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Max Sherman, Iain Walker

Environmental Energy Technologies Division
Lawrence Berkeley National Laboratory
Berkeley, CA 94720

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Philosophy and approaches for airtightness requirements in the USA

Max H. Sherman[1] Iain S. Walker[1]

1 Lawrence Berkeley National Laboratory
1 Cyclotron Rd; MS 90-3074
Berkeley, CA 94720, USA
Contact: MHSherman@lbl.gov

ABSTRACT
Building codes and regulations are not normally done at a national level in the United States. Many states and territories have established their own codes and regulations. In addition, there are thousands of local jurisdictions and authorities that set building and hence airtightness requirements. Because of that, there are many non-governmental organizations that help states, counties, utilities and other institutions in setting airtightness methods, requirements and guidelines. This paper will provide some background of Blower Door testing and an overview of the airtightness situation in the US with respect to standards, requirements and approaches.

KEYWORDS
Airtightness, United States of America, codes, standards, requirements, blower-door

INTRODUCTION
In the United States (U.S.) the vast majority of houses, and other low-rise buildings whose ventilation is dominated by envelope air flows, are leaky. That leakage typically supplies most of the ventilation and consumes at least 1/3 of the energy required to keep them conditioned for human occupancy. The ongoing challenge with airtightness is balancing the need to make buildings tighter to save energy and for improved comfort, with the need to provide sufficient air flow to maintain indoor air quality and avoid other issues such as natural draft combustion appliance backdrafting. Where this balance is to be struck is an ongoing topic of debate in the US. The discussion in this paper focuses on residential buildings, primarily because that is currently the focus of air tightness requirements and testing in the US. Larger high rise or industrial buildings generally do not consider envelope airtightness in energy or indoor air quality (IAQ) evaluations because measurements are difficult and it is assumed that mechanical ventilation dominates. However, this is changing, with renewed efforts into measuring the leakage of larger buildings and there are several current research projects examining tightness levels of the current high rise building stock and developing improved measurement and analysis techniques primarily through research sponsored by the American Society of Heating Refrigerating and Air-conditioning Engineers (ASHRAE).

Improving airtightness has been an important part of achieving energy efficiency in the U.S. for over 30 years. There has been a steady improvement of airtightness over that time both in the existing stock, but most clearly in new construction. New homes are typically three times tighter than the existing stock and are sufficiently tight that new homes need designed ventilation systems in order to meet acceptable indoor air quality requirements. In new homes airtighness can be designed-in and energy efficient homes are at about 1 Air Change per Hour at a typical test pressure of 50 Pa (ACH50[h^{-1}]) compared with about 3-5 ACH50 for typical new construction. At these tightness levels some sort of mechanical ventilation is required to provide acceptable indoor air quality. In contrast, existing homes are much leakier – often as much as 15 to 20 ACH50, or greater. Typical attempts to reduce air leakage achieve reductions of about 20% (see for example ref. [19]). Getting beyond that level can be done but the costs to do so can become prohibitive.

The development of the fan pressurization diagnostic (i.e., the “Blower Door” test) has enabled the quantification of air leakage and, therefore, enforceable airtightness requirements. The U.S. has been active for more than 20 years at using this technique to identify and mitigate leaks in existing homes in a variety of programs and identify airtightness limits for natural draft combustion appliances. Standards [1] [2] allow house depressurization by exhaust fans in the range of 2-5 Pa, depending on the appliance, that effectively limit airtightness for homes with unvented combustion appliances inside the conditioned space. These standards are currently under revision that would allow the use of blower door test results in estimating the depressurization in some circumstances rather than measuring it directly. The U.S. has not been as proactive at setting mandatory limits on airtightness.

This paper will review the philosophy of airtightness measurement and limitations as well as approaches used the U.S.

MEASURING AIRTIGHTNESS – BLOWER DOOR TESTING

Blower Doors are used to find and fix leaks in weatherization programs, demonstrate compliance with energy efficiency program requirements (either as tightness levels for new construction or changes in airtightness for existing homes), show that a home exceeds airtightness limits required for natural draft combustion appliances, and, increasingly, the values generated by the measurements are used to estimate infiltration for both indoor air quality and energy consumption estimates. These estimates in turn are used for comparison to standards or to provide program or policy decisions.

