U.S. COMMERCIAL BUILDING AIRTIGHTNESS REQUIREMENTS AND MEASUREMENTS

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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. Since that time, the U.S. National Institute of Standards and Technology (NIST) has maintained a database of measured airtightness levels of U.S. commercial building leakages, in part to support the development and technical evaluation of airtightness requirements for national and state codes, standards and programs. This paper presents the airtightness data from the NIST database and a summary of recent developments in U.S. codes and standards. The average airtightness of the 228 buildings in the database is 25 $m^3/h{\cdot}m^2$ at 75 Pa, which is a little over 10 % tighter than the average reported by Persily in 1998. This average commercial and institutional building airtightness is tighter than the average of all U.S. houses but leakier than conventional new houses based on a large database of U.S. residential building airtightness. The data are examined for trends related to size, year of construction, type of construction and climate. The paper also discusses recent code and standards developments including the adoption of a continuous air barrier requirement in ASHRAE Standard 90.1-2010 *Energy Standard for Buildings Except Low-Rise Residential Buildings*, various U.S. state building codes, and the proposed International Green Construction Code.

KEYWORDS
Airtightness, air barrier, commercial buildings, infiltration

INTRODUCTION

Past NIST efforts have demonstrated that, despite assumptions to the contrary, typical modern U.S. commercial building envelopes are not particularly airtight (1, 2), building envelope leakiness results in a significant energy cost (3), and substantial energy savings would result through the requirement of an effective air barrier for new commercial buildings (4). This work has led to the consideration and adoption of prescriptive air barrier requirements in a number of building standards and codes, e.g., ASHRAE Standard 90.1, the U.S. Army Corps of Engineers (USACE), and several states in the U.S.. This paper presents the currently available airtightness data from the NIST database and summarizes recent developments in U.S. codes and standards.

The airtightness of building envelopes is measured using a fan pressurization (blower door) 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. ASTM Standard E779 (5) 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 (6). Typically, 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.

The airtightness data presented here are collected from a number of different studies that use a variety of 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 is based on an assumed pressure exponent value 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.

DATABASE AND ANALYSIS

Table 1 contains a summary of the air leakage data for the 228 U.S. commercial and institutional buildings included in the NIST database. Sources of these data included 9 buildings tested by NIST (7, 8, 9), 89 buildings tested by the Florida Solar Energy Center (10, 11), 41 buildings tested by Terry Brennan (13, 14, 15), and 88 buildings tested by the U.S. Army Corps of Engineers (USACE) (unpublished data including some partial school buildings), and three other buildings (12, 16). 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 Table 1 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.

		Air Leakage at 75 Pa ($m^3/h{\cdot}m^2$)			
Dataset	Qty	Mean	Standard Deviation	Min	Max
NIST	9	15.1	11.5	3.9	43.3
FSEC[1]	89	33.8	23.2	4.0	124
Brennan	39	19.8	18.2	2.7	80.7
USACE	88	19.3	10.3	3.4	63.4
Other	3	8.7	2.0	6.4	10.1
All buildings	**228**	**24.8**	**19.1**	**2.7**	**124**

[1]FSEC values differ from earlier publication due to corrected envelope surface area.

Table 1. Summary of Building Airtightness Data

As seen in Table 1, the average air leakage at 75 Pa for the 228 buildings is 24.8 $m^3/h{\cdot}m^2$, which is 12 % tighter than the average of 28.7 $m^3/h{\cdot}m^2$ for the U.S. buildings included in the earlier analysis by Persily (1). This average airtightness is tighter than the average of all U.S. houses, but leakier than conventional new houses based on a database of residential building airtightness (17).

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 past analyses [1][2].

