ANALYSIS OF THE NIST COMMERCIAL AND INSTITUTIONAL BUILDING ENVELOPE LEAKAGE DATABASE

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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 stories, location, and wall construction type for many of the buildings. The purpose of the database is 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. This paper presents an update of the currently available airtightness data from the NIST commercial building air leakage database.

The U.S. commercial building envelope leakage database now contains data for almost 350 buildings including more than 50 constructed in the past decade. The data were analysed to determine the impact on airtightness of factors such as building type and height. Significantly, recent additions to the database 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 as well as buildings designed and constructed with air barriers, both of which tend to correlate with lower building envelope air leakage.

KEYWORDS
Airtightness, air barrier, fan pressurization test, infiltration, sustainable buildings

INTRODUCTION
As described by Chan et al. (2012), the U.S. National Institute of Standards and Technology (NIST), along with other research institutes in the Czech Replubic, France, Germany, the United Kingdom and the USA, maintains a database building air leakage measurements. The NIST database focusses on whole building tests of commercial and institutional buildings and is maintained for the purposes of establishing default values for modeling (Ng et al. 2013), estimating the energy savings potential of improvements via standards and codes (Emmerich et al. 2005), and identifying progress needed in improving building airtightness. It includes basic building characteristics such as year built, floor area, number of stories, location, and wall construction type for many of the buildings, though this information is not always available from the original data sources. This paper presents 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 through 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, and several states in the U.S).

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. 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 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. 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 in both before and after 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 airightness.

DATABASE AND ANALYSIS

Table 1 contains a summary of the air leakage data for the 345 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, 38 additional buildings located primarily in Vermont and New Hampshire which 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 (12, 16). 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 to achieve a tight building envelope. This update however includes many such buildings. However, the database does not include several hundred buildings designed, built and tested to meet the USACE 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). The USACE buildings are tested and improvements to airtightness are made if they fail to meet the standard.

Table 1. 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	38	11.3	9.5	1.4	45.9	7.2	5.7	0.9	26.0
Other	9	8.8	6.6	2.6	22.7	9.0	5.7	4.3	1.6
All new data	**117**	**9.9**	**8.5**	**0.7**	**48.4**	**6.6**	**5.4**	**0.5**	**32.3**
All buildings	**344**	**19.8**	**19.2**	**0.7**	**124**	**13.3**	**11.8**	**0.5**	**77.9**

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

Table 1 presents a summary of the airtightness values for the buildings in the database, with seaprate 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 344 buildings is 19.8 $m^3/h{\cdot}m^2$, which is 20 % tighter than the average of 24.8 $m^3/h{\cdot}m^2$ for the U.S. buildings included in the earlier analysis by Emmerich and Persily (2011). Calculated flow 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).

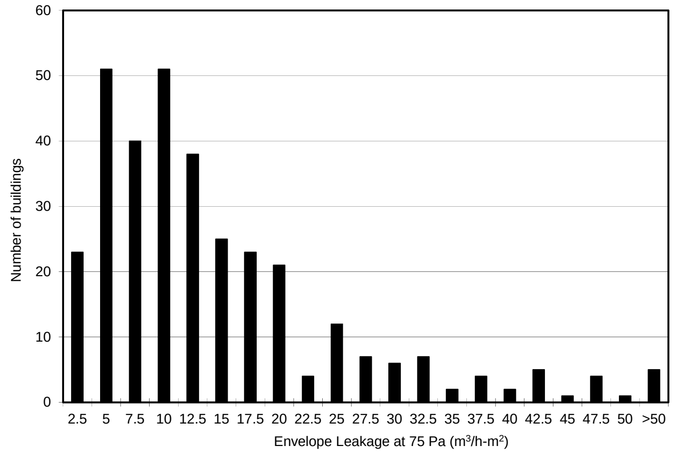

Figure 1 Frequency distribution of normalized building air leakage (6-sided enclosure)

Impact of air barrier

The most significant feature of the additional buildings in the database is that a majority are buildings in which there is reason to believe some care was 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 of the buildings were identified as such. A wide variation exists among the 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 included those with an air barrier identified as part of the design by the building tester, 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 show the measured leakage at 75 Pa (normalized to 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. As shown in Figure 2, the average of 5.4 ± 4.0 $m^3/h{\cdot}m^2$ for the 68 buildings with an air barrier is 66 % less than the average of 16.1 ± 12.6 $m^3/h{\cdot}m^2$ for the buildings without one. Despite the wide range of attention to airtightness among these buildings, 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 detail on the air barriers for most of these buildings.

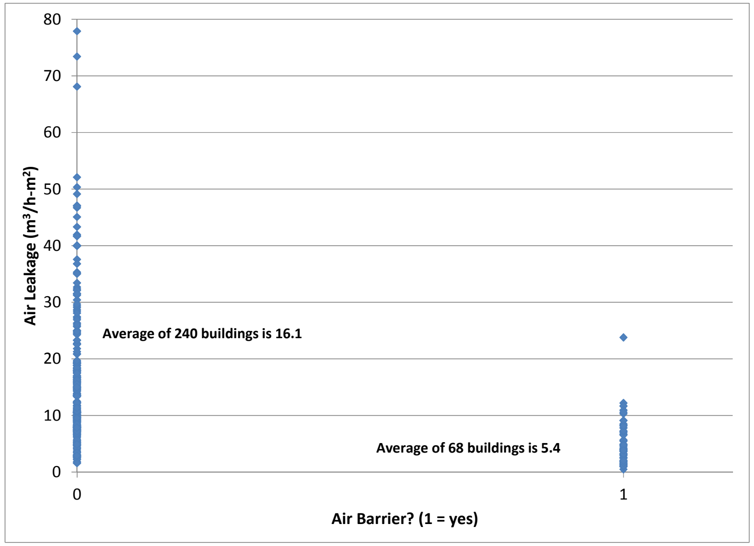

Figure 2 Normalized building air leakage (6-sided enclosure) of buildings with and without air barrier

Other Factors

The airtightness data were also analyzed to assess the impact of a number of factors on envelope airtightness including number of stories 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.

