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Pacific Northwest NATIONAL LABORATORY

Envelope Air Tightness for Commercial Buildings

Technical Brief

December 2018

R Hart
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Y Xie

U.S. DEPARTMENT OF ENERGY

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Pacific Northwest National Laboratory
Richland, Washington 99352

Contents

Background

This study was conducted by Pacific Northwest National Laboratory (PNNL) in support of the U.S. Department of Energy (DOE) Building Energy Codes Program (BECP). BECP was founded in 1993 in response to the *Energy Policy Act of 1992*, and fulfills several key functions specified under federal statute and related to building energy codes. Section 307 of ECPA, as amended, requires DOE to periodically review the technical and economic basis of the voluntary building energy codes, such as the International Energy Conservation Code (IECC) and Standard 90.1, and participate in the industry process for review and modification, including seeking adoption of all technologically feasible and economically justified energy efficiency measures. (42 U.S.C. 6836(b)) Section 304(a) of ECPA, as amended, also directs DOE to review published editions of the IECC and Standard 90.1, and issue a determination as to whether the revised edition would increase energy efficiency in residential and commercial buildings, respectively.

PNNL supports this mission by evaluating concepts being considered for future code updates, conducting technical reviews and analysis of potential changes and their associated impacts, including energy savings analysis, cost-effectiveness analysis, and providing guidance on how changes can be more readily adopted by states and localities. This helps to ensure successful implementation of advancing technologies, construction practices, and related industry standards, and encourages building practices that are proven affordable and efficient.

This technical brief represents a compilation of relevant information on a specified concept. An overview of the concept is presented, followed by supporting technical analysis, related research and recommended code language. Additional context may also be provided, such as known consideration in previous model code development, state code proceedings, or incorporation in existing codes or standards. Each brief is intended as a resource for interested and affected stakeholders, particularly those charged with considering impacts of proposed code updates. Further technical assistance may be available from PNNL to adapt content to the needs of individual states or municipalities, such as specific building types, climate weightings, or utility rates.

Learn more at www.energycodes.gov.

1.0 Envelope Air Tightness for Commercial Buildings

Air leakage can be a significant source of energy waste in buildings, contributing to higher heating and cooling costs for building owners and occupants, and increasing risk related to comfort and durability. Air tightness testing can result in more attention to envelope assembly air barrier sealing and significantly reduced building leakage. Currently, the commercial energy code allows air tightness testing for buildings covered by the commercial International Energy Conservation Code (IECC) as an alternative to meeting material selection and installation method requirements to ensure proper tightness and a controlled indoor environment. Adequate control over air leakage can provide many benefits, including reduced HVAC equipment sizing, better building pressurization, and energy savings due to reduced heating and cooling of infiltrated outside air. In moist climates, ensuring lower air leakage through whole-building testing can also result in better humidity control and reduced risk of durability issues.

1.1 Summary

This technical brief investigates the potential benefits of including air leakage testing requirements in commercial building codes. It outlines a proposed approach that could be applied based on building size and climate zone. Conducting leakage testing is currently an optional path for commercial buildings in the IECC and ASHRAE Standard 90.1, where whole-building testing is allowed as a means of demonstrating air leakage requirements are met—with a maximum leakage limit set at 0.40 cfm/ft^2 (2.0 L/s · m^2) at 0.3 in. w.g. (75 Pa). Key elements of the measure are listed below.

- The leakage testing thresholds are the same as current optional testing thresholds.
- Proposed requirements for testing vary by climate zone and building size and are based on industry-accepted cost-effectiveness analysis methods.
- As outlined in the optional compliance path, portions of buildings could be tested on a sampling basis.
- Commercial buildings under 5000 square feet can be tested using residential methods, technicians, and equipment with the maximum leakage rate set at 0.30 cfm/ft^2 (1.5 L/s · m^2) at 0.2 in. w.g. (50 Pa). This testing pressure differential is common for residential testing, and is equivalent to a leakage rate of 0.40 cfm/ft^2 (1.5 L/s · m^2) at 0.3 in. w.g. (75 Pa), the current alternative commercial test limit. Yet, implementing the residential procedure can dramatically reduce testing costs for these smaller buildings.
- Since this would be a new requirement, a backup exception is provided so that if a building fails the 0.40 cfm/ft^2 test, the building can still pass the requirement as long as the tested value is below 0.60 cfm/ft^2 and additional diagnostics are performed.

