BUILDING RESEARCH NOTE

RELATIVE TIGHTNESS OF NEW HOUSING
IN THE OTTAWA AREA

by

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Division of Building Research, National Research Council of Canada

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As part of its energy conservation research program, the Division of Building Research of the National Research Council of Canada has sponsored a research contract to investigate the relative air tightness of new houses built and sold in the Ottawa area in 1978. There were two principal purposes: to evaluate a testing procedure for checking new houses for compliance with a performance type of air leakage standard; and to obtain relative tightness data for current housing. This Note deals with the latter objective.

Initial contact was made by DBR/NRC with local members of the Housing and Urban Development Association of Canada, inviting them to participate in the program. Those who agreed were referred to the research contractor whose responsibility it was to make the final selection of houses to be tested and all other arrangements. For technical reasons testing was limited to detached housing units or to semi-detached and row housing units not having heated areas separated by a common wall. This effectively prevented some of the interested firms from participating, and subsequently other considerations forced a few more who had indicated interest in the program to withdraw. In all, 80 relative tightness tests were made involving 63 houses and 9 builders.

Prior to the research contract, DBR had prepared a draft test procedure based on the pressure difference method of testing whereby a fan is used to extract air from a house in order to produce a negative pressure within the building. This pressure difference causes air to infiltrate through the building envelope at the same rate as it is extracted by the fan. Details of the test procedure are attached as Appendix A.

When corresponding values of Q and ΔP are plotted on log-log graph paper the data fall along a straight line. Thus, the relation between rate of air flow, Q, and pressure difference, ΔP, across the building envelope can be represented by

$$Q = C(\Delta P)^n$$

The slope of the straight line gives the value of n, and the value of the constant C is equal to the value of Q when ΔP is 1. Each house has characteristic values for C and n. Test data for three houses have been plotted in Figure 1.

There are several advantages to this procedure. When pressure differences across the building envelope are low, the accuracy of the test data will be quite low owing to wind and instrument reading errors. Although it is a good test, the data for house No. 1 show this tendency. It is also very difficult to obtain the exact pressure difference across the building envelope that is needed if comparisons are to be made of different houses at a particular pressure difference. As illustrated by houses No. 26 and 63, two houses having the same rate of infiltration at one pressure difference can have different rates at other pressure differences. In houses No. 1 and 26, the values of n are similar, 0.670 and 0.669, respectively, so that the lines are almost parallel, indicating nearly constant relative air tightness independent of pressure difference.

A further advantage of the procedure is that once the house characteristics have been determined its relative tightness can be calculated for any pressure difference. This makes it possible to carry out a test at pressure differences high enough to mask the effect of wind and outside temperature and base the relative tightness on a pressure difference more representative of that occurring during the heating season. For this contract the pressure difference chosen was 10 Pa. If subsequent research indicates that another value should be used, new relative tightness values can easily be calculated and the testing will not have to be repeated.

The air flow corresponding to a particular pressure difference is a characteristic of each house. In order to establish a relative tightness value it is necessary to have some means of comparing houses. Heating load calculations are often based on air leakage expressed in air changes per hour. This is equivalent to the volume rate of air flow divided by the volume of the house. Those studying the air tightness of houses generally make use of the same terms, and this is satisfactory as long as the volumes of the houses being compared are known. If they are not known or the testing has been done at different pressure differences, then comparison is impossible.

Air tightness depends on the tightness of the building envelope or air barrier rather than the building volume. Dividing the volume rate of air flow by the area of the air barrier gives the rate of air flow per unit area or the average velocity of the air passing through the building envelope. This is, at present, the most meaningful parameter for comparing the air tightness of different houses. When details of houses are available, the rate of air flow can be converted to air changes per hour. Regardless of the units used, the relation between rate of air flow determined by this test method and average rate of air leakage during the heating season is unknown. It is impossible therefore to use these test data directly in estimating a portion of the heating load attributable to air leakage and ventilation.

