Impact of Large Building Airtightness Requirements

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ABSTRACT

Air leakage into and out of buildings affects building durability, occupant comfort, indoor air quality, and energy consumption. Recently, in response to increasing societal concern regarding the environment and rising energy costs, building enclosure airtightness is garnering more attention. Various jurisdictions in North America and worldwide have implemented or are considering implementing airtightness testing and/or quantitative airtightness performance requirements into building regulations. This paper summarizes select results from a study into the state of the industry with respect to the airtightness of large buildings in North America.

As part of this study, airtightness test results from more than 500 buildings located primarily in North America were compiled into a one-of-a-kind database. The results are presented to demonstrate historical and current airtightness levels as well as to quantify the impact or whole building airtightness regulations on the measured airtightness of building enclosures. Additionally, the results of a survey that asked industry members working in a jurisdiction with mandatory whole-building airtightness testing to respond to questions regarding the impact of the regulations as well as their perception of the regulations are presented. Finally, the paper provides commentary on the difference between air leakage and airtightness and identifies where further research is required to allow for more accurate determination of large building air leakage rates.

Overall, this paper provides the foundational information necessary to assess current airtightness performance and the impact of existing requirements so as to allow for evidence-based widespread adoption of whole-building airtightness regulations for large buildings.

INTRODUCTION AND BACKGROUND

Air leakage into and out of buildings affects building durability, occupant thermal and acoustical comfort, indoor air quality, and energy consumption. In response to increasing societal concern regarding these building performance characteristics, and in particular energy consumption, improving building enclosure airtightness to reduce air leakage is receiving increased attention. In various North American jurisdictions and worldwide, this has led to a shift in the way the industry designs, specifies, builds, and measures airtightness. One important change is a shift away from relying solely on material and component airtightness performance towards a whole building airtightness approach. This move by the industry recognizes that airtightness performance relies heavily on detailing and quality control through the entire construction process and that a method which accounts for these aspects is valuable. While whole-building airtightness testing of single-family homes is common, airtightness testing of large buildings is still relatively uncommon. In some jurisdictions mandatory whole-building airtightness testing and performance standards have already been implemented and many others are investigating and planning for implementation in the near future.

In support of potential widespread adoption of airtightness performance and testing requirements for large buildings, a study was conducted to better understand the current state of

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the industry with respect to airtightness of large buildings and to evaluate the impact of implementing testing and performance standards. This study compiled the results of more than 500 airtightness tests and surveyed industry members where whole-building airtightness regulations have already been implemented to assess the quantitative performance impact of these types of regulations as well as other factors such as the cost of construction and perceived value. This paper is a summary of select findings from a larger study by RDH Building Science (2015).

MEASURED PERFORMANCE

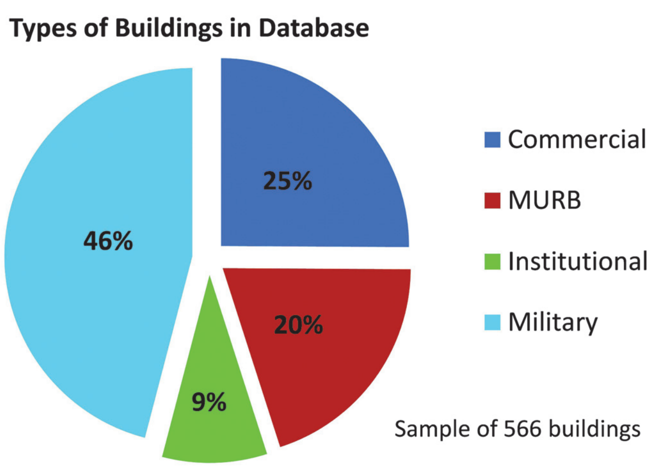
To quantify the airtightness performance of large buildings, a database of test results was compiled. The database is populated with data from various sources available in literature, from industry members that contributed data, and from unpublished test results available directly through members of the project team. Data collection efforts focused on results from the United States and Canada; however, available results from other jurisdictions were also collected, in particular from the United Kingdom. A complete set of references for the airtightness data is provided in the RDH Building Science report (2015).

In total, 721 airtightness tests were collected, within which there were 584 unique buildings, as many buildings were tested multiple times. Test results that had inconsistent reporting, unclear test boundaries, or used unclear methods were removed from the dataset, resulting in 566 test results of unique buildings that were deemed suitable for analysis and included in the database. Figure 1 presents the distribution of (a) building type and of (b) geographical location for the buildings included in the database.

