AIRTIGHTNESS TESTING METHODS FOR MULTI-UNIT HOUSING

submitted to

CANADA MORTGAGE AND HOUSING CORPORATION

by

J.A. Love
Faculty of Environmental Design
The University of Calgary

December, 1986

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Abstract

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Pressure testing is an accepted method of determining the airtightness of building envelopes. 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 (Nylund's 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 Nylund's method. An average agreement within 6.5% was found. Use of the data generated by Nylund's method to calculate common measures of airtightness is discussed.

Keywords: envelope, air infiltration, measurement technique, instrumentation, house

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AIRTIGHTNESS TESTING METHODS FOR MULTI-UNIT HOUSING

EXECUTIVE SUMMARY

Pressure testing is a commonly used method of determining the airtightness of housing. When attached dwellings are pressure tested using the procedures developed for detached housing, it is not possible to isolate air flow through the exterior envelope from air flow through party walls.

By using additional depressurization equipment in dwellings adjacent to the dwelling under test, the inter-unit pressure differential may be eliminated. Party wall leakage will not occur under these conditions. and a true measure of the airtightness of the exterior envelope may be obtained. Measurements have shown that 20 or 30% of the air flow through the envelope of a row house is due to party wall leakage. Pressure equalization is a relatively expensive and cumbersome method of obtaining correct airtightness information due to the amount of equipment and manpower required.

An alternative method (Nylund's method) is to measure indoor-outdoor pressure differentials in dwellings adjacent to the test dwelling, correcting the readings for the test dwelling by use of a formula incorporating these pressure differentials. This approach was validated at laboratory scale in Sweden some years ago, but had never been validated for full scale housing.

Seven row houses were tested by both methods, and the results were compared. Nylund's method provided relatively accurate results and appears to be a practical alternative to the pressure equalization method for many applications. Use of the data generated by Nylund's method to calculate common measures of airtightness is discussed. Further full scale validation tests are warranted by the results obtained.

Table of Contents

Executive Summary i

Table of Contents ii

List of Tables iii

List of Figures iv

1.0 INTRODUCTION 1

2.0 THEORY 4

2.1 Pressure Testing of Detached Dwellings 4

2.2 Nylund's Method 4

2.3 Leakiness of Party Walls in Wood Frame Row Housing 7

3.0 FIELD TESTS 10

4.0 RESULTS 12

5.0 DISCUSSION 15

6.0 CONCLUSIONS 21

APPENDIX A: Detailed Data from Field Tests 22

References 23

List of Tables

Table 1. Comparison of air flow through 14 row houses (housing sample 1) with 50 pascals pressure differential induced across the envelope and with pressure differentials between adjacent units unequalized and equalized.....8

Table 2. Comparison of air flow statistics (mean and standard deviation under pressure test) for interior units in 6 row housing projects.....9

Table 3. Comparison of air flow through test row houses with party wall air flow eliminated by pressure equalization and by Nylund's simplified method.....12

Table 4. Comparison of air flow through test row houses with party wall air flow eliminated by pressure equalization and by Nylund's method.....13

Table 5. Comparison of C_{eq} and $C_{cor.}$.....16

Table 6. Comparison of air flows at 4 pascals pressure differential calculated using C corrected by pressure equalization with n_{eq} and C corrected by Nylund's method with n.....17

Table 7. Comparison of equivalent leakage area (ELA) calculated C corrected by pressure equalization with n_{eq} and using C corrected by Nylund's method with n.....18

Table 8. Comparison of C_{eq} and n_{eq} with C and n determined for Project 7 by applying Nylund's method at additional test pressures.....20

Table A.1 C_{eq} and C_{cor} for housing sample 2.....22

Table A.2 Pressure differentials between dwellings tested and adjacent dwellings as determined by Nylund's method.....22

List of Figures

Figure 1. Diagram of possible infiltration routes in row housing....................1

Figure 2. Diagram of equipment set-up for pressure equalization method of air-tightness testing of row housing....................2

Figure 3. Test row dwelling B is embedded in a series of attached dwellings....................4