1.2 Technical Considerations

How does the proposed measure compare to current industry codes and standards?

Whole building leakage testing is currently an optional path in the IECC, where it is allowed as a means for demonstrating that air leakage limits are met. This measure modifies the building thermal envelope code section to require air leakage testing of certain buildings based on climate zone, building use and the floor area of the conditioned space. This change does not modify the maximum leakage rate (0.40 cfm/ft^2 at 75 Pa) or method of test specified in the optional path; it simply makes testing required for certain buildings. Currently, the thermal envelope code section assesses air leakage based on the selection of materials or assemblies used in construction of the air barrier, which would be retained for buildings that would not have testing required by this measure.

Why is whole-building leakage testing superior to other approaches?

While it is important that the materials and assemblies have limited leakage, that alone does not guarantee a low leakage building. Recent research (Wiss 2014) shows that 40% of buildings constructed *without* an envelope consultant have air leakage exceeding the currently optional test standard requirements, while buildings with envelope consultants all had leakage below 0.25 cfm/ft^2. Testing is the most reliable means of ensuring that the intent of this code section—limiting unintended energy waste in buildings due to air infiltration—will be achieved.

The measure retains the current IECC optional compliance path test limit of 0.40 cfm/ft^2 at 75 Pa. Since mandatory—rather than optional— testing would be a new requirement, it is appropriate to retain the current and higher limit of 0.4 cfm/ft^2 for improved building industry acceptance. Durston and Heron's review (2012) of the more stringent requirements by the U.S. Department of Defense (DOD) shows that without testing, the range of building leakage can exceed the requirement by more than double (0.9 cfm/ft^2). However, with testing included as part of the construction process, the average leakage of buildings was determined to be well below the 0.4 cfm/ft^2 limit. Therefore, based on the DOD findings, the test limit of 0.40 cfm/ft^2 is considered a realistic and achievable goal. In addition, the target is well established in the IECC, and aligns with similar optional requirements contained in Standard 90.1.

What strategies are considered to minimize compliance burdens in the field?

Three specific strategies are applied to minimize the impact of testing on building project costs:

- Testing is only required for certain building types and climate zones where analysis indicates it is cost-effective and the savings justifies the cost. Based on that analysis, size thresholds by climate zone are provided for non-residential buildings.
- It is also prudent to provide some flexibility in the test standard to allow for building industry acceptance and a transition to meeting a fixed testing requirement. Specifically, when the building envelope is complete and testing occurs, access to the air barrier for repairs is difficult. Thus, an exception is included that allows the tested leakage rate to be no more than 0.6 cfm/ft^2 as long as specific remediation efforts are made. This exception is meant to provide a modest relaxation of the requirement, but only if significant corrective actions are taken that may reduce the air leakage.
- As an additional strategy, the measure allows representative portions or a sample of spaces in the building to be tested instead of the whole building. This alternative supports more economical testing of large buildings, which can help reduce the compliance burden.

Are there existing codes and standards that require similar testing measures?

This measure is similar to the residential air leakage provisions in the 2018 IECC in that it also requires the use of ASTM E 779, but differs from those provisions in that the air leakage metric is calculated using the industry standard for non-residential buildings. For buildings where the size and climate zone indicate cost-effectiveness, testing is required with leakage thresholds at the former IECC and ASHRAE 90.1 optional levels. The measure is consistent with air leakage testing requirements and thresholds required by the State of Washington and City of Seattle commercial building energy codes (SDCI Community Engagement 2012), as well as procedures followed by the DOD for testing of commercial buildings referenced above. The City of Seattle requirements have been in place since 2009, and hundreds of commercial buildings have been tested under that code, including many large buildings. The proposed measure is less stringent than the current DOD requirements (0.25 cfm/ft^2), and case studies (Durston and Heron 2012) have shown that much lower leakage levels—in the range of 0.15 cfm/ft^2—can be achieved.

1.3 Energy and Cost Impacts

The energy savings, cost impact, and cost effectiveness are summarized here, with more detail in the Appendix.

Energy Savings: An analysis of energy impact shows that annual energy savings from air barrier improvement resulting from testing due to the measure ranges from $5.07 to $71.88 per thousand square feet of floor area in offices in climate zones where testing is recommended. More details are found in the cost-effectiveness analysis referenced in the Appendix.

