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Seasonal Variation in Airtightness of Two Detached Houses

by A.K. Kim and C.Y. Shaw

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RÉSUMÉ

Des essais de mise en pression par ventilateurs ont été effectués sur deux maisons inoccupées, une fois toutes les deux semaines pendant un an (de mai 1982 à juillet 1983), pour déterminer la variation saisonnière de l'étanchéité à l'air. Les deux habitations étaient isolées et à ossature de bois. La maison n° 1 comportait plus d'isolant que l'exigeait le code du bâtiment local et était dotée d'un pare-vapeur en polyéthylène pour améliorer son étanchéité à l'air. La maison n° 2, moins étanche à l'air, comportait diverses caractéristiques murales et n'avait été dotée d'un pare-vapeur en polyéthylène que sur deux murs seulement.

Lors des essais d'étanchéité à l'air, on a mesuré l'humidité relative intérieure, les températures extérieure et intérieure, ainsi que la teneur en humidité des poteaux et des sablières de l'ossature pour savoir s'il existait une relation entre ces facteurs et l'étanchéité à l'air. Les résultats de ces essais ont révélé que l'étanchéité à l'air était plus élevée en fin d'été que au début de l'été. La maison n° 1, dotée d'un pare-vapeur en polyéthylène, a montré une certaine amélioration de l'étanchéité à l'air au cours de l'été et le tau

Seasonal Variation in Airtightness of Two Detached Houses

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ABSTRACT: Fan pressurization tests on two unoccupied houses were conducted once every two weeks for a period of a year (May 1982 to July 1983) to determine the seasonal variation in airtightness. Both houses are of insulated wood frame construction. House No. 1 was built with more insulation than is required by the local building code, and a polyethylene vapor barrier was applied with special care to improve its airtightness. House No. 2, a less airtight house, was built with various wall construction features and a polyethylene vapor barrier in only two walls.

Indoor relative humidity, indoor and outdoor air temperatures, and moisture content of the stud and top plates of the wood framing were measured at the time of airtightness testing to determine whether a correlation exists between these factors and house airtightness. The results indicate that air leakage varies throughout the year, with the minimum value in late summer and fall and the maximum value in winter and early spring. The difference is more pronounced in the leakier house. There is also indication of a rough correlation between envelope airtightness and indoor humidity ratio.

KEY WORDS: air leakage, measurement, pressure, fan, weather, residential

A measure of airtightness is given by the amount of air that leaks through a building envelope at a specified pressure difference. Air leakage of houses is generally considered to be constant throughout the year, but a recent study by Warren and Webb [1] indicates that there is seasonal variation on the order of 40% for some houses in the United Kingdom. Persily [2] shows, too, that the air leakage values of some American houses are, on the average, about 22% lower in the summer months than in the winter. The reason for this variation is not yet understood completely, but it is presumed that the contraction and

¹Research officers, Division of Building Research, National Research Council, Ottawa, Canada K1A 0R6.

expansion of building materials as a result of changes in relative humidity have some effect on the airtightness of buildings.

To investigate the magnitude of seasonal variations in air leakage of Canadian houses, fan pressurization tests were conducted on two unoccupied houses once every two weeks for a period of a year (May 1982 to July 1983). Indoor relative humidity value, indoor and outdoor air temperatures, and the moisture content of the wood framing were measured at the time of airtightness testing. Specifically, the study was designed to determine (1) the seasonal variation in airtightness of the two houses and (2) the effect of indoor humidity on airtightness.

Test Houses

Both test houses are of insulated wood frame construction. House No. 1 (HUDAC MARK XI project house) [3] is a two-story detached house with a full basement located in a developed residential area in the city of Gloucester, Ontario. The house walls are of standard 38 by 89-mm (2 by 4-in.) wood studs with 38 by 38-mm (2 by 2-in.) horizontal wood furring strips nailed on the inside. To improve airtightness, a 0.10-mm (4-mil) polyethylene sheet was installed between the studs and furring to create an insulated space on the inside of the vapor barrier. Inside this sheet, all the electrical outlets and wiring were installed without cutting through the polyethylene. Special care was taken to seal all joints in the polyethylene sheet. A cross-section of the wall at the intersection with the second floor is shown in Fig. 1.

House No. 2, less air tight, is located in an open field near the Ottawa airport. It was built as an experimental house for studying different wall construction features. For this reason, a polyethylene vapor barrier was included in only two of the wall construction details. A few of the details are shown in Fig. 2.

