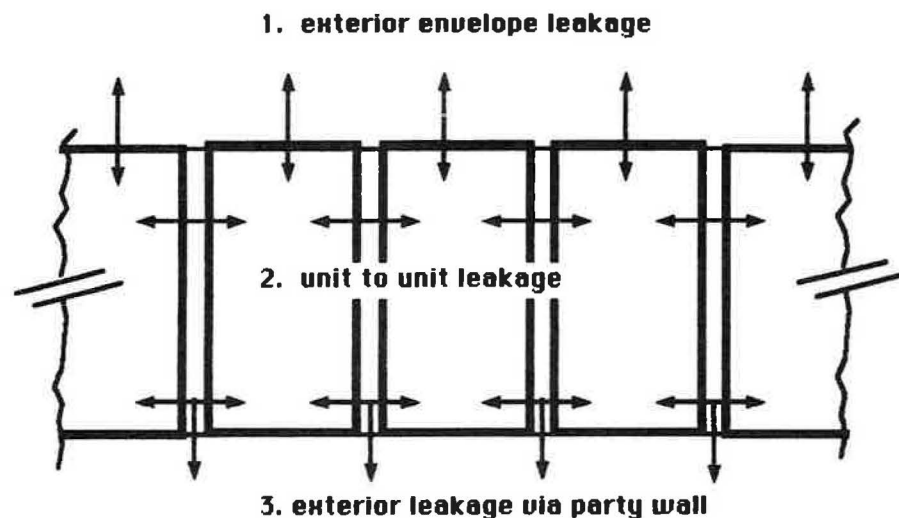|	Unit Code	Q_4 (calculated airflow at 4 pascals induced indoor-outdoor pressure differential)				
		calculated using n_{eq} $Q_4 = C_{eq}(4)$ ft^3/min	(L/s)	calculated using n $Q_4 = C_{cor}(4)$ ft^3/mi	(L/s)	percent discrepancy for SI
end unit	6a	140	67	130	62	7.5
interior units	6b	120	59	120	58	1.7
	6c	160	76	150	69	9.2
	6d	140	68	110	53	22.0
	6e	180	85	160	75	11.8
				Average		10.4

1. exterior envelope leakage

2. unit to unit leakage

3. exterior leakage via party wall

Figure 1. Possible infiltration routes in row
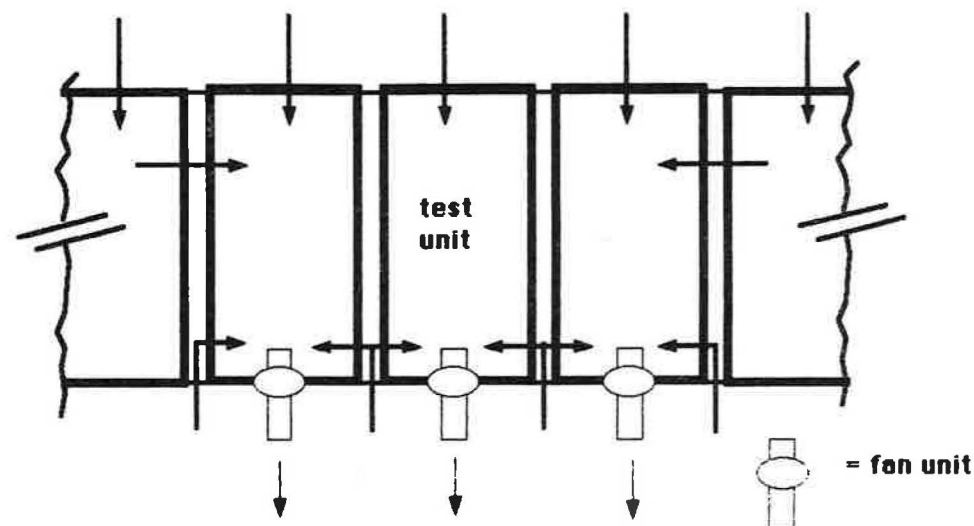housing (arrows indicate airflow)

test
unit

= fan unit

Figure 2. Equipment setup for pressure equalization
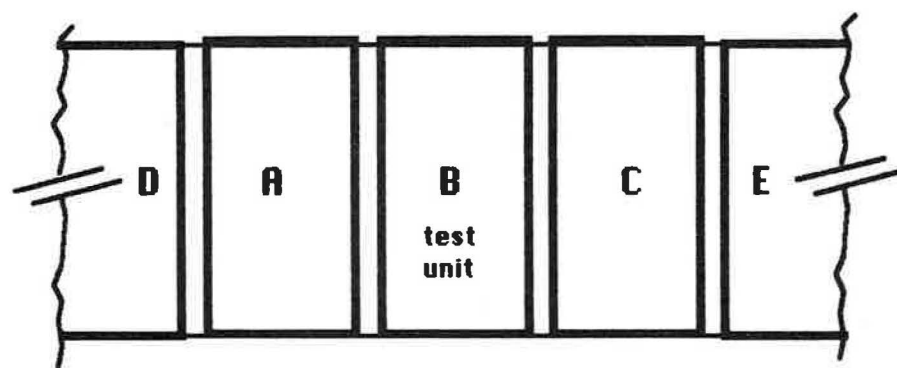method of airtightness testing of row
housing (arrows indicate airflow)