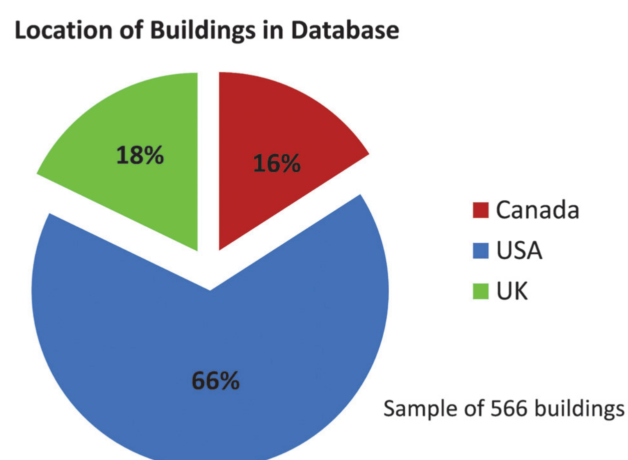
Figure 1 illustrates that the majority of buildings in the database are "military" and located in the United States. This finding is because one of the major jurisdictions currently requiring airtightness testing is the United States Army Corps of Engineers (USACE & ABAA 2012). Hundreds of buildings have been tested for compliance with USACE regulations and these results form approximately 46% of the total database population. The impact of this large sampling of USACE buildings can also be seen in Figure 2, which shows the distribution of airtightness performance for all of the buildings in the database. A significant decrease in frequency is noticeable at 1.25 $L/(s \cdot m^2)$ (0.25 cfm/ft^2), which is the USACE performance requirement. This significant decrease suggests that buildings are often retested so that they achieve the requirement.

As part of the data collection process, information on various building characteristics was collected, including age, height, floor area, enclosure area, general construction type, and air barrier type. An analysis of this data is possible; however, this paper focuses on changes in airtightness performance over time because of gradual evolution in construction materials and practices as well as because of the implementation of testing requirements. The database contains buildings constructed between 1956 and 2014. To assess the change in the airtightness of large buildings over this time period, the test results were plotted versus the year of construction in Figure 3. This figure indicates a general trend of improving airtightness in modern construction and, in particular, this figure illustrates a narrowing of the expected range in performance values.

Buildings in the database may have been tested for a number of reasons, whether as part of investigations, as part of voluntary high-performance building programs, for general research, or for compliance with mandatory testing requirements. Different reasons for testing would likely also relate to expected airtightness of the building. For example, if a building is being designed and constructed with the knowledge that it will be tested upon completion, it is reasonable to expect that it would be more airtight than the general population of build-



(a)



(b)

Figure 1 *Charts of (a) distribution of building types in the airtightness database and (b) geographical location of buildings in the airtightness database.*

