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Trends in building and ductwork airtightness in USA

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1 General introduction

The current U.S. building stock consists of 130 million residential households plus 5.5 million non-residential buildings. The U.S. is building about 700,000 homes per year[1] and 50,000 non-residential buildings. A majority of residential and non-residential buildings use forced air heating and cooling systems because they have cooling, even in climates with moderate summer temperatures.

2 Building airtightness

2.1 Introduction

For both residential and non-residential buildings, the key motivation for airtightness limits is energy conservation. Existing airtightness requirements include both prescriptive limits and measured values for input to energy ratings and energy performance modelling. However, airtightness also supports indoor air quality, moisture management and the preservation of building materials and contents from outdoor air pollutants. Prior to energy codes or standards requiring tighter buildings, studies have shown trends of those in colder climates typically built tighter than those in warmer climates [1].

Some states have adopted the Residential International Energy Conservation Code (IECC-R) energy codes [2] that have prescriptive airtightness requirements of 3 ACH50 (3 air changes per hour at a pressure differential of 50 Pa) for most of the country. These IECC airtightness requirements have been in place since 2009. Many new homes are required to meet an energy target, involving a calculation that includes an assumed or measured air leakage. For example, many homes are rated using ANSI/RESNET/ICC 301 - 2019 [3] that compares the rated home to a baseline home with a Specific Leakage Area[2] of 0.00036 in^2/ft^2. Airtightness for energy ratings using the Residential Energy Services Network (RESNET) standards has been in use since 1995. The U.S. Environmental Protection Agency (EPA) Energy Star for homes program that includes airtightness requirements has also been used since 1995.

For multifamily dwellings, compartmentalization also contributes to improved air quality by reducing air leaking from other units, rather than only from outside. Compartmentalization therefore reduces the transport of key occupant-generated contaminants, such as tobacco smoke. Compartmentalization also reduces stack pressure, reducing uncontrolled infiltration and

[1] https://www.census.gov/programs-surveys/ahs.html

[2] Specific Leakage Area is equivalent leakage area at 4 Pa calculated from a blower door test divided by floor area.

associated energy consumption. Improved compartmentalization can also help mechanical systems operate as intended.

Compartmentalization requirements have been included in the de-facto U.S. national ventilation standard, ASHRAE 62.2, as well as non-industry consensus standards such as EPA Energy Star. A compartmentalization air leakage requirement has been in ASHRAE 62.2 since the 2010 edition. The current ASHRAE 62.2 requirement is a maximum of 100 L/s per 100 m^2 of the dwelling-unit boundary area at a test pressure of 50 Pa.

Similarly, there is a patchwork of requirements in the U.S. for non-residential buildings. Prior to the initial adoption of continuous air barrier (CAB) requirements in ASHRAE Standard 90.1-2010 (based on materials and assemblies and later adding a whole building testing option in 2016), requirements for air barriers or specific airtightness targets were limited to a variety of voluntary programs (such as U.S. Green Building Council LEED (Leadership in Energy and Environmental Design) and smaller local programs such as Efficiency Vermont) and a few state and local building codes. A significant step forward for airtightness in U.S. non-residential buildings was the 2009 requirement by the U.S. Army Corps of Engineers (USACE) for all new U.S. military buildings to meet an airtightness requirement with pressurization testing [4].

The 2012 International Energy Conservation Code [5] has requirements for a CAB with material or assembly airtightness values or a whole building test. The 2021 International Green Construction Code (IgCC) [6] includes the same requirements as the 2012 IECC but also includes a whole building testing requirement consistent with the USACE value. Many U.S. state building codes also include requirements for CABs either through reference to IECC, IgCC, ASHRAE Standard 90.1 or 189.1, or their own independent requirement. Also, the U.S. General Services Administration (GSA 2021) requires all new U.S. federal buildings under the Public Buildings Service to include an air barrier with a whole building air leakage rate limit, referring to the requirements in IgCC 2018.

