CHANGE IS IN THE AIR (BARRIER!)

ABSTRACT

Air barrier requirements for commercial buildings are undergoing substantial changes in the 2022 ASHRAE 90.1 Standard and the 2024 IECC. Continuous air barriers have been required in most buildings for a number of years. Recently the model commercial energy codes, ASHRAE 90.1 Standard and the 2024 IECC have been updated to provide more specific and stringent requirements for buildings. This presentation will provide expert insight from two individuals who have been engaged in the code development process for years and were specifically involved with the air leakage updates in both the ASHRAE 90.1 Standard and the International Energy Conservation Code. The air barrier updates include clarifications to the whole building performance testing methods and stringency, design phase requirements, material and assembly requirements, and on-site installation verification requirements. We will discuss the appropriateness of applications and the interaction between the building and energy code requirements. A discussion on new code development updates, design-based applications, and construction best practices will also take place.

LEARNING OBJECTIVES

- Discuss the impact of air barrier systems on energy efficiency.
- Recognize the changing building and energy codes and their interaction with building enclosure systems.
- Evaluate how to implement an air barrier strategy to comply with the code and owner performance requirements.
- Explain how specific examples and air barrier systems can be applied to current and future project designs.

SPEAKERS

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INTRODUCTION

Building energy codes are advancing toward providing greater levels of energy efficiency with the ultimate goal of obtaining net zero energy buildings. The *International Energy Conservation Code* (IECC) will, beginning in 2024, have the following intent for its commercial energy provisions:

> *The International Energy Conservation Code-Commercial provides market-driven, enforceable requirements for the design and construction of commercial buildings, providing minimum efficiency requirements for buildings that result in the maximum level of energy efficiency that is safe, technologically feasible, and life cycle cost-effective, considering economic feasibility, including potential costs and savings for consumers and building owners, and return on investment. Additionally, the code provides jurisdictions with supplemental requirements, including ASHRAE 90.1, and optional requirements that lead to the achievement of zero energy buildings, presently, and through glide paths that achieve zero energy buildings by 2030 and on additional timelines sought by governments, and achievement of additional policy goals as identified by the Energy and Carbon Advisory Council and approved by the Board of Directors. Requirements contained in the code will include, but not be limited to, prescriptive- and performance-based pathways. The code may include nonmandatory appendices incorporating additional energy efficiency and greenhouse gas reduction resources developed by the Code Council and others.*
>
> *The code will aim to simplify code requirements to facilitate the code's use and compliance rate. The code is updated on a three-year cycle with each subsequent edition providing increased energy savings over the prior edition. This code is intended to provide flexibility to permit the use of innovative approaches and techniques to achieve this intent. This code is not intended to abridge safety, health or environmental requirements contained in other applicable codes or ordinances." (ICC, 2021b)*

Required for obtaining these energy efficiency goals, air barriers and, more widely, air leakage requirements are increasing stringency in both required levels and in the verification of these proposals as the energy codes are developed. For non-low-rise residential buildings, the two pertinent documents to follow to understand the changes in air barrier requirements are ASHRAE Standard 90.1[3] and IECC. ASHRAE 90.1 is mandated as the federal minimum energy code in the Energy Policy Act of 2005. Both the IECC and ASHRAE 90.1 are on three-year development cycles. Local governments can choose to adopt one or both energy standards as their code requirements. The IECC is also written to reference ASHRAE 90.1 as an alternate compliance path, so both documents are relevant to energy compliance and air leakage.

THE CURRENT STATE

The current status of state code adoption is surveyed by the Department of Energy (DOE).[4] **Figure 1** presents the DOE's map of the status for commercial

