INFILTRATION: JUST ACH_{50} DIVIDED BY 20?

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Translating blower door measurements into an average infiltration rate has bedeviled the retrofitter and researcher alike. The rate of air infiltration is constantly varying, yet the pressurization test is typically a single measurement. Nevertheless, many researchers have sought to develop a correlation between a one-time pressurization test and an annual infiltration rate.

ACH Divided by 20

In the late 1970s, a simple correlation between a one-time pressurization test and an average infiltration rate grew out of experimentation at Princeton University. For a few years, the correlation remained as "Princeton folklore" because no real research supported the relationship. In 1982, J. Kronvall and Andrew Persily compared pressurization tests to infiltration rates measured with tracer-gas for groups of houses in New Jersey and Sweden. They focused on pressurization tests at 50 Pascals* because this pressure was already used by the Swedes and Canadians in their building standards. (This measurement is typically called "ACH_{50}.") Other countries and groups within the United States have also adopted "ACH_{50}" as a measure of house-tightness. Persily (now at the National Bureau of Standards) obtained a reasonably good estimate of average infiltration rates by dividing the air change rates at 50 Pascals by 20, that is:

$$\textit{average infiltration rate (ACH)} = \frac{ACH_{50}}{20} \quad (1)$$

* The pascal is a measure of air pressure similar to the indirect measures "inches of water" or "inches of mercury". The pressure of one atmosphere corresponds to 0.101 megapascals.

In this formula, ACH_{50} denotes the hourly air change rate at a pressure difference of 50 Pascals between inside and outside. Thus, for a house with 15 ACH at 50 Pascals (ACH_{50} = 15), one would predict an average air change rate of (15/20 =) 0.75 ACH.

Persily's simple formula yields surprisingly reasonable average infiltration estimates even though it ignores many details of the infiltration process. These "details" are described below:

- *Stack effect.* Rising warm air induces a pressure difference, or "stack effect", that causes exfiltration through the ceiling and infiltration at (or below) ground level. The stack effect depends on both the outside temperature and the height of the building. A colder outside temperature will cause a stronger stack effect. Thus, given two identically tall buildings, the one located in a cold climate will have more stack-induced infiltration. A taller building will also have a larger stack effect. Even though outside temperature and building height affect average infiltration rates, neither is measured by the pressure test. During the summer, stack effects disappear because the inside air is usually cooler (especially when the air-conditioner is operating). Wind-induced pressure therefore becomes the dominant infiltration path.
- *Windiness and wind shielding.* Wind is usually the major driving force in infiltration, so it is only reasonable to expect higher infiltration rates in windy areas. Thus, given two identical buildings, the one located in a windy location will have more wind-induced infiltration. Nevertheless, a correlation such as ACH_{50}/20 does not include any adjust-

