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Pressurization Testing of Federal Buildings

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ABSTRACT: Seven federal buildings ranging in size from 1900 to 48 000 m^2 of floor area were pressure tested to determine the airtightness of the building envelopes. These tests are part of a larger project to evaluate the thermal integrity of the envelopes of federal buildings. The buildings were pressurized using the air-handling equipment in the buildings and a constant-injection, tracer gas technique to measure the airflow through the fans. In addition, selected windows in some of these buildings were pressure tested separately to determine the airtightness of individual components.

The results of the whole building and component pressurization tests are presented and discussed. In addition, the component pressurization test results are used to estimate the contribution of the windows to the total building air leakage. The results of the building pressurization tests are compared empirically to measured infiltration rates on the same buildings. The large building infiltration model developed by Shaw and Tamura of the National Research Council of Canada is applied to the buildings to predict air infiltration rates induced by weather.

KEY WORDS: air infiltration, air leakage, airtightness, component pressurization, large building infiltration, pressurization testing

Whole building pressurization testing has been used for many years to evaluate the airtightness of single-family homes [*1,2*]. In this test method, a fan induces a large and uniform pressure difference across the building envelope, and the airflow rate required to induce this pressure difference is measured. The rate of airflow required to induce a specific pressure difference between inside and outside serves as a measure of the airtightness of the building shell. Although the test conditions differ considerably from those which normally induce air exchange, pressurization testing provides a quick and quantitative

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measurement of building tightness. The technique has been used to evaluate the airtightness of a small number of large buildings [3,4].

As part of a project to evaluate the thermal integrity of eight federal buildings located throughout the country [5,6], a whole building pressurization test method was developed that employs the air handlers in the building. Most previous pressurization measurements on large buildings involved bringing a high capacity fan to the building as is done on a smaller scale for homes. In addition to using the existing air-handling equipment to pressure test the buildings, these tests employed a constant-injection, tracer gas measurement technique to measure the airflow rate required to induce each inside-outside pressure difference.

The federal buildings discussed in this paper were all constructed in the last ten years, most within the last five, and the occupiable floor areas range from about 1900 to 48 000 m^2. Seven of the eight federal buildings were subjected to whole building pressurization tests. As part of the evaluation of their thermal envelopes of these buildings, pressurization testing also was applied to individual windows to evaluate the airtightness of these components [7].

Test Methods

The buildings were pressure tested in a manner similar to that used in houses [1]. A large airflow into the building induced a large and constant pressure difference across the building envelope. Several different pressure differences were induced, and the flow required to induce each pressure difference was measured.

During the whole building pressurization tests, the building ventilation system was arranged as shown in Fig. 1. The supply fans were operating while all

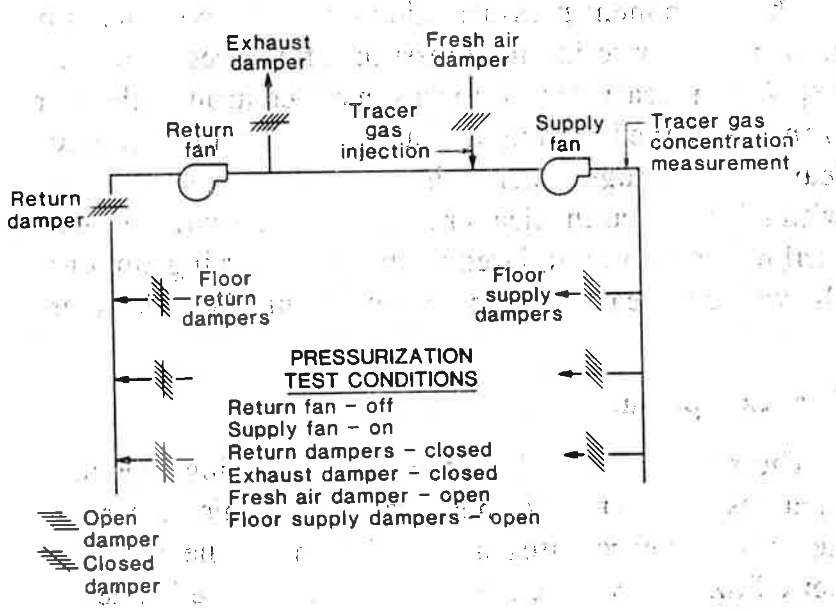

FIG. 1—*Building pressurization testing set-up.*

return and exhaust fans were turned off. All return dampers were closed so that the supply air flowing into the building only could leave the interior through outside doors, windows, and other leakage sites. The airflow through the supply fans was measured using a constant-flow, tracer gas injection scheme [8].