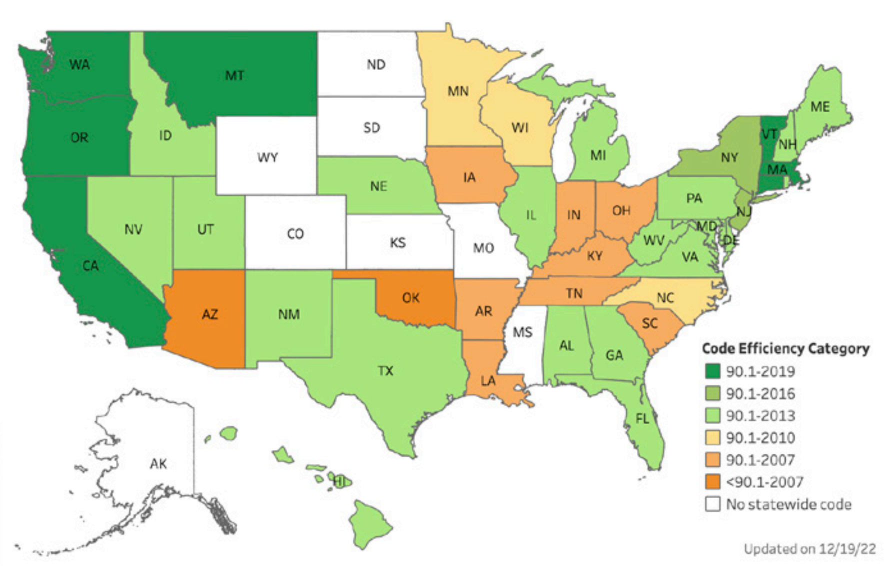

FIGURE 1. State commercial building energy code adoption as of June 2022. *Source: US Department of Energy Building Codes Assistance Project.* https://www.energycodes.gov/state-portal.

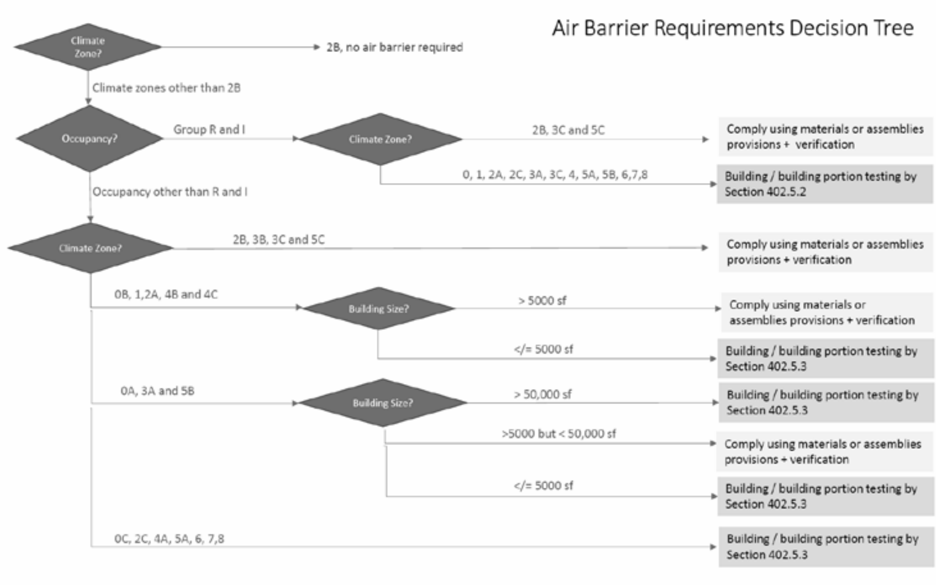

FIGURE 2. IECC-2021, Confusingair barrier requirements decision tree for the International Energy Conservation Code 2021.

energy code adoption as of June 22, 2022. While many states are lagging behind in adoption of the model commercial energy codes, we will consider ASHRAE 90.1-2016[5] and IECC 2018[6] as the baseline in this paper.

Both ASHRAE 90.1 and IECC have multiple compliance paths: prescriptive and performance. In both codes, air leakage provisions are mandatory across all the compliance paths, although a few minor exceptions are noted in **Tables 1**, **2**, and **3**.

In a prescriptive complying air barrier, the user must comply by meeting the air barrier requirements outlined in the text of the code or standard, but demonstrating on-site air leakage performance is not required. Starting with the prescriptive path, the code stringency can be described by examining the following requirements (see **Table 1**):

- Compliance specification options (material, assembly, and/or whole building)
- Design documentation requirements
- Installation verification through on-site inspection of the air barrier

