Airtightness of Commercial Buildings in the U.S.

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ABSTRACT

In 1998, Persily published a review of commercial and institutional building airtightness data that found significant levels of air leakage and debunked the "myth" of the airtight commercial building. This paper updates the earlier analysis for the United States by including data from over 100 additional buildings. The average airtightness of 28.4 $m^3/h{\cdot}m^2$ at 75 Pa is essentially the same as reported by Persily in 1998. This average airtightness is in the same range as that reported for typical U.S. houses and is also similar to averages reported for commercial buildings built in the United Kingdom prior to recent airtightness regulations. Additionally, the trend of taller buildings being tighter and the lack of correlation between year of construction and building air leakage observed are consistent with the earlier report. This new analysis also found a trend (with considerable scatter) towards tighter buildings in colder climates. Although this study more than doubles the number of buildings in the air leakage database, any conclusions from this analysis are still limited by the number of buildings and lack of random sampling.

KEYWORDS

Airtightness, commercial buildings, infiltration, ventilation

INTRODUCTION

Persily (1998) published a review of commercial and institutional building airtightness data that found significant levels of air leakage and debunked the "myth" of the airtight commercial building. That analysis also failed to support correlations between airtightness and building age or construction. This paper updates the earlier analysis by adding over 100 U.S. buildings – more than doubling the number of U.S. buildings in the database.

Many discussions in the popular press and the technical literature still refer to commercial and institutional buildings, and newer buildings in particular, as being airtight. "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 frequently 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 or airflow analysis for the buildings in question.

Building envelope airtightness is also one critical input to building airflow models, such as CONTAM (Dols and Walton 2002), 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 (Emmerich et al. 2005). Importantly, these airflow rates can also be used to predict indoor contaminant levels and occupant exposure to indoor pollutants, and to evaluate the impacts of various indoor air quality control strategies. Therefore, it is important to have reliable values of envelope airtightness for commercial and institutional buildings.

In mechanically ventilated buildings, a tight envelope is desirable, 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.

This paper reports on the analysis of measured envelope airtightness data from over 200 U.S. commercial and institutional buildings assembled from both published literature and previously unpublished data. The buildings include office buildings, schools, retail buildings, industrial buildings and other building types. It is the largest such collection and analysis that has been presented to date. This paper summarizes the data, analyzes the data for trends, and compares the results to the earlier study.

MEASURING ENVELOPE AIRTIGHTNESS

The airtightness of building envelopes is measured using a fan pressurization test in which a fan is used to create a series of pressure differences across the building envelope between the building interior and the outdoors. The airflow rates through the fan that are required to maintain these induced pressured differences are then measured. Elevated pressure differences of up to 75 Pa are used to override weather-induced pressures such that the test results are independent of weather conditions and provide a measure of the physical airtightness of the exterior envelope of the building.

ASTM Standard E779 (ASTM 1999) 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 large building, the building's own air-handling equipment sometimes can be employed to induce the test pressures. A Canadian General Standards Board test method, CGSB 149.15, describes the use of the air-handling equipment in a building to conduct such a test (CGSB 1996). In other cases, a large fan is brought to the building to perform the test such as described by the Chartered Institution for Building Services Engineers' test method, CIBSE TM-23 (CIBSE 2000).

Often, the test results are reported in terms of the airflow rate at some reference pressure difference divided by the building volume, floor area or envelope surface area. Such normalization accounts for building size in interpreting the test results. In other cases, the pressure and flow data for measurements performed at multiple pressure differences are fitted to a curve of the form:

$$Q = C \cdot \Delta p^{n} \tag{1}$$

where Q is the airflow rate, Δp is the indoor-outdoor pressure difference, 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.

The airtightness data presented here are collected from a number of different studies that use different units and reference pressure differences. The results are presented here as airflow rates at an indoor-outdoor pressure difference of 75 Pa normalized by the above-grade 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 $m^3/h{\cdot}m^2$, which can be converted to cfm/ft^2 by multiplying by 0.055.

