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Field Studies of the Air Tightness of Residential Buildings

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ABSTRACT: The heat loss (gain) due to air leakage becomes increasingly significant as more thermal insulation material or systems are added to a house to reduce the conductive heat loss (gain). It is quite clear that a standard energy procedure is needed whereby the housing industry and the energy agencies can practically evaluate or estimate the energy demand due to air leakage or infiltration for a new residential structure or a reinsulated existing house.

The two major techniques that have been utilized more recently to either quantify the air infiltration rate or characterize the air leakage of a house are the "tracer gas technique" and the "induced pressure technique." The former can provide the absoluted air infiltration rate under various ambient conditions; whereas the latter can give an estimate on the relative air tightness of a house. Each one has its advantages or drawbacks in practice. However, they do compliment each other in situations where a large number of houses need to be measured.

A typical case is presented here to show that both techniques were applied to the same group of houses. The measured air infiltration rates from the tracer gas technique, and equivalent air leakage area from the induced pressure technique do show good agreement in concluding the air tightness of these houses. The existence of such air infiltration rate differences was also detected through the energy consumption test conducted among the same group. Some of the practical aspects of these two approaches are also presented.

KEY WORDS: air infiltration, tracer gas method, induced pressure method, air leakage, residential buildings, measurements

The importance of air leakage or infiltration rate on the overall energy consumption of a building has been recognized by energy related governmental officials, code authorities, and the construction trade. Also recognized are, first, the need to have a standard way of measuring the air leakage or infiltration rate; second, the need to quantify the leakage per-

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formance of not just components such as windows, and doors, but the exterior walls, ceilings, floors, and the whole structure. With such information, one can compare the air tightness among buildings.

The tracer gas dilution method and the induced pressure technique have been the two most common methods of measuring the infiltration or air leakage rate of a structure. The tracer gas technique is a direct way of measuring the air infiltration rate of a structure under the variables of wind and indoor-outdoor temperature difference. The induced pressure technique is an indirect method in that it measures the total air leakage of a structure under a net pressure difference. The result indicates the air tightness of the structure, which can relate to the air infiltration rate under the same pressure difference.

Four test houses were built during 1974 near Columbus, Ohio. These houses are side by side, identical in layout and construction, except the exterior opaque wall systems. These houses were unoccupied, and heated by an electric, forced air furnace. All four houses were instrumented and monitored by the research team from Ohio State University, headed by C. F. Sepsy.

One of the goals of this testing program was the measurement of air infiltration rate or air leakage. Both the tracer gas dilution method and the induced pressure method were used at different times for this purpose. The results of these two approaches are compared, and the experiences related to each application are discussed.

Description of the Test Houses

Four two-story, four-bedroom houses were constructed by the same crew, following the same procedure. Doors and windows have no special air infiltration treatment other than caulking and weather stripping, commonly done by a builder. The construction details of these four houses are listed in Table 1.

Tracer Dilution Method

The experiment was conducted with an electron capture detector using sulfur hexafluoride (SF_6), as a tracer gas. The concentration of such tracer gas can be detected in the range of 5 to 65 ppb.

The tracer gas analyzer used was fully automated and was designed to automatically measure and record the concentration level of the tracer gas. It was situated in the basement, near the heating furnace.

The furnace fan was turned on in order to continuously mix the air within the house. The tracer gas was introduced into the supply air duct at fixed time intervals. The concentration of the tracer gas was continuously

TABLE 1—*Construction details.*

House No.	1	2	3	4
Location	far west building	...	...	far east building
Orientation	due north	due north	due north	due north
Color of aluminum siding	slate blue	jade green	pearl gray	butternut
Stud frame[a] sidewalls	1/2 in. extruded polystyrene foam (experimental product)	1 in. extruded polystyrene foam (experimental product)	1/2 in. fiberboard	1 in. extruded polystyrene foam
Interior wall insulation	3 1/2 in. R-11 stapled fiberglass asphalt (impregnated) kraft paper vapor seal	none asphalt (impregnated) kraft paper vapor seal	3 1/2 in. R-11 stapled fiberglass asphalt (impregnated) kraft paper vapor seal	3 1/2 R-11 stapled fiberglass asphalt (impregnated) kraft paper vapor seal

[a] 1 in. = 25.4 mm.

monitored at the return air duct. The decay of the concentration level of the tracer gas over the same time interval was then used to determine the instantaneous air infiltration rate.