TABLE 1. Comparison of baseline energy codes/standards

	ASHRAE 90.1-2016	IECC-2018
Compliance testing options	Materials, assembly, or whole building	Materials, assembly, or whole building
Maximum air leakage level	Materials ≤ 0.004 cfm/ft² @ 75 Pa	Materials ≤ 0.004 cfm/ft² @ 75 Pa
	Assemblies ≤ 0.04 cfm/ft² @ 75 Pa	Assemblies ≤ 0.04 cfm/ft² @ 75 Pa
	Whole buildings ≤ 0.40 cfm/ft² @ 75 Pa	Whole buildings ≤ 0.40 cfm/ft² @ 75 Pa
Whole building testing requirements	Option, not required	Option, Not required
Exceptions	Semiheated spaces in Climate Zones 0 through 6	Air barriers not required in Climate Zone 2B
	Single wythe concrete masonry buildings in Climate Zone 2B	
Installation verification	Design and installation verification *or* whole building air leakage testing	None specified
Performance modeling compliance	Design phase: Model-specified air leakage (energy savings credit for performance ≤ 0.40 cfm/ft²)	Follow mandatory requirements (0.40 cfm/ft² @75 Pa)
	Construction phase: Adjust model for actual tested air leakage, energy savings credit for performance better than 0.40 cfm/ft²)	
Simplified path compliance	COMcheck compliance: default 0.40 cfm/ft² air leakage input	Default 0.40 cfm/ft² air leakage input; reduced air leakage package for 0.25 cfm/ft² @ 75 Pa

TABLE 2. Comparison of current/active energy codes/standards

	ASHRAE 90.1-2019	IECC-2021
Compliance testing options	Materials, assembly, or whole building	Materials, assembly, dwelling unit (Group R and I) or whole building (required under certain conditions)
Maximum air leakage level	Materials ≤ 0.004 cfm/ft² @ 75 Pa	Materials ≤ 0.004 cfm/ft² @ 75 Pa
	Assemblies ≤ 0.04 cfm/ft² @ 75 Pa	Assemblies ≤ 0.04 cfm/ft² @75 Pa
	Whole buildings ≤ 0.40 cfm/ft² @ 75 Pa ("oops clause" allows up to 0.60 cfm/ft²)	Whole buildings ≤ 0.40 cfm/ft² @75 Pa ("oops clause" allows up to 0.60 cfm/ft²)
		Dwelling units ≤ 0.30 cfm/ft² @ 50 Pa, sampling allowed.
Whole building testing requirements	Required with exceptions for (1) buildings over 50,000 ft², which can be tested in parts; and (2) cases when verification of the design and installation of the continuous air barrier is conducted	Required for occupancies other than Groups R and I, with multiple exceptions for Climate Zone and building size
Exceptions	Semiheated spaces in Climate Zones 0 through 6	Air barriers not required in Climate Zone 2B;
	Single-wythe concrete masonry buildings in Climate Zone 2B	
Design and installation verification	Third-party verification required when whole building testing is not being performed	Verification required when testing by dwelling unit or whole building testing is not done
	Design to be detailed and identified in construction documents as continuous	Installation of continuous air barrier verified by the code official, a registered design professional, or approved agency. Includes review of construction documents, inspection during construction and a final commissioning report
Performance modeling compliance	Design phase: Model-specified air leakage (energy savings credit for performance ≤ 0.40 cfm/ft²)	Follow mandatory requirements (0.40 cfm/ft² @75 Pa)
	Construction phase: Adjust model for actual tested air leakage, energy savings credit for performance better than 0.40 cfm/ft²)	
Simplified path compliance	COMcheck compliance: Default 0.40 cfm/ft² @75 Pa air leakage input	Default 0.40 cfm/ft² air leakage input; reduced air leakage package allowed for 0.25 cfm/ft² @ 75 Pa

In a performance-based complying air barrier the user must comply by meeting the performance values in both energy modeling and on-site building performance. The code stringency for the performance path can be described by examining the following requirements (see **Table 1**):

- Modeling of the energy performance of the entire building, including specified air leakage performance
- Required whole building testing and exceptions for climate zone and building size to determine its actual level of air tightness
- Updating the energy model to reflect the actual building performance

THE NEXT STEP

ASHRAE 90.1-2019 and IECC 2021 took a step forward in energy efficiency requirements, with the IECC 2021 requiring whole building testing under certain conditions. The requirements are shown in **Table 2**.

ASHRAE 90.1-2019, undertook primarily a reorganization of the air barrier section (5.4.3) which establishes whole building testing performance as the overall performance metric in the standard. It also provides additional guidance for buildings that are tested and miss the requirement (informally known as the "oops clause"), clarifies testing options for large buildings, improves the design and detailing requirements, and moves the material and assembly requirements to the product information section (5.8).