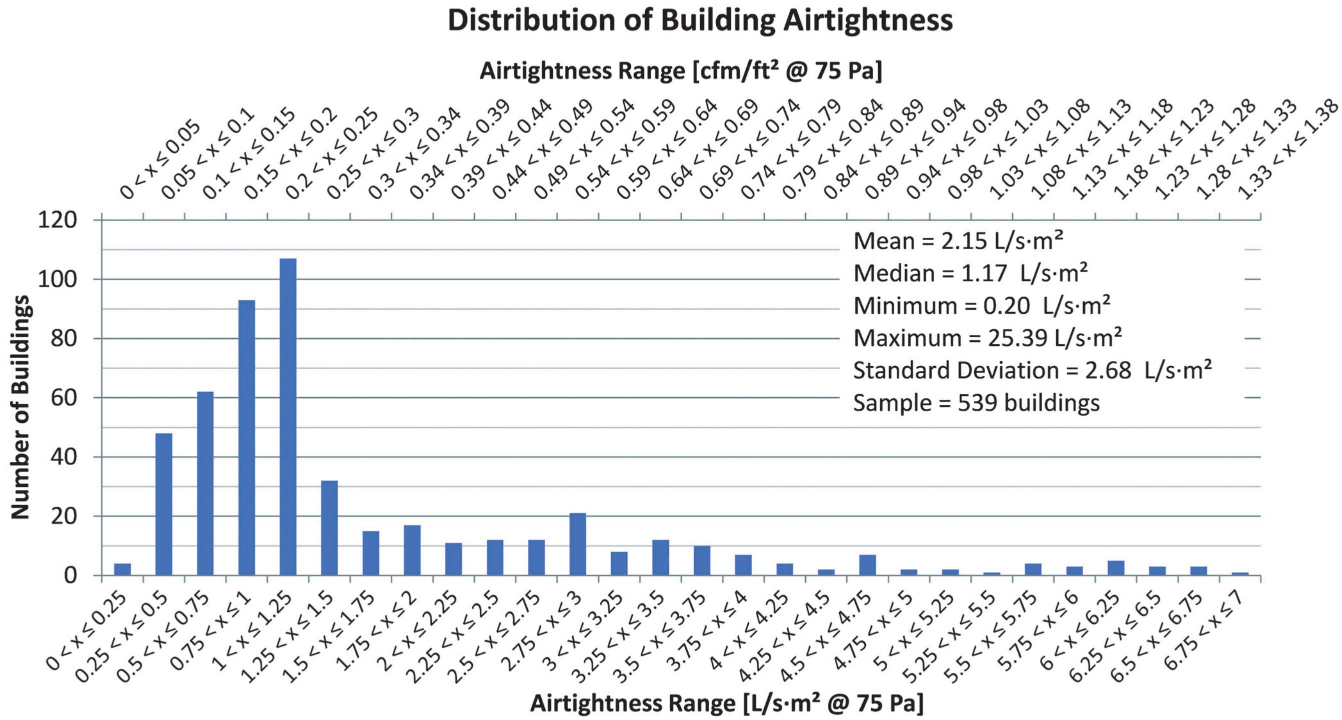


Figure 2 *Distribution of airtightness of all of the buildings in the database. Note the significant reduction in frequency at approximately 1.25 L/(s·m^2) (0.25 cfm/ft^2), which corresponds to the USACE performance requirement.*

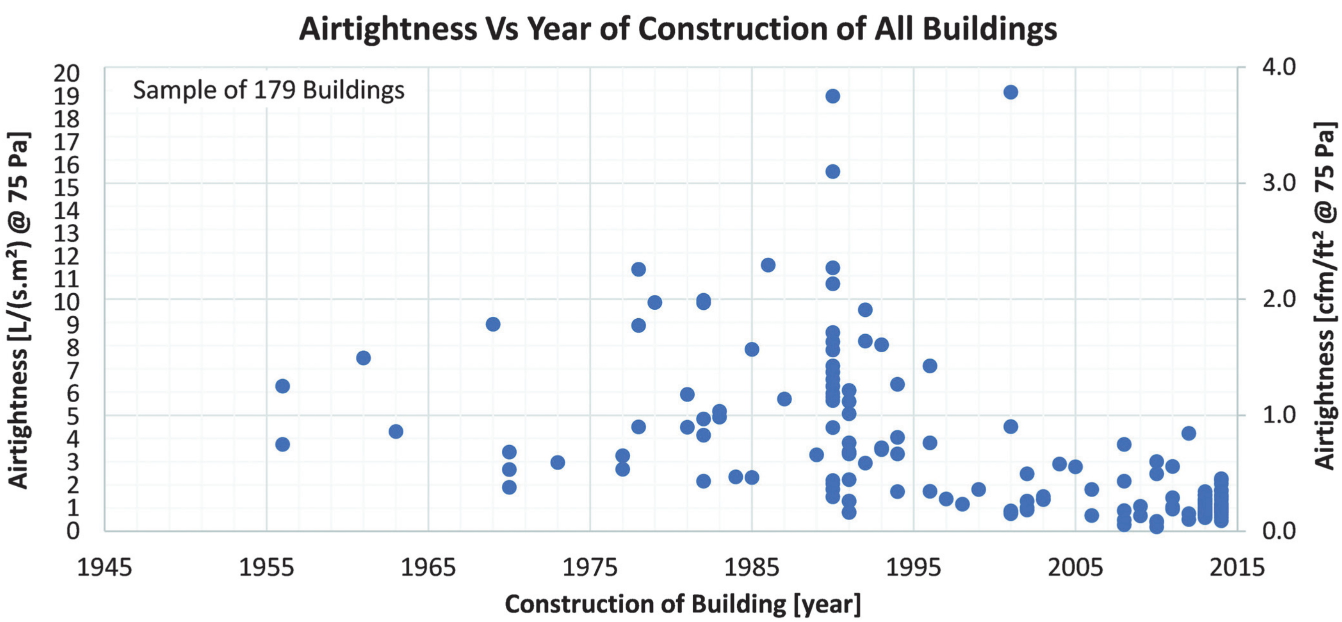


Figure 3 *Chart of airtightness of all buildings in the database versus the year of construction. In this case year of construction refers to either the year the building was originally built or the most recent year at which modifications to the air barrier were performed.*

ings. To specifically assess the airtightness of buildings that were designed to meet mandatory performance and/or testing requirements, Figure 4 plots the distribution of buildings tested for research purposes (Research), tested for compliance with USACE (USACE), or tested for compliance with State of Washington (Washington State 2012) or Seattle Energy Code (City of Seattle 2014) requirements (Washington). Buildings categorized as Research include all buildings for which testing was voluntary (i.e., investigation, green building program, etc.).

