Analysis of U.S. Commercial Building Envelope Air Leakage Database to Support Sustainable Building Design

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Abstract

In 1998, NIST 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 (Persily, 1998). Since then, NIST has expanded and maintained a database of whole building envelope leakage measurements of U.S. commercial and institutional buildings. In addition to building leakage values collected from research publications, low-energy building programs and private pressurization testing firms, the database includes basic building characteristics such as year built, building type, floor area, number of storeys, location, and wall construction type for many of the buildings. The purposes of the database are to support the design and construction of low-energy buildings, to establish default values for building simulation, to estimate the energy savings potential of airtightness requirements in standards and codes, and to identify opportunities for additional improvements in building airtightness performance.

The U.S. commercial building envelope leakage database contains data for almost 400 buildings including about 70 constructed in the past decade. The average air leakage for the buildings is 20% tighter than the average for the 228 buildings included in a similar 2011 analysis. The data were analysed to determine the factors that impact airtightness such as building type and height. Recent additions to the database include numerous buildings constructed to meet the specifications of sustainable building programs such as the U.S. Green Building Council's LEED rating system, as well as buildings designed and constructed with air barriers. The analysis found that the 79 buildings with an air barrier had an average air leakage almost 70% less than the average for the 290 buildings not specified as having an air barrier thus demonstrating the critical need to design and construct commercial buildings with an air barrier to support sustainable building design.

Key words: airtightness, air barrier, blower door, fan pressurization test, infiltration, sustainable buildings.

1. Introduction

As described by Chan et al. (2012), the U.S. National Institute of Standards and Technology (NIST), as well as other research institutes in the Czech Republic, France, Germany, the United Kingdom and the USA, maintains a database of building air leakage measurements. The NIST database focuses on whole building tests of commercial and institutional buildings and is maintained for the purposes of supporting the design and construction of low-energy buildings (Emmerich, 2006), establishing default values for modelling (Ng et al. 2012 and 2013, Persily et al. 2007), estimating the energy savings potential of improvements via standards and codes (Emmerich et al. 2005), and identifying needed improvements in building airtightness. The database includes basic building characteristics such as year built, floor area, number of storeys, location, and wall construction type for many of the buildings, though complete information is not always available from the original data sources. This paper presents analysis of the currently available airtightness data from the NIST database.

Past NIST efforts have demonstrated that, despite assumptions to the contrary, typical modern U.S. commercial building envelopes are not particularly airtight (Persily, 1998; Emmerich and Persily, 2011), building envelope leakiness results in a significant energy cost (Emmerich and Persily, 2005), and substantial energy savings would result from the requirement of an effective air barrier for new commercial buildings (Emmerich et al., 2007). This work has led to the consideration and adoption of prescriptive air barrier requirements in a number of building standards, codes, and programs (e.g., ASHRAE Standard 90.1, the USACE (U.S. Army Corps of Engineers) and several U.S. state building codes).

2. Energy Impacts

Emmerich et al. (2005) reported on a simulation study of the energy impact and cost effectiveness of improving envelope airtightness in low-rise U.S. commercial buildings to provide input to the ASHRAE Standard 90.1 committee in its consideration of adding a continuous air barrier system requirement to the standard. An air barrier system is the combination of interconnected materials, flexible joint systems, and components of the building envelope that provide the airtightness of the building as described in the Whole Building Design Guide by the National Institute of Building Sciences (http://www.wbdg.org/resources/airbarriers.php). The previous standard included detailed quantitative limits for air leakage through fenestration and doors but only very general qualitative guidance for the opaque portion of the building envelope (ASHRAE, 2001). For example, the standard required sealing, caulking, gasketing, or weather-stripping such locations as joints around fenestration and doors, junctions between floors, walls, and roofs, etc. However, there was no quantitative air leakage limit specified for either the wall and other envelope components or the building as a whole. This might be considered analogous to requiring that care be taken when installing insulation but not requiring any minimum R-value.

Annual energy simulations and cost estimates were prepared for a two-storey office building, a one-storey retail building, and a four-storey apartment building. Each building was modelled with both frame and masonry construction. The apartment building and masonry construction results are not included here due to space limitations but can be found in Emmerich et al. (2005). The combined airflow-building energy modelling tool (McDowell et al. 2003) was used to estimate the energy impact of envelope airtightness for five U.S. cities representing different climate zones (Miami, Phoenix, St. Louis, Bismarck and Minneapolis). Building model parameters were chosen such that the buildings would be considered typical of new construction and meet then current ASHRAE Standard 90.1 requirements.

The two storey office building has a total floor area of 2250 m^2, a window-to-wall ratio of 0.2 and a floor-to-floor height of 3.66 m including a 0.92 m plenum per floor. The internal heat gains for the occupied spaces include lighting, receptacle loads, and occupants. These gains are all applied using a peak value and fraction of peak schedule. The lighting peak is 10.8 W/m^2, the peak receptacle load is 6.8 W/m^2, and the peak occupancy density is 53 persons per 1000 m^2.