Tracer gas [sulfur hexafluoride (SF_6)] was injected at a constant and known rate into the airstream being brought into the building at a location close to the outside air intake vent. The tracer gas concentration was measured in the supply duct downstream from the injection point. Under conditions of good mixing of the tracer with the airflow, the airflow rate can be determined from the SF_6 injection rate and the measured concentration according to

$$Q = i/c \tag{1}$$

where

Q = airflow rate,
i = tracer gas injection rate, and
c = tracer gas concentration.

The air flow rate Q into the building was modulated either by adjusting the outside air intake dampers or the intake vanes on the centrifugal supply fans. In buildings with more than one large supply fan, individual fans could be turned on or off to further adjust the flow. For each induced flow rate Q, the inside-outside pressure differences was measured at several locations as discussed in following paragraphs. All of the pressurization tests were conducted under relatively mild wind speed conditions (less than 2 m/s) and at outside temperatures between 10 and 20°C in order to avoid weather-induced pressure differences during the tests.

The component pressurization tests were conducted by measuring the airflow necessary to induce pressure differences across individual components [7]. A temporary enclosure was installed around the component being tested from inside the building, and air was blown into this enclosure so that it could leave only through leaks in the window being tested. The airflow was induced with a large vacuum cleaner and measured with an electronic flowmeter. The airflow rate was modulated by diverting varying amounts of the airflow out of the vacuum cleaner at a point upstream of the flowmeter.

Test Equipment

The equipment used in the whole building pressurization measurements includes flowmeters to measure the SF_6 injection rate, an electron capture detector gas chromatograph to determine the SF_6 concentration, and magnetic linkage pressure gages to determine the inside-outside pressure difference. The SF_6 flowmeters were variable-area, float-type rotameters equipped with a control valve to adjust the SF_6 injection rate. Each flowmeter was individually calibrated for SF_6 by the manufacturer within an accuracy of ±1% of full scale. The SF_6 concentration downstream of the injection was measured with the same system used in the tracer gas measurements of air infiltration rates of these buildings [6].

The gas chromatograph/electron capture detector was calibrated within ±3% in the range of 10 to 250 ppb. The inside-outside pressure differences induced during the pressurization tests were measured with magnetic linkage pressure gages that were individually calibrated against an inclined manometer. The pressure gages were accurate within roughly ±0.6 Pa. The induced pressure differences across the building shell were measured at several locations in each building. The same pressure gages were used in the pressure tests of individual components. The flowmeters used in these tests were electronic devices utilizing hot-wire anemometer principles and had an accuracy of ±2%.

Details of Whole Building Pressurization

The following section briefly describes the test buildings and outlines the details of the whole building pressurization measurement in each building, including location and number of pressure difference measurements, fan operation, and pressure differences achieved.

Anchorage

The federal building in Anchorage is a 48 470-m² building divided into six connected modules. The modules vary in height from two to six stories. The building has six supply fans of varying capacities, one for each module. All of the modules are open to each other, and the airflow from any of the six fans pressurizes the entire building. All six fans were used in the pressurization tests, and, therefore, SF_6 was injected in and sampled from six locations in the building.

Four different inside-outside pressure differences were induced in this building, ranging from 14 to 38 Pa. For the lowest pressure difference, only four of the six fans were operated. The next highest pressure difference employed five of the fans, and the other pressure differences were obtained using all six fans. The pressure differences were measured at two ends of the building on the ground floor and at the fifth floor of one of the modules. The variation in pressure difference among these three locations was only ±1 Pa.