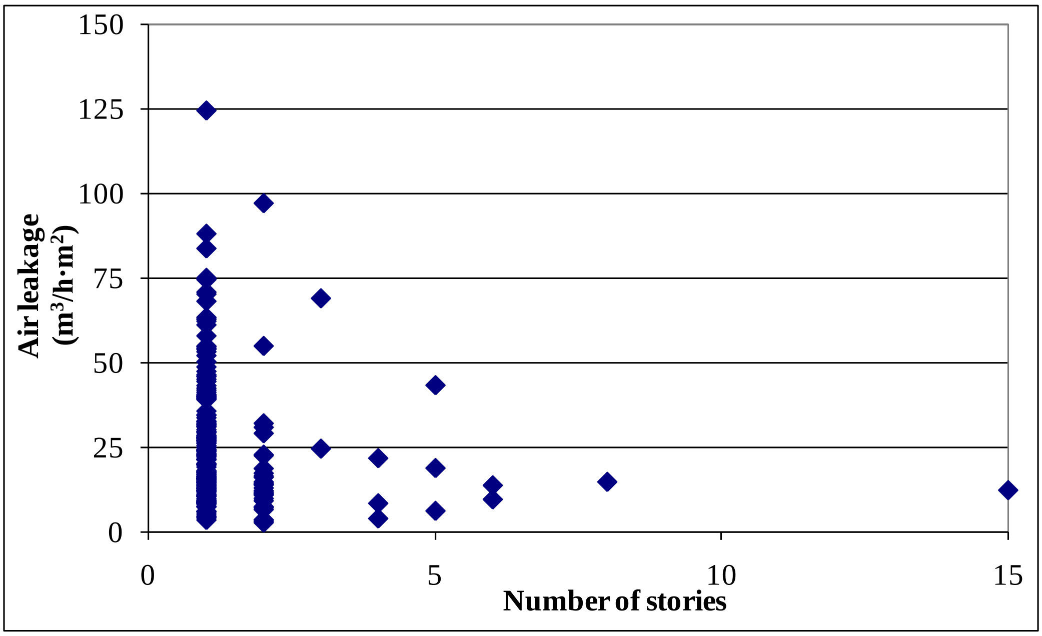

Figure 1: Normalized building air leakage vs. height of building (in stories)

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 would be tighter than older ones, the data indicate no significant trend.

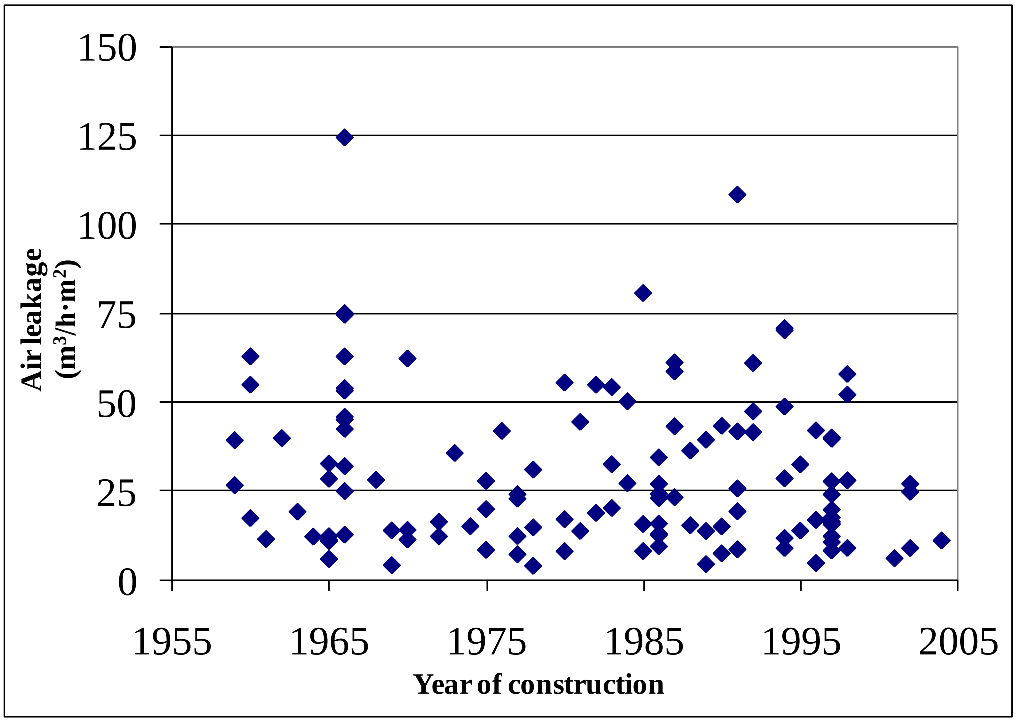

Figure 2: Normalized building air leakage vs. year of construction

Figure 3 is a plot of the air leakage at 75 Pa vs. wall construction type for 200 of the buildings from the database. While the data suggests that buildings with frame and frame/masonry wall types are somewhat leakier than the other types, the large standard deviations for the individual categories do not support any firm conclusions. Additionally, data interpretation is complicated by a lack of clear definition of construction types and and because the use of different terms for wall construction may not be consistent among those reporting the leakage data.