The retail building is a one-storey building with a total floor area of 1125 m^2, a window-to-wall ratio of 0.1 and a floor-to-floor height of 3.9 m including a 0.9 m plenum. The lighting peak is 16.2 W/m^2, the peak receptacle load is 2.6 W/m^2, and the peak occupancy density is 162 persons per 1000 m^2.

The HVAC system modelled for the office building included water-source heat pumps (WSHPs) with a cooling tower and a boiler serving the common loop. Each zone had its own WSHP rejecting/extracting heat from the common loop. The HVAC system modelled for the retail building was a packaged rooftop unit including a DX cooling coil and a gas furnace, with a separate system for each individual zone. The St. Louis, Bismarck and Phoenix buildings included economizers. The heating setpoint was 21.1 °C with a setback temperature of 12.8 °C and the cooling setpoint was 23.9 °C with a setup temperature of 32.2 °C.

Three different airtightness levels (no air barrier, target, and best achievable) were modelled in each building. The values for the no air barrier level varied for each location, while the target and best achievable construction cases were the same for all locations. The values for the no air barrier (i.e., baseline) case were established through an analysis of the airtightness data available at the time of the study. The dataset was adjusted by excluding buildings older than 1960 (even though examination of the data by U.S., Canadian and U.K. authors have found no trends toward increased airtightness in more recent buildings), all industrial buildings, and one extremely leaky building. The data were then divided into north (Standard 90.1 climate zones 5 and above) and south (Standard 90.1 climate zones 4 and below) subsets for the North American buildings only. However, the available data were inadequate to support a breakdown by the individual climate zones. Finally, within those North and South subsets, average airtightness was calculated for short buildings (3 storeys and less) and tall buildings (4 storeys and up) as the data demonstrated that the tall buildings are tighter on average. The average measured value from the short buildings in the south was used as the baseline value in the warmest climate (Miami) and the average measured value from the short buildings in the north was used as the baseline value in the coldest climate (Bismarck). The values for the remaining locations were assigned by linearly interpolating between these values using the number of heating degree days for the location. The resulting baseline whole building air leakage values at 75 Pa with no air barrier were as follows:

Miami	11.8 L/s-m^2
Phoenix	11.1 L/s-m^2
St. Louis	9.1 L/s-m^2
Minneapolis	7.2 L/s-m^2
Bismarck	6.6 L/s-m^2

In addition to the baseline level, all buildings were modelled at two levels of increased airtightness. Both published building airtightness data and current commercial buildings airtightness standards were considered in selecting these levels. The ‘target’ level was selected to represent a level of airtightness that can be achieved through good construction practice, while the ‘best achievable’ level is based on the tightest levels reported for nonresidential buildings. About 6 % of the buildings listed in the database at the time of the study would meet the selected target airtightness level (1.2 L/s-m^2). Achieving the tightest level (0.2 L/s-m^2) would require an aggressive program of quality control during construction and airtightness testing, combined with efforts to identify and repair any leaks. In all cases, the air leakage was distributed uniformly over all above-grade envelope surface areas.

Energy simulations were performed using TRNSYS (Klein, 2000) - a transient system simulation program with a modular structure that was designed to solve complex energy system problems by dividing the problem into a series of smaller components. The infiltration in the buildings was modelled using a TRNSYS type based on an updated version of the AIRNET model (Walton, 1989), which is included in the multizone airflow and contaminant dispersal program CONTAM (Walton and Dols, 2005). Infiltration is the airflow through leaks in the building envelope driven by pressure differentials caused by weather and mechanical system operation, which is distinct from intentional outdoor air intake via the ventilation systems. Note that unintentional airflow through mechanical systems may also be significant through damper and duct leakage but was not included in this study.

As shown in Tables 1 and 2, the annual average infiltration for the office and retail buildings with

Table 1. Annual average infiltration and HVAC energy cost savings for target office building.

City	**Annual Average Infiltration (h^{-1})**		**Gas Savings**		**Electrical Savings**		**Total Savings**
	Baseline	**Target**					
Bismarck	0.22	0.05	$1,854	42%	$1,340	26%	$3,195
Minneapolis	0.23	0.05	$1,872	43%	$1,811	33%	$3,683
St. Louis	0.26	0.04	$1,460	57%	$1,555	28%	$3,016
Phoenix	0.17	0.02	$124	77%	$620	9%	$745
Miami	0.26	0.03	$0	0%	$769	10%	$769

Table 2. Annual average infiltration and HVAC energy cost savings for target retail building.

City	**Annual Average Infiltration (h^{-1})**		**Gas Savings**		**Electrical Savings**		**Total Savings**
	Baseline	**Target**					
Bismarck	0.20	0.02	$1,835	26 %	$33	2 %	$1,869
Minneapolis	0.22	0.02	$1,908	28 %	$364	18 %	$2,272
St. Louis	0.24	0.01	$1,450	38 %	$298	9 %	$1,748
Phoenix	0.13	0.00	$176	64 %	$992	14 %	$1,169
Miami	0.21	0.01	$6	98 %	$1,224	14 %	$1,231

the baseline air leakage rate ranges from 0.13 h^{-1} to 0.26 h^{-1} depending on the climate. Reducing the air leakage rate to the target level reduces the annual average infiltration rates by an average of 83% for the office building and 94% for the retail building. (Note that outdoor air ventilation requirements are met for these buildings through operation of the mechanical ventilation systems.)