Ann Arbor

The federal building in Ann Arbor is a 5270-m², four-story building with a terraced roof construction; that is, each story has less floor area than the story below. There is a post office in part of the lower two floors which has its own air-handling system. The lobby also has a separate air handler. The rest of the building is served by a main air handler located on the third floor. This building was pressurized using only the main supply fan. Four inside-outside pressure differences were induced, ranging from about 10 to 60 Pa. The pressure differences were measured at two locations on the ground floor and on the third floor.

The post office on the first floor, which occupies about 16% of the total building volume, is not served by the fan used in the pressurization test. Although there is not a great deal of communication between the main volume and the post office, a significant pressure difference did develop between the post office and the outside during these tests. The post office-outside pressure difference was about one half of the main volume-outside pressure difference. In analyzing the test data, the total building volume (including the post office) was assumed to be involved in the test.

Columbia

The federal building in Columbia is a 21 600-m^2, 15-story building. It also has a two-story courthouse attached through an underground passageway, but only the 15-story tower was pressure tested. The building has two large air-handling systems located in a mechanical room on the 15th floor. The first floor, basement, and lobby are served by two air handlers located in the basement. Although two large fans are in this building, only one fan running at partial capacity was needed to induce inside-outside pressures from 26 to 60 Pa. The pressure difference was measured at the odd-numbered floors from 3 to 13.

Huron

The federal building in Huron is a 6910-m^2 building with four stories. Two main supply fans in a mechanical penthouse serve two zones which communicate freely. Both fans were used to pressurize the building for some of the data points, and only one for the others. The induced pressure differences ranged from 17 to 50 Pa and were measured at the two locations on each of the four floors.

Norfolk

The Norfolk federal building is an eight-story building with a floor area of 18 570 m^2. The building has one large supply fan in the mechanical penthouse, which was sufficient to induce inside-outside pressure differences from 8 to 30 Pa. These pressure differences were measured on each floor of the building.

Pittsfield

This two-story building has a floor area of 1860 m^2 and a separate fan for each story. The locations for communication between the floors include two stairwells, an elevator shaft, and other smaller leakage sites. It was not obvious that we would be able to develop the same pressure difference on the two floors since each floor is served by a separate fan; however, we were able to develop essentially identical pressure differences on each floor. These pressure differences were measured at two locations on each floor and ranged from 25 to almost 100 Pa.

Springfield

The Springfield federal building is a 14 560-m^2, five-story building. Two large supply fans located in a penthouse serve the north and south zones, respectively. On the upper floors, the two zones are connected through passageways. On the first two floors, both zones open onto an atrium. During the pressurization test, all doors between the zones and into the atrium were open. The north zone fan was used to obtain pressure differences of 10 and 14 Pa, while both fans were used to induce a 23-Pa pressure difference. The inside-outside pressure differences were measured on all five floors of the north zone and on the second and fourth floors of the south zone.

Whole Building Pressurization Results

The following section presents the results of the pressurization tests on the seven federal buildings and some analysis of these data. In addition, the airtightness values of these buildings are compared to measurements made in several Canadian office buildings.

The test data for each building is in the form of several combinations of airflow Q and inside-outside pressure difference Δp. For each building, the Q and Δp values are fit to a curve of the form

$$Q = C\Delta p^n \qquad (2)$$

Table 1 presents equations for the curve fits for each of the seven buildings and the ranges of pressure differences that were achieved. Five of the seven exponents n are, as expected, in the approximate range of ½ to 1. The exponent for Springfield is quite large due to difficulties in maintaining the low flow rates at a constant level, however the flow at 23 Pa was repeatable and is believed to be accurate. There are many ways to quantify the results of pressurization tests. The test results for homes are often presented in terms of the induced flow rate at an inside-outside pressure difference of 50 Pa. The ranges of measured pressure differences in Table 1 are variable over the seven

TABLE 1—*Curve fits to pressurization data for the federal buildings and the pressure measurement range.*