The meteorological variables, such as air temperature, wind velocity, and direction were recorded at a nearby weather station. In order to have relatively wide ranges of wind velocity and air temperature, the tracer gas analyzer stayed in each house for at least three days (72 h). One set of measurements were made for Houses 1 and 3. Two sets of measurements were made for Houses 2 and 4—one for the attic, trap door open; and one for the attic, trap door closed.

The infiltration data were analyzed with the recorded wind velocities and temperature differences. Several mathematical models were developed to correlate the wind velocities and the temperature differences. The model outlined next yields the best fit (according to linear regression used), to the data obtained (InF is in air changes per hour)

$$\text{InF} = A + B\,(\Delta T) + C(V)^2$$

where

- A = intercept,
- B = temperature coefficient,
- C = velocity coefficient,
- ΔT = air temperature difference between indoor and outdoor (deg F), and
- V = the wind velocity (kilometre (mile) per hour).

In order to demonstrate the functional relationship between infiltration rate and temperature or wind velocity, two figures were prepared. First, the infiltration data of wind velocity less than 3.2 km/h (2 mph) were plotted against the temperature difference, as shown in Fig. 1. One can detect the linear relationship with the temperature difference, and the second power relationship with the wind velocity, Fig. 2.

Table 2 lists the results of the most accurate infiltration models for these four houses. These models generated two sets of curves in Fig. 3—one set for 0°C (0°F) temperature difference, and another for 22.2°C (40°F). It appears from Fig. 3 that Houses 1, 2, and 4 perform very close together, while House 3 does show a larger infiltration rate when the wind velocity is over 16 km/h (10 mph). However, at low wind velocity and low temperature difference, the infiltration rates are very close to each other.

Also, if the attic trap door were open, then the infiltration rates of Houses 2 and 4 approach that of House 3. Note also the infiltration data for House 3 did not exceed 17.7 km/h (11 mph). The dotted line indicates only the extrapolated values from the model.

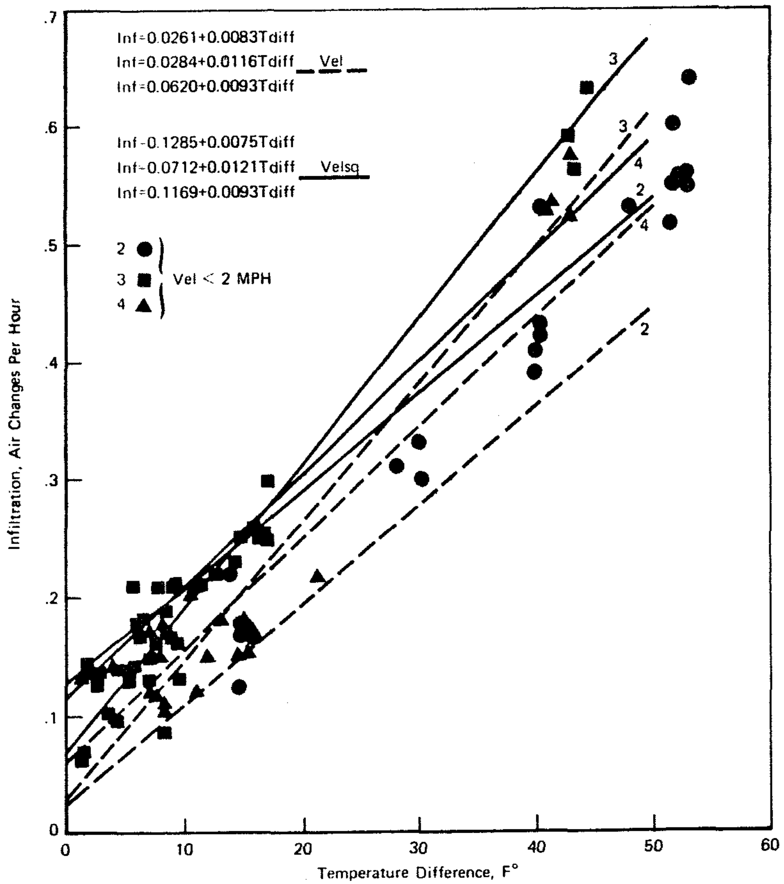

FIG. 1—*Isolated temperature difference dependence.*

Induced Pressure Method

Two of the four houses (No. 3 and 4) were subjected to the induced pressure method for air leakage. The major piece of equipment involved were a centrifugal blower, rated as 1.10 m^3/s (2300 ft^3/min) at 68.5 mm (2½ in.) of water pressure; pitot tube assembly; manometers to measure pressure differentials; connecting ducts; and damper. The duct work was made flexible so that both positive and negative pressure can be induced for the same building envelope. The whole assembly can be moved around in a van truck.