LEAKAGE/INFILTRATION RATIO

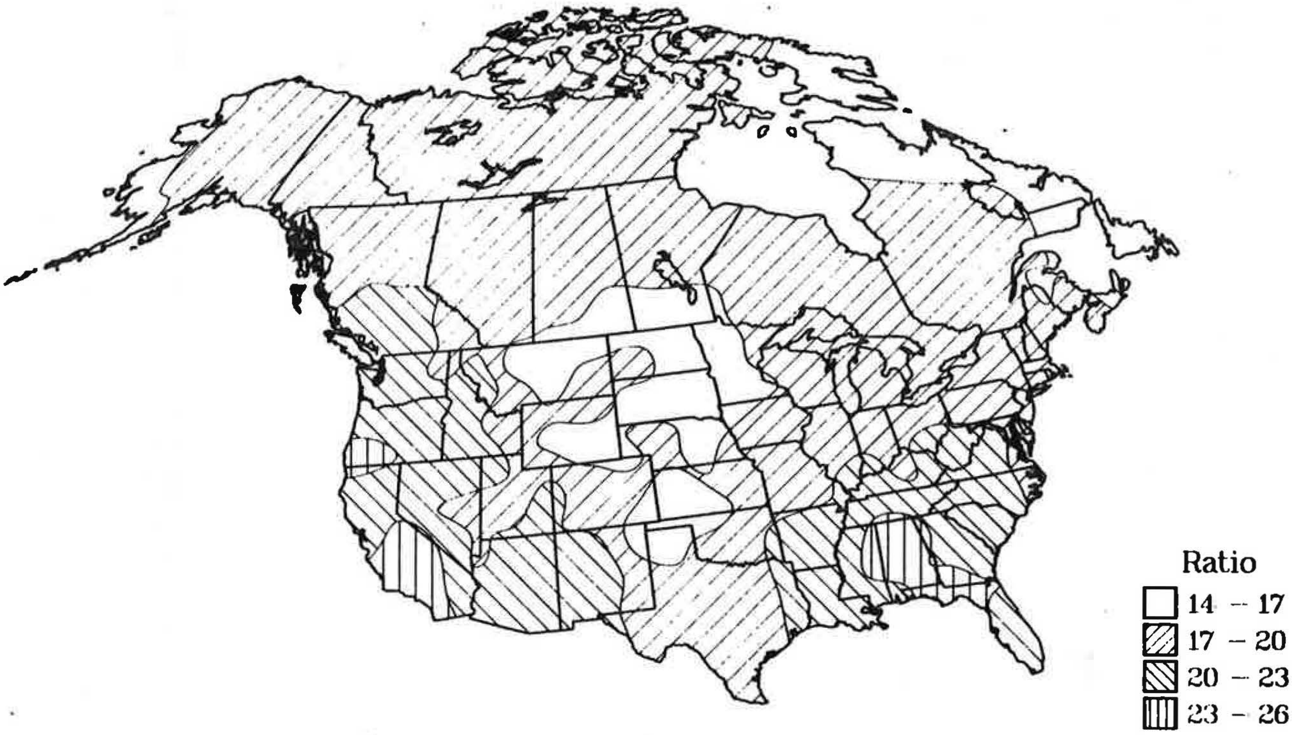

Figure 1. Climate correction factor, "C", for calculating average infiltration rates in North America. Note that the climate correction factor depends on both average temperatures and windiness. It also includes possible air infiltration during the cooling season. For these reasons, locations in greatly dissimilar climates, such as Texas and Vermont, can have equal factors. Select the value nearest to the house's location and insert in Equation 2. This map is based on data from 250 weather stations.

ment for windiness at the house's location. Trees, shrubs, neighboring houses, and other materials also shield a house from the wind's full force. Since a brisk wind can easily develop 10 Pascals on a windward wall, the extent of shielding can significantly influence total infiltration. A pressurization test does not directly measure the extent of shielding (although a house with good shielding may yield more accurate measurements since it is less affected by wind).

- *Type of leaks.* The leakage behavior of hole in the building envelope varies with the shape of the hole. A long thin crack, for example, responds less to variations in air pressure than round holes. The pressure-air change curve (determined with a calibrated blower door) often gives clues to the types of leaks in a house.

A person conducting pressurization tests on a particular house can collect considerable information regarding these details. For example, it is easy to measure a house's height and estimate the wind exposure. The kinds of cracks can often be judged through careful inspection of the building construction. Climate data, including windiness and temperatures, can be obtained from local weather stations.

Ideally, this additional information should be applied to the Persily formula in order to get a correlation factor more accurate for that house. Unfortunately, the Persily formula was developed from data in just a few houses in New Jersey and Sweden, and cannot be easily adjusted to other locations and circumstances. Should a retrofitter in Texas also use $ACH_{50}/20$, or is dividing by 15 more appropriate for the Texas climate and house construction types?

The LBL Infiltration Model

Researchers at Lawrence Berkeley Laboratory developed a model to convert a series of fan pressurization measurements into an "equivalent leakage area". (See **EA&R**, Mar/Apr '86, pp.7-8.) The equivalent leakage area roughly corresponds to the combined area of all the house's leaks.

A second formula converts the equivalent leakage area into an average infiltration rate in air changes per hour. This formula combines the physical principles causing infiltration with a few, subjective estimates of building characteristics to create relatively robust estimates of infiltration. ASHRAE has approved the technique, and describes the formulae in *ASHRAE Fundamentals.* The LBL infiltration model is now the most commonly accepted procedure for estimating infiltration rates.

In a recent research communication*, Max Sherman at LBL used this model to derive the theoretical correlation between pressure tests at 50 Pascals and annual average infiltration rates. His major contribution was to create a climate factor to reflect the influence of outside temperature (which determines the stack effect) and windiness. Sherman estimated the climate factor using climate data for North America and plotted it (see Figure 1). Since the factor reflects both temperature and seasonal windiness, a cold, calm location could have the same climate factor as a warm, windy location. The map also reflects summer infiltration characteristics. Note how Texas and Vermont have the same climate factors.

Sherman found that the correlation factor in the revised formula could be expressed as the product of several factors:.

$$\textit{correlation factor}, N, = C \times H \times S \times L$$

where,

C = climate factor, a function of annual temperatures and wind (see Figure 1)
H = height correction factor (see Table 1)
S = wind shielding correction factor (see Table 2)
L = leakiness correction factor (see Table 3)

Values for each of the factors can be selected by consulting Figure 1 and Tables 1-3. An estimate of the average annual infiltration rate is thus given by,

* "Estimation of Infiltration from Leakage and Climate Indicators", *Energy and Buildings*, (in press).