Figure 4. Air flows induced when a row house is depressurized....................5

Figure 5. Graphical method of determining party wall leakage flows....................7

1.0 INTRODUCTION

In multi-unit housing, infiltrating air may flow through party walls between adjacent dwellings as well as directly in through exterior walls (see Figure 1). Outdoor-indoor leakage contributes to

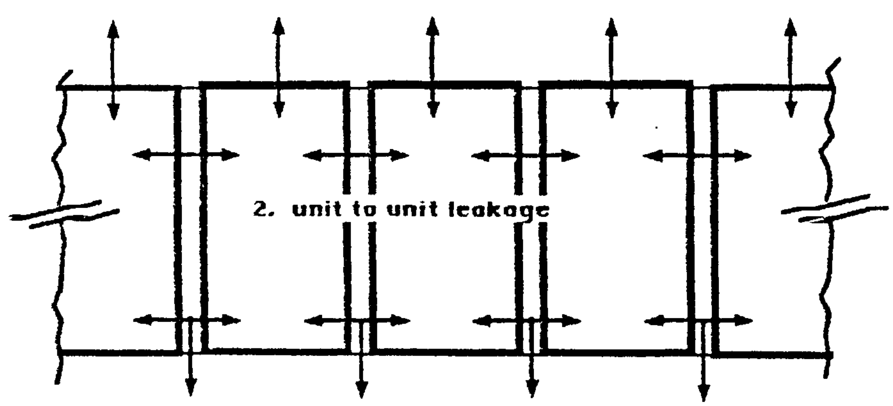

Figure 1. Diagram of possible infiltration routes in row housing.

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. It is often desirable, or even necessary, to be able to distinguish the two types of leakage.

Pressure testing has been widely accepted as a method for determining the airtightness of housing[1]. Results of pressure testing are used to stipulate code requirements[2] and as a criterion for certification of energy efficient dwellings[3]. Researchers have also validated a mathematical relationship between airtightness of the *exterior* envelope as measured by pressure testing and infiltration[4]. 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. This project was undertaken to conduct pilot field tests of a simplified method of testing the airtightness of attached housing and determining party wall leakage.

Party wall leakage can be eliminated during pressure testing by eliminating pressure differentials between the test dwelling unit and adjacent dwellings. One additional pressure testing apparatus is required for each neighbouring dwelling in which the pressure is to be equalized (see Figure 2). The equipment operators communicate by walkie-talkie and adjust

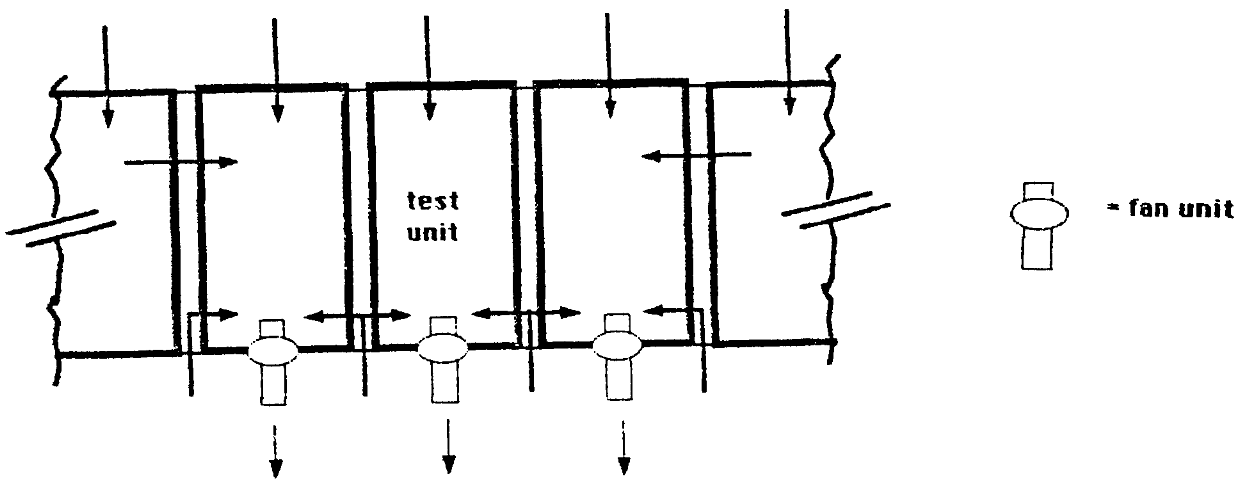

Figure 2. Diagram of equipment set-up for pressure equalization method of airtightness testing of row housing.

