Myths About Building Envelopes

By Andrew K. Parsley, Ph.D.
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It is often assumed that commercial and institutional buildings are fairly airtight and that envelope air leakage does not have a significant impact on energy consumption and indoor air quality in these buildings. Furthermore, it is assumed that more recently constructed buildings are tighter than older buildings. However, very little data is available on the airtightness of building envelopes in commercial and institutional buildings.

The data that exist show significant levels of air leakage in these buildings and do not support correlations of airtightness with building age, size or construction. This article presents the available airtightness data and the limited conclusions that can be drawn from these data.

Many discussions in the popular press and the technical literature refer to commercial and institutional buildings and newer buildings in particular, as being airtight. These “tight buildings” often are blamed for a host of indoor air quality problems including high rates of health complaints and more serious illnesses among building occupants.

Furthermore, discussions and analyses of energy consumption in commercial and institutional buildings generally are based on the assumption that envelope air leakage is not a significant portion of the energy used for space conditioning. These statements are almost never supported by any test data for the buildings in question. Also, they are based often on confusion between building envelope tightness and low ventilation rates.

Building envelope airtightness is important based on its relevance to the estimation of building ventilation rates as they impact energy consumption and indoor air quality. Envelope airtightness is one critical input to building airflow models, which predict air leakage rates through the building envelope induced by outdoor weather and ventilation system operation. These predicted airflow rates can be used to estimate the energy consumption associated with air leakage and to investigate the potential for energy savings through improvements in envelope airtightness and in ventilation system control.

In addition, these airflow rates can be used to predict indoor contaminant levels and occupant exposure to indoor pollutants, and to evaluate the impact of various indoor air quality control strategies. Therefore, it is important to have reliable values of envelope airtightness for commercial and institutional buildings.

In discussions of envelope airtightness and ventilation, it is important to distinguish between envelope leakage or infiltration and outdoor air intake or ventilation. Leakage and infiltration refer to the unintentional and uncontrolled flow of outdoor air into a building through leaks in the building envelope caused by pressures induced by weather and ventilation equipment operation.

Outdoor air intake and ventilation are the intentional and, ideally, controlled flow of outdoor air into a building via either a mechanical or natural ventilation system. A building can be very tight in terms of leakage and have sufficient, or even too much, outdoor air ventilation. Similarly, a building can have a very leaky envelope, but have insufficient outdoor air ventilation under some circumstances, particularly during mild weather conditions.

In mechanically ventilated buildings, a tight envelope is desired, as envelope leakage has several potentially negative consequences. These include uncontrolled and unconditioned outdoor air intake, thermal comfort problems, material degradation and moisture problems that can lead to microbial growth and serious indoor air quality problems.

Building envelope airtightness can be measured with fan pressurization testing, which provides a numerical value that quantifies the physical airtightness of a building.

This article reports on the analysis of envelope airtightness data from 139 commercial and institutional buildings assembled from the published literature. The buildings include office buildings, schools, retail buildings, industrial buildings and a number of other building types.

It is the only such collection and analysis that has been presented to date, and therefore is the only known basis for making statements regarding the airtightness of this group of buildings. Nonetheless, the number of buildings is small and are not random samples of the building stock at large. Therefore, any conclusions from this analysis have limited generalizability.

About the Author
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Measuring Envelope Airtightness

The airtightness of building envelopes is measured using a fan pressurization test in which a fan is used to increase (or decrease) the pressure within a building above (or below) the outdoor pressure. The airflow rate through the fan that is required to maintain this induced pressure difference is measured.

Generally, a series of pressure differences is induced during a pressurization test, ranging from about 10 Pa (0.04 in. of water) to as high as 75 Pa (0.3 in. of water). These elevated pressures are used to override the pressure differences induced by weather effects, that is, indoor-outdoor air temperature difference and wind speed. Therefore, the test results are independent of weather conditions and provide a measure of the physical airtightness of the exterior envelope of the building.

As mentioned earlier, envelope airtightness values can be used in airflow models to predict building infiltration rates induced by weather and ventilation system operation. No simple calculation method or rule-of-thumb exists that relates envelope airtightness to infiltration in commercial buildings. This is due to the complexity of these buildings and the effects of ventilation system operation. Generally, multizone airflow models must be used to relate airtightness to infiltration.8, 9, 21

ASTM Standard E779 is a test method that describes the fan pressurization test procedure in detail, including the specifications of the test equipment and the analysis of the test data. In conducting a fan pressurization test in a commercial building, the building’s own air-handling equipment sometimes can be employed to induce the test pressures. A Canadian General Standards Board (CGSB) standard describes the use of the air-handling equipment in a building to conduct such a test.4 In other cases, a large fan is brought to the building to perform the test.