Blower doors are used for several purposes in the U.S.:

1. The most common application is in weatherization programs where contractors need to show that air leakage is reduced in order to meet program requirements. In this application the blower door is also used in the process of finding and fixing leaks.
2. To show that a house complies with air leakage limits of voluntary energy efficiency programs, such as the U.S. Environmental Protection Agency (EPA) Energy Star program (www.energystar.gov) or Passive House (www.passivehouse.us) standards.
3. To show that a house complies with building codes such as the credit available in California State building code [3] for tighter envelopes or forthcoming tightness limits in the International Energy Conservation Code [4].
4. To show that a house is leaky enough to avoid depressurization limits for natural draft combustion appliances.
5. To show that a house is leaky enough to not require mechanical ventilation. This is often the case in weatherization programs where limited funds mean that adding a whole house mechanical ventilation system is prohibitively. Typical target leakage is about 12/13 ACH50 (2000 L/s at 50 Pa for a typical home).
6. To determine air leakage for use in energy use calculations. This is commonly the case for homes using voluntary rating systems such as The National Association of Home Energy Raters [5].

This range of applications requires different approaches to air leakage testing. Compliance with standards, for example, requires that the measurement protocols be clear and easily reproducible, even if this reduces accuracy. Conversely, public policy analyses are more concerned with getting accurate aggregate answers than reproducible individual results.

"Blower Door" is the popular name for a device that is capable of pressurizing or depressurizing a building and measuring the resultant air flow and pressure. The name comes from the fact that in the common utilization of the technology there is a fan (i.e. blower) mounted in a door; the generic term is "Fan Pressurization". Blower-Door technology was first used in Sweden around 1977 as a window-mounted fan [6] and to test the tightness of building envelopes [7]. That same technology was pursued at Princeton University (in the form of a Blower *Door*) to help find and fix the leaks [8].

Early on in its development in the US, blower door test results were used as input to models to estimate air flow rates. In its early days a rule of thumb was developed that simply related Blower-Door data to seasonal air change rate: Namely that a representative air change rate can be estimated from the flow required to pressurize the building to 50 Pa divided by 20. More sophisticated models were developed based on physical principles to related airtightness to air flow rates using weather as the driving force. The LBL Infiltration model [9] is based on using blower door results to calculate a leakage area for the home and assuming a pressure exponent of 0.5 in the pressure-flow relationship. An enhanced model [10] has been developed using the measured pressure exponent and leakage coefficient as well as a few other advances such as separating out stacks from other building leakage components. Both of these models can be found in the ASHRAE Handbook of Fundamentals [11]. The LBNL model is used as the basis of energy impacts of ventilation in RESNET home energy ratings. The enhanced model is used in the Canadian HOT2000 software used in the R-2000 program [12].

In the US the idea of using blower door test results in energy calculations was developed in ASHRAE Standard 119 Air Leakage Performance for Detached Single-Family Residential Buildings [13] that set limits on allowable airtightness depending on climate. ASHRAE Standard 136 A Method of Test of Determining Air Change Rates in Detached Dwellings [14] was also developed to relate measured air leakage to annual average ventilation rate suitable for use in IAQ calculations by using weather factors that vary depending on climate. The calculations from Standard 136 had been primarily used in weatherization programs to find a Building Tightness Limit (BTL)[1] and more recently used in ASHRAE Standard 62.2 *Ventilation and Acceptable Indoor Air Quality in Low-Rise Residential Buildings* [15] for determining the ventilation credit to be given to homes that can be used to reduce the mechanical ventilation requirements.