Figure 4 clearly indicates a significant reduction in the mean average airtightness of buildings that were built to meet a performance and/or testing requirement. The mean average airtightness for Research, USACE, and Washington buildings are 3.52, 1.00, and 1.30 L/(s·m^2) (0.69, 0.20, and 0.26 cfm/ft^2) respectively. Interestingly, the most airtight of the Research buildings has similar or even better performance to that of the best performing USACE or Washington buildings; however, the range of performance for the Research buildings is much larger with the least airtight building two orders of magnitude leakier than the most airtight (approximately 0.2 L/(s·m^2) [0.04 cfm/ft^2] versus 25 L/(s·m^2) [5.0 cfm/ft^2]). Overall, this chart suggests that the implementation of airtightness requirements by the USACE and Washington/Seattle has had a substantial impact on the airtightness of buildings and has reduced the mean average airtightness by 72% and 63% respectively.

The data for the Research buildings presented in Figure 4 includes data from buildings which are much older than the population of buildings in the USACE and Washington datasets. As a result, it is possible that the perceived impact of the airtightness regulations is the result of gradual evolution in building materials, design, and construction practices rather than the result of more stringent airtightness regulations. To provide a fairer comparison, buildings that were constructed prior to the year 2000 were removed from the datasets and the distribution of these results is provided in Figure 5. Removing older buildings from the analysis ensures the comparison is for buildings using similar techniques and materials; consequently, any improvement in airtightness can be attributed to the regulation of whole-building airtightness.

Figure 5 illustrates that when buildings of similarly modern construction are compared, buildings in which whole-building airtightness is regulated are noticeably more airtight. The mean average airtightness of USACE and Washington buildings are 0.94 L/(s·m^2) (0.19 cfm/ft^2) and 1.12 L/(s·m^2) (0.22 cfm/ft^2) respectively. These are 55% and 43% improvements in performance as compared to the average airtightness of 2.12 L/(s·m^2) (0.42 cfm/ft^2) for buildings constructed in the year 2000 or later for which there was no testing requirement. It is also apparent that in both jurisdictions with regulations, buildings are consistently able to meet and exceed the current performance targets.

