C-1: Envelope Air Leakage Testing (C402.4)

Summary: Building air leakage increases energy use for heating and cooling. Testing can result in significantly reduced building leakage and consequently allow for reduced HVAC equipment sizing, better building pressurization, and energy savings due to reduced heating and cooling of infiltrated outside air. In moist climates, leakage testing can also result in better humidity control.

DOE proposal C-1 was revised on December 18, 2015.

Stakeholder Feedback: There were two public comments received for proposal C-1. Comments are summarized below, followed by a DOE review:

- One comment was generally supportive of air barrier testing.
- One comment pointed out that the removed exception related to air barrier construction, not testing, and that costs were different.
  Review: An earlier cost-effectiveness analysis[1] of air barrier construction found that it was not cost-effective for masonry walls in Phoenix, AZ, Climate Zone 2B.

In response to these comments and other external review, DOE will revise its proposal to not strikeout the exception for Climate Zone 2B and clarify the references to occupancy groups.

= = = IECC PROPOSAL:

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 (0.2 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.

C402.5.1.1 Air barrier construction. The *continuous air barrier* shall be constructed to comply with the following:

1. The air barrier shall be continuous for all assemblies that are the thermal envelope of the building and across the joints and assemblies.

[1] S. Emmerich, T. McDowell, and W. Anis. "Investigation of the Impact of Commercial Building Envelope Airtightness on HVAC Energy Use." National Institute of Standards and Technology for U.S. Department of Energy Office of Building Technologies, June 2005. http://fire.nist.gov/bfrlpubs/build05/art007.html.

2. Air barrier joints and seams shall be sealed, including sealing transitions in places and changes in materials. The joints and seals shall be securely installed in or on the joint for its entire length so as not to dislodge, loosen or otherwise impair its ability to resist positive and negative pressure from wind, stack effect and mechanical ventilation.
3. Penetrations of the air barrier shall be caulked, gasketed or otherwise sealed in a manner compatible with the construction materials and location. Joints and seals associated with penetrations shall be sealed in the same manner or taped or covered with moisture vapor-permeable wrapping material. Sealing materials shall be appropriate to the construction materials being sealed and shall be securely installed around the penetration so as not to dislodge, loosen or otherwise impair the penetrations' ability to resist positive and negative pressure from wind, stack effect and mechanical ventilation. Sealing of concealed fire sprinklers, where required, shall be in a manner that is recommended by the manufacturer. Caulking or other adhesive sealants shall not be used to fill voids between fire sprinkler cover plates and walls or ceilings.
4. Recessed lighting fixtures shall comply with Section C402.5.7. Where similar objects are installed that penetrate the air barrier, provisions shall be made to maintain the integrity of the air barrier.

C402.5.1.2 Air barrier compliance ~~options~~. A *continuous air barrier* in buildings with gross conditioned floor area equal to or greater than the value shown in Table C402.5.1.2 shall meet the provisions of Section C402.5.1.2.1. A *continuous air barrier* for the opaque building envelope in buildings with gross conditioned floor area less than the value shown in Table C402.5.1.2 shall ~~comply with~~ meet the provisions of Section C402.5.1.2.1 or C402.5.1.2.2 or C402.5.1.2.3.

Table C402.5.1.2
MINIMUM BUILDING SIZE REQUIRING AIR LEAKAGE TESTING

Occupancy Groups R & I		All Other Occupancy and Use Groups	
Climate Zone	Building Floor Area, ft^2 (m^2)	Climate Zone	Building Floor Area, ft^2 (m^2)
5A, 6A, 7	6000 (600)	5A, 6A, 7	40,000 (3,700)
4A, 6B	9,000 (800)	0A, 1A, 4A, 6B	75,000 (7,000)
0A, 1A, 8	17,500 (1,600)	5B, 8	200,000 (18,600)
0B, 1B, 3A, 5B	25,000 (2,300)	0B, 1B, 2A, 3A	350,000 (32,500)
2A, 3B, 4C	50,000 (4,600)	2B, 3B, 3C, 4B, 4C, 5C	NR
4B	60,000 (5,600)		
2B, 3C, 5C	NR		

NR = Not Required

Note: Climate Zones 0A and 0B to be included in table above only if another proposal introducing these new very hot climate zones is approved.