Building	Curve Fit[a]	Range of Measured Pressure Difference, Pa
Anchorage	$Q = (2.14 \times 10^4)\Delta p^{0.61}$	14 to 38
Ann Arbor	$Q = (3.17 \times 10^3)\Delta p^{0.67}$	11 to 61
Columbia	$Q = (1.83 \times 10^4)\Delta p^{0.47}$	26 to 60
Huron	$Q = (1.58 \times 10^3)\Delta p^{0.64}$	17 to 50
Norfolk	$Q = (8.08 \times 10^3)\Delta p^{0.74}$	8 to 30
Pittsfield	$Q = (2.55 \times 10^3)\Delta p^{0.36}$	25 to 97
Springfield	$Q = (9.90 \times 10^1)\Delta p^{2.09}$	10 to 23

[a] Q is in units of m^3/h, and Δp is in Pa.

buildings, but they all have measurements at roughly 25 Pa. In addition, the measurements close to 25 Pa were repeatable in the buildings that had flow exponents out of the range from ½ to 1. Therefore, the flow at 25 Pa as determined with Eq 2 is used to compare the airtightness of these buildings. By using the 25-Pa flow rates as a measure of airtightness, we need not compare values extrapolated out of the range of measurements.

The 25-Pa flow rates in units of building volumes or air changes per hour (ACH) and $m^3/h/m^2$ of building envelope (wall and roof) area are presented in Table 2. The flows are normalized by envelope area to provide a measure of the construction quality of the building shells in terms of airtightness. Note that these flow rates in ACH are significantly larger than the infiltration rates induced by weather. The 50-Pa exchange rates of the buildings are about 1.5 times the 25-Pa flows shown in the table (assuming $n = 0.65$ in Eq 2) and are low compared to those measured in homes. U.S. homes generally range from about 5 to greater than 20 ACH at 50 Pa [*9*]. Swedish and Canadian homes are being built with 50-Pa flow rates of less than 2 ACH [*10,11*]. Thus, the 50-Pa flow rates of these federal buildings correspond to very tight houses.

TABLE 2—*Pressurization test results in terms of 25-Pa flow rates.*

Building	Flow at 25 Pa, Volumes/h	Flow at 25 Pa, $m^3/h/m^2$ of Envelope Area
Anchorage	0.80	6.7
Ann Arbor	0.86	4.1
Columbia	0.67	6.0
Huron	0.45	1.9
Norfolk	1.45	7.2
Pittsfield	0.95	3.5
Springfield	1.43	9.2

In comparing the pressurization test results of the federal buildings to each other and to residential buildings, the important factor of surface to volume ratio arises. Figure 2 shows the surface to volume ratios S/V in m^2/m^3 for the federal buildings and two sample houses. The one-story house is assumed to have a 110-m^2 square floor area and 2.5-m ceilings. The two-story home also has a square floor plan with roughly 100 m^2 on each floor and a 5-m building height. We see in the figure that the large sizes of the federal buildings lead to values of S/V that are about one third of those associated with homes.

Figure 3 shows the 25-Pa flows listed in Table 2. The vertical scale on the left shows the 25-Pa flows in ACH for the seven federal buildings and the two sample houses shown in Fig. 2 (2.0 ACH at 50 Pa—very tight). The vertical scale on the right shows the 25-Pa flows in $m^3/h/m^2$ of envelope area. We see that in moving from ACH to $m^3/h/m^2$ the ranking of the buildings' tightness changes significantly. Also, the spread in the leakage values using the second measure is larger than the spread in ACH. The most significant change occurs for the sample houses which are almost the leakiest in terms of ACH but almost the tightest in terms of $m^3/h/m^2$ of envelope area. Thus, while the federal buildings appear to be quite tight in terms of ACH compared to houses, the airtightness per unit of envelope area is not as impressive.

The airtightness of the federal buildings in units of $m^3/h/m^2$ is worse if one considers the fact that the roofs are of low-slope, built-up design, constructed to be impervious to both water and air. Therefore, it might be more appropri-