TABLE I (a) HOUSE DETAILS

House No.	Type (1)	Finished Floor Area m^2	Heated Volume m^3	Air Barrier Area m^2	Garage (2)	Heating		Domestic Hot Water (3)	Fire-Place (5)	Chimney		Fresh Air Inlet
						Fuel (3)	System (4)			Htg (6)	FP (6)	
1	SL	151	556	367	AB	G	A	G	S	B	S	x
2	2S	188	765	318	A	O	A	O	S	M	M	-
3	2S	202	805	438	AB	G	AC	G	M	B	M	-
4	SL	142	528	296	D	G	A	G	M	B	M	x
5	2S	134	428	214	A	G	A	G	S	B	S	-
6	SL	122	507	368	AB	G	AC	G	S	B	S	x
7	2S	161	682	385	AB	G	AC	G	M	B	M	-
8	2S	157	531	324	GA	G	A	G	S	B	S	x
9	2S	202	805	438	AB	G	AC	G	M	B	M	-
10	2S	205	772	372	AB	O	A	O	M	M	M	-
11	2S	192	677	349	AB	G	A	G	M	B	S	-
12	2S	158	664	335	A	G	A	G	M	B	M	-
13	2S	141	505	284	AB	G	AC	G	S	B	S	x
14	2S	147	564	326	AB	G	A	G	M	B	M	-
15	2S	177	611	330	AB	G	A	G	S	B	S	x
16	2S	134	466	276	AB	G	A	G	M	B	M	-
17	2S	185	773	401	AB	G	AC	G	M	B	S	-
18	SL	170	606	386	AB	G	A	G	M	B	M	x
19	B	131	458	211	CP	G	A	G	S	B	S	x
20	2S	118	426	221	A	G	A	G	M	B	M	-
21	1½S	175	589	382	AB	G	A	G	S	B	S	x
22	2S	139	574	293	AB	G	A	G	M	G	M	-
23	2S	151	591	306	AB	G	A	G	M	B	M	-
24	2S	170	659	298	A	G	AC	G	M	S	M	-
25	2S	190	582	399	AB	E	AC	E	S	-	S	x
26	2S	177	603	281	A	G	A	G	M	B	M	x
27	B	157	380	291	B	G	A	G	S	B	S	x
28	B	107	429	222	None	E	A	E	-	-	-	-
29	SL	162	525	331	AB	G	A	G	S	B	S	x
30	2S	117	391	217	A	G	A	G	S	B	S	-
31	SL	117	453	306	A	G	AC	G	M	B	M	-
32	2S	153	533	280	AB	G	A	G	M	B	M	-
33	2S	183	658	325	A	E	AC	E	S	-	S	x
34	2S	137	403	212	CP	G	A	G	S	B	S	x
35	2S	163	576	340	B	G	AC	G	M	B	M	-

TABLE I b HOUSE DETAILS

House No.	Type (1)	Finished Floor Area m^2	Heated Volume m^3	Air Barrier Area m^2	Garage (2)	Heating		Domestic Hot Water(3)	Fire-Place (5)	Chimney		Fresh Air Inlet
						Fuel (3)	System (4)			Htg (6)	FP (6)	
36	2S	149	530	280	A	G	A	G	S	B	S	x
37	B	99	461	226	None	E	A	E	-	-	-	-
38	2S	150	486	324	B	G	A	G	M	B	M	-
39	2S	135	451	229	A	G	A	G	S	B	S	-
40	B	142	522	266	A	G	AC	G	S	B	S	-
41	B	125	354	206	CP	G	A	G	-	B	-	x
42	B	91	440	240	None	E	A	E	-	-	-	-
43	SL	161	644	273	A	G	AC	G	M	B	M	-
44	2S	143	496	263	A	G	A	G	S	B	S	x
45	2S	133	470	254	A	G	A	G	M	B	M	-
46	2S	121	395	209	A	G	A	G	S	B	S	-
47	SL	148	549	319	AB	G	AB	G	S	B	S	x
48	B	131	363	207	CP	G	A	G	-	B	-	x
49	B	101	476	236	None	O	A	E	-	S	-	-
50	1½S	150	602	281	AB	O	A	O	M	M	M	-
51	SL	175	680	370	AB	G	AC	G	M	B	M	-
52	2S	182	642	290	A	G	A	G	M	B	M	x
53	2S	127	487	243	A	G	AC	G	S	B	M	x
54	2S	195	751	387	AB	G	A	G	M	B	S	-
55	B	105	579	221	A	G	A	G	M	M	S	x
56	2S	191	709	353	AB	O	A	O	M	M	M	-
57	B	120	514	289	None	E	A	E	-	-	-	-
58	SL	181	643	377	AB	G	AC	G	M	B	M	-
59	2S	166	587	273	D	G	A	G	M	B	M	x
60	2S	118	392	212	A	G	A	G	S	B	S	-
61	2S	131	504	314	A	G	A	G	S	B	S	x
62	2S	157	583	304	A	G	AC	G	M	G	M	-
63	B	104	440	235	None	E	A	E	-	-	-	-
* I	2S	109	399	228	AB	E	A	E	-	-	-	-
II	2S	109	399	228	AB	E	A	E	-	-	-	x
III	2S	109	399	228	AB	S	A	E	-	-	-	-
IV	2S	109	399	228	AB	HP	A	E	-	-	-	-

SYMBOLS

(1) 2 - 2 storey
1½ - 1½ storey
SL - Split level
B - Bungalow & Split Level Entrance

(2) A - Attached garage at grade
AB - Built in garage at grade
B - Built in garage in basement
CP - Carport
D - Detached Garage

(3) O - Oil
G - Gas
E - Electricity
S - Solar & Electricity
HP - Heat Pump & Electricity

(4) A - Forced Air
AC - Air conditioned

(5) B - B Vent
S - Insulated steel
M - Masonry

(6) S - Steel lining
M - Masonry

* HUDAC House No.