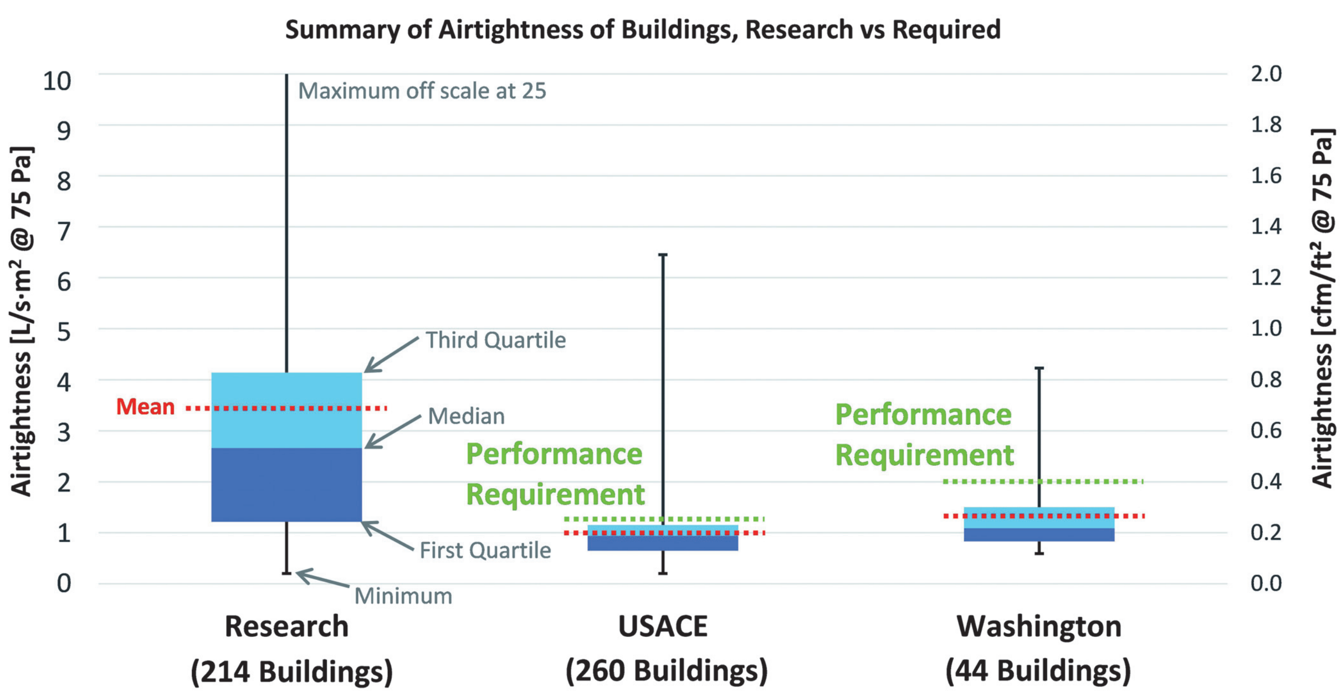


Figure 4 *Chart of the distribution of airtightness performance of buildings tested for research purposes, for compliance with USACE requirements and for compliance with Washington State or Seattle Energy Code requirements. Note that all of the testing performed for the latter was at a time when testing and reporting of the result was required, but compliance with a performance target was not yet required.*

Even with the older buildings removed from the dataset, it is apparent that some of the modern buildings in jurisdictions without airtightness requirements continue to exhibit relatively poor airtightness performance, with the maximum two orders of magnitude higher than the minimum. In addition to reducing the average airtightness, regulations have also decreased the expected range of performance which substantially improves the ability to predict airtightness performance. This improved predictive capability is important for efforts such as energy modeling for code compliance and design of mechanical systems where it is necessary to make reasonable assumptions about building performance during the design phase.

Overall, the quantitative airtightness testing results collected in the database provide strong support for the conclusion that airtightness regulations have improved the average airtightness of buildings in those jurisdictions as compared to similar buildings in other nonregulated jurisdictions, and that they have substantially reduced the typical range of performance.

QUALITATIVE PERCEPTION

To supplement the quantitative comparison of airtightness performance, a survey was conducted of industry members working in the State of Washington where airtightness performance requirements have been implemented. For reference, the first versions of the Washington State Energy Code (WSEC) and Seattle Energy Codes (SEC) to include a whole-building airtightness testing requirement were dated 2009, and came into effect July 1, 2010 and January 1, 2011 respectively. The 2009 SEC required testing of all new commercial buildings, while the 2009 WSEC required testing of all new commercial buildings over 5 stories in height. (Commercial buildings are defined in the same manner as for the 2012 International Building Code.) In the 2009 version of these codes, only testing of the buildings was required, and the result had to be reported, but a performance target did not have to be achieved.

The new 2012 WSEC and SEC also require whole-building airtightness testing, and both are applicable to all new commercial buildings. Both codes specify a minimum airtightness of 2.0 L/(s·m^2) (0.40 cfm/ft^2) at 0.3 inches of water gauge (75 Pa). Under both codes, if the building fails to meet the airtightness performance target, measures must be taken to inspect and seal the air barrier "to the extent practicable." Once a report documenting this sealing work has been submitted to the code official and owner, there is no need to retest the building to ensure compliance with the performance target. These codes came into effect in December 2013; however, only recently have buildings to which the new codes apply started to reach completion and, consequently, relatively few buildings have been tested that require compliance with the performance target.