2.2 Airtightness indicator

For homes, the most used metric is ACH50 - that is the flow through the building envelope at 50 Pa, measured using a blower door or other fan pressurization system, divided by house volume. The single pressure (50 Pa) test metric is chosen over multi-point approaches (such as those in ASTM E779) [6] for simplicity since there is only one measurement point, there are no calculations, and it can be more reproducible over variable weather conditions.

Another airtightness indicator is CFM50/ft^2 (L/s•m^2), where the measured airflow rate at 50 Pa is normalized by the building surface area including all six faces of the dwelling. This metric is often used for reporting multifamily compartmentalization.

Sometimes a leakage area metric is used rather than an airflow rate. For residential buildings, this value is often Specific Leakage Area (SLA), which is unitless and reported at 4 Pa.

In non-residential buildings, it is also common to normalize the measured airflow rate by the envelope area, although codes and standards vary on whether that includes the floor slab and underground envelope surfaces. Some values are reported at pressures of 75 Pa to match the pressures commonly used when rating curtain wall components, such as windows.

2.3 Requirements and drivers

2.3.1 Building airtightness requirements in the regulation

The IECC energy airtightness requirement for residential buildings is 3 ACH50 nationally, except locations with mild climates where the requirement is 5 ACH50. These requirements have remained unchanged since their inception in 1998. Most testing is conducted by a third party independent of the builder.

The U.S. EPA Energy Star program has an airtightness requirement for the reference design home of 3 ACH50 [7]. The EPA Energy Star program also includes extensive checklists for air sealing individual building components. This checklist approach is also used by the U.S. Department of Energy (DOE) Weatherization program. The DOE Zero Energy Ready Home program [8] has requirements that vary with climate, as shown in Table 1.

Table 1: DOE Zero Energy Home Program Air Leakage Limits

2009 IECC Climate Zone	1-2	3-4	5-7	8
Air Leakage Limit (ACH50)	≤3.0	≤2.5	≤2.0	≤1.5

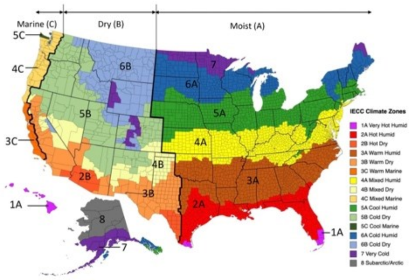

Figure 1: IECC Climate Zone Map RESNET. 2022. From International Energy Conservations Code, 2021

In residential buildings, whole building airtightness requirements have been part of high-performance home programs for over 30 years, but regulations have only required testing since 2009 (for IECC). Those requirements were 7 ACH50, with a non-testing visual inspection option.

Current airtightness requirements for non-residential buildings are summarized in Table 2. As with residential buildings, airtightness requirements for non-residential buildings were limited primarily to a few high-performance building programs until around 2010.

Table 2: Non-residential Air Tightness Limits

	Air Leakage at 75 Pa ($L/s{\cdot}m^2$)		
Standard or code	**Material**	**Assembly**	**Whole building[2]**
ASHRAE 90.1-2022	0.02	0.2	**2.0**
ASHRAE/ICC/USGBC/IES 189.1-2023	References 90.1	References 90.1	1.0
IECC	0.02	0.2	2.0
IgCC-2021	Same as 189.1	Same as 189.1	1.25
USACE ECB 2009-29	0.02	-	1.25
GSA P100-2021	0.02	0.2	1.25
[2]Whole building limits are based on 6-sided enclosure including slab and below-grade walls.			

For multifamily residential buildings, the EPA Energy Star program has a compartmentalization requirement limit of 0.3 cfm/ft^2 (1.5 $L/s/m^2$) at 50 Pa. ASHRAE 62.2 (2021) [9] specifies a compartmentalization limit of 0.2 cfm per ft^2 (100 L/s per 100 m^2) of the dwelling-unit boundary area by means of a blower door test at a test pressure of 50 Pa. The requirement was relaxed to 0.3 cfm/ft^2 (150 L/s per 100 m^2) for several years but has since returned to the more stringent requirement. This change was based on results from field measurements under the EPA Energy Star program that showed the lower limit was easily achieved in practice.