There are two popular procedures for using blower doors. The first is to measure air flow and envelope pressures at multiple pressure stations and this method is standardized in ASTM Standard E779 Standard Test Method for Determining Air Leakage Rate by Fan Pressurization [16]. This multi-point testing allows for the calculation of both C and n in the power law leakage equation:

$$Q = C \cdot \Delta P^n$$

where C is the leakage coefficient (or flow coefficient) and n the pressure exponent. The exponent is typically near 2/3 but theoretically can be anywhere from ½ to 1. Some

[1] As explained in a later section, standard 62.2 is being used in place of the Building Tightness Limit, which is no longer being recommended as an approach for finding optimal airtightness.

applications use these coefficients directly (specifically the enhanced model discussed above) but others used derived quantities such as leakage area at 4 Pa or 10 Pa reference pressures. The LBNL model uses the 4 Pa leakage area defined in ASTM E779. These lower pressures are used for leakage area calculations because they are closer to typical envelope pressures than the test pressures used in the ASTM standard (10-60 Pa). ELA4 is calculated by equating the power law equation to an orifice flow equation at the reference pressure:

$$ELA4 = C\sqrt{\frac{\rho}{2}}(4)^{n-0.5}$$

or by extrapolating from Q50 and converting to orifice flow:

$$ELA4 = Q50\left(\frac{4}{50}\right)^{0.65}\sqrt{\frac{\rho}{8}}$$

where ρ is the density of air.

The second procedure measures the air flow at a fixed pressure of 50 Pa (one of the test procedures in ASTM E1827 [17]). This is referred to as Q50 or CFM50 if the air flow is measured in CFM – which is almost universal in the US. 50 Pa was chosen because it is a high enough pressure that the results are not very sensitive to fluctuations in test conditions (due to wind) – resulting in more repeatable test results, but not too high as to distort the building envelope and open (or close) leaks in the envelope. It also results in air flows that can be produced and measured by typical blower door equipment. Lastly, the fixed pressure approach allows rapid evaluation of tightness measures as they are carried out – a key issue when tightening to a limit. If a leakage area is to be calculated from single point measurements an exponent is assumed – usually 0.65 or 2/3. These typical pressure exponents are based on the analysis of large datasets [18]. This extrapolation using a fixed exponent introduces additional errors when the exponent is different from the assumed value. An estimate of this error can be made knowing that the standard deviation of n is around 0.08 [19]. There is a debate in the U.S. over whether the uncertainties caused by the noise associated with low pressure measurements is greater or less than the bias caused by not knowing the exponent. The authors are currently preparing an analysis of this issue.

A notable exception to the 50 Pa measurement pressure is for duct leakage, where duct pressurization tests are performed at 25 Pa. This fixed pressure testing of ducts is almost universal with the exception of the DeltaQ test that tests ducts over a range of pressures. Both approaches are covered by ASTM E1554 Determining Air Leakage of Air Distribution Systems by Fan Pressurization [20]. The pressurization test procedure is also included found in many other documented locations such as RESNET Standards, BPI standards, weatherization programs, energy efficiency programs for national, state, utility and labeling schemes.

Norms and normalization

The metrics above all refer to the total amount of leakage of the tested envelope. For setting norms or standards, or for comparing one structure to another it is often desirable to normalize this total by something that scales with the size of building. In that way buildings of different sizes can be evaluated to the same norm.

There are three quantities commonly used to normalize the air leakage: building volume, envelope area, and floor area. Each has advantages and disadvantages and each is useful for evaluating different issues:

Building volume is particularly useful when normalizing air flows. When building volume is used to normalize such data the result is normally expressed in air changes per hour at the reference pressure. 50 Pa is often used as the reference pressure because this pressure is commonly used for air flow measurements. This is referred to as ACH50 (or *n50* in Europe). Many people find this metric convenient since infiltration and ventilation rates are often quoted in air changes per hour and ACH can be used to estimate changes in relative concentration of pollutants in IAQ analyses. Rules of thumb are often applied to convert ACH50 to air flow under natural conditions, e.g., dividing ACH50 by 13 to get a natural air change rate.

$$n50 = ACH50 = Q_{50} / DwellingVolume$$

Being based on Q50, this quantity has the same accuracy limitations. In addition, there is a practical limitation that the volume of a dwelling may be time consuming to measure. In addition, programs using this metric do not all agree on the methods for determining building volume.

Envelope area is particularly useful if one is looking to define the construction quality of the envelope. Dividing a leakage parameter (particularly leakage area) by the envelope area makes the normalized quantity a kind of porosity. Although this normalization can sometimes be the hardest to use due to difficulty in determining envelope area for all but very simple structures, it can be particularly useful in attached buildings were some walls are exposed to the outdoors and some are not.