It was June 1976 when this air leakage test assembly was set up, and it took only a half day to finish the testing for both houses. The temperature differential between indoor and outdoor was within 3°C (5°F), and the wind velocity was below 8 km/h (5 mph). The data were found quite reproducible as the same procedure was repeated twice for each house.

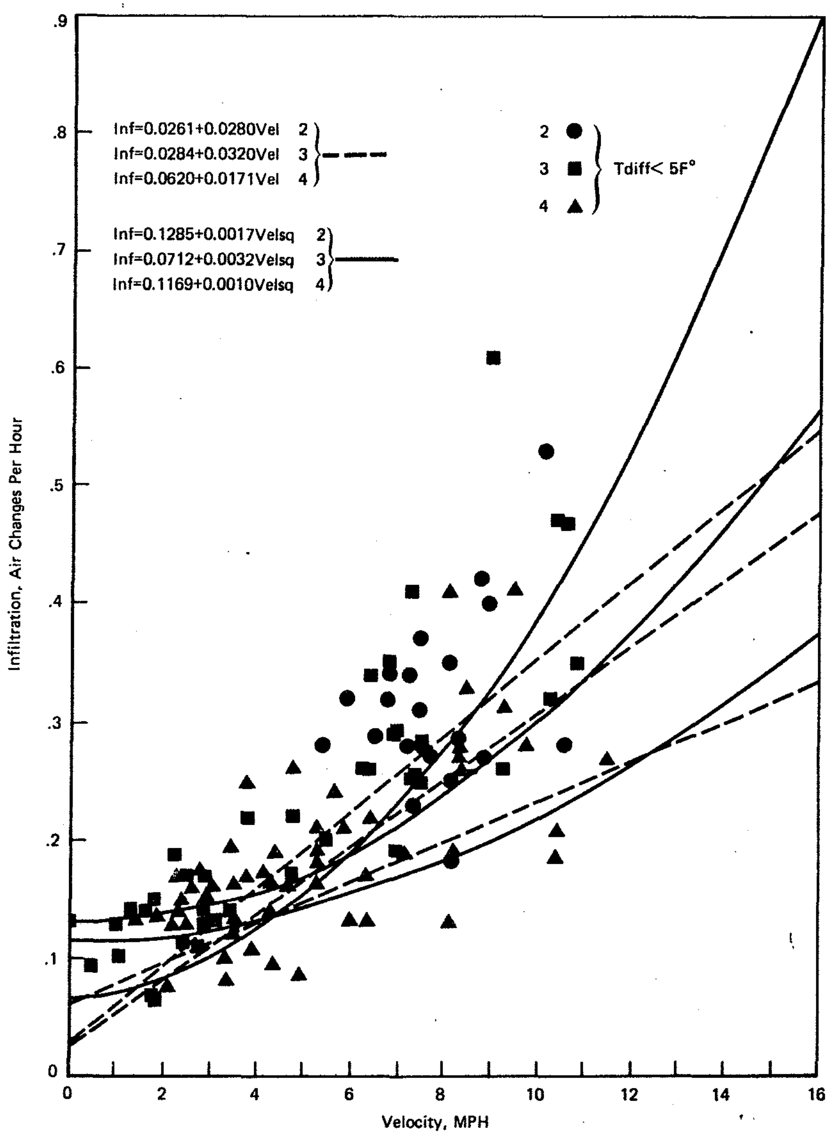

FIG. 2—*Isolated velocity dependence.*

TABLE 2—*Infiltration models for Dow houses.*

House	*A* Intercept	*B* *T*Diff Coefficient	*C* Velsq Coefficient
1	0.0650	0.0095	0.0018
2 (door open)	0.1285	0.0079	0.0026
2 (door close)	0.1285	0.0075	0.0017
3	0.0712	0.0121	0.0032
4 (door open)	0.1169	0.0183	0.0005
4 (door close)	0.1169	0.0093	0.0010