Testing requirements for non-residential buildings vary widely depending on the applicable code or standard for a given location. In many cases, no testing is required for buildings larger than a specified floor area.

For non-residential buildings, ASHRAE/IES Standard 90.1 [10] requires whole building pressurization testing by an independent 3rd party, which must not exceed 2.0 $L/s{\cdot}m^2$ at 75 Pa. If the measured airtightness exceeds this value, but not 3.0 $L/s{\cdot}m^2$, then the standard requires diagnostic evaluation and visual inspection. ASHRAE Standard 189.1, Standard for the Design of High-Performance Green Buildings Except Low-Rise Residential Buildings [11], which serves as the technical content of the International Green Construction Code, has envelope airtightness requirements that parallel Standard 90.1. The main difference is a more stringent whole building airtightness requirement of 1.0 $L/s{\cdot}m^2$ at 75 Pa.

2.3.2 Incentive for Building airtightness

The U.S. instituted tax credits starting in 2023 for homes ($2,500 for single family and $500 to $42,500 for multifamily) that meet Energy Star Program V3.1 requirements [12] for the reference design home:

- 4 ACH50 in Climate Zone (CZs) 1,2
- 3 ACH50 in CZs 3, 4, 5, 6, 7, 8.

Many energy conservation programs include rebates and incentives for home air sealing. However, most of them do not require blower door testing and rely on checklists.

Incentives for airtightness in non-residential buildings are generally available only in limited state or local jurisdictions, and some utility programs. There are also federal tax credits associated with higher performance buildings that may include airtightness as an efficiency measure, but airtightness itself is not directly targeted.

In single family construction, where airtightness requirements exist, all homes are tested. For multifamily buildings, there are usually sampling procedures that require testing of only a few units but increase the number of units to be tested upon failure. One example is the Home Energy Ratings procedure [13].

2.3.3 Sanctions

In most cases, the airtightness specification is a requirement that the building must meet in order to comply with regulations. Without such compliance, building permits will not be completed and the building cannot be occupied. Lack of compliance for meeting airtightness requirements may mean that better energy performance is needed in some other building component. This trade-off can often be accounted for using compliance calculations in software. In some cases, a building may be deemed acceptable even if the airtightness misses the target after remediation but is improved from the original value.

2.4 Building airtightness in energy performance calculations

2.4.1 Calculation

Residential Buildings

A range of calculation procedures are used depending on the regulation or rating scheme. In California's building regulations, an annual average calculation based on ASHRAE Handbook of Fundamentals (2021 Chapter 16) is used. These calculations use either the original Lawrence Berkeley National Laboratory (LBNL) model [14] or the more complex AIM2 model [15] with variable pressure exponent and more complex/sophisticated leakage distribution and wind shelter calculations.

The IECC has several compliance paths. The main ones are Prescriptive and Total Building Performance:

Prescriptive: No energy calculation is required. Component performance is specified (e.g., insulation levels or window and equipment minimum performance specifications).

Total Building Performance: An energy calculation (hourly for a year) is required to compare a proposed design to the prescriptive design. This allows some flexibility while maintaining energy performance.

Energy Rating Index: Requires the use of the RESNET calculation procedures where a home is compared to a 2006 code compliant home to generate an energy rating index that must be below a value specified according to the climate zone (ranging from 51 % to 55 %). The hourly average air change rate for the year is calculated using the models in the ASHRAE Handbook of Fundamentals [16] for infiltration, and combined with mechanical systems using ASHRAE 62.2 [9].