Tables 1 and 2 also summarize the annual heating and cooling energy cost savings for the office and retail buildings at the target air leakage level relative to the baseline level. The annual cost savings are largest in the heating dominated climates.

3. U.S. Commercial Building Airtightness Database and Analysis

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. ASTM Standard E779 (ASTM, 2010) 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. For 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, 2010). 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. While traditionally most of the data available to NIST was normalized by above-grade surface area (i.e., 5-sided box), many U.S. codes and standards now prescribe requirements normalized by total enclosure surface area (i.e., 6-sided box).

The airtightness values in the database are collected from a number of different sources 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 either the above-grade or total surface area of the building envelope. For some buildings in the database, complete dimensions were not available for the conversion between above-grade and total (e.g., due to the lack of specific details on the below-grade wall area). For these buildings, an assumption was made that there were no below-grade walls and the conversion was based merely on adding the footprint of the floor slab to the building envelope surface area. When these data were lacking, a conversion factor of 1.5 was used for the ratio of the 6-sided to 5-sided envelope surface area based on the average value for other buildings in the database. Data are based on an average of pressurization and depressurization tests unless only one mode was available. Also, when necessary, conversion of air leakage at a pressure other than 75 Pa 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. In cases where existing buildings were tested both

Table 3. Summary of Building Airtightness Data.

		5-sided Air Leakage at 75 Pa ($m^3/h{\cdot}m^2$)				6-sided Air Leakage at 75 Pa ($m^3/h{\cdot}m^2$)			
Dataset	Qty	Mean	Std Dev	Min	Max	Mean	Std Dev	Min	Max
Efficiency Vermont	36	9.6	10.3	0.7	48.4	6.4	6.9	0.5	32.3
ASHRAE RP 1478	16	7.0	5.0	1.4	20.4	5.3	3.7	1.0	13.6
Washington	18	10.5	4.1	3.0	17.5	7.2	2.8	2.0	11.6
Other VT/NH	79	14.8	10.8	1.4	45.9	9.8	7.3	0.9	31.5
Other	10	8.3	6.4	2.6	22.7	5.4	4.1	1.6	13.6
All new data	**159**	**9.9**	**8.5**	**0.7**	**48.4**	**6.6**	**5.4**	**0.5**	**32.3**
All old data	**228**	**24.9**	**19.2**	**2.7**	**124**	**16.7**	**12.7**	**1.6**	**77.9**
All buildings	**387**	**19.5**	**17.2**	**0.7**	**124**	**13.1**	**11.4**	**0.5**	**77.9**

Note: Convert to cfm/ft^2 by multiplying by 0.055

before and after an airtightness retrofit, only the before (or as-found) value is included in the database. A future paper will address the impact of such retrofits on airtightness.

Table 3 contains a summary of the air leakage data for the 387 U.S. commercial and institutional buildings included in the NIST database. Significant sources of new data since Persily and Emmerich (2011) include 41 buildings built or renovated under the Efficiency Vermont program which provides technical assistance and financial incentives to help Vermont households and businesses reduce their energy costs, 16 recently built mid- and high-rise buildings tested under ASHRAE research project 1478 (Anis et al., 2013), 79 additional buildings located primarily in Vermont and New Hampshire that were tested by several building envelope consultants, 18 buildings in Washington state that were tested due to a local code requirement that includes a non-mandatory target airtightness level, and three other buildings. The buildings in the database were tested for a variety of purposes and were not randomly selected to constitute a representative sample of U.S. commercial buildings.

In the past, the NIST commercial building air leakage database did not include many buildings known to be designed or constructed with the intent of achieving a tight building envelope. This update includes many such buildings but does not, however, include several hundred buildings designed, built and tested to meet the USACE maximum whole building airtightness 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). The USACE buildings are tested and improvements to airtightness are made if they fail to meet the standard.

Table 3 presents a summary of the airtightness values for the buildings in the database, with separate summaries using 5-sided and 6-sided surface area normalizations. As seen in the table for 5-sided normalization, the average air leakage at 75 Pa for the 387 buildings is 19.5 $m^3/h{\cdot}m^2$, which is 20% tighter than the average of 24.9 $m^3/h{\cdot}m^2$ for the U.S. buildings included in the earlier analysis by Emmerich and Persily (2011). Perhaps of more interest is the fact that the average of the new data is 50% tighter than the old data. Calculated pressure exponents were available for 149 of the buildings with an average of 0.62 and a standard deviation of 0.086. Figure 1 shows a frequency distribution of the normalized building air leakage (based on 6-sided enclosure) for all of the buildings.