In this paper relative tightness is defined as the equivalent average velocity of infiltrating air equal to the volume rate of infiltration under a pressure difference of 10 Pa divided by the area of the air barrier. The area of the air barrier is further defined as the area of the building envelope (ceiling, walls and floors) that separates the heated volume from outside conditions. Unheated garages and ventilated crawl spaces are considered to have outside conditions.

Houses currently built in the Ottawa area vary widely in size, type, style, finish and construction detail. Those selected for testing were representative of current construction, but owing to the many differences existing and the limited number that could be tested it was impossible to relate relative tightness to specific details. Pertinent details of the houses tested have been tabulated in Table I.

Initially, it was thought that the type of house would be significant, and the houses were classified accordingly in four categories: 2-storey, 1½-storey, split level, and bungalow, the latter including split level entrance type houses. Differentiating the first three types proved to be extremely difficult because each type seemed to blend into the other. In the end the decisions tended to be somewhat arbitrary.

Size of house is also given, expressed in three different ways, finished floor area, volume, and area of the air barrier. Both style and type of house affect the relations of these factors and therefore the relation of relative tightness to size. To illustrate the differences that do occur details and test results for the three houses used in Figure 1 have been tabulated in Table II in order of relative tightness.

The remaining details are those that could cause a significant difference between the test results and the actual rate of infiltration-exfiltration occurring under normal occupancy conditions, for the tests were carried out with chimneys and fresh air inlets sealed off. Additional information such as exterior finish, number and location of exhaust fans, construction details, etc., was obtained, but space does not permit its inclusion in this report.

TABLE II EFFECT OF SIZE FACTOR ON RELATIVE TIGHTNESS

House No.	Type	Finished Floor Area m^2	Volume m^3	Air Barrier Area m^2	Constant C	Coefficient n	Air Flow Q_{10} m^3/s	AC/h	Relative Tightness mm/s
26	2S	177	603	281	0.0363	0.653	0.169	1.01	0.601
63	B	104	440	235	0.0448	0.574	0.169	1.38	0.719
1	SL	151	556	367	0.0580	0.670	0.273	1.77	0.744

The 63 houses listed are a fair sample of 1978 houses. In some cases tests were carried out on two or three examples of the same model, and in order not to bias the test results unduly they were averaged and reported as a single house. The initial testing, carried out by the contractor, combined a learning experience and a proving out of the test procedure, both of which contributed to some questionable results. The procedure was therefore modified slightly and a number of houses were retested to check the earlier results. In such cases the results were averaged or the initial test discarded.

Results for the 63 representative houses are given in Table III and displayed graphically in Figures 2 to 6. In addition, the four HUDAC research houses located in Orleans were recently tested by DBR. Details of these houses and their test results have also been included in the tables and figures for comparison.

One of the more interesting aspects of the investigation is that there appears to be no significant difference in the various items that can be associated with type of house. Bungalows tend to have slightly lower values of n, C and air flow (Q_{10}), but when the area of the air barrier is included they tend to have a slightly higher relative leakage value.

The range of relative tightness values shown in Figure 5 is about 2 if extreme cases are excluded, but these data cannot be used to predict the amount of air infiltration-exfiltration that will occur in practice. Subject to the living habits of the occupants, it is fairly clear that the relative infiltration-exfiltration values will have a relation similar to that of the relative tightness values.

Undoubtedly the most interesting aspect of the test results is the relative tightness of houses constructed by different builders and their relation to the experimental HUDAC Houses (Figure 6). It is evident that each builder produces houses within a characteristic range of relative tightness values. The differences cannot be explained by differences in construction detail or finish because similar details were widely used, although in a few cases the construction detail did undoubtedly contribute to the looseness of the envelope. There was a distinct impression that the relative tightness of a house varied with the quality of the workmanship. As several different trades and subtrades are involved, the degree of supervision and inspection may also be an important factor.

The current <u>Residential Standards Canada</u> require workmanship and design to be equal to good building practice. Although good building practice is not defined, the results of this series of tests suggest that some builders are better than others in this respect. It is also reasonable to deduce that by avoiding some design details and improving the quality of workmanship, supervision, and inspection, a significant improvement could be made in the relative tightness values of Canadian houses at a minimal increase in cost.