The same procedure often is used to measure the airtightness of single-family residential buildings, where the test equipment is generally referred to as a blower door.19 Chapter 25, Ventilation and Infiltration, of the 1997 ASHRAE Handbook—Fundamentals2 contains a short description of fan pressurization testing.

<table>
<thead>
<tr>
<th>Dataset</th>
<th>County/State</th>
<th>Number of Buildings</th>
<th>Mean Number of Stories</th>
<th>Mean Age (years)</th>
<th>Range of Ages (years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>NIST offices</td>
<td>USA</td>
<td>8</td>
<td>6.1</td>
<td>18.3</td>
<td>8–23</td>
</tr>
<tr>
<td>NRC offices</td>
<td>Canada</td>
<td>8</td>
<td>18.9</td>
<td>27.5</td>
<td>24–34</td>
</tr>
<tr>
<td>BRE offices</td>
<td>USA</td>
<td>10</td>
<td>NA</td>
<td>10.8</td>
<td>7–35</td>
</tr>
<tr>
<td>Fla. offices</td>
<td>USA/Fla.</td>
<td>22</td>
<td>1.0</td>
<td>25.8</td>
<td>4–67</td>
</tr>
<tr>
<td>NRC retail</td>
<td>Canada</td>
<td>10</td>
<td>NA</td>
<td>31.4</td>
<td>18–44</td>
</tr>
<tr>
<td>Fla. retail</td>
<td>USA/Fla.</td>
<td>6</td>
<td>1.0</td>
<td>21.8</td>
<td>4–32</td>
</tr>
<tr>
<td>Fla. other</td>
<td>USA/Fla.</td>
<td>25</td>
<td>1.7</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Other</td>
<td>Canada</td>
<td>1</td>
<td>5</td>
<td>10</td>
<td>10</td>
</tr>
</tbody>
</table>

NA means that this information is not available for that group of buildings.

Table 1: Summary of commercial buildings analyzed.

<table>
<thead>
<tr>
<th>Dataset</th>
<th>Air Leakage at 75 Pa, m³/h·m²</th>
</tr>
</thead>
<tbody>
<tr>
<td>NIST offices</td>
<td>13.3</td>
</tr>
<tr>
<td>NRC offices</td>
<td>10.6</td>
</tr>
<tr>
<td>BRE offices</td>
<td>23.3</td>
</tr>
<tr>
<td>Fla. offices</td>
<td>36.0</td>
</tr>
<tr>
<td>NRC retail</td>
<td>49.3</td>
</tr>
<tr>
<td>Fla. retail</td>
<td>33.0</td>
</tr>
</tbody>
</table>

Table 2: Summary of airtightness data.
The results of a fan pressurization test are in the form of a series of indoor-outdoor pressure differences and the airflow rates required to induce them. The results of such a test, based on these data, are reported using a variety of parameters. Often, the test results are reported in terms of the airflow rate at some reference pressure divided by the building volume, floor area or surface area. Such normalization accounts for building size in interpreting the test results.

In other cases, the pressure differences and airflow rates are fitted to a curve of the form:

$$Q = CA_p^n$$  \hspace{1cm} (1)

where $Q$ is the airflow rate induced to maintain the indoor-outdoor pressure difference $Ap$, $C$ is referred to as the flow coefficient, and $n$ is the flow exponent. Once the values of $C$ and $n$ have been determined from the test data, the equation can be used to predict the airflow rate through the building envelope at any given pressure difference. Often, especially in houses, this equation is used to calculate the airflow rate at an indoor-outdoor pressure difference of 4 Pa (0.016 in. of water).

This airflow rate is used to estimate the so-called effective leakage area of the building, which is the area of an office with a discharge coefficient of 1 that would result in the same airflow rate at the reference pressure difference. Effective leakage area sometimes is calculated at pressure differences other than 4 Pa (0.016 in. of water) and for other values of the discharge coefficient.

The airtightness data presented here are collected from a number of different studies that use different units to report envelope airtightness. The results are presented here as airflow rates at an indoor-outdoor pressure difference of 75 Pa (0.3 in. of water) normalized by the surface area of the building envelope. (When necessary, this conversion was based on an assumed value of the flow exponent of 0.65.)

The values of envelope airtightness are given in units of m³/h·m², which can be converted to cfm/ft² by multiplying by 0.055.

Another common airtightness unit used in houses is the effective leakage area at 4 Pa (0.016 in. of water) which can also be normalized by the surface area of the building. To convert the 75 Pa airflow rate to the 4 Pa EIA normalized by the surface area, in units of m²/m² of leakage area per m² of wall area, multiply by 0.16.

Table 3: Air leakage values for U.S. houses.