indoor-outdoor pressure differentials so that they are all the same: under these conditions. no air flow will occur between connected units. This is operationally easier than maintaining the pressure differential between units at zero because the pressure differentials to be monitored are larger and less pitot tube need be used. 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.

An alternative method. hereafter referred to as "Nylund's method". was proposed in 1981[5]. This method involves the use of a single testing apparatus. Measurements of indoor-outdoor pressure differentials in dwellings 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 had never been attempted prior to this project[6].

The objective of this project was to evaluate Nylund's method by conducting field tests on full scale housing. Eight townhouses were to be tested by both the pressure equalization method and Nylund's method. and the results compared.

2.0 THEORY

2.1 Pressure Testing of Detached Dwellings

In pressure testing detached dwellings[7], a powerful fan is used to generate a range of pressure differentials (from 5 to 50 pascals) across the building envelope (pressures generated by wind and by stack effect would normally be in the vicinity of 4 pascals). A calibrated nozzle is used to determine air flow generated by the fan. An equation of the form

$$Q = C\,\Delta P^{n} \qquad (1)$$

is fitted to the data

where Q is the air flow rate (L/s)

C is a constant determined by measurement (L/s·Pa^{n})

ΔP is the pressure differential across the building envelope (Pa)

n is the flow exponent determined by measurement.

2.2 Nylund's Method

Nylund's method is directed at the testing of a row dwelling (B) connected to other dwellings as shown in Figure 3.

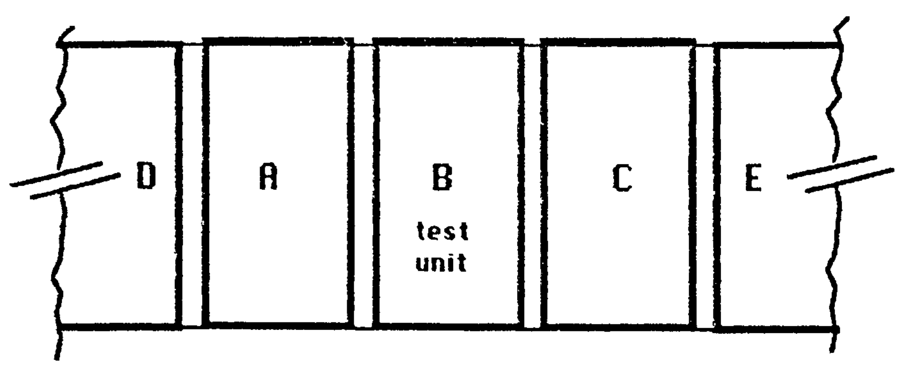

Figure 3. Test row dwelling B is embedded in a series of attached dwellings

The theory is based on a couple of assumptions:

1. that 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 air flow rates under pressure in dwellings A through E will be equal for a given pressure differential ΔP_i. Thus

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

where Q_i is the total air flow induced through the envelope of the dwelling under test. i being any of A through E and

2. that the flow through party walls is much smaller[8] than the flow through the exterior envelope of any dwelling.

If a fan is used to depressurize unit B, air flows will be induced as shown in Figure 4 (flows would be reversed in the case of positive pressurization).