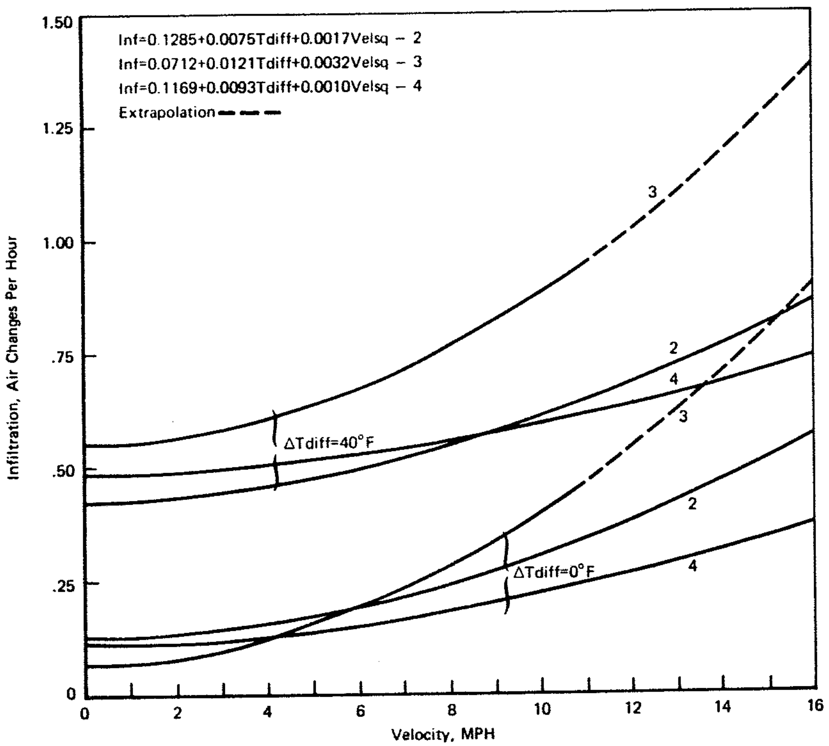

FIG. 3—*Infiltration models of form (Inf* = A + B T*diff* + C*Velsq).*

The air flow rate, Q, as measured through the pitot tube assembly, is proportional to the overall leakage area, and the static pressure difference

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

From the data of Q and ΔP, a curve can be constructed for each house. By comparing such curves, one can have a reasonably good idea on their relative tightness. For instance

$$\frac{Q_1}{Q_2} = \frac{C(A_1)(\Delta P)^n}{C(A_2)(\Delta P)^n} = \frac{(A_1)}{(A_2)}$$

Figure 4 shows the curves of air flow rate versus pressure differential for both houses in the pressure mode. Figure 5 shows the same curves in the vacuum mode. Judging by the curves, House 4 is appreciably tighter than House 3, which agrees with the results of the tracer gas tests described previously.

If Figure 3 is reexamined, with wind velocity at 16 km/h (10 mph) and a temperature difference of 22.2°C (40°F), the air infiltration rate difference is about 0.275 air change per hour, which represents an air flow rate difference of 187 m^3/h 6600 ft^3/h (total living space of the test house is about 679 m^3 (24 000 ft^3), including the basement).

From the air leakage curves of Figs. 4 and 5, the average leakage rate difference under 2.5 mm (0.1 in.) of water pressure difference is about 0.17 m^3/s (360 ft^3/min), which is 6054 m^3/h (21 600 ft^3/h). If one accepts the assumption that a 16 km/h (10 mph) wind and 22.2°C (40°F) indoor and outdoor temperature difference would produce a pressure difference about 0.1 in. of water, then a relationship can be drawn between the two air leakage test methods applied to the same test houses. That is, the air infiltration rate *difference* as tested by the tracer gas method is about one third of the air leakage rate difference as tested by the induced pressure technique under similar pressure difference. This is only a preliminary step toward correlating the results of these two methods.