Table 1. Height Correction Factor. Select the most appropriate value and insert it in Equation 2.

number of stories	1	1.5	2	3
correction factor, "H"	1.0	0.9	0.8	0.7

Table 2. Wind Shielding Correction Factor. Select the most appropriate value and insert in Equation 2.

extent of shielding	well-shielded	normal	exposed
correction factor, "S"	1.2	1.0	0.9

Table 3. Leakiness Correction Factor. Select the most appropriate value and insert in Equation 2.

type of holes	small cracks (tight)	normal	large holes (loose)
correction factor, "L"	1.4	1.0	0.7

$$\textit{average air changes per hour (ACH)} = \frac{ACH_{50}}{N}$$

This formula provides a more customized "rule-of-thumb" than the original ACH/20, when additional information about the house is available.

An Example

The application of the climate correction is best shown in an example. Suppose you are pressure-testing a new, low-energy house in Rapid City, South Dakota. It is a two-story house, on an exposed site, with no surrounding vegetation or nearby houses to protect it from the wind.

1. At 50 Pascals, you determine that the ACH_{50} is 14.
2. You consult Figure 1, and determine that the house has a climate factor, "C", of 14 - 17. Since Rapid City is near a higher contour line, select 17.
3. The house is two stories tall, so the the appropriate height correction factor, "H" (from Table 1), is 0.8.

4. The house is very exposed to wind, and there are no neighboring houses or nearby trees and shrubs. The appropriate wind shielding correction factor, "S" (from Table 2), is 0.9.

5. The house is new, and presumably well-built. The appropriate leakiness factor, "L" (from Table 3) is 1.4.

6. Calculate N:

$$N = 17 \times 0.8 \times 0.9 \times 1.4$$
$$= 17$$

7. Calculate the average annual infiltration rate.

$$ACH = \frac{ACH_{50}}{17}$$
$$= \frac{14}{17}$$
$$= 0.82$$

The difference in this case (between dividing by 20 and 17) is not great—only 17%—but it demonstrates how the building conditions and location can affect the interpretation of pressurization tests.

Sherman compared his results to that reported by Persily. Sherman noted that he obtained a correlation factor (N) of about 20 for a typical house in the New Jersey area. Thus, Sherman's theoretically-derived correlation factor yields results similar to Persily's empirically-derived correlation factor.

The range of adjustment can be quite large. In extreme cases, the correlation factor, N, can be as small as 6 and as large as 40. In other words, the $ACH_{50}/20$ rule-of-thumb could overestimate infiltration by a factor of two or underestimate it by a factor of about three.

This formula is still only a theory; it has not been validated with field measurements. Moreover, there is considerable controversy regarding the physical interpretation of the climate factor. For example, the formula yields a year-round average infiltration rate rather than just for the heating season. Such a result is useful for houses with both space heating and cooling, but may be misleading for some areas.

Recommendations

There is no simple way to accurately convert a single pressure-test of a building to an average infiltration rate because many building and climate-dependent factors affect true infiltration. Long-term tracer-gas measurements are the only reliable way to obtain average infiltration rates. However, tracer-gas measurements are impractical for retrofitters and even most conservation researchers. A simplified, rule-of-thumb to let the retrofitter quickly translate a pressure-test to an infiltration rate is clearly attractive.

Persily and Kronvall developed a crude conversion technique, $ACH_{50}/20$, that provides reasonable results. On the other hand, it was impossible to customize the relationship of $ACH_{50}/20$ to local conditions. What are the components of the magic number, 20?

Now, Sherman has created a similar conversion factor that can be modified to reflect local building and climate conditions. This correlation factor accounts for the windiness, climate, stack effect, and construction quality. Some judgement is needed to select the appropriate correction factors, but the blower-door user can now understand the quantitative impact of local conditions on infiltration. For example, a three-story house will have significantly more infiltration than a ranch house—even though the pressure tests are identical—due to a greater stack effect. (Clearly an infiltration standard should take these factors into account.)

Of course, Sherman's correlation factor still cannot account for occupant behavior or perversities in the building's construction. Nor is it a substitute for tracer-gas measurements. Field measurements must also be conducted to validate the formula. Still, it puts a scientific foundation behind what was previously an empirically derived relationship. It is a modest step forward in the efficient and accurate use of the blower door.

— Alan Meier