Table 1 provides a brief description of the two test houses. Neither was occupied during the test period, so that there was no internal moisture generation. The only sources of moisture were, therefore, outdoor moisture carried in by air infiltration and, perhaps, ground moisture entering through basement walls and the floor.

Tests

The air leakage values of the test houses were determined by means of the fan pressurization test method. Two identical apparatuses were used, each consisting of a 40.6-cm-diameter axial fan with a direct-drive d-c motor. The free discharge capacity of the fan is 1200 L/s.

Each apparatus was located inside the test house, with the discharge side of the fan connected by ductwork to an infill panel in an outside window of

FIG. 1—Typical wall detail and location of moisture pins, House No. 1.

House No. 1 and to an infill panel in a patio door of House No. 2. Both the window and the patio door could be closed on completion of the test without moving the apparatus. The flow rate of the fan was measured with a 20.3-cm orifice plate in House No. 1 and with a pair of total pressure averaging tubes in House No. 2 [4].

Inside-to-outside pressure differences were measured using a diaphragm-type pressure transducer (static error band of 5% full scale). Four pressure taps were installed on the outside faces of the four exterior walls. The taps were manifolded before being connected to the pressure transducer in order to provide an average value of outdoor pressure [5].

Each tightness test consisted of measuring the air leakage values at seven or eight pressure differences ranging between 10 and 100 Pa. Measured air leakage values and pressure differences can be correlated by an expression of the form

$$Q = C(\Delta p)^n \quad (1)$$

FIG. 2—Wall details and location of moisture pins, House No. 2: (a) first story; (b) second story.

TABLE 1—Description of test houses.

	House No. 1	House No. 2
Type	single, detached, 2-story	single, detached, 2-story
Floor area, m ²	118	195
Ceiling area, m ²	63.7	97.5
Volume (including basement), m ³	386	520
Outside envelope area, m ²	228	316
Outside wall area, m ²	164	218
Window area, m ²	15.5	17.0
Outside door area, m ²	4.2	5.6
Length of sash crack for window, m	67.6	93.3
Exterior wall finish	brick veneer and aluminum siding	brick veneer, plaster, concrete block and wood siding
Interior wall finish	plaster board	plaster board
Vapor barrier	complete polyethylene vapor barrier	partial polyethylene vapor barrier
Airtightness	tight	leaky
Window	triple-glazed, wood frame, casement	double-glazed, wood frame, removable

where

Q = air leakage value, L/s,

C = flow coefficient for house, L/(s · Pa ^{n}),

Δp = pressure difference across exterior wall, Pa, and

n = flow exponent.

The values of C and n , or the value of leakage at a specific pressure difference, therefore can be used to characterize the airtightness of the house. In this study, the interpolated leakage at a pressure difference of 50 Pa, designated Q_{50} , is used as the indicator of the airtightness of the test houses.

Moisture pins (16 in House No. 1 and 8 in House No. 2) were installed at various locations in the exterior walls of the houses. The detailed locations of a few selected moisture pins are shown in Fig. 1 for House No. 1 and in Fig. 2 for House No. 2. All pins were fixed into wood framing members.

Indoor wet- and dry-bulb temperatures were measured using a sling psychrometer. The daily mean outdoor air and dew-point temperatures on the test date were obtained from the office of Environment Canada. Moisture contents of the wood framing were measured using a moisture meter with an error band of 1% during each air leakage test.

Repeatability Test and Wind Influence

Although all tests were conducted on relatively calm days (wind speed less than 10 km/h), some variation from one test to another was unavoidable. To corroborate the repeatability of the test results and to determine the effect of wind speed on them, a special series of fan pressurization tests were conducted on House No. 1 over a period of seven days. During this time, the air leakage values of the house were determined repeatedly on two calm days, and five air leakage tests were performed on five days when wind speeds ranged from 2 to 24 km/h. The results of the repeatability tests and of the tests with different wind speeds are given in Tables 2 and 3, respectively, in terms of C , n , Q_{50} , and correlation coefficient.

The flow exponent, n , based on the repeatability tests (Table 2), varied between 0.68 and 0.7. To facilitate comparison, values of flow coefficient and leakage were calculated assuming a constant value of $n = 0.69$ (see Table 2). The variation in flow coefficient, C , is less than 0.5%, suggesting excellent repeatability of the pressurization test results.