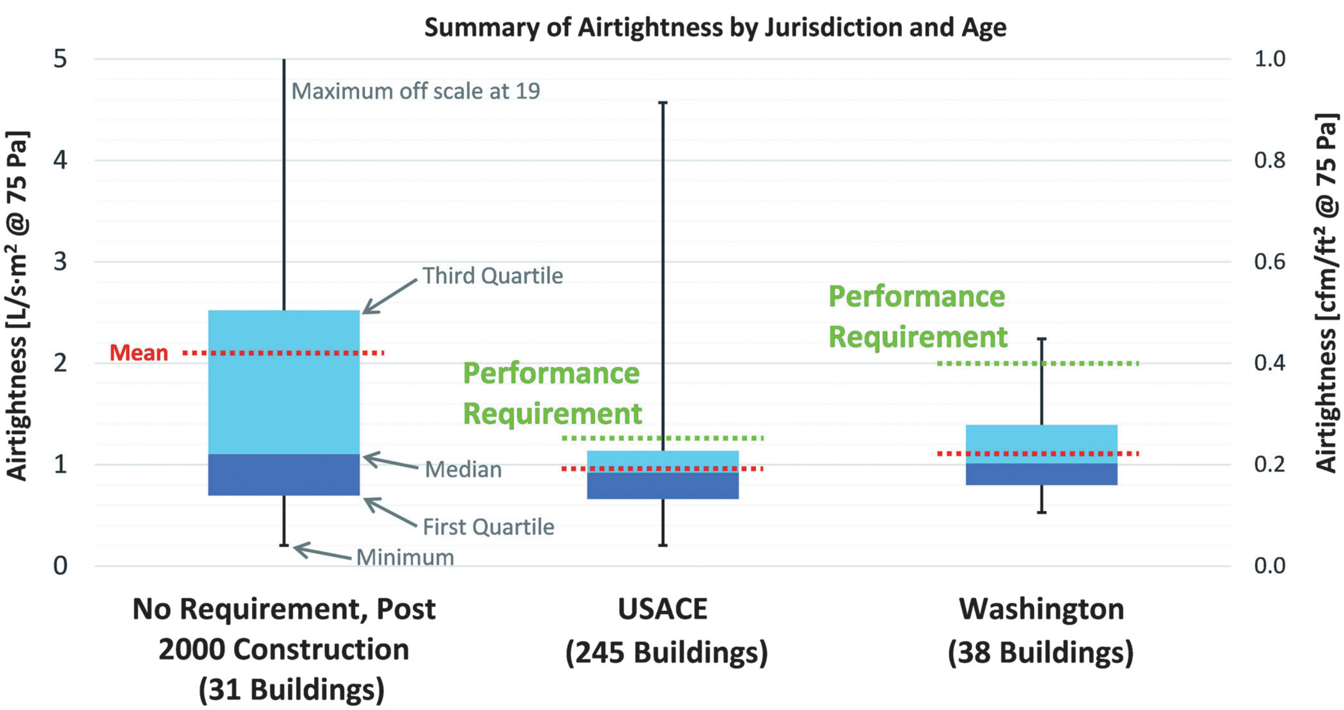
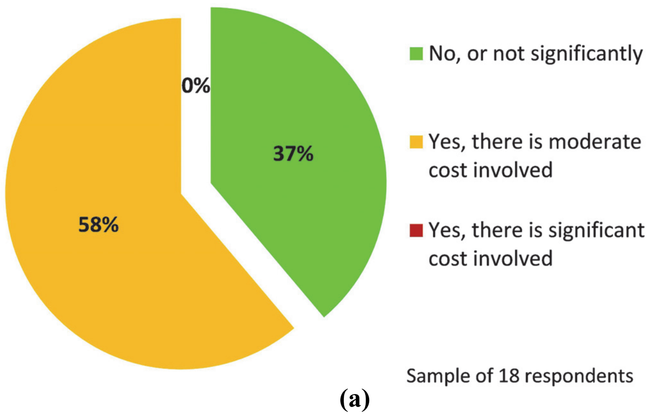


Figure 5 *Distribution of airtightness performance of buildings tested for research purposes (i.e., no requirement), for compliance with USACE requirements, and for compliance with Washington State or Seattle Energy Code requirements but limited to buildings tested more recently than the year 2000. By filtering out test results of older buildings, a more direct comparison is possible between typical modern construction practices and the jurisdictions with mandatory testing. Note the change in* y*-axis scale for this figure as compared to Figure 4.*



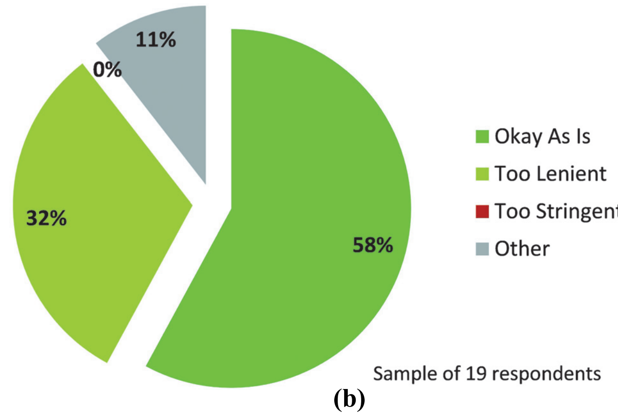


Figure 6 *(a) Chart of responses to the question, "Aside from the cost of the test itself, do you feel that whole-building air leakage requirements increase the total cost of construction?" and (b) chart of responses to the question, "Choose one of the following statements that best represents your opinion of the current whole-building air leakage target in your jurisdiction." This survey was distributed in the State of Washington where the guideline performance testing requirement is set at 2.0 L/(s·m^2) (0.40 cfm/ft^2).*

To gain an understanding of how these regulations have impacted the building industry in Washington State, and specifically Seattle, survey participants were asked a series of question pertaining to impact and perception of the requirements. The responses to three of these questions are summarized in Figure 6 and Figure 7.