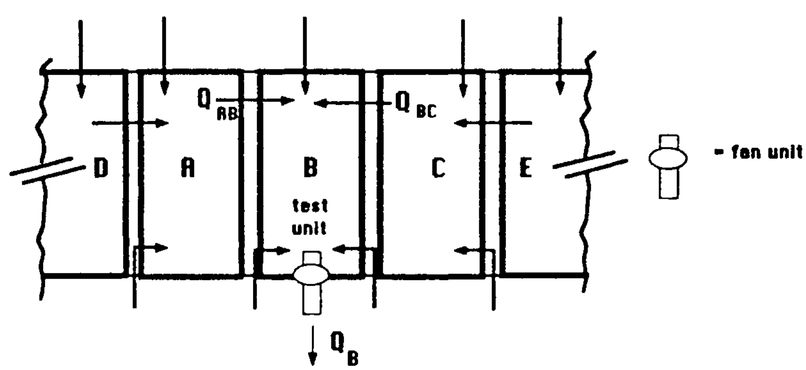

Figure 4. Air flows induced when a row house is depressurized.

According to the assumptions stated above, there are three parallel flows such that

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

where ΔP_i is the indoor-outdoor pressure differential for the row dwelling indicated (note that an indoor-outdoor pressure differential will be induced in units adjacent to the test unit when air flows through the party wall)

It is assumed that tests are conducted when pressure effects on A and C caused by wind and temperature are negligible compared with the depressurization due to party wall leakage when B is under test. It is also assumed that air flow from dwellings D and E is small enough to be ignored.

If unit B is pressure tested with 50 pascals as the reference pressure differential, then values are known or can be measured and computed for $\Delta P_B{}^n$, Q_{B50} (the air flow through the pressurization apparatus), $\Delta P_A{}^n$, 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 50 pascals with party wall leakage eliminated will be given by

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

Nylund suggests[9] that a factor R may be defined

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

where Q_A' and Q_C' are the air flows through exterior walls only, but under the assumptions used in Nylund's method would be very close to Q_{AB} and Q_{BC}

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

$$Q_{B50\ cor} = Q_{B50} - Q_{AB} - Q_{BC} + R \quad (8)$$

In cases where party walls are very airtight, R would approach zero. Q_{AB} and Q_{BC} could then be obtained graphically from the uncorrected leakage curve for B, given the measured values for ΔP_A and ΔP_C (see Figure 5)