DATA AND DISCUSSION

Table 1 contains a summary of the air leakage data for the 201 U.S. commercial and institutional buildings that are considered here. Sources of data included 9 buildings tested by NIST (Persily and Grot 1986, Persily et al. 1991, Musser and Persily 2002), 90 buildings tested by the Florida Solar Energy Center (Cummings et al. 1996 and 2000), 2 buildings tested by Pennsylvania State University (Bahnfleth et al. 1999) 23 buildings tested by Camroden Associates (Brennan et al. 1992 and previously unpublished data), and 79 buildings tested by the U.S. Army Corps of Engineers (previously unpublished data including some partial school buildings). The buildings were tested for a variety of purposes and were not randomly selected to constitute a representative sample of U.S. commercial buildings. None of the buildings are known to have been constructed to meet a specified air leakage criterion, which has been identified as a key to achieving tight building envelopes in practice.

TABLE 1
Summary of Building Characteristics and Airtightness Data

		Air Leakage at 75 Pa ($m^3/h{\cdot}m^2$)			
Dataset	#	Mean	Standard Deviation	Min	Max
NIST	9	15.1	11.5	3.9	43.3
FSEC	88	41.7	34.3	4.0	168
Brennan	23	14.0	13.3	2.7	60.6
ACoE	79	19.7	10.3	3.4	63.4
PSU	2	9.8	0.4	9.5	10.1
All buildings	**201**	**28.4**	**35.8**	**2.7**	**168**

As seen in Table 1, the average air leakage at 75 Pa for the 201 buildings is 28.4 $m^3/h{\cdot}m^2$, which is essentially the same as the average of 28.7 $m^3/h{\cdot}m^2$ for U.S. buildings included in the earlier analysis by Persily. This average airtightness is tighter than the average of all U.S. houses but leakier than conventional new houses based on a large database of residential building airtightness (Sherman and Matson 2002). The average of the U.S. commercial buildings is also similar to averages reported by Potter (2001) of 21 $m^3/h{\cdot}m^2$ for offices, 32 $m^3/h{\cdot}m^2$ for factories and warehouses, and 26.5 $m^3/h{\cdot}m^2$ for superstores built in the United Kingdom prior to new building regulations which took effect in 2002.

The airtightness data were also analyzed to assess the impact of a number of factors on envelope airtightness including number of stories, year of construction, and climate. It is important to note that the lack of random sampling and sample size limits the strength of any conclusions concerning the impacts of these factors. Also, not all of these parameters were available for all buildings in the database. Figure 1 is a plot of the air leakage at 75 Pa vs. the reported number of stories of the building and shows a tendency toward more consistent tightness for taller buildings. The shorter buildings display a wide range of building leakage. This result is consistent with the earlier analysis by Persily (1998).

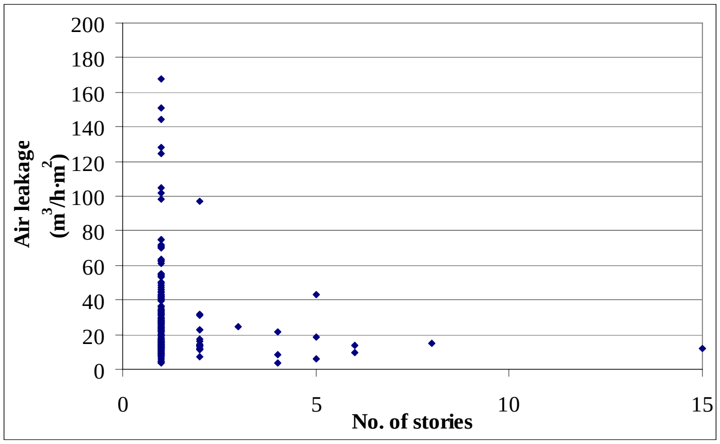

Figure 1: Normalized building air leakage vs. height of building (in stories)

Figure 2 is a plot of the air leakage at 75 Pa vs. the year of construction of the building for buildings built more recently than 1955. While common expectation is that newer commercial buildings must be tighter than older ones, the data simply give no indication that this is true. This result is also consistent with the earlier analysis by Persily (1998) despite the addition of numerous newer buildings in this dataset.