For the RESNET Home Energy Rating Index, if a home does not have whole house mechanical ventilation, the infiltration rate is based on measured envelope leakage using the following equations (but not less than 0.3 ACH). Natural infiltration is calculated from ASHRAE Handbook of Fundamentals 2021, Chapter 16. This refers either to the enhanced or simplified model from ASHRAE and for both models the stack and wind components are combined in quadrature (i.e. squared, added and the sum square rooted). The stack and wind coefficients are obtained from tables omitted here for brevity.

- Basic model:

$$Q = \frac{A_L}{1000}\sqrt{C_s|\Delta T| + C_w U^2}$$

Where:
Q: airflow rate (m^3/s)
A_L: effective air leakage area (cm^2)
C_s: stack coefficient based on number of stories ($(L/s)^2/(cm^4 K)$)
ΔT: average indoor-outdoor temperature difference for time interval of calculation (K)
U: wind speed (m/s)
C_w: wind coefficient – based on assumed shelter class 4 and number of stories ($(L/s)^2/[cm^4(m/s)^2]$)

- Enhanced model :

$$Q_s = cC_s\Delta T^n$$
$$Q_w = cC_w(sU)^{2n}$$

Where:
Q_s: stack airflow rate (m^3/s)
Q_w: wind airflow rate (m^3/s)
c: flow coefficient ($m^3/(sPa^n)$)

C_s: stack coefficient – based on number of stories ($(Pa/K)^n$)
U: wind speed (m/s)
C_w: wind coefficient – based on number of stories ($(Pa.s^2/m^2)^n$)
s: shelter factor – based on shelter class 4) and number of stories,
n: pressure exponent

If a home does have a whole house mechanical ventilation system, the mechanical ventilation rate and natural infiltration are combined in quadrature. The mechanical ventilation system flow rate is calculated according to ASHRAE 62.2-2013 as total ventilation rate (L/s) = 0.15 x floor area (m^2) + 3.5 x (number of bedrooms + 1).

For the IECC Energy Rating Index, the older ASHRAE 62.2-2010 calculation is used for the mechanical ventilation airflow rate calculation (coefficient for the floor area component of 0.05 instead of 0.15 $L/s/m^2$) for the reference case, and the design airflow rate for the home being rated. The mechanical airflow rate is added to the natural infiltration rate using Equation 43 of 2001 ASHRAE Handbook of Fundamentals page 26.24 and the "Whole House Ventilation" provisions of the 2001 ASHRAE Handbook Page 26.19. Natural infiltration can be calculated using any of the methods in the ASHRAE Handbook as no date or version is given.

In California building regulations [17], there is no requirement for airtightness levels and no mandatory testing. However, the energy code alternative compliance manual uses a multizone combined house/duct airflow network in an hourly energy calculator to estimate the energy impact of ventilation. The California regulations have prescriptive and software simulation paths to compliance and they both have the same ventilation airflow requirements. The energy simulation software must be approved by the California Energy Commission. There is an approval process where the software has to provide similar annual energy use as a standardized calculation.

The software uses the current ASHRAE 62.2-2022 method for total ventilation rate (Q_{tot}), which is the same as the ASHRAE 62.2-2013 equation mentioned previously. Infiltration rate, Qinf, is based on an annual average calculation:

$$Q_{inf} = 0.052 \times Q_{50} \times wsf \times \left[\frac{H}{H_r}\right]^{0.4}$$

Where:
Q_{50}: envelope airflow at 50 Pa from a blower door test (cfm) – limited to not being less than the Q_{50} based on an envelope leakage of 2 ACH_{50}.
H_r: reference height – 8.2 ft (2.5 m)
H: vertical distance between highest and lowest above grade points (ft, m)
wsf: weather and shielding factor (listed in Table 150.0-D of the CEC 2022 Building Energy Efficiency Standard)

The wsf factor is a single annual number, which is correct for an IAQ approach (effective annual ventilation rate) but not for energy calculations, as discussed by Turner et al. [18]. The mechanical fan flow, Qfan, is then:

$$Q_{fan} = Q_{tot} - F\left(Q_{inf} \times A_{ext}\right)$$

Where:
F = 1 for balanced ventilation systems and Q_{inf}/Q_{tot} otherwise
Qtot: total required ventilation rate
Qinf: infiltration rate
A_{ext}: 1 for single-family detached homes, or the ratio of exterior envelope surface area that is not attached to garages or other dwelling units to total envelope surface area. For multifamily dwelling units $Q_{fan} = Q_{tot}$.