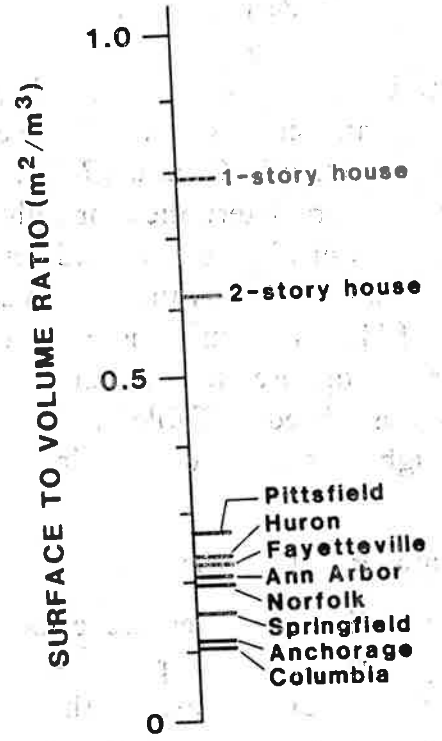

FIG. 2—*Surface to volume ratios of federal buildings and houses.*

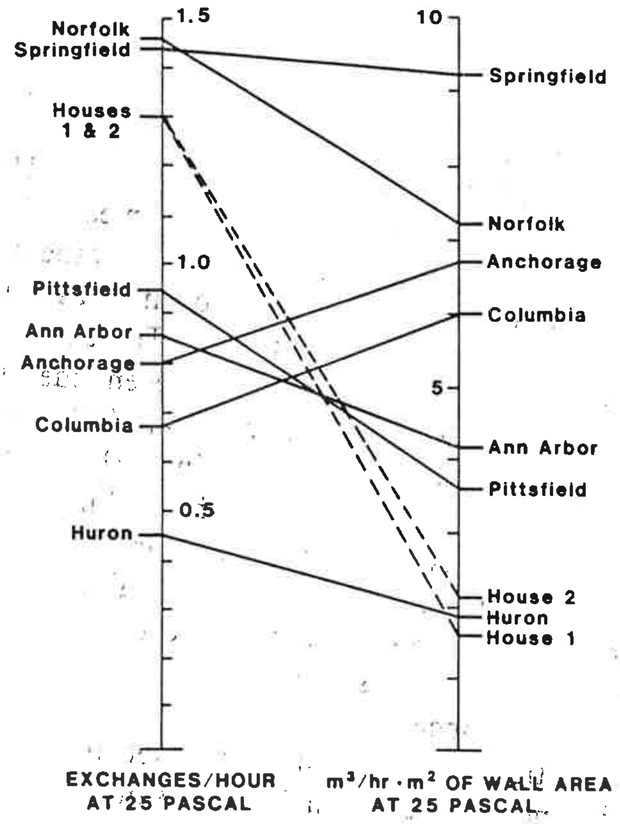

FIG. 3—*Results of pressurization test results.*

ate to normalize the 25-Pa flows by the wall area alone instead of using the total envelope area, including the roof. Normalizing the leakage rate with the wall area will lead to higher values of the 25-Pa flows in $m^3/h/m^2$.

These values of induced flow per unit envelope area may be compared to values obtained previously in Canada [*3, 12*]. In the Canadian work, building leakage coefficients were determined for eight office buildings with construction dates ranging from 1964 to 1974 and heights from 9 to 25 stories. Seven of the eight Canadian buildings ranged from 2.4 to 6.2 $m^3/h/m^2$ at 25 Pa, and one had a value of 11.0 $m^3/h/m^2$. These Canadian values are flows per square metre of wall area as opposed to envelope area as used in Table 2. Comparing these values to those listed in Table 2, we see that the federal buildings are comparable in tightness to these Canadian buildings.

Results of Component Pressurization

Windows were individually pressure tested in six of the eight buildings. Because of the large variation in component size and frame arrangements, it was difficult to seal the test apparatus. For these reasons, only a small number of components were tested and the results should be considered preliminary. The results are expressed in units of L/s of induced air flow at 75 Pa/m of crack length for windows and include both frame and sash leakage. The American Society of Heating, Refrigerating, and Air-Conditioning Engineers' "Handbook of Fundamentals" [*13*] lists a window leakage standard of 0.77 L/s/m (sash leakage only), varying somewhat with window type. Table 3 shows the results of the window pressurization tests for the six buildings tested. In addition, this table lists samples of window leakage measurements from the literature [*4,14,15*].