Cost Impact: This measure will increase the cost of construction of new commercial buildings as whole building air leakage testing will be required except for primarily residential buildings (Group R[1] and I[2] building occupancies). Based on a survey of professional commercial building air barrier testing companies, it was determined that the cost of air leakage testing fell into three ranges:

- $350 or $0.12 to $0.07 per square foot for buildings up to 5000 square feet
- $0.50 to $0.15 per square foot for buildings between 5000 and 50,000 square feet
- $0.15 to $0.09 per square foot for buildings between 50,000 and 100,000 square feet, with decreasing costs for larger buildings.

As demand for air leakage testing in commercial buildings increases, more companies will enter the market to provide these services. Therefore, a gradual decrease in cost is expected as more companies are available to do the testing.

Cost-effectiveness: Pacific Northwest National Laboratory performed a cost-effectiveness analysis using the established DOE methodology (Hart and Liu 2015). Results of the analysis indicate that the average savings-to-investment ratio (SIR) and simple payback period (SPP) for commercial building testing with a limit of 0.40 cfm/ft^2 (1.5 L/s · m^2) at a pressure differential of 0.3 inch w.g. (50 Pa) in office buildings vary by size, as shown in the table below.

Building size range, floor area square feet	<5000	5000 to 50,000	>50,000
Average SIR	7.3	2.2	3.2

[1] **Residential Group R:** uses intended for sleeping purposes. Group R is divided into four sub groups: **R-1** occupants are transient in nature; **R-2** occupancies containing sleeping units or more than two dwelling units where the occupants are more permanent in nature; **R-3** one and two family dwelling, or adult and child care facilities that provide accommodation for five or fewer persons of any age for less than 24 hours; **R-4** are intended for occupancy as residential care/assisted living facilities including more than five but not more than sixteen occupants, excluding staff.

[2] **Institutional Group I:** uses intended in which people are cared for or live in a supervised environment, having physical limitations because of health or age are harbored for medical treatment or other care or treatment or in which the liberty of the occupants is restricted. Group I is divided into four sub groups: **I-1** houses more than 16 persons, on a 24 hour basis, who because of age, mental disability or other reasons, live in a supervised residential environment that provides personal care services. The occupants are capable of responding to an emergency situation without physical assistance from staff; **I-2** buildings are used for medical, surgical, psychiatric, nursing or custodial care on a 24 hr basis of more than five persons who are not capable of self-preservation (Less than five people shall be considered an R-3); **I-3** is inhabited by more than five persons who are under restraint or security and is occupied by persons who are generally incapable of self-preservation due to security measures not under the occupant's control.

Average SPP (years)	7.1	13.1	10.2

A measure is cost-effective when the SIR is greater than 1.0, indicating that the present value of savings is greater than the incremental cost. Under ASHRAE 90.1 criteria, cost-effectiveness is proven when the simple payback is shorter than the scalar threshold of 22.2 years. Based on the cost-effectiveness analysis results, air barrier testing is specified for buildings that have both an SIR greater than 1 and a simple payback that is less than the 90.1 scalar threshold based on climate zone and building size.

As a result of breaks in cost assumptions, the most climate zones qualify for testing for buildings below 5000 square feet, with fewer climate zones requiring testing for buildings larger than 50,000 square feet, and the fewest climate zones requiring testing for buildings between 5000 and 50,000 square feet.

1.4 Sample Code Language

Suggested code language for the measure is summarized and provided below. Air-leakage testing is required for buildings and climate zones where the analysis demonstrated it to be cost-effective.

- In non-excepted climate zones, an envelope testing limit of 0.40 cfm/ft^2 (1.5 L/s · m^2) of the *testing unit enclosure area* at a pressure differential of 0.3 inch w.g. (75 Pa) is applied, which matches the current commercial optional testing limit. Under ASTM E 779, tests at a lower pressure of 0.30 cfm/ft^2 at 50 Pa can be made and mathematically converted to the required test pressure. This allows smaller buildings to be tested with residential equipment and technicians.
- Exceptions are provided for climate zone 2B where air barriers are not required and in other climate zones by building size where testing was not found to be currently cost-effective. Existing compliance options associated with air barrier materials or assemblies are retained for buildings that do not have a specified testing requirement.
- An exception is included that allows the tested leakage rate to be no more than 0.6 cfm/ft^2 as long as specific remediation efforts are made.
- In addition, some clarifications are made, including better use of the defined terms *building thermal envelope* and *continuous air barrier,* which should improve compliance.