Impact of air barrier

The most significant feature of the additional buildings in the database is that many are buildings in which there is reason to believe some care was

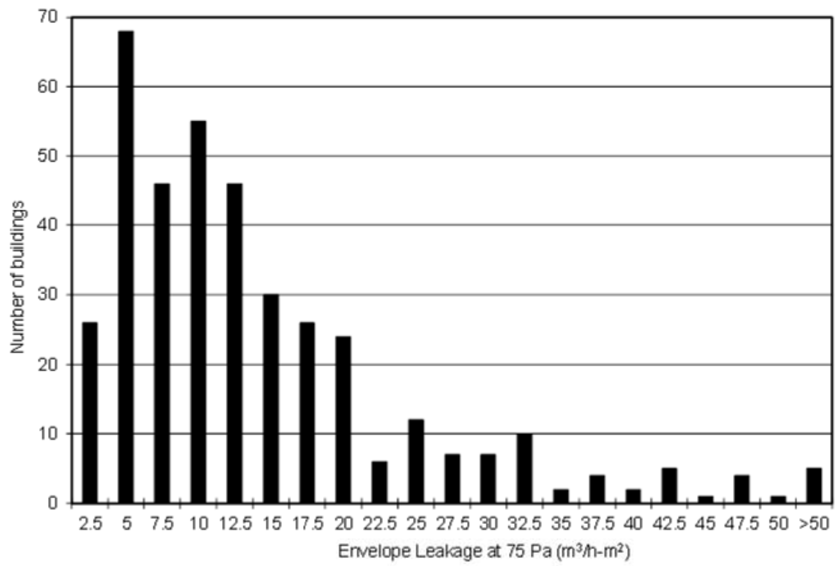

Figure 1. Frequency distribution of normalized building air leakage (6-sided enclosure).

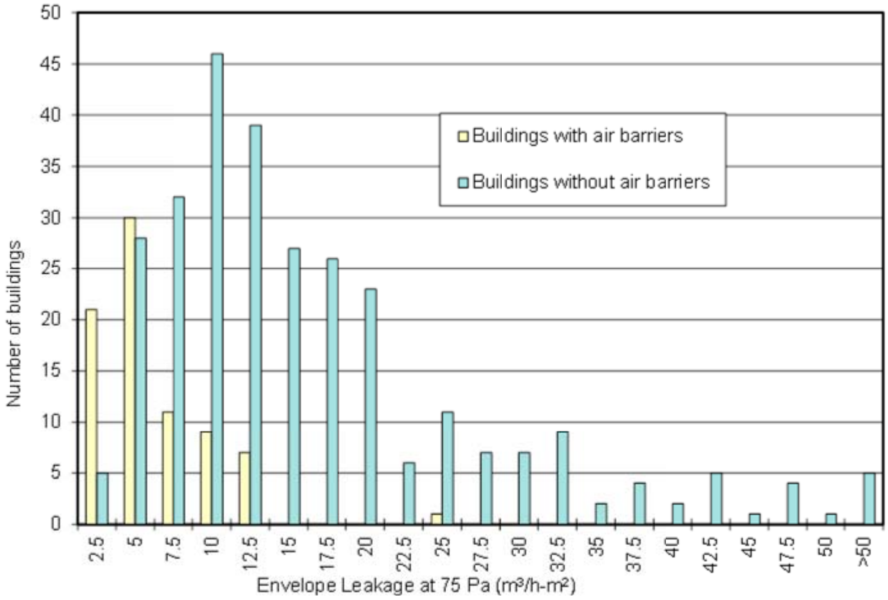

Figure 2. Frequency distribution of normalized building air leakage (6-sided enclosure) of buildings with and without air barrier.

taken to achieve a tight building envelope, including both many new buildings and several retrofit cases. This is in sharp contrast to the buildings included in past publications in which very few were identified as such. There is a wide variety of measures taken to limit or reduce air leakage among these buildings and detailed descriptions of the air barrier or measures are rarely available. Some of the new buildings would not fully meet the air barrier requirements of standards such as ASHRAE Standards 90.1 or 189.1 while others would exceed those requirements by having a high degree of attention to airtightness during design, construction and commissioning. However, very few of the buildings had a specific mandatory airtightness limit such as that required by the USACE. Buildings counted as having an air barrier for the purposes of this analysis include those identified by the building tester as having one, buildings participating in the Efficiency Vermont program, those known to have used a building envelope consultant, and those in Washington state with a code requirement for an air leakage test but with a non-mandatory target value.

Figure 2 shows a frequency distribution of the measured leakage at 75 Pa (normalized by the 6-sided enclosure area) of the buildings with and without an air barrier designation as described above. Existing buildings tested after air sealing are excluded from Figure 2 and will be addressed in a future publication. It can be seen that Figure 1 is actually a bimodal distribution consisting of the two separate distributions shown in Figure 2. As shown in Figure 2, the average of (5.0 ± 3.7) $m^3/h{\cdot}m^2$ for the 79 buildings with an air barrier is almost 70% less than the average of (15.6 ± 11.9) $m^3/h{\cdot}m^2$ for the 290 buildings not specified as having an air barrier (note that undoubtedly at least a few of these buildings were built with air barriers). Despite the wide range of attention to airtightness among the buildings designated as having air barriers, the standard deviation of the leakage for the buildings with air barriers is also much smaller than the non-air barrier buildings, thus, making the air leakage of such buildings more predictable. However, it is still difficult to predict an expected level of airtightness from a specific air barrier approach due to the lack of detailed descriptions of the air barriers for most of these buildings.