Floor area can often be the easiest to determine from a practical standpoint because all homes need it for real estate documentation and occupants often know it. Because usable living space scales most closely to floor area, this normalization is sometimes viewed as being more equitable. Specific Leakage Area (SLA) is used in both RESNET and California Building Standards and is defined as the ratio of ELA to Floor area. In the California standard, this ratio is multiplied by a factor of 10,000 for convenience to create values roughly in the range of 1 to 10.

$$SLA = \frac{ELA}{FloorArea}$$

ASHRAE Standard 119 has created a dimensionless metric, called Normalized Leakage (NL), which is both based on ELA and normalized by floor area:

$$NL = 1000 \cdot \frac{ELA}{FloorArea} \left(NumberOfStories \right)^{0.3}$$

where the number of stories terms helps correct for the fact that buildings that are taller will have more infiltration for a given amount of leakage. The factor of 1000 is a scaling term that makes the normalized leakage be approximately the same magnitude as the natural air changes per hour. Normalized leakage more accurately describes the relative amount of infiltration when comparing two dwellings in the same climate.

APPLICATIONS OF AIRTIGHTNESS TESTING

The applications of airtightness testing depend on the purpose for testing. The US differentiates between "codes" and "standards". A "code" is a regulation that has the force of law in a particular jurisdiction. Most building codes are issued and enforced at the local level and there are a few thousand such jurisdictions in the U.S. A "standard" is not regulatory, however, many codes refer to standards. For example, ASHRAE Standard 62.2 is a standard for achieving acceptable indoor air quality. But it is not a regulation. Building codes refer to ASHRAE 62.2 in legislation by requiring compliance with the standard.

Because there are so many code bodies, there exists "model codes" which are created by an independent body and are used either completely or as a basis for the local codes. The relevant model code for energy in buildings is the International Energy Conservation Code (IECC) promulgated by the International Code Council (ICC) whose adoption varies by state [21]. The latest (2012) version of the IECC has introduced maximum air leakage levels for residential buildings that depend on climate, as defined by DOE Climate zones. The requirements are 5 ACH50 for mild climates (Climate zones 1 and 2) and 3 ACH50 elsewhere. It also requires a prescriptive checklist of airtightness measures, such as the use of air barriers and sealants. There are no training requirements, meaning that anyone can perform the testing. There are also no third party requirements for testing or verification – thus allowing builders to self-certify.

There are jurisdictions that do not use the IECC codes and have their own energy code. The State of California (which is approximately 10% of the U.S. housing stock), for example has its own state energy code. The California code uses specific leakage areas calculated from Q50, that can be derived from single or multi-point blower door tests, to be used in compliance software that uses it to calculate hour by hour ventilation rates. There is no requirement to test for air leakage. If no test is done, a default SLA is set in the standard of 4.3 (this includes a multiplier of 10,000 as noted above). This is lowered to 3.8 for a home with sealed ducts (verified by duct testing) and 3.2 for a home with no duct system. There is also a credit of an SLA reduction of 0.5 for a home with an air retarder that requires no testing. Credit can be taken for air leakage below these limits. There is a restriction for homes with an SLA below 1.5 requiring balanced mechanical ventilation. Finally, there is a requirement that homes comply with ASHRAE Standard 62.2.

In addition to these whole house airtightness limits, codes regulate other aspects of air leakage. A key example is for homes with attached garages where the house-garage interface is required to be substantially air tight and gasketed doors are required. ASHRAE Standard 62.2 has similar requirements and additionally requires that any ducts in the garage meet a tightness limit of 6% of total fan flow at 25 Pa. Other code requirements for windows and insulation have indirect impacts on air leakage.

RESNET has a standard method for rating homes that includes air leakage testing. By referring to ASHRAE Standard 119, that in turn, refers to ASTM E779, this requires multipoint testing. The metric used is SLA[2] with a default of 0.00048. A house tighter than this will get a better rating and a looser house a lower rating. RESNET is currently working on new standards for home diagnostics that include air leakage testing and will have a single-point test procedure as well as multipoint.

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[2] Note: RESNET's definition of SLA does not include the factor of 10,000. There is no standard for SLA.