<table>
<thead>
<tr>
<th>Airtightness</th>
<th>Air leakage at 75 Pa</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tight, 2hr at 50 Pa</td>
<td>1.0 m³/h·m²</td>
</tr>
<tr>
<td>One-story house</td>
<td>2.0 m³/h·m²</td>
</tr>
<tr>
<td>Two-story house</td>
<td></td>
</tr>
<tr>
<td>Moderately tight, 2hr at 50 Pa</td>
<td>3.0 m³/h·m²</td>
</tr>
<tr>
<td>One-story house</td>
<td>4.0 m³/h·m²</td>
</tr>
<tr>
<td>Two-story house</td>
<td></td>
</tr>
<tr>
<td>Typical, 10hr at 50 Pa</td>
<td>6.0 m³/h·m²</td>
</tr>
<tr>
<td>One-story house</td>
<td>8.0 m³/h·m²</td>
</tr>
<tr>
<td>Two-story house</td>
<td></td>
</tr>
<tr>
<td>Leaky, 20hr at 50 Pa</td>
<td>12.0 m³/h·m²</td>
</tr>
<tr>
<td>One-story house</td>
<td>16.0 m³/h·m²</td>
</tr>
<tr>
<td>Two-story house</td>
<td></td>
</tr>
</tbody>
</table>

The one-story house is assumed to have a floor area of 150 m² (1610 ft²) and a ceiling height of 2.4 m (8 ft). The two-story house is assumed to have a floor area of 100 m² (1080 ft²) on each floor. Both houses are assumed to have a square floor plan.

Table 3 contains a summary of the buildings that are considered here, including information on building type, location, number of stories and age. The largest number of buildings tested, 69 of the 139 buildings, were part of a study conducted by the Florida Solar Energy Center (FSEC). Of these 69 buildings fall into the categories of office buildings, schools, retail buildings, industrial buildings and other.

The other 70 buildings considered include office buildings from the United States, Canada, and the U.K., school buildings from New York, and Canada, retail buildings from Canada, and industrial buildings from Sweden.

It should be apparent from Table 1, and from closer examination of the data on which this table is based, that the 139 buildings are not a representative collection of commercial buildings around the world or within any given country. Rather each data set was obtained in an individual study conducted to demonstrate the applicability of a measurement technique and to obtain some limited airtightness data for a building type in a given area. The small number of buildings, relative to the number of commercial buildings and their lack of representativeness limits the generalizability of any conclusions drawn from studying the data.

There is a predominance of one-story buildings except for office buildings, and almost all of the buildings from the Florida study have only one story. The mean ages

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of the buildings in the data sets all range from about 20 to 30 years and the ranges of ages in each data set are similar, with the exception of the NRC buildings which tend to be somewhat older than the rest of the buildings.

Table 2 summarizes the airtightness data, again grouped by building data set as in Table 1. For each of the data sets, except the "other" category in Table 1, Table 2 presents the mean air leakage rate at 75 Pa in units of m³/h·m², as well as the standard deviation and the minimum and maximum values. These values are also presented for all 139 buildings, the buildings only in the Florida study, and the 70 buildings not from the Florida study. The mean airtightness value for all the buildings is 27.1 m³/h·m², but the range and standard deviation are large. The buildings from the Florida study tend to be leakier than the rest, with a mean airtightness value of 34.0 m³/h·m² compared to 20.3 m³/h·m² for the rest of the buildings.

The three tightest groups of buildings are the schools in New York and the industrial buildings in Sweden. There is no particular reason to expect these buildings to be tighter than the rest, other than the tendency of buildings in Nordic countries to be tighter than in North America and the rest of Europe. Among the four data sets of office buildings, the mean airtightness values are lowest in the Canadian buildings, followed by the United States (NIST), U.K. (BRB) and Florida buildings.

Table 3 presents airtightness values for single-family residential buildings in units of the airflow rate at 75 Pa normalized by surface area. As mentioned earlier, these residential building tightness values are presented as reference points for comparison, and are not based on any particular buildings. Comparing these residential leakage values to those for the commercial buildings in Table 2 shows that the mean airtightness values for the commercial buildings fall in the range of typical to leaky houses.

Therefore, in terms of airtightness per unit envelope area (a measure of airtightness of the envelope construction itself), the commercial buildings that have been evaluated are not particularly airtight relative to U.S. houses and some are quite leaky. Note that the airtightness values of typical U.S. houses are not exceptional when compared with houses constructed with the goal of achieving high levels of airtightness, particularly those in the Nordic countries and Canada, where values less than 2 h⁻¹ at 50 Pa are not uncommon.

Analysis
The airtightness data for commercial and institutional buildings were analyzed to assess the impact of a number of factors...
on envelope airtightness including building age, wall construction, building type and number of stories. It is important to note that the small number of buildings tested limits the strength of any conclusions concerning the impacts of these factors on envelope airtightness.