TABLE III TEST RESULTS

House No.	Exponent n	Constant C	Air Flow (ΔP = 10 Pa) m^3/s	Relative Tightness mm/s
1	0.670	0.0580	0.273	0.744
2	0.698	0.0353	0.175	0.550
3	0.620	0.0880	0.365	0.833
4	0.655	0.0312	0.139	0.470
5	0.633	0.0415	0.179	0.836
6	0.630	0.0605	0.257	0.698
7	0.685	0.0827	0.405	1.060
8	0.675	0.0560	0.263	0.812
9	0.650	0.0640	0.287	0.815
10	0.703	0.0475	0.235	0.632
11	0.684	0.0610	0.296	0.848
12	0.650	0.0423	0.189	0.564
13	0.633	0.0680	0.288	1.014
14	0.655	0.0625	0.282	0.865
15	0.659	0.0630	0.280	0.848
16	0.614	0.0629	0.259	0.938
17	0.654	0.0730	0.333	0.830
18	0.690	0.0425	0.211	0.547
19	0.659	0.0313	0.140	0.664
20	0.635	0.0467	0.205	0.928
21	0.715	0.0660	0.335	0.877
22	0.655	0.0665	0.302	1.031
23	0.700	0.0475	0.235	0.768
24	0.617	0.0615	0.251	0.842
25	0.675	0.0505	0.240	0.602
26	0.653	0.0363	0.169	0.601
27	0.642	0.0424	0.186	0.639
28	0.620	0.0470	0.197	0.887
29	0.681	0.0628	0.303	0.915
30	0.672	0.0394	0.186	0.857
31	0.660	0.0539	0.245	0.801
32	0.640	0.0536	0.237	0.846
*I	0.652	0.0359	0.161	0.706
II	0.605	0.0300	0.119	0.522

House No.	Exponent n	Constant† C	Air Flow (ΔP = 10 Pa) m^3/s	Relative Tightness mm/s
33	0.710	0.0480	0.252	0.775
34	0.642	0.0355	0.155	0.731
35	0.720	0.0513	0.268	0.788
36	0.632	0.0535	0.235	0.839
37	0.645	0.0315	0.141	0.624
38	0.691	0.0468	0.229	0.709
39	0.670	0.0370	0.170	0.742
40	0.653	0.0563	0.255	0.959
41	0.634	0.0272	0.115	0.558
42	0.649	0.0410	0.184	0.814
43	0.678	0.0520	0.247	0.905
44	0.620	0.0540	0.222	0.855
45	0.645	0.0505	0.225	0.886
46	0.650	0.345	0.155	0.742
47	0.681	0.0630	0.300	0.940
48	0.669	0.0278	0.129	0.623
49	0.568	0.0810	0.299	1.267
50	0.679	0.0355	0.166	0.591
51	0.693	0.0700	0.345	0.932
52	0.685	0.0263	0.125	0.431
53	0.650	0.0420	0.189	0.778
54	0.676	0.0920	0.432	1.116
55	0.647	0.0328	0.145	0.656
56	0.700	0.0365	0.180	0.510
57	0.597	0.0765	0.297	1.028
58	0.693	0.0685	0.341	0.905
59	0.657	0.0318	0.144	0.527
60	0.619	0.0366	0.155	0.731
61	0.653	0.0510	0.231	0.736
62	0.699	0.0517	0.258	0.869
63	0.574	0.0445	0.168	0.715
Avg.	0.658	0.0513	0.233	0.785
*III	0.650	0.0302	0.135	0.592
IV	0.591	0.0308	0.120	0.526

† Units of C are $m^3/s \cdot Pa^n$

* HUDAC House No.