Wind around and over a house causes variations in pressure; the amount and pattern of pressure depends on wind direction, building shape, and nearby buildings. Pressures are positive on windward sides and negative on leeward sides. Because of this difference, the correct flow equation under windy conditions should take the form

$$Q = \sum_{i=1}^N C_i (\Delta p_i)^n \quad (2)$$

where i is the variable for the various walls.

As it is neither practical to solve for C_i explicitly from the just-mentioned equation nor possible to conduct all pressurization tests under calm conditions, Eq 2 was not used. Thus, the validity of Eq 1 using "average" outside pressure was checked using data measured under various wind speeds and two wind directions. The calculated C and n values for various wind speeds are shown in Table 3 as well as in Fig. 3. The flow exponent, n , varied between 0.69 and 0.7. Again, to facilitate comparison the exponent, n , was assumed to be constant at 0.69, and C and Q_{50} were recalculated. The results indicate that for wind from the exposed side of the house, northwest, the flow coefficient for a wind speed of 16 km/h is about 4% less than that obtained under calm conditions (1.6 km/h). For wind approaching from the shielded side of the house, southwest, the variation in flow coefficient is less than 5% for wind speeds up to 24 km/h. Assuming that the data obtained under a wind speed of 1.6 km/h are correct, Fig. 3 shows that at wind speeds less than 10 km/h the wind effect is negligible.

TABLE 2—Repeatability test (House No. 1).

Test	C , L/s(Pa) ⁿ	n	Q_{50} , ^a L/s	Correlation Coefficient	C (n fixed) L/s(Pa) ⁿ	n	Q_{50} (n fixed), L/s	Correlation Coefficient
(a) WIND SPEED = 4.8 km/h								
1	19.9	0.697	304	0.9999	20.4	0.690	304	0.9999
2	19.7	0.700	303	0.9999	20.4	0.690	303	0.9999
3	20.4	0.692	305	0.9996	20.5	0.690	305	0.9993
(b) WIND SPEED = 1.6 km/h								
4	21.1	0.688	311	1.000	20.9	0.690	311	0.9999
5	22.0	0.677	311	0.9996	21.0	0.690	312	0.9978
6	22.0	0.678	311	1.000	21.0	0.690	312	0.9994
7	22.0	0.677	311	1.000	21.0	0.690	312	0.9994

^a Q_{50} = air leakage rate at 50 Pa pressure difference.

TABLE 3—Effect of wind on air leakage value (House No. 1).

Test	Wind Direction	Wind Speed, km/h	C , L/s(Pa) ⁿ	n	Q_{50} L/s	Correlation Coefficient	C (n fixed), L/s(Pa) ⁿ	n	Q_{50} (n fixed), L/s	Correlation Coefficient
1	NW	1.6	21.1	0.688	311	1.000	21.0	0.690	311	0.9999
2	NW	4.8	20.4	0.692	305	0.9996	20.5	0.690	305	0.9993
3	NW	16.0	20.4	0.689	302	0.9999	20.3	0.690	302	0.9998
4	SW	9.6	21.2	0.686	311	0.9999	20.9	0.690	311	0.9999
5	SW	12.8	20.4	0.695	309	0.9996	20.8	0.690	309	0.9996
6	SW	12.8	20.6	0.693	310	0.9999	20.8	0.690	309	0.9999
7	SW	24.0	19.8	0.693	298	1.000	20.1	0.690	298	0.9999

FIG. 3—Effect of wind on air leakage, House No. 1.

Results and Discussion

An attempt was made to correlate the seasonal variation of house air leakage with one or other of the parameters (indoor and outdoor humidity ratios, air temperatures, and moisture content of wall framing), which also vary seasonally. In text that follows, the air leakage value at a pressure difference of 50 Pa (Q_{50}) is used to characterize house tightness.

Figures 4 and 5 show the variation of Q_{50} , daily mean outdoor temperature, and indoor and daily mean outdoor humidity ratios with time for Houses Nos. 1 and 2, respectively. The results indicate a seasonal variation in airtightness. The houses were tightest in late summer and fall and leakiest in winter and early spring. In each case the maximum air leakage value was about 20% greater than the minimum value. The results also show that (in general) as the humidity ratios and outdoor temperatures decreased, the air leakage values increased.