For non-residential buildings there are a range of calculation procedures and techniques reflecting the potential unique attributes of individual buildings in commercial building construction. A summary of these techniques can be found in Persily et al. [19].

2.4.2 Default values

Different energy performance calculators use a range of default values. For example:

- California uses a default envelope leakage based on vintage, of 7.7 ACH50 prior to 2006, 6.8 ACH50 for 2006-2013 and 5.0 since 2013.
- RESNET ratings use a minimum default of 0.3 ACH50.

2.5 Building airtightness test protocol

2.5.1 Qualification of Airtightness testers

For residential buildings, RESNET ratings require training and third-party checks. A Building Performance Institute (BPI) certification is often required in energy programs and code compliance evaluation. The BPI offers training as part of home energy auditor certification [20].

For non-residential buildings, the Air Barrier Association of America has certification programs for testers (https://www.airbarrier.org/wba-overview/).

2.5.2 National guidelines

For residential buildings, ASTM E779 [6] is the U.S. standard for multipoint measurements. ASTM E1827 [21] is the standard for single point measurements - almost always at 50 Pa. However, most testing is done using procedures in ANSI/RESNET 380 [22] or blower door manufacturer's instructions rather than following the more detailed, research-oriented procedures in the ASTM test methods. Each method has slightly different guidelines for building preparation and pressure tap location.

For testing non-residential buildings, ASTM E779 can be used. ASTM E3158 [23] is a method specifically used for testing large/multizone buildings.

2.5.3 Requirements on measuring devices

Requirements for measuring devices are usually provided in test method reference documents such as ANSI/RESNET Standard 380 and the ASTM test standards. They may also be specified in individual energy program requirements and training. For example, Standard 380 requires a maximum error of 5% of flow and, for pressure, 1% of reading or 0.25 Pa (0.001 in. H_2O), whichever is greater.

2.6 Building airtightness Tests performed

2.6.1 Tested buildings

About 10 % to 15 % of new residential buildings are tested as part of the Energy Star for Homes program. In addition, nearly half of new residential buildings (single and multifamily) are tested as part of the RESNET rating program. Forty-three states have adopted some form of the IECC. Note that there may be some overlap in states that use RESNET ratings to show compliance with the IECC. Only a small number of non-residential buildings are required to be air leakage tested.

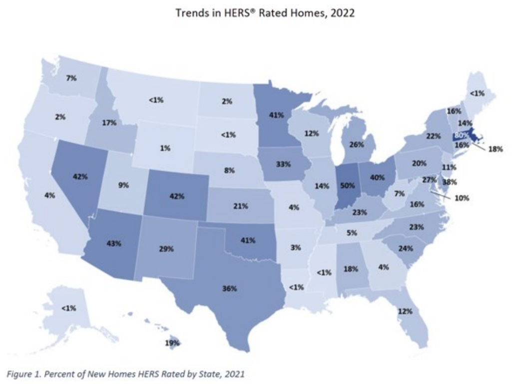

Figure 2: Percentage of homes with RESNET ratings that include envelope and duct leak testing. Figure from: "Trends in HERS rated Homes". RESNET. 2022 [24].

2.6.2 Database

There is no national database of home airtightness. However, LBNL created the Residential Diagnostics Database (ResDB), which is a limited database of nearly 150,000 tests on homes performed up to about 2010 (resdb.lbl.gov). The National Institute of Standards and Technology has collected and published non-residential building airtightness data for 25 years, with the last published update nearly a decade ago [1].