In Table 3 we see a wide variation in the measured window leakage rates, even for the relatively small number of windows tested. The operable windows in the Columbia building are very leaky, along with some cracks around windows in the Fayetteville buildings through which daylight is visible. Most of the other windows tested are somewhat leakier than the standard of 0.77 L/s/m. As mentioned earlier, the standard applies to sash leakage only, while our measurements include both sash and frame leakage. The field tests of many new residential windows (sash and frame leakage) yielded an average value very close to this standard [*14*]. The office building from Ref. *15*, built in the mid-1960s, has very leaky windows. Several windows from Canadian supermarkets and shopping centers [*4*] had leakage values comparable to those in the office buildings discussed in this report. Most of the windows tested in the federal buildings and those in the literature are leakier than the 0.77 L/s/m standard.

Window leakage rates can be combined with the total window crack length to estimate the net window leakage in the buildings. These window leakage values are compared with the total building leakage from the whole building pressurization tests to determine the fraction of total building leakage associ-

TABLE 3—*Results of window pressurization tests.*

Building	Window	Air Flow Rates at 75 Pa, L/s/m
Anchorage	inoperable	3.22, 0.67, 1.09, 0.89, 0.98
Ann Arbor	inoperable	0.91, 1.04
Columbia	operable	4.41, 5.56, 3.61, 3.22
Fayetteville	inoperable	0.44, 0.32
	window cracks[a]	7.40, 5.96
Norfolk	inoperable	1.23, 1.56, 1.47
Pittsfield	operable	1.30, 0.41
Past Measurements		**Air Flow Rates at 75 Pa, L/s/m**
Window leakage standard (Ref *11*)		0.77
Residential windows (Ref *12*)		mean value of 0.81
Office building (Ref *13*)		1.36, 3.54, 3.55, 3.56, 4.13, 4.97, 5.08, 10.81, 11.94, 16.04
Supermarkets and shopping malls (Ref *14*)		0.20, 0.20, 0.55, 0.60, 1.10, 1.10, 1.20, 2.40

[a]These are cracks around particularly leaky windows.

ated with windows. This fraction is generally around 20% for houses [9]. Since only a small number of windows were tested in the buildings, the measured leakage values may not be representative of the building average. Therefore, in calculating the fraction of building leakage associated with windows, the standard of 0.77 L/s/m is used along with two and three times this value.

In addition, the average of the measured values is used when available. Table 4 presents the results of these calculations of the fraction of total building leakage attributable to windows at 25 Pa. The total building leakage is based on the equations in Table 1. Although it is not entirely clear as to which window leakage value is appropriate for each building, the windows account for about 10 to 20% of the total building leakage at 25 Pa. This percentage is similar to the fraction of leakage associated with windows in homes.

TABLE 4—*Fraction of total building leakage associated with windows.*

Building		Window Leakage at 25 Pa[a], L/s/m	Fraction of Building Associated with Windows, %
Anchorage		0.36	8.8
		0.72	17.6
		1.08	26.4
	Measured[b]	0.55	13.4
Ann Arbor		0.36	6.2
		0.72	12.4
		1.08	18.6
	Measured[b]	0.53	9.1
Columbia		0.36	6.4
		0.72	12.8
		1.08	19.2
	Measured[b]	1.74	30.9
Huron		0.36	13.3
		0.72	26.6
		1.08	39.9
Norfolk		0.36	6.4
		0.72	12.8
		1.08	19.2
	Measured[b]	0.68	12.1
Pittsfield		0.36	8.3
		0.72	16.6
		1.08	24.9
	Measured[b]	0.43	10.0
Springfield		0.36	7.1
		0.72	14.2
		1.08	21.3

[a] 0.36, 0.72, and 1.08 L/s/m correspond to 1, 2, and 3 times the standard of 0.77 L/s/m at 75 Pa.

[b] This value is the average for all the windows tested in this building.