Comparing the indoor humidity ratios of the two test houses, it is noteworthy

FIG. 4—Seasonal variation of air leakage, outdoor temperature, and humidity ratio, House No. 1.

FIG. 5—Seasonal variation of air leakage, outdoor temperature, and humidity ratio, House No. 2.

thy that the indoor humidity in House No. 2 was generally lower than that in House No. 1 in winter and higher in summer. This is probably due to differences in both basement moisture gains and airtightness. Because House No. 1 was tighter than House No. 2, its indoor humidity ratio was probably affected less by outdoor conditions.

Figures 6 and 7 show the time variation of moisture content in the wall framing for Houses Nos. 1 and 2, respectively. The air leakage values at 50 Pa also are shown. The moisture readings have been corrected for temperature at the tip of the moisture pin. This was estimated from the thermal resistance values of the wall components and the indoor and outdoor air temperatures. The results indicate that the moisture contents of the walls in both houses were reasonably low (in the range of 8 to 14%), and that a trace of seasonal variation in the moisture content of the wood framing could be detected.

Figure 6 shows that Pin No. 10 measured a higher moisture content than all the other moisture pins, and that its pattern of variation was different from theirs. The reason for this difference is that Pin No. 10 was located on the inside of the polyethylene vapor barrier on the east side of the second floor header, while all other pins were located on the outside of the polyethylene. Moreover, Pin No. 10 was the only one located on the cold side of the wall, as shown in Fig. 1.

Figure 7 shows that Moisture Pins Nos. 6 and 7, located in first-story studs, give slightly higher moisture content values. This could have been due to their

FIG. 6—Seasonal variation of moisture content of wood framing, House No. 1.

FIG. 7—Seasonal variation of moisture content of wood framing, House No. 2.

location (first versus second story) or, more probably, to the absence of a vapor barrier.

It appears that there is a correlation between airtightness and indoor and daily mean outdoor humidity ratio as well as daily mean outdoor temperature. An attempt was made, therefore, to correlate the air leakage value at 50 Pa with these parameters. Various models were tested. The results shown in Table 4 suggest that the best single-parameter model would be a power law expression relating air leakage value and indoor humidity ratio (Fig. 8).

$$Q_{50} = R \cdot (W_i)^\alpha \quad (3)$$

where

Q_{50} = air leakage value at 50 Pa, L/s,

R = dimensional constant, L/s,

W_i = indoor humidity ratio, kg/kg, and

α = exponent.

The values of R and α were determined as 182.6 and -0.11 for House No. 1 and 607.4 and -0.12 for House No. 2. The difference in R is the difference in the air leakage characteristics of the two houses. To facilitate comparison, the air leakage values and indoor humidity ratios of each house were

TABLE 4—Models of air tightness correlation.^a

Model	House No. 1					House No. 2				
	R_1	R_2	R_3	R_4	Correlation Coefficient	R_1	R_2	R_3	R_4	Correlation Coefficient
$Q = R_1$	312.6				0.0	1098.0	...	...	...	0.0
$Q = R_1 + R_2 \cdot (W_i)$	344.4	-4751.0			0.3749	1247.0	-2.08×10^4	...	...	0.7128
$Q = R_1 + R_2 \cdot (W_o)$	324.2	-2097.0			0.2161	1195.0	-1.63×10^4	...	...	0.6018
$Q = R_1 + R_2 \cdot (T_o)$	486.0	-0.6136			0.2207	2643.0	-5.435	...	...	0.6099
$Q = R_1 + R_2 \cdot (\sqrt{T_o})$	657.5	-20.53			0.2220	4184.0	-183.0	...	...	0.6134
$Q = R_1 \cdot (W_i)^{R_2}$	182.3	-0.1067			0.4211	607.4	-0.1172	...	...	0.7763
$Q = R_1 \cdot (W_o)^{R_2}$	270.2	-2.64×10^{-2}			0.2400	772.2	-653×10^{-2}	...	...	0.6467
$Q = R_1 \cdot (T_o)^{R_2}$	6632.0	-0.5415			0.2143	2.54×10^6	-1.372	...	...	0.6074
$Q = R_1 \cdot e^{R_2 \cdot (W_i)}$	345.5	-15.12			0.3656	1252.0	-18.57	...	...	0.7074
$Q = R_1 + R_2 \cdot (W_i) + R_3 \cdot (W_o)$	363.7	-1.07×10^4	3676.0		0.4614	1247.0	-2.08×10^4	-1.674	...	0.7128
$Q = R_1 + R_2 \cdot (W_i) + R_3 \cdot (\sqrt{T_o})$	190.3	-6.25×10^3	9.77		0.3877	437.3	-2.58×10^4	50.19	...	0.7171
$Q = R_1 + R_2 \cdot (W_i) + R_3 \cdot (W_o) + R_4 \cdot (\sqrt{T_o})$	526.9	-1.06×10^4	4.59×10^3	-10.04	0.4696	246.3	-2.49×10^4	-1.88×10^3	61.82	0.7181