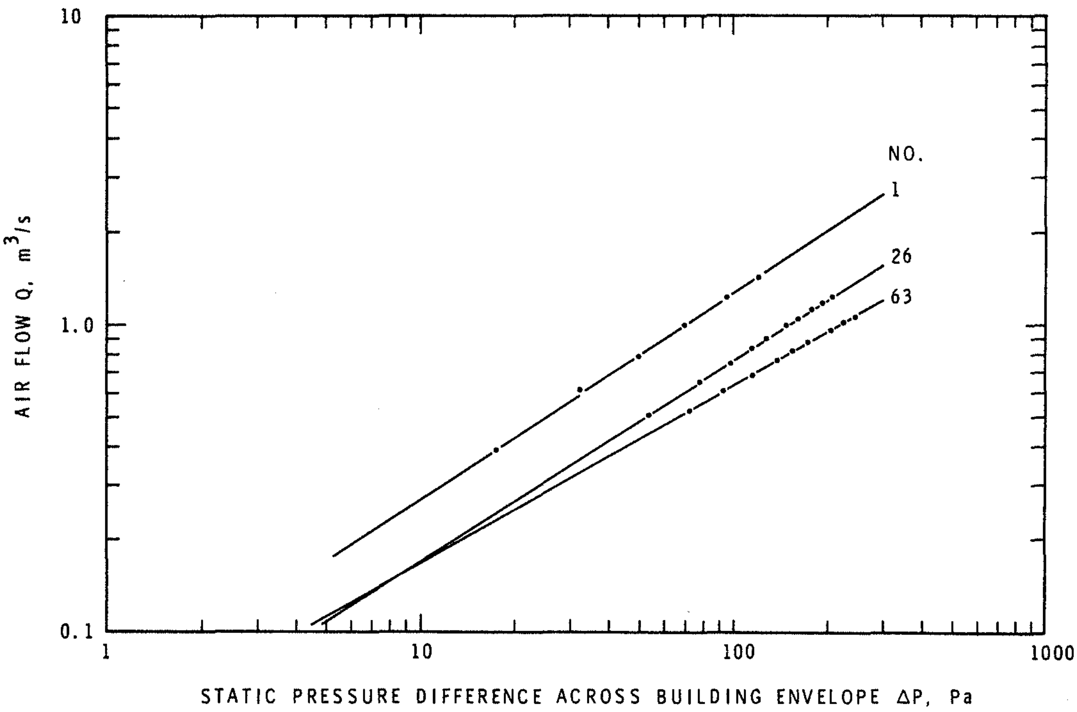

FIGURE 1
SAMPLE TEST RESULTS

BR 5849 - 2

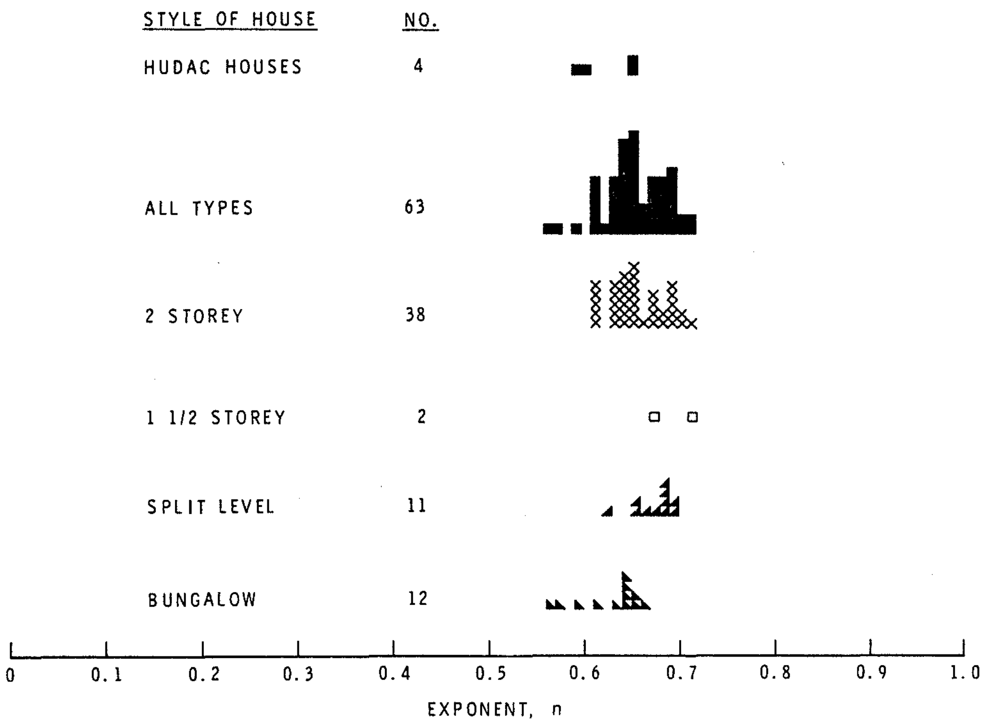

FIGURE 2
DISTRIBUTION OF EXPONENT n FOR DIFFERENT STYLES OF HOUSE

BR 5849 - 3

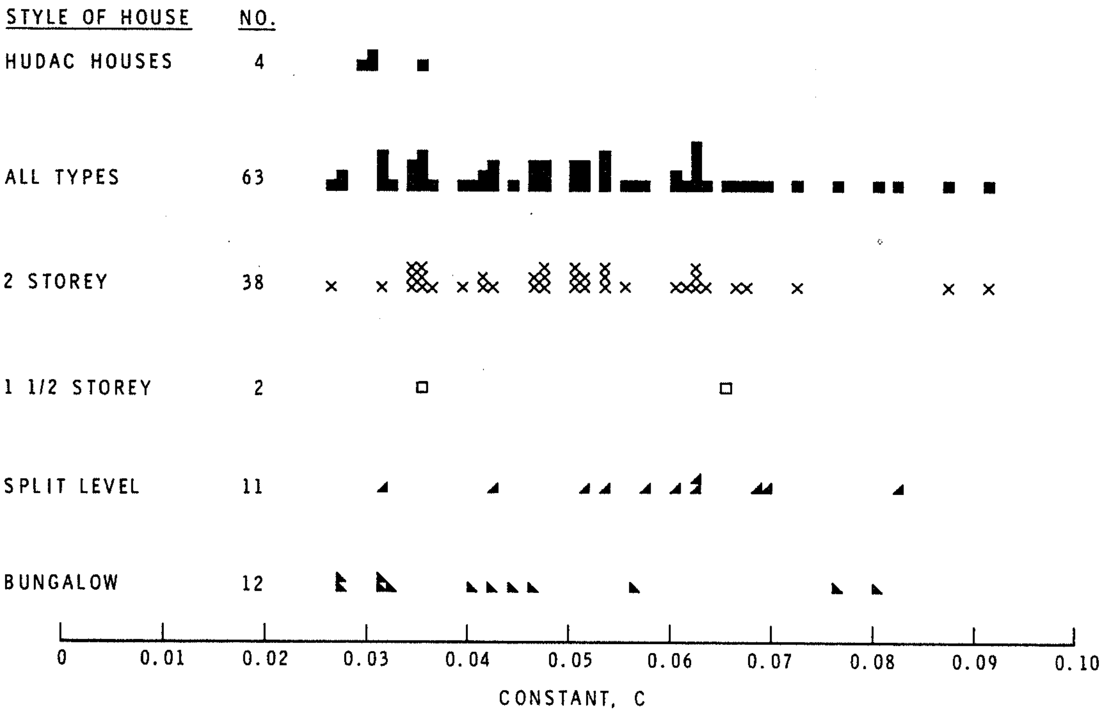

FIGURE 3

DISTRIBUTION OF CONSTANT C FOR DIFFERENT STYLES OF HOUSE

BR 5849-4

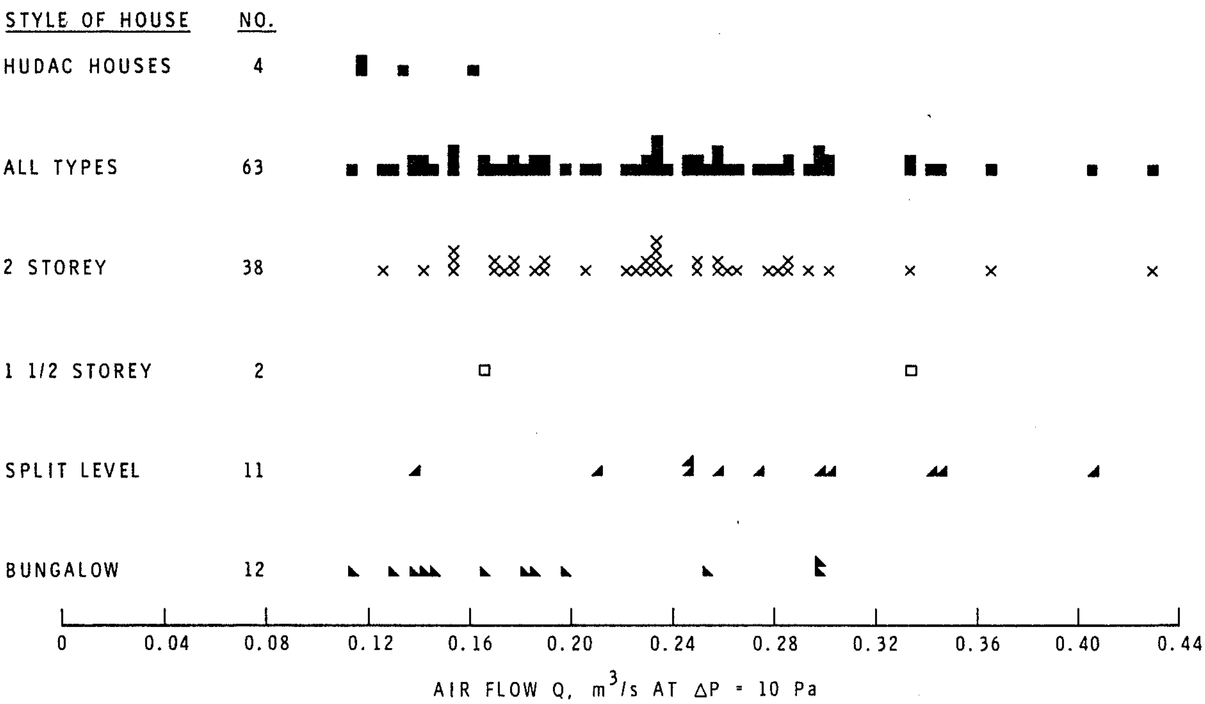

FIGURE 4

DISTRIBUTION OF AIR FLOW AT THE REFERENCE PRESSURE DIFFERENCE FOR DIFFERENT STYLES OF HOUSE

BR 5849-5

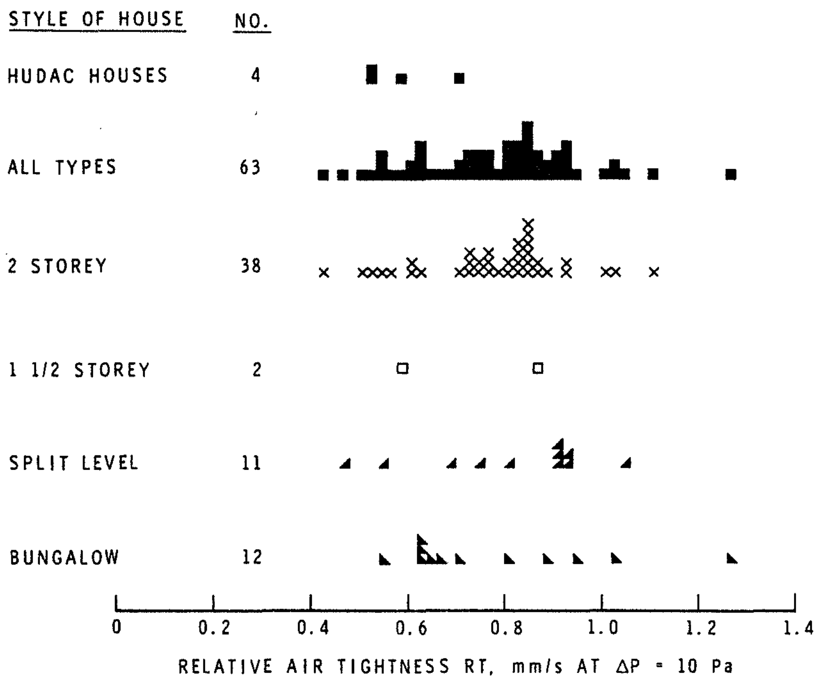

FIGURE 5

DISTRIBUTION OF RELATIVE AIR TIGHTNESS VALUES FOR DIFFERENT STYLES OF HOUSE