2.6.3 Evolution of the airtightness level

Residential envelope leakage requirements in the IECC were originally set at 7 ACH50 nationwide in 2009. Since 2012 they have not changed and are 3 ACH50 across the U. S. except for 5 ACH50 in IECC/DOE Climate Zones 1 and 2. The 2024 IECC-R has new prescriptive values of 4 ACH50 in Climate Zones 0, 1 and 2, 3 ACH50 in Climate Zones 3 through 5, and 2.5 ACH50 in Climate Zones 6 through 8.

IECC commercial buildings air leakage testing recently changed to allow buildings under 10,000 ft^2 (460 m^2) to be tested using residential test methods. The new leakage limit is 0.30

cfm/ft^2 at 50 Pa (1.5 L/s per m^2 at 50 Pa). As with residential buildings the proposed IECC 2024 requirements will be 0.35 cfm/ft^2(1.8 L/s per m^2) of the building thermal envelope area at a pressure differential of 0.3 inch water gauge (75 Pa), or if testing by dwelling unit 0.27 cfm/ft^2 (1.4 L/s per m^2) of the testing unit enclosure area at a pressure differential of 0.2 inch water gauge (50 Pa).

2.7 Guidelines to build airtight

Many individual programs have guidelines - usually in the form of checklists. Examples include:

- ENERGY STAR Qualified Homes, Version 3 (Rev. 04), Inspection Checklists for National Program Requirements
- IECC Air Barrier and Insulation Inspection Checklist
- BPI Technical Standards for Certified Shell Specialists.
- National Institute of Building Sciences Whole Building Design Guide
- Air Barrier Association of America Air Barrier System Specification

2.8 Conclusion

For residential buildings, the main change over the past few decades is that more states are adopting the IECC envelope leakage requirements. Some states that currently have no envelope leakage requirements, such as California, are beginning to consider them. This is particularly true with respect to home retrofits, rather than new construction.

3 Ductwork airtightness

3.1 Introduction

The status of air leakage for ducts is similar to the envelope. The key motivation for increased duct leakage testing has been energy and energy ratings. High-performance home programs (e.g., RESNET, Energy Star and other voluntary programs) have led the way on duct testing and establishing acceptable limits. Duct leakage became important in the early 1990s due to recognition of its impact on energy use. Some states have duct testing requirements (California first) and voluntary programs (e.g., US EPA Energy Star). There are simple metrics that scale with home size – such as, airflow at a fixed pressure per unit home floor area.

For commercial buildings, leakage for high pressure (over 750 Pa) duct sections has had a testing requirement for many years. More recently there has been interest in testing and air sealing lower pressure duct sections.

3.2 Airtightness indicator

For residential ducts, the following metrics are used: airflow (through leaks) at a fixed pressure of 25 Pa (CFM25), this flow expressed as a percentage of the total system airflow, or this flow normalized by floor area (CFM25/ft^2) (essentially a simplifying assumption relating system total airflow to floor area). There are other metrics that separate supply and return leaks or test at actual operating pressures conditions (DeltaQ). These test methods are in ASTM E1554 [25]. There is no national requirement for duct testing in residential buildings.

Commercial buildings have used another metric of Leakage Class (CL):

$$CL = \frac{Q}{A\Delta P^{0.56}}$$

where:
Q: duct leak airflow (cfm)
A: surface area of ducts (square feet)
ΔP: test pressure (in. water).

Newer commercial building duct testing uses a metric of air leakage from a fixed pressure test divided by the system airflow - expressed as a percentage.