Other Factors

The airtightness data were also analyzed to assess the impact of a number of factors on envelope airtightness including the number of storeys and building type. It is important to note that the lack of random sampling and the small sample size limits the strength of any conclusions concerning the impacts of these factors. As mentioned previously, not all of these parameters were available for all buildings in the database. Also, given that Figure 2 showed the impact of an air barrier on building airtightness, the analyses described below were conducted separately for the buildings without air barriers.

Past analysis has shown that the air leakage at 75 Pa shows a tendency toward more consistent tightness for taller buildings (Emmerich and Persily, 2005 and 2011). However, data were available for relatively few buildings of 4 storeys or more, which limited the robustness of this finding. ASHRAE Research Project RP 1478 was initiated to help address this

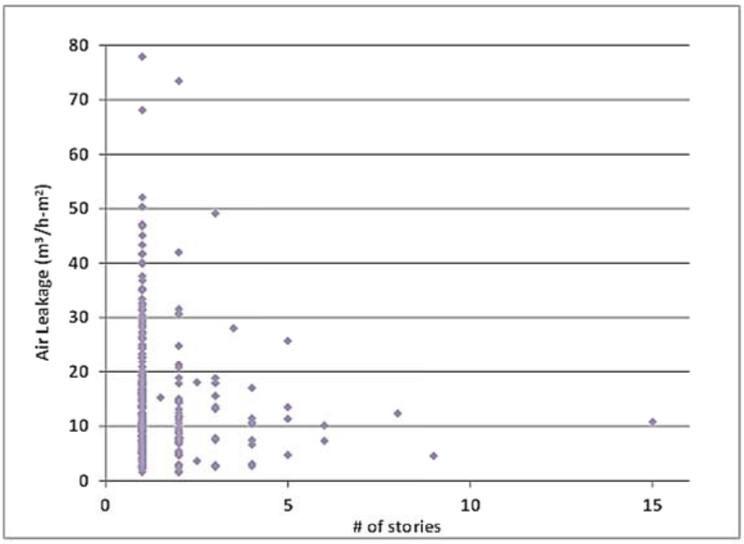

Figure 3. Normalized building air leakage versus height of building (in stories).

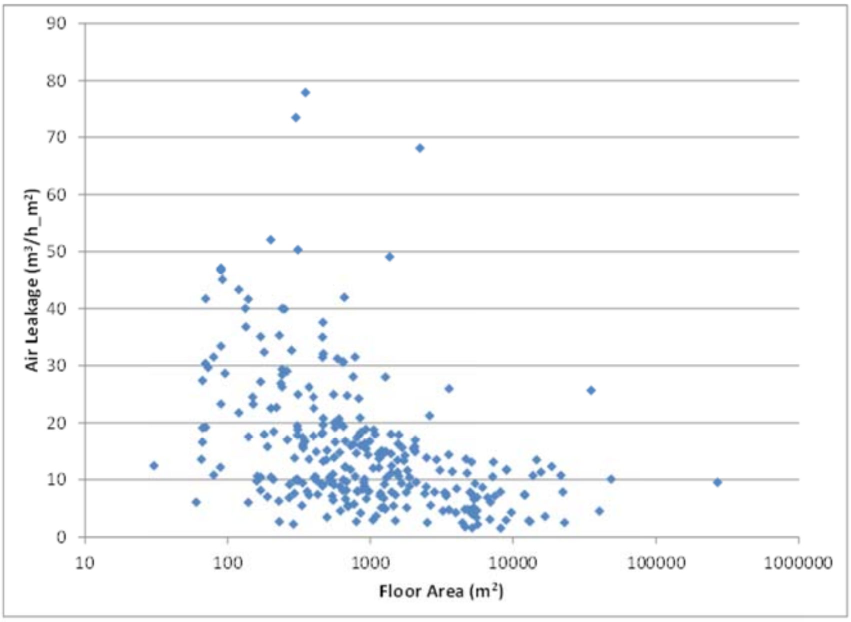

Figure 4. Normalized building air leakage versus building floor area.

lack of such data, and, largely due to the results of that project, the number of mid- and high-rise buildings in the database has more than doubled. Figure 3 is a plot of the air leakage at 75 Pa (normalized by 6-sided enclosure surface area) versus the reported number of storeys of the building for the buildings without air barriers. These data still shows a weak tendency toward more consistent tightness for taller buildings (one building over 16 storeys is not shown). The average leakage for the 18 buildings of 4 or more storeys is (10.0 ± 5.4) $m^3/h{\cdot}m^2$, while the average for the 269 buildings of 3 or fewer storeys is (16.0 ± 11.7) $m^3/h{\cdot}m^2$. As before, the shorter buildings display a wider range of building leakage.

Since it is believed that the relationship (though weak) between building height and airtightness could be due to differences in design and construction techniques of small and large buildings, further analysis was conducted to look for a relationship between airtightness and floor area as an alternative indicator of building size. Figure 4 is a plot of the air leakage at 75 Pa (normalized by 6-sided enclosure surface area) versus floor area for the buildings without air barriers. These data show a somewhat stronger tendency toward more consistent tightness for larger buildings based on floor area than based on height. The average leakage for the 41 buildings of 5000 m^2 or more is (7.5 ± 4.6) $m^3/h{\cdot}m^2$, which is less than half the average for the 246 buildings of less than 5000 m^2 which is (17.0 ± 12.3) $m^3/h{\cdot}m^2$. As before, the smaller buildings display a wider range of building leakage.