C402.5.1.2.1 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 (0.2 L/s · m^2) of the *building thermal envelope* area at a pressure differential of 0.3 inch water gauge (75 Pa).

Exceptions:

1. For buildings having over 50,000 ft^2 (5,000 m^2) of gross conditioned floor area, air leakage testing shall be permitted to be conducted on less than the whole building provided the following portions of the building are tested:
    a. The entire floor area of all stories that have any spaces directly under a roof,
    b. The entire floor area of all stories that have a building entrance or loading dock, and

c. Representative above-grade sections of the building totaling at least 25% of the wall area enclosing the remaining conditioned space.

The measured air leakages shall then be area-weighted by the surface areas of the building envelope in a, b, and c above to determine a whole building value. The test(s) of the areas in c shall be applied to the remainder of the building envelope surface area not included in a, b and c.

2. 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 and any leaks noted shall be sealed if such sealing can be made without destruction of existing building components. In addition, a visual inspection of the air barrier shall be conducted and any leaks noted shall be sealed if 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.

C402.5.1.2.2~~1~~ Materials. Materials with an air permeability not greater than 0.004 cfm/ft^2 (0.02 L/s·m^2) of tested material area under a pressure differential of 0.3 inch water gauge (75 Pa) when tested in accordance with ASTM E 2178 shall comply with this section. Materials in Items 1 through 16 shall be deemed to comply with this section, provided joints are sealed and materials are installed as air barriers in accordance with the manufacturer's instructions.

1. Plywood with a thickness of not less than 3/8 inch (10 mm).
2. Oriented strand board having a thickness of not less than 3/8 inch (10 mm).
3. Extruded polystyrene insulation board having a thickness of not less than 1/2 inch (12.7 mm).
4. Foil-back polyisocyanurate insulation board having a thickness of not less than 1/2 inch (12.7 mm).
5. Closed-cell spray foam a minimum density of 1.5 pcf (2.4 kg/m^3) having a thickness of not less than 1 1/2 inches 38 mm).
6. Open-cell spray foam with a density between 0.4 and 1.5 pcf (0.6 and 2.4 kg/m^3) and having a thickness of not less than 4.5 inches (113 mm).
7. Exterior or interior gypsum board having a thickness of not less than 1/2 inch (12.7 mm).
8. Cement board having a thickness of not less than 1/2 inch (12.7 mm).
9. Built-up roofing membrane.
10. Modified bituminous roof membrane.
11. Fully adhered single-ply roof membrane.
12. A Portland cement/sand parge, or gypsum plaster having a thickness of not less than 5/8 inch (15.9 mm).
13. Cast-in-place and precast concrete.
14. Fully grouted concrete block masonry.
15. Sheet steel or aluminum.
16. Solid or hollow masonry constructed of clay or shale masonry units.

C402.5.1.2.3~~2~~ Assemblies. Assemblies of materials and components with an average air leakage not greater than 0.04 cfm/ft^2 (0.2 L/s · m^2) of tested assembly area under a pressure differential of 0.3 inch of water gauge (w.g.)(75 Pa) when tested in accordance with ASTM E 2357, ASTM E 1677 or ASTM E 283 shall comply with this section. Assemblies listed in Items 1 through 3 shall be deemed to comply, provided joints are sealed ~~and the requirements of Section C402.5.1.1 are met~~.

1. Concrete masonry walls coated with either one application of block filler or two applications of a paint or sealer coating.
2. Masonry walls constructed of clay or shale masonry units with a nominal width of 4 inches (102 mm) or more.
3. A Portland cement/sand parge, stucco or plaster not less than 1/2 inch (12.7 mm) in thickness.