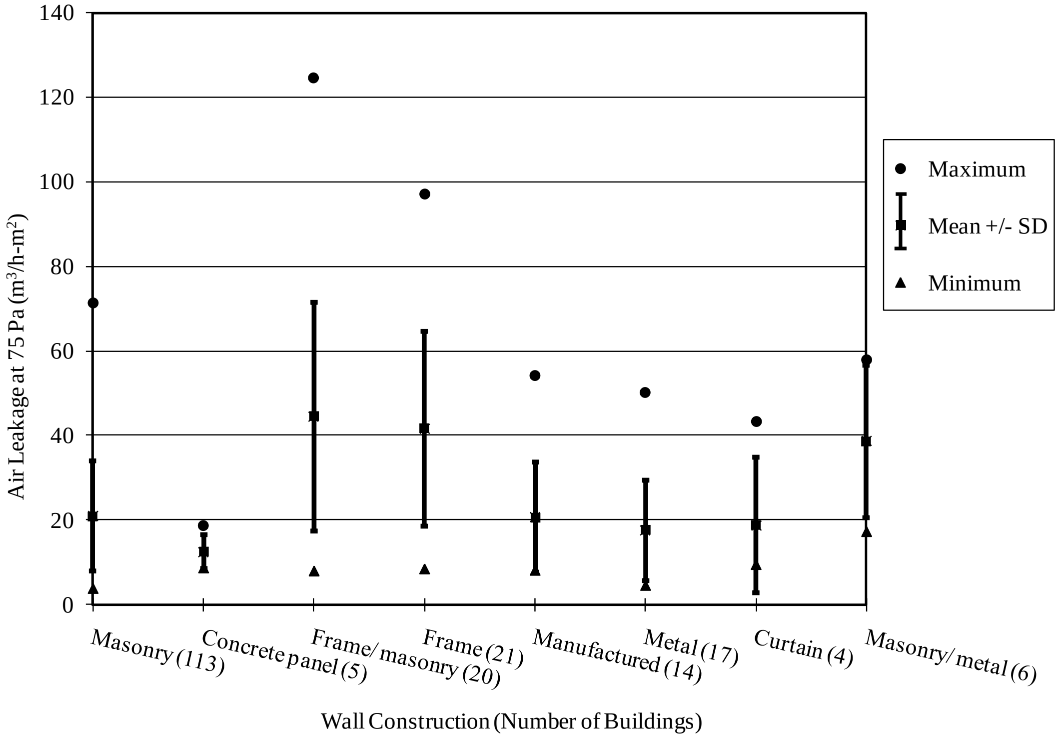

Figure 3: Normalized building air leakage vs. Wall type

The USACE requires new army buildings to meet a maximum whole building airtighness specification of 4.5 $m^3/h\ m^2$ at 75 Pa based on the entire building enclosure area including the slab and any below grade walls (USACE 2009). New buildings are tested and improvements to airtightness are made if they fail to meet the standard. The tightness of the 'typical' buildings in the NIST database (after conversion to a basis including the below-grade walls and slab) are compared to the tightness of the new USACE buildings (Zhivov 2010) in Figure 4. The average USACE building is about 84 % tighter than the average 'typical' building, conclusively demonstrating improvements in tightness can be achieved through a rigorous specification and testing program in new buildings. Importantly, the variation in tightness of the USACE buildings is also significantly reduced, with a standard deviation that is only 37 % of the average compared to a standard deviation of 77 % of the average for the NIST database. By specifying and testing to a maximum tightness limit, the increased certainty enables better prediction of infiltration, building energy use, and design and operation of a building's HVAC system.

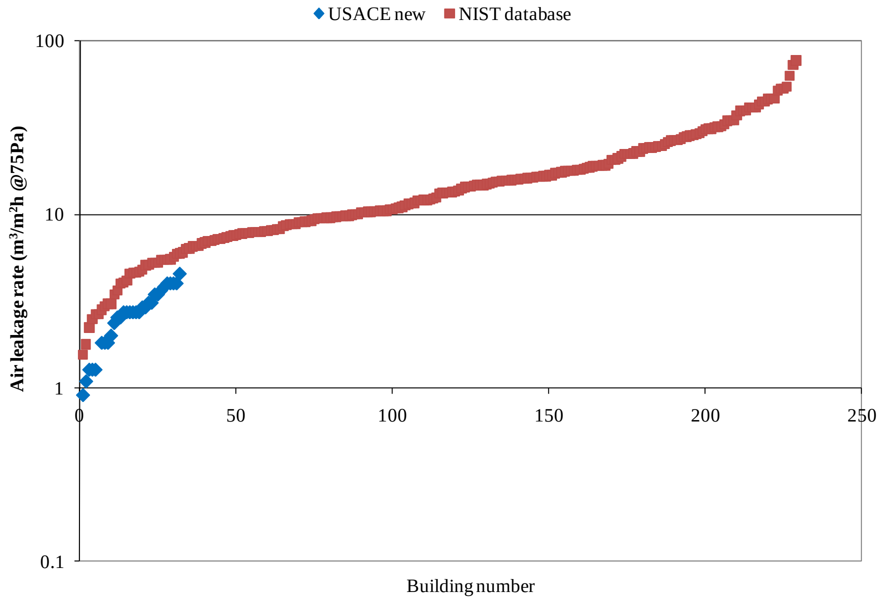

Figure 4. Comparison of commercial building airtightness for NIST database (typical buildings) and USACE data (designed and tested to meet 4.5 $m^3/h\ m^2$ at 75 Pa).