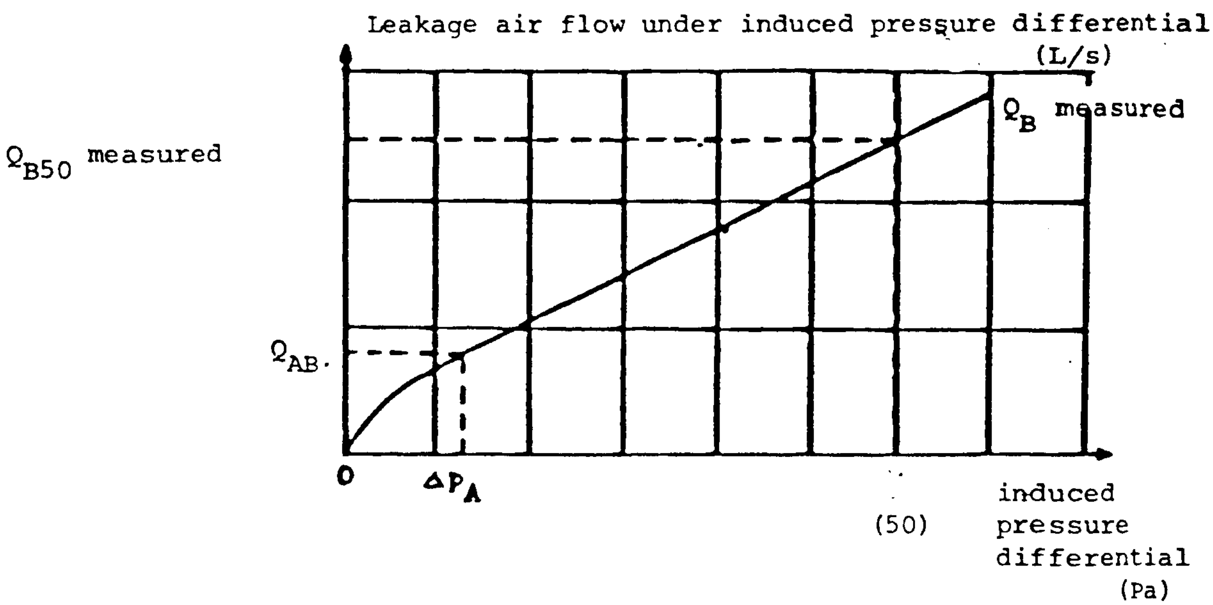

Figure 5. Graphical method of determining party wall leakage flows

2.3 Leakiness of Party Walls in Wood Frame Row Housing

In the course of previous research projects . the author measured airtightness of 14 wood frame row houses. The pressure equalization method was used to determine the contribution of party walls to overall leakiness of the envelope (see Table 1). The data from this work was reviewed to obtain an indication whether wood frame row houses in Canada have airtightness characteristics conforming to the assumptions on which Nylund's method is based.

Table 1. Comparison of air flow through 14 row houses (housing sample 1) with 50 pascals pressure differential induced across the envelope and with pressure differentials between adjacent units unequalized and equalized.

Unit Code	Q_{50} unequalized air flow (L/s)	Q_{50eq} equalized air flow (L/s)	$Q_{50} - Q_{50eq}$ (L/s)	$(Q_{50} - Q_{50eq})$ as percentage of Q_{50}
end units				
1a	450	350	100	22
2a	300	250	50	17
2b	310	220	90	29
3a	730	490	240	33
4a	530	320	210	42
5a	590	390	200	34
5b	550	420	130	24
Mean	490	350	140	29
interior units				
3b	670	430	240	36
3c	870	510	360	41
5c	540	400	140	26
5d	480	230	250	52
5e	660	400	260	39
5f	690	450	240	33
5g	450	250	200	44
Mean	620	380	240	39

These results show that party wall leakage is significant compared with leakage through the exterior envelope. As well, the airtightness of dwellings within the same cluster varied noticeably. Additional data was tabulated to indicate the range of these variations (see Table 2).

Table 2. Comparison of air flow statistics (mean and standard deviation under pressure test) for interior units in 6 row housing projects.

Project Code	Number of Units Tested	Q_{50} unequalized air flow (L/s) mean	standard deviation	standard deviation as percent of mean
1	2	600	61	10
2	2	480	86	18
3	3	740	110	15
4	4	380	66	17
5	7	580	90	16
9	2	450	11	3
			range	3 to 18 percent

It was possible that these violations of the assumptions on which Nylund's theory was based might introduce enough error to make the method insufficiently accurate. Field tests were undertaken to determine whether this was the case.

3.0 FIELD TESTS

Several test sites and test dates were arranged.

The indoor-outdoor pressure differentials to be measured by Nylund's method are of the same magnitude as those induced by wind, so conditions must be very calm when attempting to validate the method. Wind necessitated abandonment of testing on 2 occasions.

Dwellings in two other complexes tested were so leaky that the equipment available was not sufficiently powerful to induce a 50 pascal pressure differential across the envelope. The researchers were using first generation depressurization equipment. Second generation equipment permits a wider range of flows to be measured through the use of a range of measurement orifices, so this would not be a problem for researchers with more sophisticated equipment.

On yet another occasion, one of the occupants who had agreed to permit testing left a key with a neighbour. The neighbour was absent on the day arranged for testing, so testing could not proceed. Fortunately, acceptable test results were finally obtained for 7 row houses in two complexes.

In Nylund's method, units adjacent to the test unit (A and C in Figures 3 and 4), as well as test unit B, are prepared for testing by the sealing of all intentional openings such as ventilation ducts and dryer exhaust ducts. For each of dwellings A and C, the indoor-outdoor pressure differential in dwellings adjacent to the test unit is then determined while the indoor-outdoor pressure differential in test units B is maintained at 50 pascals, a pressure differential commonly used as a reference in airtightness testing.