Figure 6a clearly indicates that respondents generally felt that the cost implications of airtightness testing on the project were either minor or not significant, and Figure 6b indicates that respondents generally felt that the current airtightness performance target of 2.0 L/(s·m^2) (0.40 cfm/ft^2) is achievable. The latter finding is consistent with the testing results, which indicate that buildings are consistently able to achieve the stated airtightness performance target in Washington/Seattle despite there being no consequence for failure until recently.

Figure 7 illustrates the responses to the question "In general, do you feel that whole building air leakage requirements are beneficial and worthwhile in terms of increased building performance and quality of design/workmanship?" This question is of particular importance as it provides the respondents with an opportunity to holistically evaluate whether the regulated airtightness requirements are worth the additional effort and expense. The responses to this question indicate that the vast majority of respondents (84%) feel that the airtightness regulations are both beneficial and worthwhile, while only 5% of respondents felt they were neither beneficial nor worthwhile.

Overall, the survey results indicated a strong positive perception of the current airtightness regulations in the State of Washington and Seattle, both with respect to limited cost, achievability, and benefit to the project. These findings provide qualitative indication that perceived barriers to implementation can be readily overcome to the net benefit of building projects.

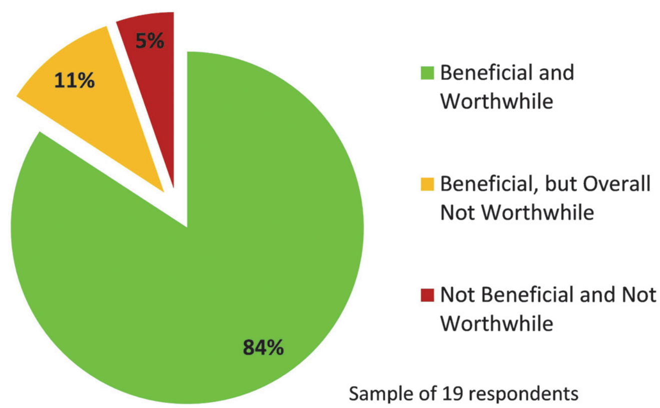


Figure 7 *Chart of responses to the question "In general, do you feel that whole-building air leakage requirements are beneficial and worthwhile in terms of increased building performance and quality of design/workmanship?"*

AIRTIGHTNESS AND ENERGY

One of the key drivers for improving the airtightness of buildings is to reduce the energy consumption associated with conditioning air that infiltrates through the building enclosure. That said, it is important to recognize the difference between air leakage and airtightness. For the purpose of this paper, air leakage is defined as *the in-service exfiltration or infiltration of air through the building enclosure* and airtightness is defined as *a physical property of the building enclosure that represents the resistance to airflow that it provides*. The amount of air leakage that occurs is dependent on a number of factors, including climate (wind and temperature), local exposure, building height, mechanical system operation, occupant behavior, and the airtightness of the building enclosure. It is air leakage, rather than airtightness, which is of significance with respect to energy consumption as well as various other performance considerations including air quality, moisture durability, and occupant comfort.

As an example, it is necessary to accurately predict air leakage rates for predictive energy modeling exercises such as those used for code compliance and sizing of mechanical systems. Analysis of the airtightness database has shown that airtightness regulations have substantially reduced the range in expected performance, which consequently allows designers to more accurately predict the airtightness of a building prior to construction; however, airtightness of the building enclosure alone is insufficient to predict air leakage. In large part this is because of variable pressure differences across the building enclosure as the result of wind, stack effect, and mechanical ventilation systems. These pressure differences can commonly cause building enclosures to experience a range of –25 to 25 Pa (–0.1 to 0.1 in. w.c.) from the interior to the exterior. (Ricketts 2014). Figure 8 illustrates the range of typical in-service pressure differences that buildings experience as well as the pressure flow relationships for building enclosures with a range of airtightness performance levels. This figure clearly illustrates that despite knowledge of the airtightness of a building enclosure, it is still difficult to accurately predict the in-service air leakage of buildings.

Because of both the complexity and quantity of contributing factors, calculation of building infiltration rates is difficult and often inaccurate with limited measured results available for large buildings to allow for validation of existing infiltration models. As other aspects of building energy consumption are improved, and as energy codes move towards performance-based targets such as energy use intensity (EUI) to define compliance, the importance of accurate in-service air leakage rates will increase. Further research is required in this area to validate and, as necessary, create, infiltration models that can account for the various factors that affect large building air leakage.