Building Age: The first parameter, building age, has been cited in “conventional wisdom” as a prime determinant of airtightness with references to “hermetically-sealed modern office buildings” and the “fact” that new buildings are tighter than older buildings. Figure 1 is a plot of the airtightness at 75 Pa versus year of construction for the 117 buildings for which the year of construction is reported. The 69 buildings in the Florida study are distinguished from the rest of the buildings in the plot. No correlation between airtightness and year of construction is evident for the buildings as a group, or for the two subsets of buildings. The buildings constructed before 1960 appear to be leakier than the rest, but the number of such buildings is too small to draw any firm conclusions. Regardless of the situation with the older buildings, there is no suggestion that newer buildings are tighter.

One might speculate that buildings get leakier as they get older, as seals deteriorate and buildings settle. This suggestion was investigated by plotting airtightness against the age of the building when tested. Since the date of the pressurization tests was not given in the references, the difference between the year of publication and year of construction of the building is used as a surrogate for the building age. Figure 2 is a plot of the airtightness versus this measure of building age when tested. Again, no correlation between airtightness and age is evident, with the exception of a relatively small number of older buildings.

Wall Construction: In many of the buildings tested, information was available on wall construction, and the airtightness data were examined relative to this factor. Figure 3 presents the air leakage at 75 Pa for each type of wall construction considered. For each wall type, the plot shows the mean value of envelope air leakage value plus and minus one standard deviation, and the minimum and maximum values. The number of buildings of each wall type is shown on the horizontal axis. The wall types of the buildings in the references generally were not described in any detail, therefore the classifications may not be the same for each group of buildings.

In addition, the Florida study included some wall types not included in the other studies, including frame/masonry, frame, masonry/frame and masonry/metal. Examining the mean air leakage values, it is seen that the masonry, concrete panel, manufactured, metal, curtain and masonry/frame buildings were similar in airtightness, with insignificant differences in the mean values relative to the values of the standard deviations.

These mean air leakage values are all around 25 m³/h·m². The frame/masonry and frame buildings appear to somewhat leakier, about 55 m³/h·m², but their mean values appear to be dominated by some particularly leaky buildings. In addition, the masonry/metal building is in the 55 m³/h·m² range, but there is only one building with that wall type. Therefore, for the buildings studied, wall construction does not appear to have a significant impact on envelope airtightness. However, it appears that frame walls may be somewhat leakier.

Building Type: The airtightness values also were examined with respect to the type of building. Figure 4 presents the air leakage at 75 Pa by building type. As in Figure 3, the mean plus and minus one standard deviation and the minimum and maximum air leakage values are presented for each building type, along with the number of buildings of that type. The three most common building types, office, school and industrial, all have a mean value of about 25 m³/h·m². In addition, the mean air leakage values for the restaurants, assembly buildings and hotels also are in that same range. The mean for the retail buildings is somewhat higher, over 40 m³/h·m².

The health care and sports buildings also are leakier, but there are very few of these buildings. It is interesting to note that the minimum air leakage for the four most common building types, including retail, are all very similar. This similarity could indicate that there is nothing inherent in this building type that would preclude the existence of a tight envelope. As in the case of wall construction, building type does not appear to have a significant impact on envelope airtightness for the buildings studied, with the exception that the retail buildings in this group are somewhat leakier.

Number of Stories: The air leakage values were also examined relative to the number of stories of the buildings tested. Figure 5 is a plot of the air leakage at 75 Pa versus number of stories, based on those buildings for which the number of stories was reported. This plot reveals an impact of building height on airtightness, with the taller buildings appearing to be tighter and the shorter buildings covering the full spectrum of airtightness values. All of the buildings with 15 stories or more have air leakage values less than 12 m³/h·m². The buildings with five to 10 stories are around 20 m³/h·m², with one exception, and the one and two story buildings range from as low as about 3 m³/h·m² to as high as 124 m³/h·m².

All of the taller buildings (15 stories or greater) are office buildings, with one from the NIST study of U.S. office buildings and the rest from the NRC study in Canada. They also all have concrete panel or curtain wall construction. The mid-height buildings (five to 10 stories) are also office buildings, plus one
five-story apartment building. Three of the buildings with air leakage values of about 20 m³/h·m² or less have concrete panel walls and one has masonry walls; the leakiest of the group (about 43 m³/h·m²) has a curtain wall.

Without additional study of the construction it is difficult to explain the trends seen in Figure 5, but it appears that the type of construction seen in the taller buildings lends itself to more airtight envelopes. Taller buildings might require more careful design and construction to deal with the more demanding structural requirements, such as increased wind loads, and with the control of rain penetration.

The one and two story buildings do not necessarily have the same level of performance requirements, and they include more types of wall constructions than the taller office buildings. These factors may result in buildings that are much leakier. However, some of the shorter buildings achieve the same levels of airtightness as the taller buildings. Finally, even the tighter buildings have airtightness values that correspond to only moderately tight single-family residential buildings, according to the classifications in Table 3.

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References