To achieve greater precision, a liquid micromanometer was used to measure smaller pressure differentials. Unfortunately, loss of liquid in the micromanometer necessitated the use of a less precise diaphragm actuated instrument in the testing of the two units in project 7.

Dwellings were tested by both Nylund's method and the pressure equalization method. In order to test the assumption that there is no leakage through the party wall between the unit adjacent to the test unit and the unit one removed from the test unit, the indoor-outdoor pressure differential in the unit one removed was monitored while the test unit was depressurized to 50 pascals. No deflection of the pressure gauge was observed.

A suggestion was made that unit-to-unit pressure differentials between the test unit and adjacent units be used in lieu of indoor-outdoor pressure differentials in order to simplify some aspects of pressure measurement (such as the need to communicate between adjacent units by walkie talkie). However, unit-to-unit pressure differentials were found to be about 3 times greater than indoor-outdoor pressure differentials. Hence unit-to-unit pressure differentials could not be substituted for indoor-outdoor pressure differentials and it was necessary to continue communicating by walkie-talkie.

Detailed results are presented in Section 4.

4.0 RESULTS

Detailed data obtained in the course of field testing may be found in Appendix A. Table 4 provides a comparison of results obtained by the pressure equalization method and Nylund's simplified method (equation 8 with R taken as zero). This comparison was performed with data from Project 6 only. Note that the unequalized air flow for the units tested ranged from 420 to 530 L/s.

Table 3. Comparison of air flow through test row houses with party wall air flow eliminated by pressure equalization and by Nylund's simplified method (equation 7).

Unit Code	Q_{50} unequalized air flow (L/s)	Q_{50eq} equalized air flow (L/s)	Q_{50cor} Q_{50} corrected by Nylund's simplified method (equation 7) (L/s)	Percent Discrepancy Between Q_{50eq} and Q_{50cor}
end unit				
6a	420	350	300	-16
interior units				
6b	530	360	300	-20
6c	540	360	300	-20
6d	420	300	180	-40
6e	490	360	260	-28
mean	480	-	-	-33
standard dev	58	-	-	-

It is evident that application of Nylund's simplified method did not give an accurate estimate of the air flow through the test dwelling with air flow through the party walls eliminated. Q_{50cor} was recomputed using equation 6 (see Table 4)

Table 4. Comparison of air flow through test row houses with party wall air flow eliminated by pressure equalization and by Nylund's method.

Unit Code	Q_{50} unequalized air flow (L/s)	Q_{50eq} equalized air flow (L/s)	Q_{50cor} Q_{50} corrected by Nylund's method (L/s)	Percent Discrepancy Between Q_{50eq} and Q_{50cor}
end unit				
6a	420	350	330	- 5.7
interior units				
6b	530	360	370	- 2.8
6c	540	360	380	- 5.5
6d	420	300	270	- 10.0
6e	490	360	330	- 8.3
			Range for Project 6	- 2.8 to + 10.0
end unit				
7a	470	350	380	+ 8.6
interior unit				
7b	430	250	280	+ 12.0
			Range for Project 7	+ 8.6 to + 10.3
	Range for all 7 units tested			-2.8 to + 12.0

An estimate of the air flow through the row houses with party wall leakage eliminated was obtained with an accuracy that might be sufficient for many applications, and warrant use of the simplified and less costly test method. The maximum discrepancy between results for the pressure equalization method and Nylund's method was 12 percent, and the mean discrepancy was 9.1 percent. As was noted in Section 3, it was necessary to use a less precise pressure gauge in testing the dwellings in project 7, so it is possible that accuracy would have been better with a more sensitive instrument.

From Table 3, it may be determined that the standard deviation was 12 percent of the mean in the case of the unequalized air flow for project 6. This is within the range of 3 to 18 percent found for 6 other row housing projects (see Table 2).