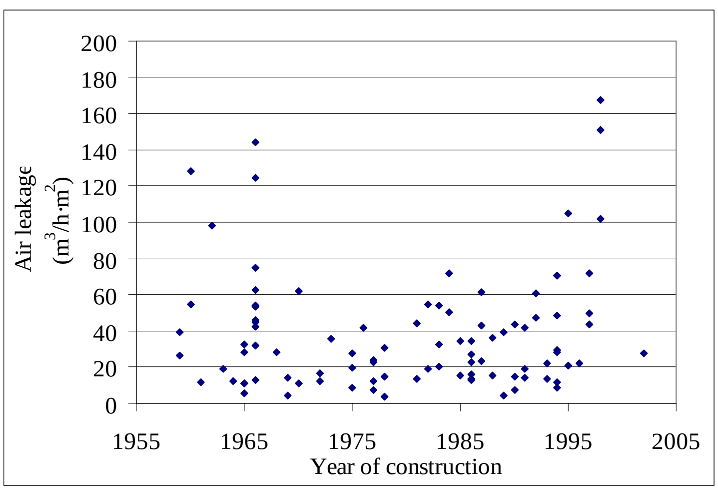

Figure 2: Normalized building air leakage vs. year of construction

Figure 3 is a plot of the air leakage at 75 Pa vs. the climate where the building is located as measured by annual heating degree-days base 18 °C for buildings of 3 stories or fewer (189 of the buildings). Approximate heating degree-day values were used for some of the building as either the locations were not precisely known or they were in locations without published heating degree-day data. Although the data show considerable scatter, they do indicate a general trend toward somewhat tighter constructions in the colder climates. The average air leakage was 33 $m^3/h{\cdot}m^2$ for buildings in locations with less than 2000 heating degree-days compared to 18 $m^3/h \cdot m^2$ for building in locations with more than 2000 heating degree-days. Although there are data from numerous locations, there are little data from the northern U.S. and even less from the western U.S. If possible, future efforts should focus on collecting data in those regions.

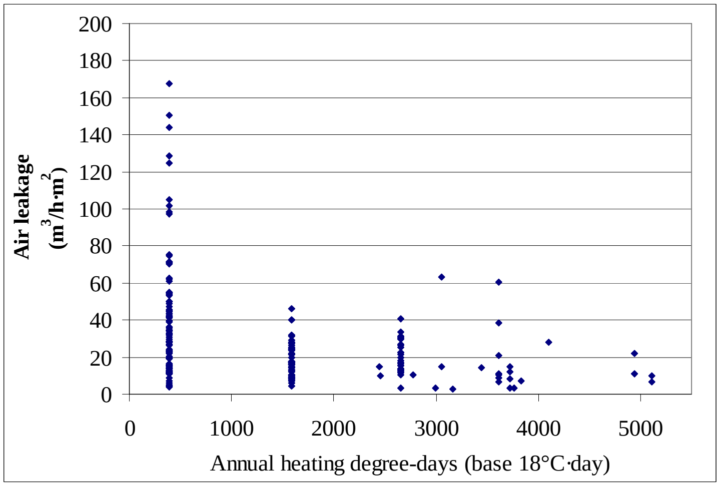

Figure 3: Normalized building air leakage vs. climate (in heating degree-days base 18 °C).

SUMMARY

This paper presents a summary of available measured U.S. commercial and institutional building airtightness data. The overall average airtightness of 28.4 $m^3/h \cdot m^2$ at 75 Pa is essentially the same as reported by Persily in 1998. This average airtightness is in the same range as that reported for typical U.S. houses and is also similar to averages reported for commercial buildings built in the United Kingdom prior to recent airtightness regulations. Additionally, the trend of taller buildings being tighter and the lack of correlation between year of construction and building air leakage observed are consistent with the earlier report. This study also found a trend (with considerable scatter) towards tighter buildings in colder climates. Although this study more than doubles the number of buildings in the air leakage database, any conclusions from this analysis are still limited by the number of buildings and lack of random sampling.

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