Reason. This proposal modifies the building thermal envelope section to require air leakage testing of certain buildings based on climate zone, building use and the floor area of the conditioned space. The

minimum floor area of buildings where air leakage testing is required is based on cost-effectiveness analysis. Based on that analysis, separate thresholds are provided for residential and institutional buildings (Group R[2] & I[3] building occupancies) and a separate threshold for all other building occupancies. The testing requirement is currently an optional path in the IECC where whole building air leakage testing is allowed as a means of meeting air leakage requirements. This change does not modify the maximum leakage rate or method of test, it simply requires testing for certain buildings and for other buildings testing is retained as an option. The current options for compliance associated with the materials or assemblies used in construction of an air barrier are retained and would continue to be compliance options for buildings that would not have testing required by this proposal.

In addition to the testing compliance changes, some clarifications are made to the referred areas in each of the paths, defined terms are inserted where appropriate, and italics are added for defined terms. The phrase "and the requirements of Section C402.5.1.1 are met" is struck from the *Assemblies* compliance section (renumbered to C402.5.1.2.3), as it is redundant with the same requirement called out in the charging paragraph, C402.5.1. Note that in the prior optional path when testing was used for compliance, sections C402.5.1.1, C405.5.2, C405.5.3, C405.5.4, and C405.5.8 were not required. Requirement for these sections has been retained with testing, as meeting the requirements of these sections is important in creation of a good air barrier and testing is really just a compliance verification path like the Materials and Assemblies paths. Further, the proposed testing limit of 0.40 cfm/ft^2 with a fallback to 0.60 cfm/ft^2 could result in increased leakage without the actual requirements for a *continuous air barrier* in these sections.

While it is important that the materials and assemblies have limited leakage, that alone does not guarantee a low leakage building. Recent research[4] shows that 40% of buildings constructed **without** an envelope consultant have air leakage exceeding the currently optional test standard, while buildings with envelope consultants had leakage below 0.25 cfm/ft^2. Requiring testing will ensure that the goal of this section of the code—limiting unintended air infiltration in buildings—will be achieved.

The proposal retains a test limit of 0.40 cfm/ft^2 as is currently required for optional testing. This is less stringent than the current Department of Defense requirements (0.25 cfm/ft^2) and case studies[5] have shown that much lower leakage levels–in the range of 0.15 cfm/ft^2–can be achieved. Since mandatory—rather than optional— testing would be a new requirement, it was felt appropriate to retain the current and higher limit of 0.4 cfm/ft^2 for improved building industry acceptance. The review of more stringent requirements by the Department of Defense[5] shows that while the range of building leakage can exceed

---

[2] **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.

[3] **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.

[4] Wiss, J. (2014). ASHRAE 1478-RP Measuring Airtightness of Mid- and High-Rise Non-Residential Buildings. Elstner Associates, Inc. for ASHRAE. https://www.ashrae.org/resources--publications/periodicals/enewsletters/esociety/2014-12-10-articles/completed-research-december-2014.

[5] Durston, J. L., and Heron, M. (2012). "Summary and Analysis of Large Building Air Leakage Testing for the U.S. Department of Defense." Atlanta GA. http://c.ymcdn.com/sites/www.nibs.org/resource/resmgr/BEST/best3_durston.2.9.pdf.

the requirement by more than double (0.9 cfm/ft^2) the average leakage of buildings tested is well below the 0.4 limit when leak testing is part of the construction process. Therefore, a test limit of 0.40 cfm/ft^2 is a realistic and achievable goal.

It was also prudent to provide some flexibility on the test standard to allow for building industry acceptance and a transition to a fixed requirement, because when the building envelope is complete and testing occurs, access to the air barrier for repairs is difficult. So an exception is included that allows the tested leakage rate to be below 0.6 cfm/ft^2 as long as specific remediation to be undertaken. This exception is meant to provide a modest relaxation of the requirement, but only if significant corrective actions are taken that may result in improving the air leakage. Another exception for large buildings (over 50,000 ft^2) allows representative portions of the building to be tested. This exception will make compliance more economical for large buildings.

This proposal is similar to the residential air leakage provisions in the 2015 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 in the manner that is the industry standard for non-residential buildings. The proposal requires the same level of air leakage testing that is required by the State of Washington and City of Seattle commercial building energy codes[6] as well as procedures followed by the US Department of Defense 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.