Sample code language is outlined below based on the current 2018 IECC. Similar language can also be adapted to state and local codes that are based on the IECC or contain similar provisions. Similar concepts could be applied to ASHRAE standard 90.1.

Modify Sections C402.5, and C402.5.1 as follows and add table C402.5.1 and section C402.5.1.3 :

C402.5 Air leakage—thermal envelope (Mandatory). The *building thermal envelope* ~~of buildings~~ shall comply with Sections C402.5.1 through C402.5.8, or the building *thermal envelope* shall be tested in accordance with ASTM E 779 at a pressure differential of 0.3 inch water gauge (75 Pa) or an equivalent method approved by the code official and deemed to comply with the provisions of this section when the tested air leakage rate of the building thermal envelope is not greater than 0.40 cfm/ft^2 (2.0 L/s · m^2). Where compliance is based on such testing, the building shall also comply with Sections C402.5.5, C402.5.6, and C402.5.7.

Italicize defined terms as shown in the following sections:

C402.5.1 Air barriers. A *continuous air barrier* shall be provided throughout the *building thermal envelope*. The continuous *air barrier*~~s~~ shall be ~~permitted to be~~ located on the inside or outside of the *building* *thermal envelope*, located within the assemblies composing the *building thermal envelope*, or any combination thereof. The air barrier shall comply with Sections C402.5.1.1 and C402.5.1.2.

Exception: Air barriers are not required in buildings located in *Climate Zone* 2B.

No changes to sections C402.5.1.1.1

C402.5.1.2 Air barrier compliance ~~options~~. A *continuous air barrier* for the opaque building envelope shall comply with the following:

1. Buildings or portions of buildings including group R and group I occupancy shall meet the provisions of Section C402.5.1.2.1 or C402.5.1.2.2.
2. Buildings or portions of buildings of other than group R and group I occupancy shall meet the provisions of Section C402.5.1.2.3.

   Exceptions to item 2:

   1. Buildings in climate zones 2B, 3B, 3C, and 5C.
   2. Buildings larger than 5000 square feet floor area in climate zones 0B, 1, 2A, 4B, and 4C.
   3. Buildings between 5000 and 50,000 square feet floor area in climate zones 0A, 3A and 5B.
3. Buildings or portions of buildings that do not complete air barrier testing shall meet the provisions of Section C402.5.1.2.1 or C402.5.1.2.2.

Note: Climate Zones 0A and 0B should be included in exceptions above if in the applicable code.

No changes to sections C402.5.1.2.1 & C402.5.1.2.2

C402.5.1.2.3 Non-Residential Building Thermal Envelope Testing. The *building thermal envelope* shall be tested in accordance with ASTM E 779 or an equivalent method *approved* by the code official. The measured air leakage shall not exceed 0.40 cfm/ft^2 (2.0 L/s · m^2) of the *building thermal envelope* area at a pressure differential of 0.3 inch water gauge (75 Pa). Alternatively, portions of the building shall be tested and the measured air leakages shall be area-weighted by the surface areas of the building envelope in each portion. The weighted average test results shall not exceed the whole building leakage limit. In the alternative approach, the following portions of the building shall be tested:

1. The entire envelope area of all stories that have any spaces directly under a roof,
2. The entire envelope area of all stories that have a building entrance, exposed floor, or loading dock, or are below grade, and
3. Representative above-grade sections of the building totaling at least 25 percent of the wall area enclosing the remaining conditioned space.

Exception to C402.5.1.2.3: Where the measured air leakage rate exceeds 0.40 cfm/ft^2 (2.0 L/s•m^2) but does not exceed 0.60 cfm/ft^2 (3.0 L/s•m2), a diagnostic evaluation using smoke tracer or infra-red imaging shall be conducted while the building is pressurized along with a visual inspection of the air barrier. Any leaks noted shall be sealed where such sealing can be made without destruction of existing building components. An additional report identifying the corrective actions taken to seal leaks shall be submitted to the code official and the building owner, and shall be deemed to satisfy the requirements of this section.

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Appendix

Cost-effectiveness Analysis Detail

Purpose: Determine cost-effectiveness of air barrier testing for commercial buildings, excluding those with dwelling or sleeping units.