Figure 5 is a plot of the air leakage at 75 Pa (normalized by 6-sided enclosure area) versus building type for 270 of the buildings without air barriers from the database (only categories with at least 7 buildings are shown). The average air leakage ranges from a low of (12.3 ± 8.8) $m^3/h{\cdot}m^2$ for education buildings to a high of (27.7 ± 20.4) $m^3/h{\cdot}m^2$ for industrial. While the data suggests that retail, restaurants and industrial buildings are leakier than the other types (office, education, public assembly, and long-term healthcare), the large standard deviations for the individual categories do not support any firm conclusions.

Figure 6 is a plot of the air leakage at 75 Pa (normalized by 6-sided enclosure area) versus wall construction type for 214 of the buildings without

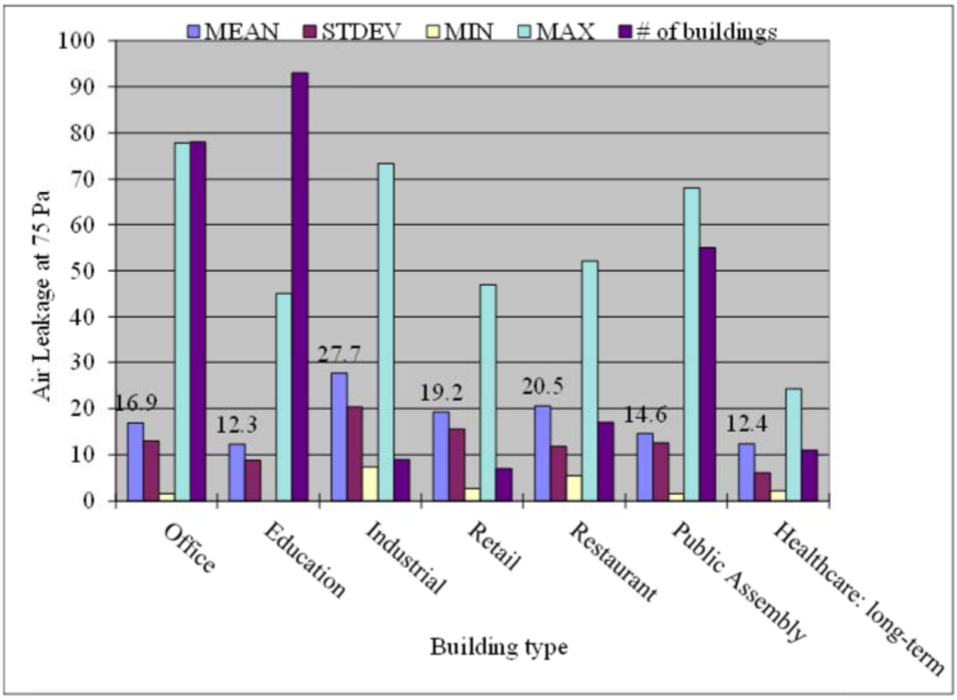

Figure 5. Normalized building air leakage versus building type.

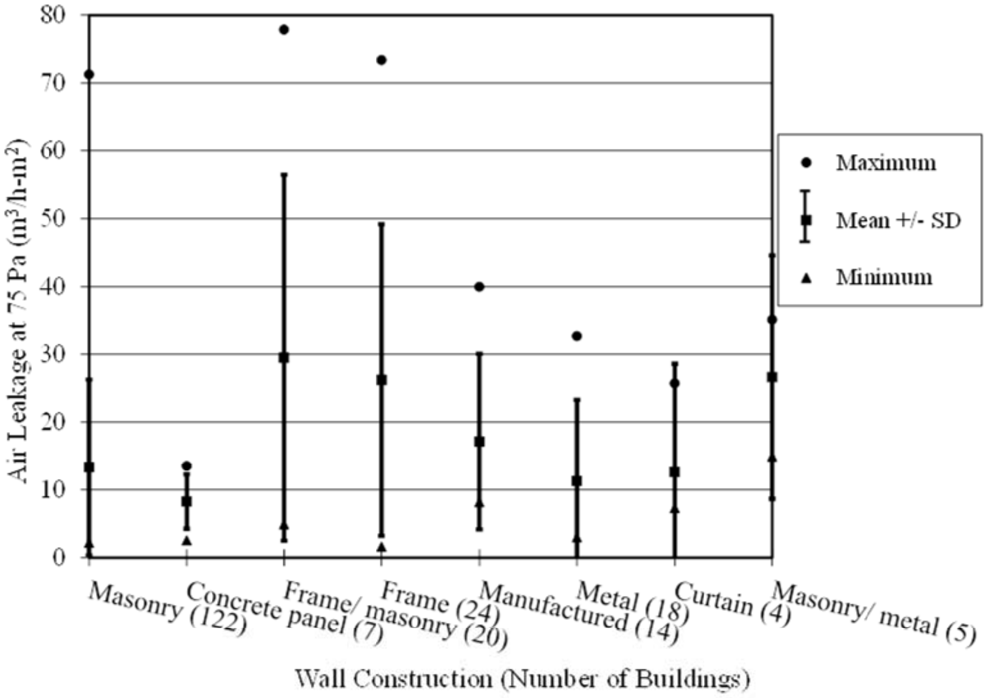

Figure 6. Normalized building air leakage versus wall type.