3.3 Requirements and drivers

3.3.1 Ductwork airtightness requirements in the regulation

Some states and voluntary energy programs have requirements for duct leakage. The U.S. EPA Energy Star program [26] and the IECC specify ≤ 4 CFM25 per 100 ft^2 of conditioned floor area or 40 CFM25, whichever is larger (this requirement is at rough-in before the home is complete with drywall, grilles, etc.). The respective allowed values are doubled to 8 CFM25 per 100 ft^{2}and 80 CFM25 when the home is complete. In California, the building regulations require duct leakage to be less than 6 % of total system airflow. This leakage specification is also required for compliance with ASHRAE 62.2. Some states have adopted other duct leakage limits, such as 6 CFM25 per 100 ft^2 (North Carolina) or 12 CFM25 per 100 ft^2 (Kentucky).

Often in energy performance calculations (RESNET and California Title 24 building regulations) a typical duct leakage is assumed and there is credit calculated if ducts perform better than the default. The credit is usually calculated using ASHRAE Standard 152 [27].

Commercial high-pressure ducts are required to have leakage class below 4.0, but building regulations (IECC) allow for testing of only representative duct sections. ASHRAE 90.1 goes beyond this and limits duct leakage to a fraction of the system airflow. The upper limit for the whole system is 5 %, the duct system alone is 3 %, and leakage to outdoors must be less than 2 %.

3.3.2 Incentive for Ductwork airtightness

For existing homes, there are many programs that require or provide incentives for improving duct leakage, such as the DOE Weatherization Program and multiple voluntary utility programs. Some energy programs give rebates for duct sealing efforts.

Most non-residential buildings must meet the requirements of ASHRAE 90.1, which has been adopted as a de-facto energy code in most states. Therefore, meeting building regulations requires a level of duct tightness.

3.3.3 Ductwork airtightness justifications

In residential building regulations, it is almost exclusively a test of the heating and cooling ducts and none of the ventilation ducts. This is primarily because the most common ventilation systems in residential buildings are exhaust systems.

In commercial buildings, ducts are often separated based on the pressure in the duct system - e.g., upstream and downstream of a variable air volume box. Ventilation ducts in commercial buildings are sometimes tested, with large vertical or horizonal ducts serving multiple spaces being tested separately.

Tests may be performed by installing contractors, however, regulations often require testing by third-parties.

3.3.4 Sanctions

In most cases, meeting the duct tightness specification is a requirement that the building must meet in order to comply with regulations. Without such compliance, building permits will not be completed and the building cannot be occupied. Lack of compliance in meeting duct airtightness requirements means that better energy performance is needed. In some cases, another building component may make up for this - typically accounted for using standardized compliance calculations in software.

3.4 Ductwork airtightness in the energy performance calculation

3.4.1 Calculation

For the RESNET Home Energy Rating Index, the reference home has an assumed duct energy efficiency of 80 % (the portion of the heating or cooling energy entering the duct system that reaches conditioned space) and the rated home uses the ASHRAE Standard 152 calculation method. ASHRAE Standard 152 uses a steady state thermal model that includes leakage and conduction losses. These losses are based on standard heat exchanger pipe heat transfer and simplified calculations for temperatures of the space surrounding the ducts.

In California, a multizone airflow and thermal model is used to calculate the impacts of duct leakage. The results are then used as a reference that other compliance software (using proprietary algorithms) must match. Duct efficiency is calculated using procedures based on ASHRAE Standard 152.

3.4.2 Default values

California uses a default duct leakage based on vintage. Prior to 2013, the default duct leakage value was 15 %. Since 2013 and the introduction of minimum duct performance requirements, the default duct leakage value is 5 %.

3.5 Ductwork airtightness test protocol

3.5.1 Qualification of ductwork Airtightness testers

While there are no national requirements, both the Building Performance Institute (BPI 2017 ANSI/BPI-1200-S-2017 Standard Practice for Basic Analysis of Buildings) and RESNET (RESNET 2019 Mortgage Industry National Home Energy Rating Systems Standards) have training and certification requirements for duct leakage testers. Most qualified testers perform the testing as part of regulatory or energy efficiency program compliance.