Energy Savings: An analysis of energy impact shows that savings from air barrier testing in the proposal ranges from $1.69 to $12.59 per thousand square feet of floor area in large offices and from $6.69 to $44.82 per thousand square feet of floor area in mid-rise apartment buildings in climate zones where testing is recommended. More details are found in the cost-effectiveness analysis referenced in the cost impact section.

The U.S. Department of Energy (DOE) develops its proposals through a public process to ensure transparency, objectivity and consistency in DOE-proposed code changes. Energy savings and cost impacts are assessed based on established methods and reported for each proposal, as applicable. More information on the process utilized to develop the DOE proposals for the 2018 IECC can be found at: https://www.energycodes.gov/development/2018IECC.

Cost Impact. This proposal will increase the cost of construction of new commercial and high-rise multi-family residential buildings as whole building air leakage testing will be required. Based on a survey of professional commercial building air barrier testing companies, it was determined that the cost of air leakage testing for buildings could range from a minimum of about $4,000 to $7,000 for the small and relatively simple buildings to about twice that ($8,000 to $14,000) for larger and more complex buildings. As demand for air leakage testing in commercial buildings increases, more companies will enter the market to provide these services. This will lead to a gradual decrease in cost as more companies are available to do the testing. It is possible that small buildings (up to about 5,000 ft^2) could likely use residential air leakage testing firms such as those associated with HERS ratings; however, the current proposal does not require small building testing, except as an optional path. An examination of prices for residential air leakage testing indicated costs can be less than $350 per home. Given that both the residential and commercial air leakage testing protocols are based on the same ASTM E 779 standard, there is not likely to be much difference in the equipment and training needed for a company to perform small building commercial air leakage testing as well as residential air leakage testing.

[6] http://buildingconnections.seattle.gov/2012/03/01/air-barriers-and-pressure-testing/.

Cost-effectiveness: PNNL performed a cost-effectiveness analysis using the established DOE methodology.[7] Results of the cost-effectiveness analysis showed that the average savings-to-investment ratio (SIR) was 1.8 in large offices and 1.6 in mid-rise apartment buildings. A proposal is cost-effective when the SIR is greater than 1.0, indicating that the present value of savings is greater than the incremental cost. The cost-effectiveness results were reviewed and air barrier testing was required by climate zone for buildings that have present value savings exceeding the testing cost based on building size. The complete cost-effectiveness analysis is available at: https://www.energycodes.gov/development/2018IECC.

Formatting note: If preferred by ICC staff, the Table C402.5.1.2 could be formatted as follows with the same requirements. The proponents of this proposal would consider this an editorial change.

Table C402.5.1.2
MINIMUM BUILDING SIZE REQUIRING AIR LEAKAGE TESTING

Climate Zone	Building Floor Area, ft^2 (m^2)	
	Occupancy Groups R & I	All Other Occupancy and Use Groups
0A	17,500 (1,600)	75,000 (7,000)
0B	25,000 (2,300)	350,000 (32,500)
1A	17,500 (1,600)	75,000 (7,000)
1B	25,000 (2,300)	350,000 (32,500)
2A	50,000 (4,600)	350,000 (32,500)
2B	NR	NR
3A	25,000 (2,300)	350,000 (32,500)
3B	50,000 (4,600)	NR
3C	NR	NR
4A	9,000 (800)	75,000 (7,000)
4B	60,000 (5,600)	NR
4C	50,000 (4,600)	NR
5A	6,000 (600)	40,000 (3,700)
5B	25,000 (2,300)	200,000 (18,600)
5C	NR	NR
6A	6,000 (600)	40,000 (3,700)
6B	9,000 (800)	75,000 (7,000)
7	6000 (600)	40,000 (3,700)
8	17,500 (1,600)	200,000 (18,600)

NR = Not Required

Note: Climate Zones 0a and 0b to be included in table above only if another proposal introducing these new very hot climate zones is approved.

[7] Hart, R., and Liu, B. (2015). *Methodology for Evaluating Cost-effectiveness of Commercial Energy Code Changes.* Pacific Northwest National Laboratories for U.S. Department of Energy; Energy Efficiency & Renewable Energy. PNNL-23923 Rev1. https://www.energycodes.gov/development/commercial/methodology.