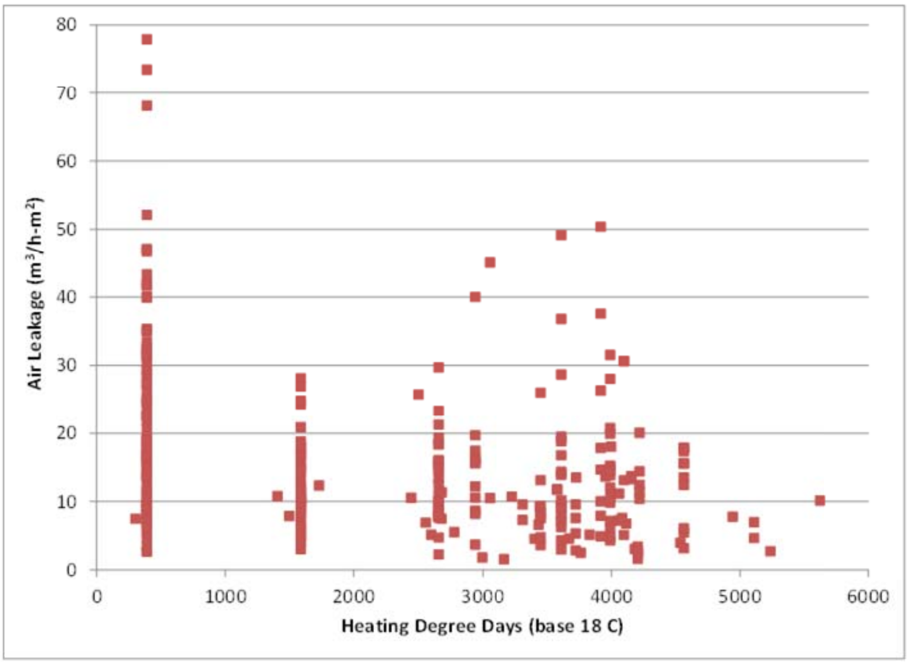

Figure 7. Normalized building air leakage versus climate (in heating degree-days base 18 °C).

air barriers from the database. While the data suggests that buildings with frame, masonry/metal 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

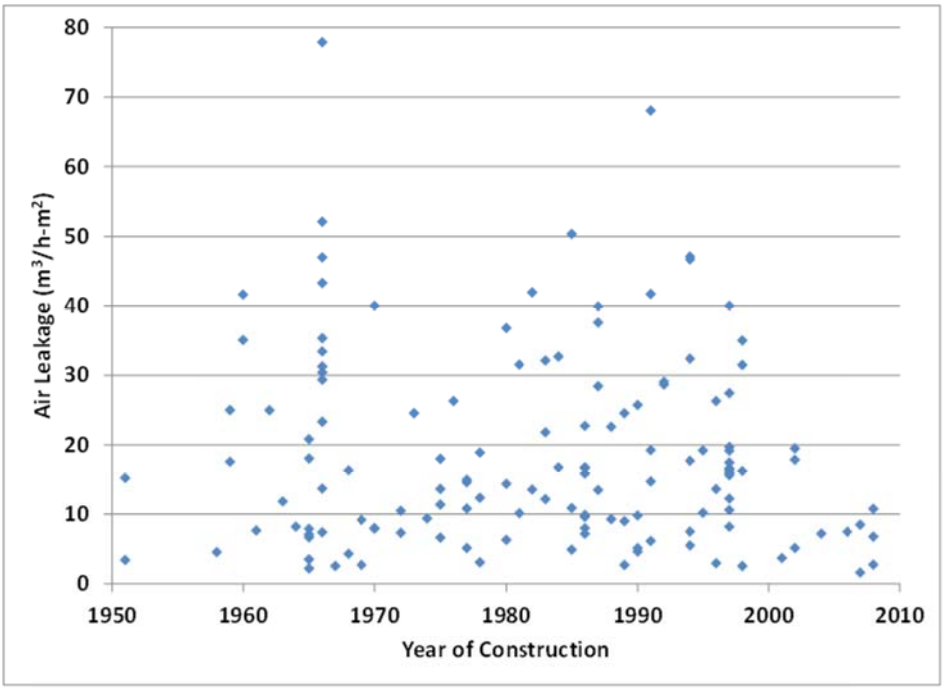

Figure 8. Normalized building air leakage vs. year of construction.

complicated by a lack of clear definition of construction types and because the use of different terms for wall construction may not be consistent among those reporting the leakage data.

Figure 7 is a plot of the air leakage at 75 Pa (normalized by 6-sided enclosure area) versus the climate where the building is located as measured by annual heating degree-days base 18 °C for buildings without air barriers (293 of the buildings). Approximate heating degree-day values were used for some of the buildings 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 indicate a general trend toward tighter constructions in the colder climates. The average air leakage was (18.6 ± 13.6) m^3/h·m^2 for 141 buildings in locations with less than 2000 heating degree-days compared to (12.6 ± 9.1) m^3/h·m^2 for 152 buildings in locations with more than 2000 heating degree-days. Although there are data from numerous locations, there are almost no data from the western U.S.