Basis of Analysis

Simulation of change in outside air leakage through the building envelope from 1.0 cfm/ft^2 to 0.4 cfm/ft^2 for the medium office prototype building using the EnergyPlus™ energy simulation software. The prototype model used in the analysis, its development, and the climate locations are described in detail in the quantitative determination[1] and are available for download.[2]

The cost-effectiveness analysis is conducted according to the U.S. Department of Energy cost-effectiveness methodology.[3] The methodology includes three scenario approaches. Scenarios 2 and 3 are alternate approaches for privately owned buildings. The long-term economic impacts for two cases are determined:

- Publicly-owned Buildings: Based on the established Federal Energy Management Program method[4] (Scenario 1).
- Privately-owned Buildings: Based on the 90.1-2019 *Scalar* Method[5] (Scenario 3).

40.0-year measure life is the accepted value designated by the ASHRAE Standard 90.1 (SSPC 90.1) code development and consensus committee for analysis of building envelope measures.

Scenario 1 factors
Electric uniform present value (UPV) factor[6] with 3% discount and U.S. Energy Information Administration (EIA) energy escalation for present value (PV) savings: 20.38.

Blended Fossil UPV factor with 3% discount and EIA energy escalation for PV savings: 24.37.
In Scenario 1, measures are found cost-effective when the savings-to-investment ratio (SIR) ≥ 1.0.

Scenario 3 factors

(90.1-2019) Scalar threshold :	Electric	22.1	96%	**Blended**
	Fossil	25.2	4%	**22.2**

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[1] Halverson M, M Rosenberg, W Wang, J Zhang, V Mendon, R Athalye, Y Xie, R Hart, and S Goel. 2014. *ANSI/ASHRAE/IES Standard 90.1-2013 Determination: Quantitative Analysis*. Pacific Northwest National Laboratory, Richland, WA. https://www.energycodes.gov/sites/default/files/documents/901-2013_finalCommercialDeterminationQuantitativeAnalysis_TSD.pdf.

[2] Download from http://www.energycodes.gov/development/commercial/90.1_models.

[3] Hart R and B Liu. 2015. *Methodology for Evaluating Cost-effectiveness of Commercial Energy Code Changes*. Pacific Northwest National Laboratory for U.S. Department of Energy; Energy Efficiency & Renewable Energy. PNNL-23923, Rev 1. https://www.energycodes.gov/development/commercial/methodology.

[4] Fuller S and S Petersen. *Life-Cycle Costing Manual for the Federal Energy Management Program*. NIST, U.S. Department of Commerce, 1995. http://fire.nist.gov/bfrlpubs/build96/PDF/b96121.pdf.

[5] Based on the approach and factors established by the ASHRAE Standard 90.1 project committee for 90.1-2019.

[6] Lavappa P and J Kneifel. *Energy Price Indices and Discount Factors for Life-Cycle Cost Analysis-2018: Annual Supplement to NIST Handbook 135*, 2018. https://nvlpubs.nist.gov/nistpubs/ir/2018/NIST.IR.85-3273-33.pdf.

In Scenario 3, measures are found cost-effective when the simple payback ≤ the scalar threshold.

Energy Prices

Commercial sector pricing is appropriate for most commercial buildings. These are used in Scenario 1, while the commercial prices selected by the ASHRAE 90.1 committee are used in Scenario 3.

Commercial prices are sourced from EIA data for the 12-month period from November 2017 to October 2018. Heating prices are weighted by typical sector fuel use weighting for natural gas and oil, resulting in a blended fossil fuel price expressed in $ per therm. UPV factors for the Scenario 1 analysis account for both fuel escalation and present value discounting. For heating, they are weighted for the fuel mix. UPV 30-year factors are adjusted to a 40-year life by applying the equivalent year 1-30 net discount rate for the 30-year UPV to years 31-40:

Energy Type			**Unit Price**		**Weight**	**UPV,30**	**UPV,40**
Natural Gas	7.84	$/ kCuFt	$0.7561	$/therm	89.4%	23.99	
Heating Oil	3.01	$/ gal	$2.1700	$/therm	10.6%	27.54	
Blended Fossil Rate			**$0.9065**	**$/therm**		**23.48**	28.19
Electricity			**$0.1069**	**$/kWh**		21.45	23.95

Energy Savings

Based on the results of the EnergyPlus analysis, the results for the medium office are prorated to other sized buildings based on the exposed building envelope area, excluding the ground floor. There are expected to be two general cost groupings as follows:

- Commercial buildings smaller than 5000 square feet can be tested using the same equipment and technicians as residential construction.
- For buildings larger than 5000 square feet, the testing becomes more complex, and more equipment and a larger field staff is required. The cost for larger building testing has a base cost with an added cost per floor area, so the total testing cost per floor area decreases as buildings get larger.