FIGURE 3. ABAA Air barrier inspection and audit *Source: Air Barrier Association of America.*

In IECC 2021 for residential occupancies (multi-family buildings) testing by dwelling unit was introduced for residential occupancies (multifamily buildings). However, the requirements and exceptions, especially in the IECC-2021, were very complicated, and compliance may therefore be difficult to achieve. **Figure 2** shows the complicated and confusing air leakage testing criteria introduced in IECC 2021. Much of the complexity and confusing language in the code that is captured in **Figure 2** is resolved with the pending updates in IECC 2024.

The path to the enhanced requirements in ASHRAE 90.1-2019 and IECC-2021 was forged by early adopters at the state level. Early adopters of enhanced air barrier requirements including whole building testing include the Commonwealth of Massachusetts, Washington State, and the cities of Seattle, Washington, and Fort Collins, Colorado. Lessons learned from Seattle's experience have been shared by both regulatory officials and consulting engineers in the city. According to a consulting engineer.[7]

> The air barrier design and testing requirements in the greater Seattle area has allowed the industry to digest the realities of whole building air barrier design and testing. From a tightness standpoint, what we have found is that if the proper care is taken, buildings indeed can be designed to meet the requirements of 0.4 CFM/SF@1.57 psf and now, 0.3 CFM/SF @ 1.57 psf.

A Seattle regulatory official[8] offered the following conclusion:

> Seattle's principal message for jurisdictions that are considering a similar path is that air barrier testing initially is difficult for all of the industry players but soon becomes routine. As a result of Seattle's record-breaking construction boom over the past several years, hundreds of new buildings in the city have pressure-tested air barriers. Although the air leakage rates of buildings constructed in the decades before this code requirement took effect are not fully understood, it appears that the leakage in these new buildings has been reduced by more than half.

The experience in Seattle has shown that there is a fast learning curve on both the construction of airtight buildings and the testing of those buildings. This learning curve may be duplicated in other jurisdictions.

In addition to following the lessons of the early adopter jurisdictions, the industry has continued to improve the tools for building air leakage verification. In particular, the development of standard test methods for air barrier testing specifically designed for compliance with code or other specifications has aided the industry in being able to conduct building testing:

- ASTM E3158, *Standard Test Method for Measuring the Air Leakage Rate of a Large or Multizone Building*[9]: As stated in the scope of ASTM E3158, "This test method applies to an air leakage rate specification with a reference pressure greater than 10 Pa (0.04 in. WC) and not greater than 100 Pa (0.40 in. WC)." The method was specifically developed because air leakage testing was being increasingly proposed in building specifications and codes. More specifically, it was initially driven by the need to meet the U.S. Army Corps of Engineers (USACE) requirement of a maximum air leakage of 0.25 cfm/ft2 of building envelope @ 0.3 w. g. (75 Pa) (USACE 2009, USACE 2012.[10,11] In collaboration with USACE, the Air Barrier Association of America developed an air leakage test protocol to enable the testing required by the USACE directive.[12] Based on this test protocol, ASTM E3158 was developed through the consensus process. ASTM E3158 enables whole building air leakage testing because it was specifically aimed at specification/code compliance and development was led by testing practitioners.
- ANSI/RESNET/ICC 380, *Standard for Testing Airtightness of Building, Dwelling Unit, and Sleeping Unit Enclosures; Airtightness of Heating and Cooling Air Distribution Systems; and Airflow of Mechanical Ventilation Systems*[13]: As stated in the standard's purpose, "The provisions of this document are intended to establish national standards for testing the airtightness of enclosures and heating and cooling air distribution systems, and the airflow of mechanical ventilation systems. This Standard is intended for use by parties including home energy raters, energy auditors, or code officials who are evaluating the performance of Residential Buildings, or of Dwelling Units or Sleeping Units within Residential or Commercial Buildings." As with ASTM E3158, ANSI/RESNET/ICC 308 is specifically aimed to evaluate specification/code compliance by practitioners. This standard is especially important for multifamily residential dwelling unit compartmentalization air leakage testing.