The Relation of Pressurization Test Results to Air Infiltration Rates

While the pressurization tests are useful for comparing buildings to each other and to airtightness standards, the question remains of how the pressurization test results are related to air infiltration rates induced by weather. This question has been studied extensively in houses [*9*] and less so in large buildings [*16-20*]. The existence of both whole building pressurization test results and air infiltration measurements for the seven federal buildings allows a comparison of the two measurements. Figure 4 is a plot which compares tracer gas measurements of infiltration rates in the buildings to the 25-Pa flow rates in ACH from the pressurization tests. The infiltration rates are measurements of the leakage induced by weather, and the rates for each building correspond to approximately the same weather conditions. The correlation between these two variables is as strong as it is for homes, but the slope of infiltration rate versus pressurization flow is steeper for these large buildings than it is for houses. Such a simple relation between pressurization and infiltration neglects the dependence of infiltration on weather conditions. A more complex model of the pressurization/infiltration relation in large buildings which accounts for weather effects is discussed in paragraphs that follow.

Shaw and Tamura, of the National Research Council of Canada, have developed a model which predicts infiltration in large buildings [*16*]. This model consists of predictive equations for infiltration based on a computer model building and wind tunnel tests of a model of a 40-story building. The buildings considered in the work of Shaw and Tamura are generally taller than the federal buildings discussed in this report. Other large building infiltration models exist but were not applied to this data [*21*].

This large building model has separate predictive equations for wind- and

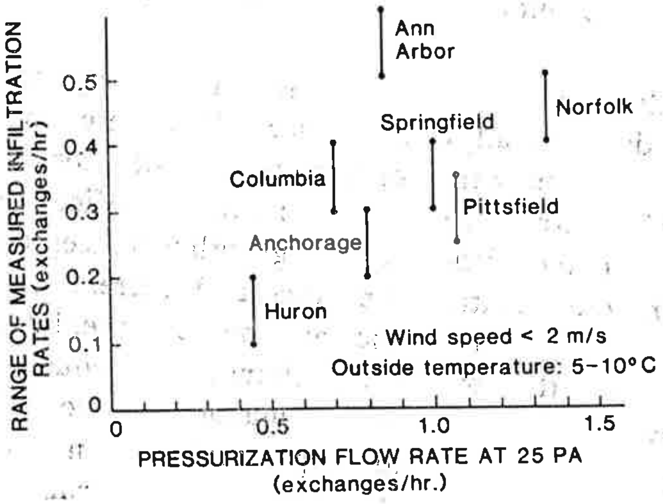

FIG. 4—*Weather-induced infiltration rates versus pressurization test results.*

temperature-induced infiltration. The wind-induced infiltration Q_w is expressed as

$$Q_w = \alpha C' \mathrm{LH}(\rho u^2 C_p/2)^n \tag{3}$$

where

α = a factor to account for wind directions other than normal to the longest building wall, which is of length L,
H = the building height,
C' and n = the building flow coefficient and exponent from Eq 2,
C' = the leakage coefficient of the walls, determined by dividing the value of C in Eq 2 by the building wall area,
ρ = the air density,
u = the wind speed, and
C_p = the wind pressure coefficient for the windward wall.

The stack-induced infiltration is expressed as

$$Q_s = C'S[3464\gamma(\Delta T/T_{\text{in}}T_{\text{out}})]^n[(\beta H)^{n+1}/n + 1] \tag{4}$$

where

S = the building perimeter,
ΔT = the inside-outside temperature difference,
β = the height of the neutral pressure level divided by the building height, and
γ = a thermal draft coefficient that accounts for the extent of vertical communication in the building.

A value of $\gamma = 0.0$ corresponds to no openings between floors, and 1.0 corresponds to a totally open interior. While there is no straightforward technique for determining the appropriate value of γ for an individual building, Shaw and Tamura suggest a value of 0.80 for office buildings, and this value was used for all the federal buildings with two exceptions. In Anchorage, all floors open onto a central lobby area, and, therefore, a value of 0.95 was used for the thermal draft coefficient. The Springfield building has a vertically open atrium on the front of the building, and a value of 0.87 was used. The neutral pressure level is assumed to equal one half the building height in all the buildings. The wind Q_w and temperature difference Q_s infiltration rates are combined to yield the net infiltration rate according to

$$Q_{ws} = \max(Q_w, Q_s)\{1 + 0.24[(\min Q_w, Q_s)/\max(Q_w, Q_s)]^{3.3}\} \tag{5}$$

The max and min functions correspond to the maximum or minimum value in the brackets.