CONCLUSION

In recognition of the broad impact of air leakage on building performance, the building industry in North America is moving towards whole-building airtightness regulations in place of existing material, assembly, and component requirements. Based on compilation of more than 500 airtightness test results, it is clear that adoption of airtightness regulations has substantially improved the airtightness of large buildings. Furthermore, the expected range of performance has been dramatically reduced, allowing for more reliable prediction of performance. Surveying industry members in the State of Washington found that implementation of these regulations had minor cost implications for building projects, that the current target of 2.0 L/(s·m^2) (0.40 cfm/ft^2) is readily achievable, and that overall requirements are perceived as both beneficial and worthwhile.

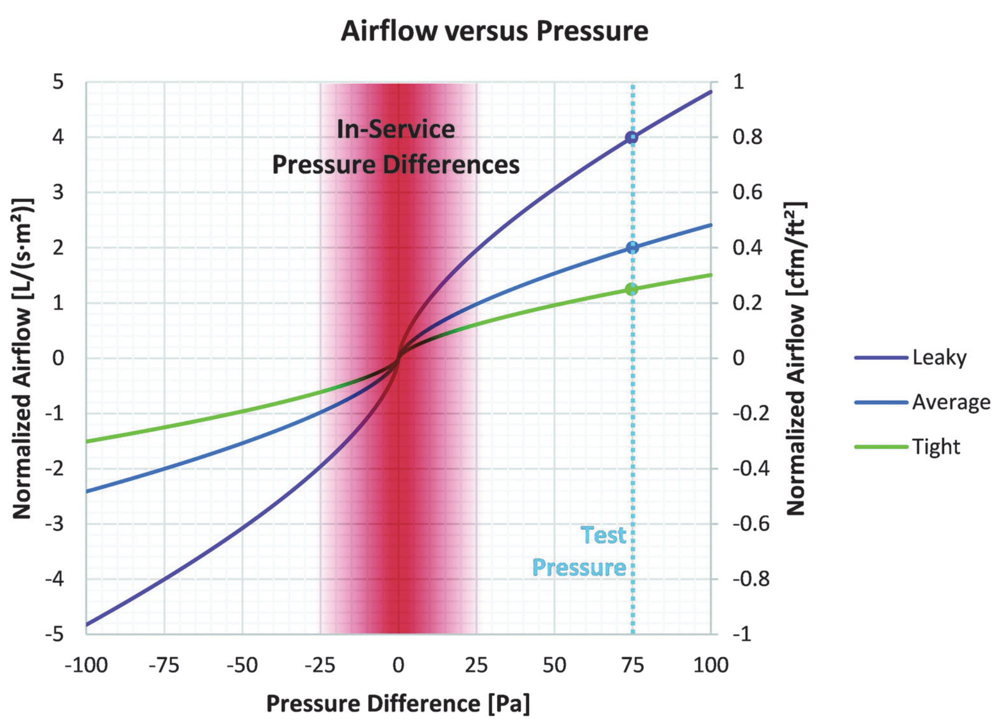


Figure 8 *Distribution in-service pressure difference that can be expected at buildings with pressure flow curves for building enclosures with different levels of airtightness. This chart shows how knowledge of the airtightness of a building is insufficient to accurately predict in-service air leakage rates.*

These documented improvements in airtightness will undoubtedly provide performance benefits; however, it is difficult to quantify these benefits as air leakage occurs based on a combination of factors, only one of which is building enclosure airtightness. While the narrowed expected range of performance allows for more reliable predictions of building airtightness during the design phase, further work is required to more accurately correlate airtightness with air leakage such that accurate predictions of performance can be made.

ACKNOWLEDGMENTS

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REFERENCES

City of Seattle. 2014. *Seattle adoption and amendment of the 2012 edition of the International Energy Conservation Code, commercial*. Seattle: City of Seattle.

RDH Building Science. 2015. Study of part 3: Building airtightness. Vancouver, BC: RDH Building Science, Inc.

Ricketts, L. 2014. *A field study of airflow in a high-rise multi-unit residential building*. Master's thesis. Civil Engineering Department. Waterloo, ON: University of Waterloo.

USACE & ABAA. 2012. *U.S. Army Corps of Engineers air leakage test protocol for building envelopes*. Champaign, IL: U.S. Army Corps of Engineers & Air Barrier Association of America.

Washington State. 2012. *Washington State energy code, commercial provisions*. Olympia, WA: Washington State.