One of the reasons for this discrepancy is that in a real case not all leakage areas of a house are available for air intake or outlet at the same time. The pressure envelope developed under real conditions will not be characterized by uniform pressure. In fact, most likely, part of the house is under positive pressure (windward), and other parts under negative pressure (leeward), or even no pressure (neutral zone). The house configuration, wind direction, and thermal stack effect all play important parts of forming the pressure distribution in a house. Perhaps it is not totally unreasonable to expect that one third of the air leakage area as found through the induced pressure technique is for air intake, one third

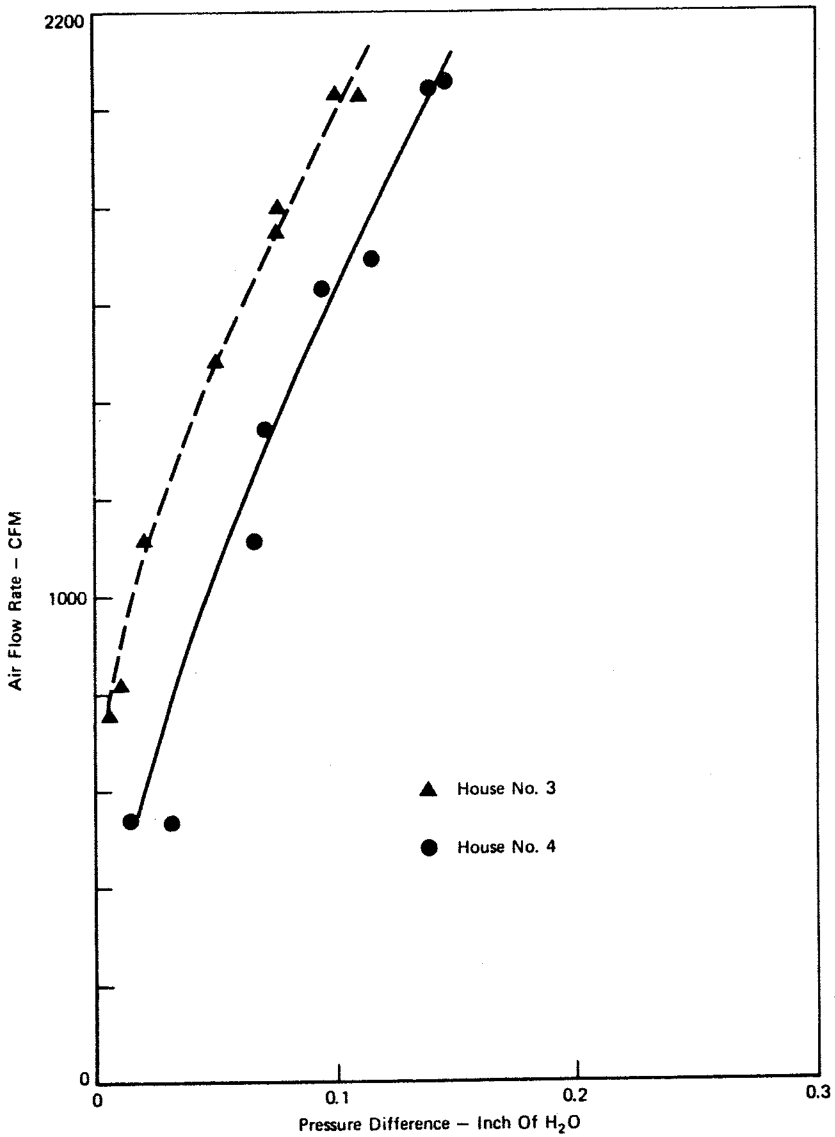

FIG. 4—*Induced pressure test (pressure mode).*

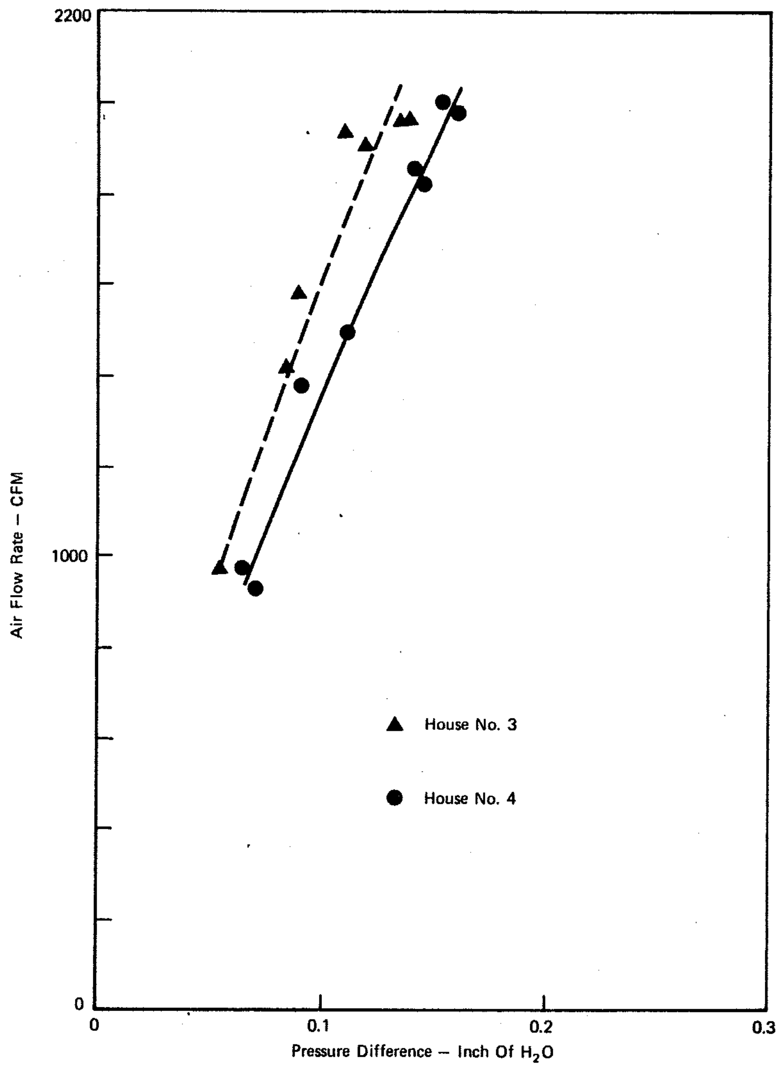

FIG. 5—*Induced pressure test (vacuum mode).*

is for air outlet, and the last third is under neutral zone, and therefore no movement of air is expected.

Conclusions

Based on the preceding experiences with these two methods, we may draw a few conclusions:

1. The tracer gas dilution method should be used when the absolute

air infiltration rates of a building envelope are sought. However, the infiltration characteristic of a building is best described by a statistic equation or a properly fitted curve, which relates the infiltration rate with temperature difference and with wind velocity.

2. When the tracer gas dilution method is used, the measurement should last some period of time in order to experience a wide range of wind velocities and temperature differences.

3. The tracer gas dilution method does demand technical skill and sophisticated instruments. These do represent economical handicaps in promoting its popular use. However, certain qualified laboratories are readily available to perform this type of test.

4. The decay curve of the tracer gas concentration as produced by the detector needs to be processed and converted to result in air changes per hour units. Also, reasonably accurate data on wind velocity and air temperature must be measured almost continuously during the same time period of tracer concentration measurement. Such data management would be best handled with the help of the electronic computers, as in this case. It may present some problems if these data were managed manually.