Past analsysis has shown that the air leakage at 75 Pa shows a tendency toward more consistent tightness for taller buildings (Emerich and Persily 2005 and 2011). However, data was available for relatively few buildings of 4 stories or more which limited the robustness of this evaluation. ASHRAE Research Project RP 1478 was initiatied to help address this lack of data, and, largely due to the results of that project, the number of mid- and high-rise buildings in the data base has more than doubled. Figure 3 is a plot of the air leakage at 75 Pa (normalized by 6-sided enclosure surface area) vs. the reported number of stories of the building. These data still shows a tendency toward more consistent tightness for taller buildings (one building over 16 stories is not shown). The average leakage for the 29 buildings of 4 or more stories is 7.7 ± 5.1 $m^3/h{\cdot}m^2$, while the average for the 268 buildings of 3 or fewer stories is 15.1 ± 12.4 $m^3/h{\cdot}m^2$. As before, the shorter buildings display a wider range of building leakage. The number of stories is not reported for the remaining buildings.

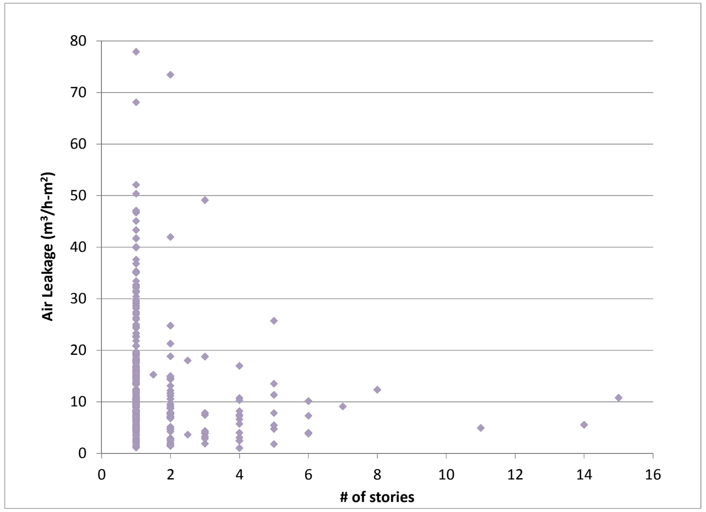

Figure 1: Normalized building air leakage vs. height of building (in stories)

Figure 4 is a plot of the air leakage at 75 Pa (normalized by 6-sided enclosure area) vs. building type for 303 of the buildings from the database (only categories with at least 10 buildings are shown). The average air leakage ranges from a low of 11.9 ± 9.2 $m^3/h{\cdot}m^2$ for education buildings to a high of 20.0 ± 11.6 $m^3/h{\cdot}m^2$ for restaurants. While the data suggests that restaurants and industrial buildings are leakier than the other types (office, education, retail, public assembly, and long-term healthcare which are all very similar), the large standard deviations for the individual categories do not support any firm conclusions.

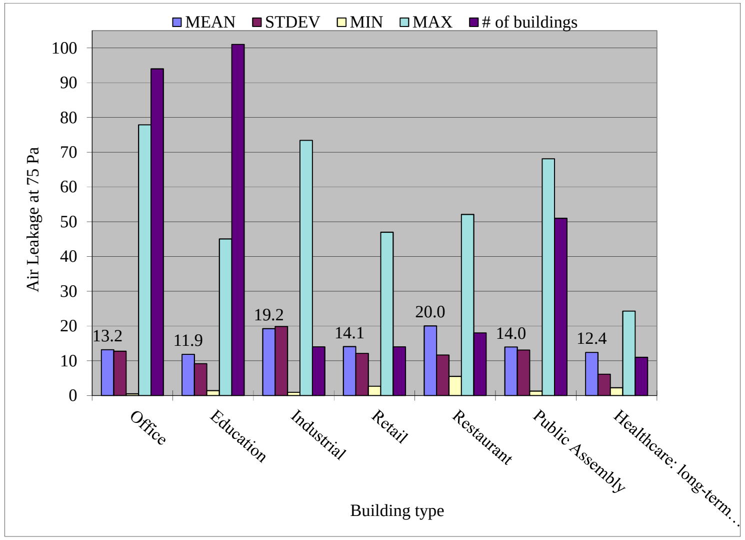

Figure 4: Normalized building air leakage vs. Building type

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) was 5.2 ± 3.6 $m^3/h{\cdot}m^2$ for the 17 buildings reported with various green labels compared to the average of 13.7 ± 11.9 $m^3/h{\cdot}m^2$ for the 327 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 the 17 green buildings overlap substantially with other factors shown above to correspond to reduced air leakage. Specifically, 11 of them have air barriers and 11 of them are 4 stories or taller; also, until recently, most green building programs paid little attention to building airtightness.

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 345 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 height or building type, but do demonstrate that buildings designed and constructed with attention to airtightness are much tighter than typical commercial buildings. 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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