To determine cost-effectiveness of three size ranges (<5000; 5000 to 50,000, and >50,000), analysis is made for six separate building sizes as follows:

Building Floor Area, ft^2	3,000	5,000	10,000	25,000	50,000	100,000
Envelope Area (excluding Floor)	5,191	7,828	12,354	23,904	36,806	56,946
Testing cost $\$/ft^2$ of floor area	$0.117	$0.070	$0.466	$0.247	$0.154	$0.095

Cost-effectiveness

The cost-effectiveness is evaluated using Scenario 1 for the public sector and Scenario 3 for the private sector.[1] For Scenario 1, the SIR indicates a measure is cost-effective when greater than 1.0. In Scenario 3, the simple payback (cost/annual savings) is compared to a scalar threshold that includes commercial discount rates and loan costs. When the payback is less than the threshold, a measure is considered cost-effective. The scalar threshold for blended savings over a 40-year measured life is 22.2 years. Testing for larger buildings will be cost-effective when a smaller size in the same pricing regime is cost-effective, except for the shift at 5000 square feet from residential style testing to more complex commercial testing. Results are shown for buildings at the 3000, 10,000, and 50,000 square foot size. Cost-effectiveness by climate zone is selected based on the smaller building analysis in three size ranges (<5000; 5000 to 50,000, and >50,000).

Present Value of Energy Savings, per 3000* square feet of floor area 3000 sq ft office building: $350 per test						
Climate Zone	Scenario 1 PV of Savings	Net LCC Savings	SIR PV sav / Cost	Scenario 3 annual Savings	Scenario 3 payback years	Both Scenarios Pass?
1A	$621	$271	1.8	$25	14.3	Yes
1B	$452	$102	1.3	$18	19.6	Yes
2A	$443	$93	1.3	$18	20.0	Yes
2B	$900	$550	2.6	$36	9.8	Yes
3A	$1,169	$819	3.3	$46	7.6	Yes
3B	$334	-$16	†	$13	†	
3C	-$116	-$466	†	-$5	†	
4A	$2,558	$2,208	7.3	$101	3.5	Yes
4B	$522	$172	1.5	$21	17.0	Yes
4C	$929	$579	2.7	$37	9.5	Yes
5A	$3,708	$3,358	10.6	$147	2.4	Yes
5B	$1,303	$953	3.7	$52	6.8	Yes
5C	$345	-$5	†	$14	†	
6A	$5,453	$5,103	15.6	$216	1.6	Yes
6B	$2,785	$2,435	8.0	$110	3.2	Yes
7	$4,146	$3,796	11.8	$164	2.1	Yes
8	$2,259	$1,909	6.5	$89	3.9	Yes
Scenario 3 discounted payback threshold for 40 year life is					**22.2**	
Note: CZ 2B is excepted from envelope air barriers.					† Beyond CE limits	

* Pass results are the same at 5000 square feet of floor area; except 3B and 5C also pass. Results from 3000 square feet are used for testing testing criteria under 5000 square feet for simplicity.

[1] Hart R and B Liu. 2015. *Methodology for Evaluating Cost-Effectiveness of Commercial Energy Code Changes*. Pacific Northwest National Laboratory for U.S. Department of Energy; Energy Efficiency & Renewable Energy, August 2015. https://www.energycodes.gov/development/commercial/methodology.

Average results for included climate zones for 3000 and 5000 square foot buildings:

- SIR: 7.3; greater than 1.0 is cost-effective
- SPB: 7.1; less than 22.2 years is cost-effective