Table 5 compares the measurements of infiltration in the seven buildings to predicted rates from the Shaw-Tamura model. The predictions are made for the same weather conditions as the measurements, a wind speed of 2 m/s and an outside temperature of 7°C. In all buildings, the predictions are much lower than the measurements, especially in Ann Arbor and Springfield. The Springfield predictions are low because the curve fit to the building's pressurization data (Eq 2) has a large value for the flow exponent ($n = 2.09$) and a correspondingly low value for the flow coefficient. This low flow coefficient value leads to low predicted infiltration rates. If, instead, we assume the exponent is equal to 0.65 and use the 25-Pa flow rate to get a new flow coefficient, these predictions are more accurate. These second Springfield predictions correspond to the Springfield-Adjusted values in Table 5.

This result of generally low predictions compared to measurements also was found by Hunt and Treado [*17*] in an eleven-story office building. They attributed the larger measured infiltration rates to toilet exhausts and other forced ventilation. However, in the seven federal buildings discussed here, the toilet, elevator, and all other exhausts were off during the infiltration measurements.

It is not clear why the predicted infiltration rates are generally so much lower than the measurements. One potential explanation for the disagreement is the existence of open elevator shafts in the buildings, which are quite susceptible to stack-induced infiltration. Another reason may have to do with the fact that during the infiltration measurement the HVAC system was running to keep the interior air well mixed. Even though the outside air supply and exhaust dampers were closed, they could have leaked. However, in Anchorage and Pittsfield, infiltration measurements were made with these

TABLE 5—*Predictions of the Shaw-Tamura large building model.*

Building	Measured Infiltration[a] Exchanges/h (Wind Speed < 2 m/s; $T_{out} \sim 7°C$)	Predicted Infiltration, Exchanges/h ($u = 2$ m/s; $T_{out} = 7°C$)
Anchorage	0.25	0.07
Ann Arbor	0.55	0.02
Columbia	0.35	0.13
Huron	0.15	0.03
Norfolk	0.50	0.15
Pittsfield	0.35	0.14
Springfield	0.40	0.01
Springfield-Adjusted	. . .	0.25

[a]Representative infiltration rate for specified weather conditions.

dampers sealed with plastic, and the measured rates were no different from the rates when the dampers were closed but not sealed. Another factor to consider is leakage due to local pressurization when the fans are running. All the buildings use ceiling plenums as return ducts, and leakage in the outside walls surrounding this plenum space will lead to the intake of outside air through these leaks and increased air exchange rates. Such plenum leaks were seen in Fayetteville, and their existence is suspected in other buildings. However, it is difficult to estimate the contribution of such leakage to the net air exchange of the building.

Another reason for the disagreement between the model predictions and the measurements may be that the model was developed for taller buildings (about 40 stories) than the federal buildings (from 2 to 15 stories). Another factor could be that the wind speed measurements at the federal buildings were made roughly 5 m above the roof, while the model calls for free stream wind speed at the building height. However, predicted infiltration rates for higher wind speeds do not exhibit significantly larger errors than the 2 m/s predictions shown in Table 5, and, therefore, wind speed measurement errors do not appear a likely source of measurement error.

Conclusions

As part of a project designed to evaluate the thermal integrity of the building envelopes of eight federal buildings, the airtightness of the envelopes were evaluated using pressurization techniques. Seven of the buildings were subjected to whole building pressurization tests, and the 25-Pa flow rates were found to vary between 0.45 and 1.45 ACH. The airtightness levels of these large buildings correspond to tight houses in terms of ACH. The airtightness of the buildings in units of flow per envelope area range from 1.9 to 9.2 $m^3/h/m^2$ and is higher than for tight houses due to the low surface to volume ratios of the federal buildings. Therefore, the airtightness in ACH from the pressurization tests provides a misleading indication of the federal buildings' airtightness.

A small number of windows in six of the buildings were pressure tested individually, and, while a wide range of leakiness levels was evident, they were generally leakier than a common window tightness standard. The fraction of total building leakage associated with windows was calculated to be about 10 to 20%, a percentage similar to that found in houses. The large building infiltration model of Shaw and Tamura was applied to the seven buildings which were pressure tested, and the predictions were lower than the infiltration rates measured with tracer gas.

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