U.S. STANDARDS AND REGULATIONS

	Air Leakage at 75 Pa ($L/s{\cdot}m^2$)[1]		
Standard or code	**Material**	**Assembly**	**Whole building[2]**
ASHRAE 90.1	0.02	0.2	-
ASHRAE 189.1	0.02	0.2	2.0
IECC	0.02	0.2	2.0
IGCC	-	-	1.3 (required)
USACE	0.02	-	1.3 (required)
GSA	0.02	0.2	1.3 (required)
GA	0.02	-	-
MA	0.02	-	-
MN	0.02	-	-
NH	0.02	-	-
OR	0.02	-	-
RI	0.02	-	-
WA	0.02	-	-
Seattle, WA	-	-	1.3 (required)

[1] 1 $L/s{\cdot}m^2 \approx 0.2\ cfm/ft^2$
[2] Whole building limits are based on enclosure including slab and below-grade walls (not specified in 189.1). Test optional unless indicated.

Table 2. Summary of Building Airtightness Data

In the U.S., commercial building construction practices are addressed by various standards, codes, and green building program requirements, and Table 2 summarizes some of the relevant air leakage limits from these requirements. ASHRAE requires continous air barriers (CAB) for most commercial buildings in both Standard 90.1 *Energy Standard for Buildings Except Low-Rise Residential Buildings* (23) and Standard 189.1 *Standard for the Design of High-Performance Green Buildings* (22). Since 2010, Standard 90.1 requires the CAB to meet either a material tightness limit (0.02 $L/s{\cdot}m^2$ under a pressure differential of 75 Pa) or an assembly tightness limit (0.2 $L/s{\cdot}m^2$ under a pressure differential of 75 Pa), but does not include a whole building tightness limit nor a requirement for whole building pressurization testing. When using the prescriptive option for energy efficiency, Standard 189.1 includes an option of a whole building test demonstrating the building meets a tightness limit of 2.0 L/s•m^2 under a pressure differential of 75 Pa although the normalization area is not specified.

The 2012 International Energy Conservation Code (IECC, 24) has similar requirements to Standard 189.1 with options for a CAB with material or assembly tightness or a whole building test with the same limit as 189.1. The Internationl Green Construction Code (IgCC) Public Version 2.0 (25) includes a requirement for a whole building test with a leakage limit of 4.57 m^3/hr/m^2 at 75 Pa in its prescriptive compliance option, which is equivalent to 1.3 L/s•m^2. Note that Standard 189.1 is an alternative compliance path within the IgCC. Several U.S. state building codes (including Georgia, Massachusetts, Minnesota, New Hampshire, Oregon, Rhode Island, and Washington) include requirements for air barriers or whole building pressurization tests (18).

Since 2009, the USACE has required that conditioned buildings be built or retrofitted to include a continuous air barrier to control air leakage through the building envelope (19). The specification requires whole building testing with a maximum leakage of 1.3 L/s•m^2 at 75 Pa based on the building enclosure area including the slab and subgrade walls. The average tightness for a set of 31 new USACE buildings was reported to be 0.8 L/s•m^2. Zhivov estimates the first cost for new construction to be \$5.40/m^2 of floor area with a simple payback in energy savings of 2 yr to 10 yr (20). Similarly, the U.S. General Services Administration (21) now requires all new U.S. federal buildings for the Public Buildings Service to include an air barrier with the whole building having an air leakage rate of not more than 1.3 L/s•m^2 at 75 Pa.

CONCLUSION

Past NIST efforts have demonstrated that, despite assumptions to the contrary, typical modern U.S. commercial building envelopes are not particularly airtight, building envelope leakiness results in a significant energy cost, and substantial energy savings would result through the requirement of an effective air barrier for new commercial buildings. The average airtightness of the 228 buildings currently available in the NIST database is 25 m^3/h·m^2 at 75 Pa, which is a little over 10 % tighter than the average reported by Persily in 1998. The data show no significant trends related to size, year of construction, or type of construction, but when compared to recent USACE tested buildings, do demonstrate that typical commercial buildings are much leakier than buildings designed and tested to meet a whole building tightness specification. Important recent developments in U.S. codes and standards include the adoption of a continuous air barrier requirement in ASHRAE Standard 90.1-2010 *Energy Standard for Buildings Except Low-Rise Residential Buildings*, the requirement for a whole building tightness limit with testing by the USACE, and inclusion of air barrier or whole building tightness limits in various U.S. state building codes and the proposed International Green Construction Code.

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