Present Value of Energy Savings, per 10,000* square foot of floor area 10,000 sq ft office building: $4660 per test						
Climate Zone	Scenario 1 PV of Savings	Net LCC Savings	BCR PV sav / Cost	Scenario 3 annual Savings	Scenario 3 payback years	Both Scenarios Pass?
1A	$1,477	-$3,183	†	$58	†	
1B	$1,076	-$3,584	†	$43	†	
2A	$1,053	-$3,607	†	$42	†	
2B	$2,143	-$2,518	†	$85	†	
3A	$2,782	-$1,879	†	$110	†	
3B	$795	-$3,866	†	$31	†	
3C	-$276	-$4,937	†	-$11	†	
4A	$6,088	$1,428	1.3	$241	19.4	Yes
4B	$1,242	-$3,419	†	$49	†	
4C	$2,210	-$2,451	†	$87	†	
5A	$8,826	$4,165	1.9	$349	13.4	Yes
5B	$3,101	-$1,559	†	$123	†	
5C	$820	-$3,840	†	$32	†	
6A	$12,977	$8,317	2.8	$513	9.1	Yes
6B	$6,627	$1,967	1.4	$262	17.8	Yes
7	$9,867	$5,207	2.1	$390	11.9	Yes
8	$5,377	$716	1.2	$213	21.9	Yes
Scenario 3 discounted payback threshold for 40 year life is					**22.2**	
Note: CZ 2B is excepted from envelope air barriers.					† Beyond CE limits	

* Pass results are the same at 25,000 square feet of floor area.

Average results for included climate zones for 10,000 and 25,000 square foot buildings:

- SIR: 2.2; greater than 1.0 is cost-effective
- SPB: 13.1; less than 22.2 years is cost-effective

Present Value of Energy Savings, per 50,000* square foot of floor area 50,000 sq ft office building: $7215 per test						
Climate Zone	Scenario 1 PV of Savings	Net LCC Savings	SIR PV sav / Cost	Scenario 3 annual Savings	Scenario 3 payback years	Both Scenarios Pass?
1A	$4,630	-$2,585	†	$183	†	
1B	$3,374	-$3,842	†	$133	†	
2A	$3,301	-$3,914	†	$131	†	
2B	$6,716	-$499	†	$266	†	
3A	$8,718	$1,502	1.2	$345	20.9	Yes
3B	$2,491	-$4,724	†	$98	†	
3C	-$865	-$8,080	†	-$34	†	
4A	$19,082	$11,866	2.6	$755	9.6	Yes
4B	$3,892	-$3,324	†	$154	†	
4C	$6,926	-$290	†	$274	†	
5A	$27,661	$20,446	3.8	$1,094	6.6	Yes
5B	$9,720	$2,504	1.3	$384	18.8	Yes
5C	$2,571	-$4,644	†	$102	†	
6A	$40,673	$33,457	5.6	$1,608	4.5	Yes
6B	$20,771	$13,556	2.9	$821	8.8	Yes
7	$30,925	$23,710	4.3	$1,223	5.9	Yes
8	$16,853	$9,638	2.3	$666	10.8	Yes
Scenario 3 discounted payback threshold for 40 year life is					**22.2**	
Note: CZ 2B is excepted from envelope air barriers.					† Beyond CE limits	

* Pass results are the same at 100,000 square feet of floor area

Average results for included climate zones for 50,000 and 100,000 square foot buildings:

- SIR: 3.2; greater than 1.0 is cost-effective
- SPB: 10.2; less than 22.2 years is cost-effective

Conclusions

Air barrier testing is cost-effective in most climate zones for smaller commercial buildings that experience lower testing costs; and in several climate zones for buildings larger than 50,000 square feet. Buildings between 5000 and 50,000 square feet have higher relative testing costs, so cost-effectiveness exceptions by climate zone are necessary. Some buildings larger than 100,000 square feet may have cost-effective air leakage testing, but that refinement is not suggested for the minimum code requirements to maintain simplicity. Air barrier testing is recommended for commercial buildings in climates where it is cost-effective, as shown by green shading in the following table. Exceptions are grouped as follows:

- Red indicates that testing is not found cost-effective for any building size up to 100,000 square feet in the climate zone. Note that buildings in climate zone 2B were cost effective under 5000 square feet, but are currently excepted from air barrier requirements.
- Orange indicates testing is not found cost-effective for buildings larger than 5000 square feet up to 100,000 square feet in the climate zone.
- The remaining white areas indicate that cost-effectiveness was not found for buildings between 5000 and 50,000 square feet.

Leakage Testing Cost-effectiveness by building size and climate zone			
	Commercial Building Floor Area		
Climate Zone	<5000	5000 to 50,000	> 50,000
1A	Yes		
1B	Yes		
2A	Yes		
2B			
3A	Yes		Yes
3B			
3C			
4A	Yes	Yes	Yes
4B	Yes		
4C	Yes		
5A	Yes	Yes	Yes
5B	Yes		Yes
5C			
6A	Yes	Yes	Yes
6B	Yes	Yes	Yes
7	Yes	Yes	Yes
8	Yes	Yes	Yes

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