Figure 8 is a plot of the air leakage at 75 Pa (normalized by 6-sided enclosure area) versus the year of construction of the building for 138 buildings without air barriers built since 1950. The year of construction was not available for about half of the buildings. While a common expectation is that newer vintage commercial buildings would be tighter than older ones, the data indicate no significant trend towards tighter buildings for buildings without air barriers. There is a lack of very leaky buildings from the past decade; however, there are a limited number of data points available in that time period. Additionally, most of the buildings from the last decade are located in cold climates, which have been observed to be a stronger indicator of tight building envelopes (see above).

The recent additions to the database also include numerous buildings constructed to meet the specifications of sustainable or high performance building programs such as the U.S. Green Building Council's LEED rating system (USGBC, 2009). The average leakage at 75 Pa (normalized by 6-sided enclosure area) is (5.3 ± 5.4) m^3/h·m^2 for the 23 buildings reported with various green labels compared to the average of (13.6 ± 11.6) m^3/h·m^2 for the 364 buildings not identified as green buildings. However, one should not draw the conclusion that these buildings are tighter *because* they have green building labels since 20 of the 23

Table 4. Summary of Building Airtightness Data.

	Air Leakage at 75 Pa (L/s·m²)		
Standard or code	**Material**	**Assembly**	**Whole building**[2]
ASHRAE 90.1	0.02	0.2	-
ASHRAE 189.1	0.02	0.2	1.25
IECC	0.02	0.2	2.0
IgCC	Same as IECC	Same as IECC	1.25
USACE	0.02	-	1.25
GSA	0.02	0.2	2.0

[2]Whole building limits are based on 6-sided enclosure including slab and below-grade walls.

green buildings were identified as having air barriers and the average leakage for green buildings with air barriers was actually slightly higher than for other buildings with air barriers.

4. U.S. Codes and Standards

In the U.S., commercial building construction practices are addressed by various standards, codes, and green building program requirements and Table 4 summarizes some of the relevant air leakage limits from these requirements. ASHRAE requires continuous air barriers (CAB) for most commercial buildings in both Standard 90.1 *Energy Standard for Buildings Except Low-Rise Residential Buildings* (ASHRAE 2010a) and Standard 189.1 *Standard for the Design of High-Performance Green Buildings* (ASHRAE 2013). Since 2010, Standard 90.1 requires the CAB to meet either a material tightness limit (0.02 L/s•m^2 under a pressure differential of 75 Pa) or an assembly tightness limit (0.2 L/s•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. The building commissioning requirements of Standard 189.1 include 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 or the implementation of a rigorous envelope commissioning program.

The 2012 International Energy Conservation Code (ICC 2011) has requirements with options for a CAB with material or assembly tightness or a whole building test. The 2012 International Green Construction Code (IgCC) (ICC 2012) includes the same requirements as the 2012 IECC but also includes a whole building testing requirement consistent with the USACE value. Many U.S. state building codes (including California, Connecticut, District of Columbia, Florida, Georgia, Illinois, Maryland, Massachusetts, Minnesota, New Hampshire, New York, North Carolina, Pennsylvania, Oregon, Rhode Island, Texas and Washington) currently (or will soon) include requirements for continuous air barriers either through reference to IECC, IGCC, ASHRAE Standard 90.1 or 189.1, or their own independent requirement (see http://www.airbarrier.org/codes/index_e.php for updated information on air barrier requirements in U.S. building codes). The impact of including an air barrier in a building envelope is shown by the fact that over 75% of the buildings with air barriers in Figure 2 would meet the whole building air leakage limit of Standard 189.1 (and the 2012 IECC/IGCC) while fewer than 25% of the buildings without air barriers would qualify.

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 (USACE 2009). The specification requires whole building testing with a maximum leakage of 1.25 L/s•m^2 at 75 Pa based on the 6-sided building enclosure area including the slab and subgrade walls. The average tightness for a set of 285 new and retrofitted USACE buildings was reported to be 0.9 L/s•m^2 (Zhivov 2013). Also, the U.S. General Services Administration (GSA 2011) 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 2.0 L/s•m^2 at 75 Pa.

5. 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 387 buildings currently available in the NIST database is about 20% tighter than the average based on 228 buildings reported by Emmerich and Persily in 2011. The data show only weak trends related to year of construction, height, floor area, wall construction and building type, but do demonstrate that buildings designed and constructed with attention to airtightness are much tighter than typical commercial buildings. The analysis found that the 79 buildings with air barriers have an average air leakage almost 70% less than the average for the 290 buildings not specified as having an air barrier, thus demonstrating the critical need to design and construct commercial buildings with an air barrier to support sustainable building design. However, the wide variation among the measures taken to limit or reduce air leakage among these buildings and the lack of detailed descriptions of the air barrier make it difficult to predict a specific level of airtightness that will result from a specific air barrier approach.

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