5.0 DISCUSSION

Given that an acceptably accurate estimate of corrected air flow at 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 50 pascals induced across the building envelope. Since this parameter is obtained by dividing the volume of the dwelling by the induced air flow at 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 Lawrence Berkeley Laboratory infiltration model[10], is determined by

$$L_0 = Q_4 \left| \frac{2\,\Delta P}{p} \right|^{0.5} \tag{9}$$

where L_0 is the effective leakage area

Q_4 is the air flow at a 4 Pa pressure differential (m^3/s)

ΔP is the pressure differential causing the flow (4 Pa)

p is the density of air (1.2 kg/m^3)

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 5.

Table 5. Comparison of C_{eq} and C_{cor}.

Unit Code	C (flow coefficient) C_{eq} determined using pressure equalization	C_{cor} calculated using equation (10)	percent discrepancy
end unit			
6a	27	25	- 7.4
interior units			
6b	22	21	- 4.5
6c	33	27	- 18.0
6d	31	22	- 29.0
6e	38	30	- 21.0
		Range for Project 6	- 4.5 to -29.0
end unit			
7a	28	26	- 7.1
interior units			
7b	12	18	- 50.0
		Range for Project 7	- 7.1 to -50.0

In 4 out of 7 cases the discrepancies are 18% or greater, which is unacceptably large. In the case of unit 7b, the discrepancy seems so large and so out of line with other results that it raises some suspicion as to the validity of the result.

Kiel, Wilson and Sherman suggest that C and n are not independent metrics, but are related by a correlation constant K as follows[11]

$$K = C \left| \frac{1.0 - n}{n - 0.5} \right| \qquad (10)$$

In this case, deviations in C might be compensated for 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 6. In all cases where the error in the estimate for C_{cor} was large, the error in the estimate for Q_4 was substantially less. In other cases the error did not change markedly. This suggests that compensation for joint variation C and n can produce more accurate results.

Table 6. Comparison of air flows at 4 pascals pressure differential calculated using C corrected by pressure equalization with n_{eq} and C corrected by Nylund's method with n.

Unit Code	Q_4 (calculated air flow at 4 pascals induced indoor-outdoor pressure differential)		
	calculated using n_{eq} $Q_4 = C_{eq}(4)$ (L/s)	calculated using n $Q_4 = C_{cor}(4)$ (L/s)	percent discrepancy
end unit			
6a	67	62	- 7.5
interior units			
6b	59	58	- 1.7
6c	76	69	- 9.2
6d	68	53	- 22.0
6e	85	75	- 11.8
	Range for Project 6		- 1.7 to - 22.0
end unit			
7a	70	65	- 7.1
interior units			
7b	35	48	+ 37.1
	Range for Project 7		- 7.1 to + 37.1

Another metric commonly used in Canada in rating the airtightness of building envelopes is equivalent leakage area (ELA), defined as:

$$ELA = 0.001157\ p_o^{0.5}\ C\ 10^{n-0.5} \qquad (11)$$

where ELA is the equivalent leakage area (m^2)

p_o is the density of outside air (kg/m^3)

C and n are the flow coefficient and flow exponent

Values of ELA calculated using metrics generated by Nylund's method are compared with values generated by the pressure equalization method in Table 7.

Table 7. Comparison of equivalent leakage area (ELA) calculated C corrected by pressure equalization with n_{eq} and using C corrected by Nylund's method with n.

Unit Code	equivalent leakage area calculated using C_{eq} and n_{eq} (m^2)	equivalent leakage area calculated using C_{cor} and n (m^2)	percent discrepancy
end unit			
6a	0.052	0.046	- 12.0
interior units			
6b	0.046	0.046	0.0
6c	0.053	0.052	- 1.9
6d	0.047	0.038	- 19.0
6e	0.058	0.049	- 16.0
	Range for Project 6		0.0 to - 19.0
end unit			
7a	0.051	0.049	- 3.9
interior units			
7b	0.028	0.035	+ 25.0
	Range for Project 7	- 3.9 to + 25.0	

As with Q_4 (see above). estimates for ELA were generally better than estimates for C_{cor}.