^a W_i = indoor humidity ratio, kg/kg; W_o = outdoor humidity ratio, kg/kg; T_o = outdoor temperature, K.

FIG. 8—Relation between air leakage and humidity ratio. Houses Nos. 1 and 2.

normalized using seasonal average values. The relation between the normalized air leakage value and the indoor humidity ratio is

$$\frac{Q_{50}}{\bar{Q}_{50}} = K \cdot \left(\frac{W_i}{\bar{W}_i} \right)^\beta \quad (4)$$

where

Q_{50} = air leakage value at 50 Pa, L/s,

$\bar{Q}_{50}$ = seasonal average of the air leakage value at 50 pa, L/s,

K = constant,

W_i = indoor humidity ratio, kg/kg,

$\bar{W}_i$ = seasonal average of indoor humidity ratio, kg/kg, and

β = exponent.

The values of β for Houses Nos. 1 and 2 were found to be -0.11 and -0.12 , respectively, and of K were 0.995 and 0.986 , respectively. As the β and K values of the two houses were so similar, the data for both houses were

FIG. 9—Relation between normalized air leakage value and humidity ratio.

combined in Fig. 9 in estimating the values of β and K applicable to both. The values of β and K were found to be -0.11 and 0.991 , respectively.

Summary

1. Air leakage values measured in two unoccupied houses show seasonal variation, being lowest in late summer and fall and highest in winter and early spring. The maximum air leakage value is approximately 20% greater than the minimum value for both houses.

2. The results indicate that there is a strong relation between air leakage value and indoor humidity ratio. For the two unoccupied houses, this relation may be expressed by the equation

$$\frac{Q_{50}}{Q_{50}} = 0.991 \left(\frac{W_i}{W_i} \right)^{-0.11}$$

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References

- [1] Warren, P. R. and Webb, B. C., "Ventilation Measurements in Housing," CIBS Symposium, Natural Ventilation by Design, London, 1980, Chartered Institution of Building Services, London.
- [2] Persily, A., "Understanding Air Infiltration in Homes," Report PU/CEES 129, Princeton University, Princeton, NJ, 1982.
- [3] Quirouette, R. L., "The Mark XI Energy Research Project-Design and Construction," Building Research Note 131, National Research Council of Canada, Division of Building Research, Ottawa, Canada, Oct. 1978.
- [4] Shaw, C. Y. and Jones, L., *ASHRAE Transactions*, Vol. 85, Part 1, 1979, pp. 85-95.
- [5] Gumley, S. J., *Journal of Wind Engineering and Industrial Aerodynamics*, Vol. 12, 1983, pp. 189-228.

DISCUSSION

David Saum¹ (written discussion)—What was the 50 Pa air changes per hour (ACH) of the leaky house? What was the percent error in ACH measurements that was not due to seasonal variations?

A. Kim and C. Y. Shaw (authors' closure)—The ACH of the leaky house at 50 Pa was about 8 ACH. The percent error in ACH measurements was less than 2%.

John Shaw² (written discussion)—I assume that the house configuration did not change between winter and summer. Therefore, what is the cause of the winter/summer differences that were observed?

A. Kim and C. Y. Shaw (authors' closure)—It seems that the moisture content of the exterior envelope has some effect on the change in house airtightness.

Donald Colliver³ (written discussion)—It takes a finite amount of time for the materials in the house to pick up/release moisture and therefore to expand or extract. Are your humidity measurements instantaneous measurements or are they an average of prior hours humidity measurements?

A. Kim and C. Y. Shaw (authors' closure)—They are instantaneous measurements.

¹Infiltec, Waynesboro, VA.

²U.S. Department of Energy, Environmental Measurements Laboratory, New York, NY 10014.

³University of Kentucky, Lexington, KY 40546-0075.

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