The Building Performance Institute (BPI) writes standards used for training and certifying contractors and refers to ASTM E779 directly as the method for assessing envelope leakage. As with RESNET, new BPI standards are currently being written that incorporate single point testing.

Standards do not have any regulatory authority, but they do represent the best knowledge of the relevant technical or professional body about the subject at hand. ANSI is the body that certifies American National Standards. ANSI standards related to airtightness measurements have been published by ASHRAE and ASTM, and BPI is seeking ANSI certification for its new standards.

The largest Federal program that involves air tightening is the Weatherization Assistance Program (WAP). This program subsidizes energy efficiency retrofits for low-income Americans and sets standards for doing so. WAP programs follow standard work specifications which are currently out for public comment. The new version of the specifications would facilitate improved air tightening by allowing funds to be used for ventilation which meets ASHRAE Standard 62.2. Until recently many weatherization practitioners used what is known as a Building Tightness Limit, which was a tightness limit that determined when a mechanical ventilation system was necessary. To avoid the expense of installing a mechanical ventilation system in a retrofit situation, it had become common practice to tighten only to this limit and then stop. This approach is not optimal for energy savings, even after the costs of a ventilation system are included. With recent changes to ASHRAE Standard 62.2, the BTL has fallen out of favour and more and more programs are tightening better and then installing mechanical ventilation systems. The State of Wisconsin has been a leader in this area and has tightened thousands of homes and put in mechanical ventilation to meet Standard 62.2.

The US Environmental Protection Agency (EPA) has several voluntary programs that refer to airtightness. For existing homes, both Home Performance with Energy Star and EPA's Home Retrofit Protocols refer to ASHRAE 62.2 for minimum ventilation rates and therefore, by reference to optional air leakage measurement for ventilation credit for leaky homes. For new homes, EnergyStar Version 3 includes airtightness limits in ACH50 based on DOE Climate Zone. In climate zones 1 and 2 the limit is 6 ACH50, for climate zones 3 and 4 it is 5 ACH50, for climate zones 6 and 7 it is 4 ACH and climate zone 8 requires an ACH50 below 3. The ACH50 value is determined using the current RESNET protocol that refers to ASTM E779 multipoint testing. EPA also has an IAQ checklist that is separate from the EnergyStar Version 3 national program requirements and requires compliance with ASHRAE 62.2. The US Green Building Council LEED for Homes Certification has climate specific envelope leakage requirements.

Looking forward: With the publication of the 2013 version of ASHRAE Standard 62.2 (and the existence of IECC 2012), we anticipate that both standards 119 and 136 will be withdrawn by ASHRAE. The critical parts (i.e. of incorporating airtightness in minimum ventilation calculations) are in 62.2 now. Airtightness requirements much more stringent than those in the IECC may not make sense as prescriptive requirements and should be considered in a whole-building context. We also expect that test methods for measuring airtightness will be updated within the next year or two.

SUMMARY

Although historically homes in the US were leaky, there is now more awareness of the necessity of building tight homes while ensuring minimum ventilation rates using mechanical systems, and the industry is adopting the mantra of "*Build Tight – Ventilate Right*". Although there is no national regulation of airtightness, many jurisdictions, regulatory bodies, codes and standards associations are beginning to include requirements for limiting envelope. Because they are driven by energy reduction, these limits often depend on climate. There is currently a range of allowable leakage levels that are not the same depending on which code or standard is being referenced. However, the US is reaching consensus on minimum ventilation rates given by ASHRAE 62.2. Although current airtightness testing of homes is restricted to homes that get energy ratings this is set to increase substantially in the future, primarily due to changes in the IECC.

There are increasing efforts to at least make testing more uniform using blower door techniques. ASTM Standard E779 has been in existence for many years and is often referred to where multipoint testing is required. For single point testing, training and certification programs and rating standards are working to have standardized procedures.

Other efforts to unify airtightness issues are looking at combustion appliance safety testing – that is of particular concern when tightening existing homes.

Production builders in the US regularly build homes with leakage below 5 ACH50. Current construction techniques can get this as low as about 1 ACH50, but achieving lower levels, such as those required for Passive House require considerable extra effort and expertise and are unlikely to become common any time soon. Furthermore the energy benefits of achieving such levels may be minor, while the system robustness decreases. Existing homes show considerable scope for tightening and most retrofit and weatherization programs make considerable efforts to address air leakage. Reductions are limited by access to leak sites making it difficult for existing homes to be tightened to the same level of airtightness as new homes, but reductions of 20% or more are readily achievable.