Another important resource is the Air Barrier Association of America (ABAA) Air Barrier Quality Assurance Program (QAP),[14] which is a jobsite program that encompasses materials, installation, and inspection of the air and moisture barrier system. ABAA QAP program's frequency is determined by the size of the building. It is designed to utilize ABAA accredited contractors, ABAA-certified installers, ABAA-evaluated materials, and ABAA-trained third-party field quality control audits during the construction process with the goal of providing the complete range of services across the construction phases is to help minimize risk and liability within the building envelope (ABAA). An example of the field quality control audits is shown in **Figure 3**.

WHAT'S NEXT: THE WRITING IS ON THE WALL

The industry is currently developing the next generation of energy codes and standards, and our understanding of most of the air leakage requirements in those documents is somewhat speculative. **Table 3** shows the provisions expected to be included in the next editions.

Addendum *t*[15] to ASHRAE 90.1-2019, which updates air leakage requirements, is final and has been published and is included in the new ASHRAE 90.1-2022. This air leakage revision in 90.1-2022 improves the overall performance requirements for whole building testing, incorporates the new whole building airtightness testing standard ASTM E3158, establishes a set of smaller buildings that cannot be exempted from the testing requirements, improves the verification requirements in the construction documentation, and distinguishes modeled and simplified values for testing versus non-testing project compliance.

The first round of proposals related to air leakage requirements in the development of IECC 2024 has also been completed. Additionally, the air leakage section of IECC 2024 will be reorganized for clarity and the exceptions simplified to facilitate compliance. This reorganization is especially important with the very confusing air barrier requirements scattered throughout IECC 2021. In addition, the revisions in the current IECC 2024 draft closely mirror the changes published in ASHRAE 90.1-2019 Addendum *t*. IECC 2024 also will include additional options for residential (R) and institutional (I) occupancies for buildings that contain dwelling units.

THE FUTURE IS AIRTIGHT

As we look to the future, we anticipate that building enclosures will be increasingly airtight through the development of new technology, an increase in construction and installation verification, and, ultimately, the formalization of building enclosure commissioning (BECx) in specifications and codes.

As was the case with the USACE air leakage directive, proposed changes to air leakage requirements are likely to be piloted before they are incorporated into model building energy codes and standards. For example, in a sustainability/green construction standard from Phius, a nonprofit passive building organization, the maximum air leakage threshold for most projects is 0.060 cfm/ft^2 @ 50 Pa, which is significantly tighter than any current code values.[16] More than 15 states include Phius certification is included as a Qualified Allocation Plan for low-income housing tax credits. A passive building standard is also currently under development by ASHRAE.

Moving beyond voluntary and above-code programs into building energy codes will require technical and market research to demonstrate feasibility and cost-effectiveness. The following items are key next steps to continue to move the energy codes forward:

- Improvements in air leakage methodology. The energy savings attributed to air barriers is evaluated for code development using EnergyPlus building energy simulation software. However, recent research comparing building energy simulation models with an airflow and contaminant transport model found that the benefits of building air tightening were not fully captured in the current building energy simulation methodology and were underestimated by as much as 55%.[17]
- Accurate costs for whole building testing and on-site verification. Cost analysis is required for the inclusion of provisions in building energy codes. Few cost surveys or data summaries on the cost of air barrier verification or whole building air leakage testing are available. An example study on the economic effects of reducing building air leakage was published in support of code development for the state of California.[18] Specific data are needed to evaluate the following: (a) the reduction in test costs as the test process becomes more common; (b) the reduction in test costs as air leakage thresholds are reduced, and (c) the frequency of verification required for performance improvement and associated implementation costs.
- Improvements to the quality of whole building testing. There can be variability in the accuracy and experience of whole building testing providers. To provide guidance and establish a testing quality control process, industry training and certification programs are beginning to be initiated. One example is ABAA's Whole Building Airtightness Program, which was introduced in a Washington state pilot in 2022.[19]
- Understanding the relationship between energy efficiency benefits and other building benefits. Currently, air leakage is addressed primarily within energy efficiency codes and standards, whereas the benefits of air leakage control for indoor environmental quality (IEQ), moisture durability, and building resilience are covered in other documents or ignored. A more holistic understanding of how these different performance facets work together and are evaluated is necessary for a complete understanding of the value of reducing air leakage. For example, both IEQ and energy efficiency performance are improved by air leakage control, but in multifamily residences, IEQ is best characterized using compartmentalization testing and energy efficiency is best characterized using whole building testing. Testing protocols are under development that can provide both measurements instead of requiring separate testing or using one measurement as a surrogate for the other measurement.[20]