5. Error checking can become a serious problem in the tracer gas dilution method. Since the ambient conditions such as wind and air temperature cannot be controlled, it is difficult to check the reproducibility of the concentration decay curves. Since these curves must be converted into air change per hour units, and that simultaneous weather data must be integrated into the correlation, it is rather difficult to detect any error of appreciable magnitude during or shortly after the measurements are done. In cases where errors are suspected, it can be difficult to pinpoint the mistake(s) (tracer detector, weather data monitor, conversion process, and so on).

6. The induced pressure method can be used to measure the relative air tightness of several houses that need to be measured. The infiltration characteristic of a building can be described by a curve which relates the air leakage rate (metres per second (cubic feet per minute)) to the static pressure difference.

7. The induced pressure method can be used to study the air leakage rate for each major component of the building envelope, such as wall, window, ceiling, and floor.

8. The basic principle for the induced pressure method is very simple, and the results of the air leakage rate (cubic metres per second (cubic feet per minute)) and pressure difference need little or no calculation.

9. The equipment setup is far less complicated and readily available.

10. Research should be directed toward correlating the air leakage rates as measured through the tracer gas technique. In other words, the induced

pressure technique will be used most widely to obtain the air leakage rates, then such data will be related back to air infiltration rates through the correlations. The technical details may not be simple at all in establishing such correlation. But the concept of using both techniques to complement each other in order to promote the air infiltration measurement in the construction industry, (for example, code body and governmental authorities), should be pursued.