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REFERENCES

[1] CGSB. 2005. *Canadian National Standard CAN/CGSB-51.71-2005 Depressurization Test*. Canadian General Standards Board, Gatineau, Canada.

[2] BPI. 2012. *Building Analyst Professional Standard*, Building Performance Institute, Malta, NY.

[3] CEC. 2008. *Title 24, Part 6, of the California Code of Regulations: California's Energy Efficiency Standards for Residential and Nonresidential Buildings*. California Energy Commission 2008. Available from http://www.energy.ca.gov/title24

[4] ICC. 2012. *2012 ICC International Energy Conservation Code*, International Code Council, Janesville, WI.

[5] RESNET 2006. *2006 Mortgage Industry National Home Energy rating System Standards*, Residential Energy Services Network, Oceanside, CA.

[6] Kronvall J. 1980 *Airtightness Measurements and Measurement Methods*, Report D8, Swedish Council for Building Research, Stockholm, 1980.
[7] Blomsterberg A., 1977. *Air Leakage in Dwellings*, Dept. Bldg. Constr. Report No. 15, Swedish Royal Institute of Technology.
[8] Harrje D.T., Blomsterberg A. and Persily A.K. 1979 *Reduction of Air Infiltration Due to Window and Door Retrofits*, CU/CEES Report 85, Princeton University.
[9] Sherman, M.H., and Grimsrud, D.T. 1980. *The Measurement of Infiltration using Fan Pressurization and Weather Data*. Report # LBL-10852, Lawrence Berkeley Laboratories, University of California.
[10] Walker, I.S. and Wilson, D.J. 1998. *Field Validation of Equations for Stack and Wind Driven Air Infiltration Calculations*, ASHRAE HVAC&R Research Journal, Vol. 4, No. 2, pp. 119-140. April 1998. ASHRAE, Atlanta, GA.
[11] ASHRAE. 2009. *Handbook of Fundamentals*. American Society of Heating, Refrigerating and Air-conditioning Engineers, Atlanta, GA.
[12] Natural Resources Canada. 2005. *R-2000 Standard*, Natural Resources Canada, Ottawa, Canada
[13] ASHRAE. 1988. *ASHRAE Standard 119, Air Leakage Performance for Detached Single-Family Residential Buildings*, American Society of Heating, Refrigerating and Air conditioning Engineers, Atlanta, GA.
[14] ASHRAE. 1993. *ASHRAE Standard 136 A Method of Test of Determining Air Change Rates in Detached Dwellings*. American Society of Heating, Refrigerating and Air conditioning Engineers, Atlanta, GA.
[15] ASHRAE. 2010. *ASHRAE Standard 62.2 Ventilation and Acceptable Indoor Air Quality in Low-Rise Residential Buildings*. American Society of Heating, Refrigerating and Air conditioning Engineers, Atlanta, GA.
[16] ASTM. 2010. *ASTM Standard E779-10. Determining Air Leakage Rate by Fan Pressurization*, American Society for Testing and Materials, West Conshohocken, PA.
[17] ASTM. 2007. *ASTM Standard E1827-96 Standard Test Methods for Determining Airtightness of Buildings using an Orifice Blower Door.* American Society for Testing and Materials, West Conshohocken, PA.
[18] Orme, M., Liddament, M., and Wilson, A.1994. *An Analysis and Data Summary of the AIVC's Numerical Database*, Tech. Note 44, Air Infiltration and Ventilation Center, Coventry, UK.
[19] M.H. Sherman, D. J. Dickerhoff. 1988. *Airtightness of U.S. Dwellings*,"ASHRAE Trans., 104(2), pp. 1359-1367.
[20] ASTM. 2007. *ASTM Standard E1554-07. Standard Test Methods for Determining External Air Leakage of Air Distribution Systems by Fan Pressurization*, American Society for Testing and Materials, West Conshohocken, PA.
[21] http://www.energycodes.gov/states/maps/residentialStatus.stm