TABLE 3. Comparison of future energy codes/standards

	ASHRAE 90.1-2022*	IECC-2024†
Compliance testing options	Materials, assembly, or whole building	Materials, assembly, dwelling unit (Group R and I) or whole building (required under certain conditions)
Maximum air leakage level	Materials ≤ 0.004 cfm/ft^2 @ 75 Pa	Materials ≤ 0.004 cfm/ft^2 @ 75 Pa
	Assemblies ≤ 0.04 cfm/ft^2 @ 75 Pa	Assemblies ≤ 0.04 cfm/ft^2 @75 Pa
	Whole buildings ≤ 0.35 cfm/ft^2 ("oops clause" allows up to 0.45 cfm/ft^2)	Whole buildings ≤ 0.35 cfm/ft^2 ("oops clause" allows up to 0.45 cfm/ft^2)
		Dwelling units ≤ 0.27 cfm/ft^2 @ 50 Pa, sampling allowed.
Whole building testing requirements	Required for buildings less than 10,000 ft^2 and single-zone buildings	Required for occupancies other than Group R and I, except for buildings < 25,000 ft^2 in Climate Zones 0-4
	Required exceptions for when verification of the design and installation of the continuous air barrier are conducted	Groups R and I occupancies can be tested by dwelling unit
Exceptions	Semiheated spaces in Climate Zones 0-6	Air barriers not required in Climate Zone 2B
	Single-wythe concrete masonry buildings in Climate Zone 2B.	
Design and installation verification	Third-party verification required when whole building testing is not being performed	Verification required when testing by dwelling unit or whole building testing. Installation of continuous air barrier verified by the code official, a registered design professional or approved agency. Includes review of construction documents, inspection during construction and a final commissioning report
	Design to be detailed and identified in construction documents as continuous	Design to be detailed and identified in construction documents as continuous
	Construction documents to include inspection details, including (a) schedule/frequency, (b) scope of work, (c) critical observations, (d) document requirements, (e) corrective actions provisions	Construction documents to include inspection details, including (a) schedule/frequency, (b) scope of work, (c) critical observations, (d) document requirements, (e) corrective actions provisions
Performance modeling compliance	Design phase: Model-specified air leakage (energy savings credit for performance ≤ 0.35 cfm/ft2)	Follow mandatory requirements (0.35 cfm/ft2 @75 Pa)
	Construction phase: Adjust model for actual tested air leakage (energy savings credit for performance better than 0.35 cfm/ft2)	
Simplified path compliance	COMcheck compliance–whole building testing: Default 0.35 cfm/ft^2 @75 Pa air leakage input	COMcheck compliance: Default 0.35 cfm/ft^2 @75 Pa air leakage input
	COMcheck compliance–verification only: Default 0.45 cfm/ft^2 @75 Pa air leakage input	Allows reduced air leakage package on a sliding scale based on percent reduction of base mandatory level
		Reduced air leakage package extended to testing by dwelling unit

*Published late 2022, includes final 90.1-2019 Addendum *t*.

†Forecasted changes based on currently proposed *International Energy Conservation Code* revisions.

REFERENCES

1 International Code Council (ICC). 2021. *International Energy Conservation Code*. Country Club Hills, IL: ICC.

2 ICC. 2021. *Leading the Way to Energy Efficiency : A Path Forward on Energy and Sustainability to Confront a Changing Climate*. Country Club Hills, IL: ICC. https://www.iccsafe.org/wp-content/uploads/ICC_Leading_Way_to_Energy_Efficiency.pdf.

3 ASHRAE. 2019. *Energy Standard for Buildings Except Low-Rise Residential Buildings*. ANSI/ASHRAE/IES Standard 90.1-2019. Peachtree Corners, GA: ASHRAE.

4 U.S. Department of Energy Building Energy Codes Program. 2022. "State Portal." https://www.energycodes.gov/state-portal.

5 ASHRAE. 6. *Energy Standard for Buildings Except Low-Rise Residential Buildings*. ANSI/ASHRAE/IES Standard 90.1-2016. Peachtree Corners, GA: ASHRAE.