BR 5849-6

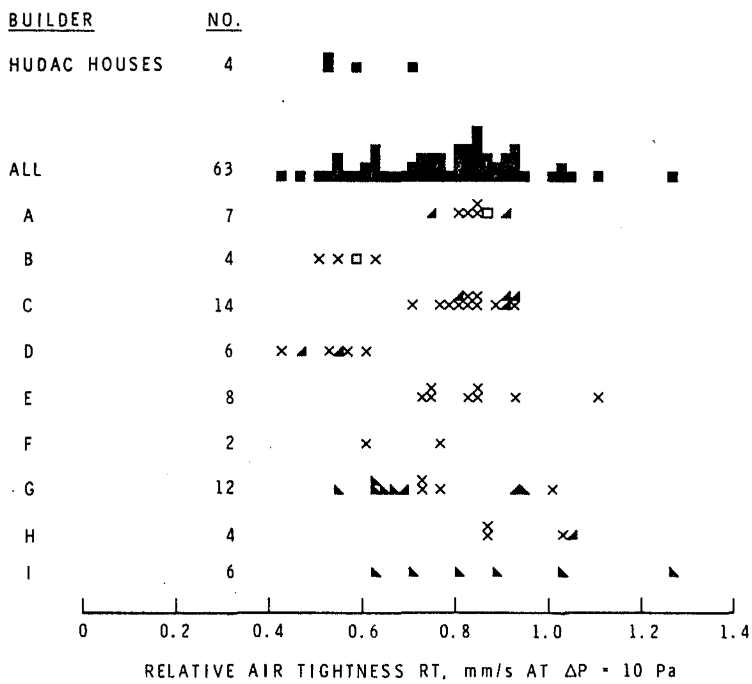

FIGURE 6

DISTRIBUTION OF RELATIVE AIR TIGHTNESS VALUES AT THE REFERENCE PRESSURE DIFFERENCE FOR DIFFERENT BUILDERS AND STYLES OF HOUSE

BR 5849-7

APPENDIX A

TEST PROCEDURE FOR DETERMINING THE AIR TIGHTNESS OF HOUSES BY THE PRESSURE DIFFERENCE METHOD

1. Describe the building and its construction by circling appropriate items in the Test Report and attach a 3 by 5 photograph. Prepare a sketch or attach sales brochure on which is shown the floor plan, adjacent buildings, trees, compass orientation, and location of chimney flues, exhaust fans and the test equipment. Include the location of the point where the outside pressure tap enters the building. Record all data and complete the test report (Appendix B).

2. Select the most convenient door or window opening and set up the apparatus in accordance with Fig. A-1. Pass pressure tubes and cables through the openings as required and seal. Ensure that duct joints and connections are airtight. Mount the pressure tap and locate thermometers in suitable locations. Adjust for minimum air flow and complete the electrical hook-up.