A corrected value of n, which should yield more accurate values of C, could be obtained by applying Nylund's method at some additional points (e.g. 40 and 60 pascals pressure drop across the envelope of the test dwelling). This would permit calculation of additional values of Q corrected by Nylund's method; with these additional values a corrected curve could be obtained, which would provide corrected values for C and n. Since the pressure differentials being measured in dwellings adjacent to the test dwelling are relatively small (3 to 7 pascals - see Table A.2) even at the 50 pascal reference differential, the range of readings obtainable would be much more restricted than in the standard testing procedure or the pressure equalization method.

Such a procedure was followed in testing project 7. Indoor-outdoor pressure differentials were measured with the test unit depressurized by 40 and 60 pascals, as well as 50 pascals. Numerical methods were used to solve equation 5 for n and C, given the data provided by measurement. This method yielded much better estimates for C and n. as is evident from the results shown in Table 8.

Table 8. Comparison of C_{eq} and n_{eq} with C and n determined for Project 7 by applying Nylund's method at additional test pressures.

Unit Code	C_{eq} (L/s·Pa^n)	n_{eq}	C (L/s·Pa^n)	n	percent discrepancy C	percent discrepancy n
end unit						
7a	28	0.65	29	0.66	+ 3.6	+ 1.5
interior units						
7b	12	0.77	14	0.77	+16.8	0.0

6.0 CONCLUSION

Due to the small number of units tested. this project can only be regarded as a pilot study. However. the results indicate that further work to validate Nylund's method is warranted. given the relative simplicity of the method and the accuracy of the results obtained in the course of this project.

APPENDIX A: DETAILED DATA FROM FIELD TESTS

Table A.1 C and n for dwellings in housing sample 2.

Unit Code	C (flow coefficient) ($L/s{\cdot}Pa^n$)		n (flow exponent)	
	C	C_{eq}	n	n_{eq}
end units				
6a	32	27	0.66	0.68
7a	32	28	0.69	0.65
interior units				
6b	30	22	0.73	0.71
6c	39	33	0.68	0.61
6d	35	31	0.64	0.58
6e	45	38	0.61	0.58
7b	29	12	0.69	0.77

Table A.2 Pressure differentials between dwellings tested and adjacent dwellings as determined by Nylund's method.

Unit Code	ΔP_A (Pa)	ΔP_B (Pa)
end unit		
6a	-	7.1
7a	-	6.0
interior units		
6b	5.7	6.6
6c	6.1	5.1
6d	6.0	6.8
6e	6.0	3.1
7b	9.5	5.2

REFERENCES

[1] See, for instance, CGSB Standard CAN142.149.10, "Determination of Air-tightness of Buildings by the Fan Pressurization Method", Canadian General Standards Board, Ottawa, 1984

[2] CGA 1986. CGA Standard CAN/CGA B149.10-M86, "Natural Gas Installation Code", p.51. Canadian Gas Association, Toronto.

[3] The Canadian "R2000" super energy efficient home program, funded by Energy Mines and Resources Canada and administered by the Canadian Home Builders Association, requires fewer than 1.5 air changes per hour under a pressure differential of 50 pascals for certification of performance.

[4] Grimsrud, D.T., M.H. Sherman, and R.C. Sonderegger, "Calculating Infiltration: Implications for a Construction Quality Standard", Thermal Performance of the Exterior Envelopes of Buildings II, Proceedings of the ASHRAE/DOE Conference, American Society of Heating Refrigerating and Air-conditioning Engineers, Atlanta, 1983, 422-452.

[5] Nylund, P.O. "Tightness and Its Testing in Single and Terraced Housing", Air Infiltration Instrumentation and Measuring Techniques, Proceedings of the First Air Infiltration Centre Conference, Oscar Faber, England, 1981, 159-72.

[6] Nylund, P.O., Tyrens AB, Sundbyberg, Sweden, April 1986, personal communication.

[7] CGSB

[8] Nylund did not quantify the threshold for his assumption of relative smallness.

[9] Nylund, personal communication, June, 1986.

[10] Grimsrud.

[11] Kiel, D., D. Wilson and M. Sherman, Air Leakage Flow Correlations for Varying House Construction Types, ASHRAE Transactions, 1985, V.91, Pt. 2.