6 International Code Council (ICC). 2018. *International Energy Efficiency Code*. Country Club Hills, IL: ICC.

7 Estrada, J. 2019. "Building Air Leakage Testing in Seattle, Washington: What We've Learned and Where We Go from Here." In *Whole Building Air Leakage: Testing and Building Performance Impacts*, edited by T. Weston, K. Nelson, and K. S. Wissink. West Conshohocken, PA: ASTM International. https://doi.org/10.1520/STP161520180018.

8 Jonlin, D. 2019. "Rookie Mistakes: Lessons from a Decade of Mandatory Air Barrier Testing." In *Whole Building Air Leakage: Testing and Building Performance Impacts*, edited by T. Weston, K. Nelson, and K. S. Wissink. West Conshohocken, PA: ASTM International. https://doi.org/10.1520/STP161520180025.

9 ASTM International. 2018. *Standard Test Method for Measuring the Air Leakage Rate of a Large or Multizone Building*. ASTM E3158-18. West Conshohocken, PA: ASTM International.

10 U.S. Army Corps of Engineers (USACE). 2009. "Building Air Tightness Requirements. Directive" *Engineering and Construction Bulletin* 2009-29. https://wbdg.org/FFC/ARMYCOE/COEECB/ARCHIVES/ecb_2009_29.pdf.

11 USACE. 2016. "Building Air Tightness and Air Barrier Continuity Requirements. Directive and Guidance." *Engineering and Construction Bulletin* 2012-16. https://www.wbdg.org/FFC/ARMYCOE/COEECB/ARCHIVES/ecb_2012_16.pdf.

12 USACE and Air Barrier Association of America (ABAA). 2012. *US Army Corps of Engineers Air Leakage Test Protocol for Building Envelopes*, version 3, May 11, 2012. Champaign, IL: U.S. Army Engineer Research and Development Center. https://www.wbdg.org/FFC/ARMYCOE/usace_airleakagetestprotocol.pdf.

13 Residential Energy Services Network (RESNET). 2019. *Standard for Testing Airtightness of Building, Dwelling Unit, and Sleeping Unit Enclosures; Airtightness of Heating and Cooling Air Distribution Systems; and Airflow of Mechanical Ventilation Systems*. ANSI/RESNET/ICC 380-2019. Oceanside, CA: RESNET. https://www.resnet.us/wp-content/uploads/ANSIRESNETICC_380-2019_vf1.24.19_cover%5E0TOC-2.pdf.

14 ABAA. n.d. "Air Barrier Quality Assurance Program." Accessed November 14, 2022. https://www.airbarrier.org/qap-overview.

15 ASHRAE. 2022. *ANSI/ASHRAE/IES Addendum t to ANSI/ASHRAE/IES Standard 90.1-2019*. Peachtree Corners, GA: ASHRAE. https://www.ashrae.org/file%20library/technical%20resources/standards%20and%20guidelines/standards%20addenda/90_1_2019_t_20220812.pdf.

16 Phius. n.d. "Qualified Allocation Plans." Accessed November 14, 2022. https://www.phius.org/resources/policy-work/qualified-allocation-plans.

17 Ng, L. C., W. S. Dols, and S. J. Emmerich. 2021. "Evaluating Potential Benefits of Air Barriers in Commercial Buildings Using NIST Infiltration Correlations in EnergyPlus." *Building and Environment* 196: 107783. https://doi.org/10.1016/j.buildenv.2021.107783.

18 Zank, B., A. Brooks, and E. Wang. 2020. *Reduced Infiltration*. Codes and Standards Enhancement (CASE) Initiative/2022 California Energy Code. 2022-NR-ENV2-D, Nonresidential Envelope, October 2020. https://title24stakeholders.com/wp-content/uploads/2020/10/2022-T24-Final-CASE-Report_Reduce-Infiltration.pdf.

19 ABAA. n.d. "Whole Building Airtightness Program." Accessed November 14, 2022. https://www.airbarrier.org/wba.

20 Jayarathne, T., M. A. Browne, and M. Gevelber. Forthcoming. "Development and Experimental Evaluation of a Zonal Infiltration Measurement Method for Multi-Unit Residential Buildings: Error Analysis, Performance Evaluation, and Study of Building Characteristics." *Buildings XV Proceedings*, Clearwater Beach, FL, December 2022.