3.5.2 National guidelines

For residential ducts, there are several national standards for duct leakage testing. The most used standard is ANSI/RESNET 380. Another standard, ASTM E1554, includes more advanced test methods for separating supply and return duct leakage, as well as a test method for evaluating duct leakage under operating conditions. The California Building Energy Efficiency Standards, Residential Appendix RA3.1 (CEC 2019) [28], which gives directions for duct leakage testing and serves as the reference method required in ASHRAE 62.2, is used for compliance in California.

For commercial duct leakage testing, the pressurization approaches in ASTM E1554 are used. High-pressure sections of duct systems are tested using the Sheet Metal and Air Conditioning Contractors' National Association (SMACNA) test methods [29, 30].

3.5.3 Requirements on measuring devices

Requirements for measuring devices are usually provided in test method refence documents such as ANSI/RESNET Standard 380, ASTM E1554, or SMACNA test methods. For example, Standard 380 requires a maximum error of 5% of flow and, for pressure, 1% of reading or 0.25 Pa (0.001 in. H_2O), whichever is greater.

3.6 Ductwork airtightness Tests performed

3.6.1 Tested Ductwork

Similar to envelope leakage, most new construction duct airtightness testing is for homes either using the RESNET rating for compliance or constructed in a state requiring testing (such as California). These represent more than half of new construction residential duct systems.

In commercial buildings, duct leakage testing is part of building regulation requirements (either IECC or ASHRAE 90.1).

3.6.2 Database

For residential construction, there is no national database of duct airtightness. However, LBNL created a limited database of duct leakage in 28,000 homes (resdb.lbl.gov).

For commercial buildings, there is no national database.

3.6.3 Evolution of the ductwork airtightness level

California began to implement residential duct leakage level requirements as a percentage of total system flow (<5 %) in the early 2000's. The only changes since have been the adoption of other metrics - specifically, normalizing leakage by floor area (e.g., 40 CFM25 per 100 ft^2). These leakage limits have been unchanged since their introduction. The trend in energy efficient residential construction is to bring all ducts inside the conditioned space rather than increasing airtightness limits.

3.7 Guidelines to build airtight ductwork

Many organizations provide training for testing and sealing ductwork. These organizations vary from state to state, often with utility companies that offer energy efficiency programs for reducing duct leakage. Other guidelines are:

– DOE Building America: Building America Solution Center (https://basc.pnnl.gov/building-components/ducts)
– EPA Energy Star duct sealing guidance for homeowners[3]

[3] https://www.energystar.gov/campaign/heating_cooling/duct_sealing

- SMACNA HVAC Duct Construction Standards - Metal and Flexible
- Air Conditioning Contractors of America (ACCA) Quality Installation Specification [31]

In addition, California building standards include thorough instructions for duct and envelope sealing (California Energy Commission. 2019 Residential Compliance Manual for the 2019 Building Efficiency Standards, Title 24, Part 6).

3.8 Conclusion

There has been little change in recent years in the requirements for duct leakage in residential buildings. The introduction of duct leakage testing has led to better practices for duct sealing and redesign of HVAC systems to bring ducts inside conditioned space. For envelope leakage, the increase in testing has led to a gradual decrease in measured leakage. Studies have shown (e.g., DOE 2015 [32]) that construction practices quickly adapt to revised envelope and duct leakage requirements.

Other related changes include the introduction of test procedures for leakage of air handling equipment (blower/furnace cabinets, air mixing boxes, and HRV/ERV enclosures) that have led to individual states (California and Florida) imposing leakage limits on these components. Most equipment is built for the national market. As a result, leakage limits for HVAC equipment originally adopted by California and Florida have led to reduced leakage nationally.

For commercial buildings, there is increased awareness of the impact duct leakage has on energy efficiency - particularly including ductwork at lower pressure (less than 500 Pa to 750 Pa). This has led to changes in building regulations, code requirements, and reductions in allowable leakage levels for all ducts and HVAC components.

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