3. Inspect the building and ensure that inside doors are open, exterior doors are closed, fireplace dampers are closed, plumbing traps are full and windows closed and locked. Switch off intake and exhaust fans and seal the openings. Turn down the thermostat of any fossil fuel fired furnace or heater and seal the chimney. Switch on any air circulation fan. Seal any fireplace.

4. Seal the duct temporarily and record the differential static pressure between inside and outside; then unseal the duct and record the differential static pressure again. Switch on the fan and adjust the flow control to create the maximum possible suction pressure to a maximum of 200 Pa. Record the differential pressure and the velocity head in the duct. Readjust the flow control to obtain data at nine more pressure differences equally spaced on log-log paper between the maximum pressure difference and one quarter of the maximum pressure difference. Switch off the fan and record the differential static pressure again.

5. Convert the velocity head to flow rate Q in m^3/s by means of a calibration equation or curve. Calculate the imposed pressure difference ΔP in Pa and plot against Q on 2 by 3 cycle log-log paper with the pressure difference as the x axis and the air leakage rate as the y axis. Draw a best fit by eye straight line through the points to extend from 1 to 100 Pa disregarding any one individual test point that is questionable. Determine the slope n of the straight line and the values of Q when ΔP is 1 Pa and 10 Pa and record. Calculate and record the relative tightness value.

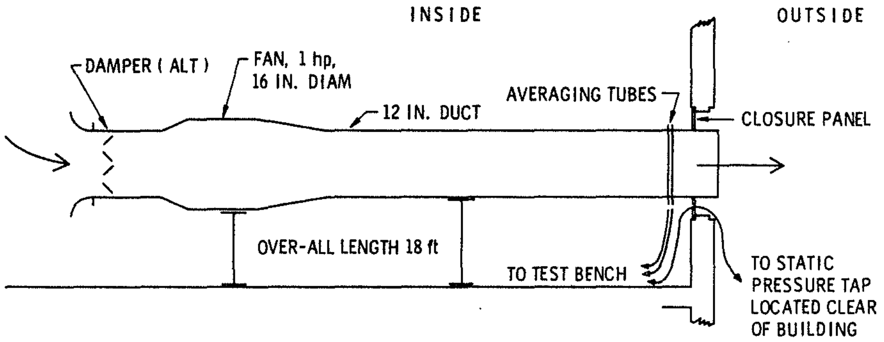

FIGURE A1

RELATIVE AIR TIGHTNESS TEST SET-UP

BR 5849-1

APPENDIX B

RELATIVE TIGHTNESS VALUE OF BUILDING ENVELOPE

Description: Bungalow, 1½ storey, 2 storey, split level, split level entrance. Roof: pitch, flat, mansard. Garage: attached, built-in. Outside finish: bk. veneer, stucco, siding. Windows: double hung, sashless, awning, casement, sealed double glazing. Heating: electric, gas, oil, heat pump, hot water, warm air, air conditioned. DHW: electric, gas, oil. Fireplace: masonry, steel lined. Furnace chimney: masonry, insulated steel, B vent. Fireplace chimney: masonry, insulated steel.

Other Comments:

Date Built: Date Tested:

Location

Weather office (a) Wind speed_________km/h (b) Direction_________

(c) Stagnation pressure_________kPa (d) Atmos press_____kPa

Elevation of pressure tube entrance above grade______m; above ____floor____m

Ext wall area above grade_________m^2 (See Notes)

Roof or attic/ceiling area_________m^2

Exposed floor area_________m^2

Bldg. envelope area (5 + 6 + 7)_________m^2

Total bldg volume________ m^3

Make up air size_________

Diff. static press. across envelope, Pa		(a) Start	(b) End	(c) Average
Outside temperature	, °C	(a) Start	(b) End	(c) Average
Inside temperature	, °C	(a) Start	(b) End	(c) Average

TEST DATA

			1	2	3	4	5	6	7	8	9	10
1	Duct vel hd	in.H_2O										
		Pa										
2	Air leakage Q	m^3/s										
3	St pres diff across env.	in.H_2O										
		Pa										
4	St pres diff, item 11C	in.H_2O										
		Pa										
5	Line 3-line 4 = ΔP	Pa										

Attach log-log graph of test data and report

(a) n = (b) $C(Q_1)$ = (c) Q_{10} m^3/s (d) RT mm/s

Attach photograph and sketch plan

Date__________________Signature____

Notes:

1) Areas and volumes are based on over-all measurements (to the air barrier) and include partitions and floors.
2) Wall areas exposed to attic space (split levels) are to be included in ceiling/attic areas.
3) Attach rough calculation sheets
4) Conversion values:
   (a) 1 ft = 0.3048 m
   (b) 1 ft^2 = 0.09290304 m^2
   (c) 1 cfm = 0.4719474 dm^3/s
   (d) 1 in.H_2O = 248.641 Pa
   (e) 1 cfm/ft^2 = 1 ft/min = 5.08 mm/s