D A B C E

test
unit

Figure 3. Test row dwelling B is embedded in a
series of attached dwellings

Q_{AB} Q_{BC}
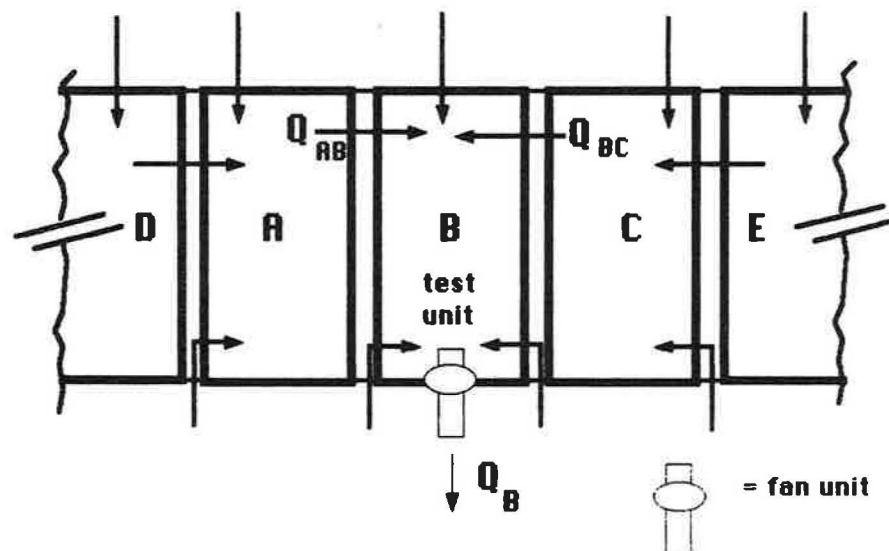
D A B C E

test
unit

Q_B = fan unit

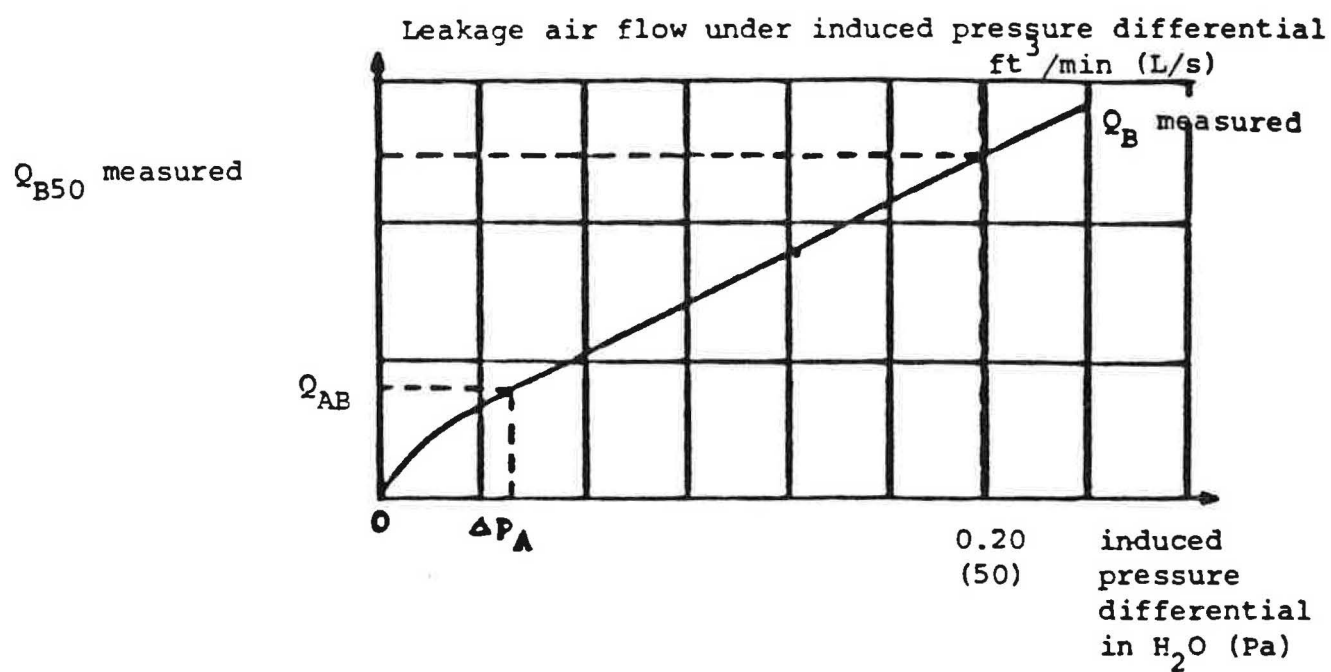Figure 4. Airflows induced when a row house is
depressurized

Figure 5. *Graphical method of determining party wall leakage flows*

Discussion

M. MODERA, Lawrence Berkeley Lab., Berkeley, CA: The pressure equalization method against which you have compared the simplified technique is problematic in itself, adding further uncertainty to the reported comparison. Pressurization of intermediate (attic and basement) zones by the secondary blower doors causes the interzone flows to be overestimated. Similarly, the pressure equalization technique is based upon the difference between flow rates with and without secondary blower doors. To avoid series-flow-resistance effects, this flow difference should be obtained by comparing the flow with the windows in the adjacent zones open, to the floor with the adjacent zones pressurized. Was this the case in your measurements?

J.A. LOVE: Mr. Modera raises some relevant questions. The adjacent units did not have windows open during the testing since we were attempting to follow the procedure specified by Nylund in which row dwellings adjacent to the test dwelling are to be "prepared in the same way as the measurement flat." It would certainly be useful to conduct tests in the manner suggested by Mr. Modera and note the significance of the effect to which he is referring.