Building Envelope and Duct Airtightness of New US Dwellings

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ABSTRACT

We analyzed the building envelope and duct system airtightness of US single-family detached homes built since 2000, where the data was part of the Lawrence Berkeley National Laboratory Residential Diagnostics Database (ResDB). The airtightness of homes is compared with the IECC guidelines, which are the basis of many state building codes. A large number of homes are considered in this analysis, representing many states: 26,000 building envelope and 11,000 duct system air leakage data. Our analysis shows that the majority of US homes built in the past ten years from ResDB are meeting IECC 2009. About 80% of all homes built since 2000 met the IECC building envelope airtightness guideline of 7 ACH50. Over 90% of the homes met the IECC 2009 duct system airtightness guideline of 12 cfm25. However, fewer homes are reaching the 2012 levels, especially in terms of building envelope airtightness. Only 30% of the homes met IECC 2012 building envelope airtightness of 5 ACH50 in climate zones 1 and 2, and 10% meeting 3 ACH50 in climate zones 3–8. Overall, only 12% of the homes in ResDB met the IECC 2012 building envelope airtightness guidelines. On the other hand, slightly over half of the US homes in ResDB are meeting the IECC 2012 duct system airtightness guideline of 4 cfm25. These comparisons of airtightness with respect to guidelines show the current status of homes built recently in the US. The data presented here are also important for estimating the energy consumption on residential heating and cooling and the extra cost of energy spent because of air leakage.

INTRODUCTION

Building envelope and duct system airtightness is important to residential energy use and estimating ventilation needs. In 2005, the total consumption by all end uses in US households was estimated to be 11.13 EJ (RECS 2005). Space heating (4.54 EJ) and air conditioning (0.93 EJ) made up half of the energy use. To minimize the energy loss due to air infiltration, the IECC 2012 now requires pressure testing to demonstrate whole-house air leakage to <5 ACH50 (air changes per hour at 50 Pa) for homes in climate zones 1 and 2, and <3 ACH50 in climate zones 3–8. In 2009, the IECC requirement on whole-building envelope was less stringent at <7 ACH50, and homes also had the option of meeting the requirement by visual inspection only. Many states in the US have adopted the IECC 2009 equivalent or more energy efficient building codes; see DOE (2012) for a US map showing the adoption status of state energy code. Moreover, some states are projected to adopt IECC 2012 or equivalent by the end of 2015. So even though not all states follow IECC (e.g., California and Washington have developed their own codes), it is useful for assessing new homes as a common set of guidelines that are widely used. But, the implementation status of state energy codes is far more complicated in reality because local jurisdictions often have the flexibility to adopt codes as they see fit (Cort and Butner 2012).

Duct system pressure testing has been mandatory in the IECC since 2009. About three-quarter of US homes use forced-air or other heating and cooling systems that are installed with ducts (AHS 2011). IECC 2012 limits the duct leakage rate, both total and to-outside, to <4 cfm25 (ft^3 per minute at 25 Pa) per 100 ft^2 of conditioned floor. In 2009, the requirement was <12 cfm25 if testing is performed post-

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construction, or <8 cfm25 if the duct-leakage-to-outside is measured instead of the total duct leakage through the system.

A general trend that new US homes are being built more airtight has been observed in recent studies (Nelson 2012; Offermann 2009; Proctor et al. 2011). However, there is considerable variability in the airtightness of US homes, as observed in an analysis of the Residential Diagnostics Database (ResDB) that considered 134,000 measurements collected by many contributors across the US (Chan et al. 2012). Using the data from ResDB, we focus here specifically on the airtightness of single-family homes that were built since 2000. Of interest is the question if these US homes are approaching the stringent airtightness requirements of IECC 2012. As homes are built more airtight, it is increasingly important to provide adequate ventilation to comply with ASHRAE 62.2 (2010). While it is beyond the scope of our discussion here, airtightening of the building envelope and duct system will impact many aspects of building performance, including indoor air quality, comfort, as well as energy consumptions.

RESDB AIR LEAKAGE DATABASE

ResDB contains air leakage and other diagnostic measurements of US homes that are contributed voluntarily by various energy auditors, building contractors, energy efficiency program managers, and researchers. The data are gathered and compiled into a database by Lawrence Berkeley National Laboratory. Over the years, more data have been gathered and re-analyzed to support calculations of air infiltration and its implications to residential energy use (Sherman and Dickerhoff 1998; Sherman and Matson 2001; Chan et al. 2005; McWilliams and Jung 2006). In 2011, a large number of whole-building envelope air leakage data from more than 100,000 homes were added to ResDB. Chan et al. (2012) described the air leakage data of single-family homes and presented a regression model that relates normalized leakage (*NL*) to house characteristics, such as climate zone, year built, and floor area. This model will be utilized in this analysis to evaluate if the building envelope airtightness of US homes continues to improve in the past ten years since 2000.

In addition, our analysis will also consider duct system air leakage data that were collected in 2011. Air leakage in the duct system can significantly impact home energy performance (Walker et al. 1999; Modera 2005). This type of data is a new addition to ResDB (previously, ResDB only contained building envelope air leakage data). To date, ResDB contains duct leakage data on approximately 20,000 homes. Our analysis will focus on homes built since 2000, which make up the majority of the data.

Whole-Building Envelope Air Leakage

E779 (ASTM 2010) is the standard used in the US to measure building envelope air leakage. Air leakage is measured by the airflow rate, $Q_{\Delta P}$ (m^3/s) through the building envelope as a function of the pressure difference, ΔP (Pa), across the building envelope. The most common pressure difference used is 50 Pa, which is low enough for standard blower doors to achieve in most houses, and at the same time high enough to be reasonably independent of weather influences. Many metrics are used to describe whole-building envelope air leakage normalized to building volume or surface area, such as ACH50, NL (normalized leakage), ELA (effective leakage area), and SLA (specific leakage area). There is no consensus from buildings codes or other energy efficiency guidelines on which one metric is preferable to the others. We selected *NL* because it has been the choice in previous data analyses of ResDB. *NL* is also used in ASHRAE 62.2 (2012) to calculate the mechanical ventilation needs of homes. Measurements of air leakage by blower door, typically available as Q_{50} (m^3/s), are converted to *NL* as follows:

$$\begin{aligned} NL &= 1000\left(\frac{ELA_4}{\text{Area}}\right)\left(\frac{H}{2.5\text{ m}}\right)^{0.3} \\ ELA_4 &= \sqrt{\frac{\rho}{2(4\text{ Pa})}}Q_{50}\left(\frac{4\text{ Pa}}{50\text{ Pa}}\right)^{n} \end{aligned} \quad (1)$$

where ELA_4 (m^2) is the area of an orifice that would result in the same airflow through the building envelope at a pressure difference of 4 Pa, and $\rho = 1.2$ kg/m^3. *n* is the pressure coefficient, assumed to equal 0.65 if it is not measured directly; see Chan et al. (2012) for a distribution of *n* from ResDB. *NL* is normalized to floor area, Area (m^2), and house height, *H* (m), according to Equation 1. Assumptions were made to compute *NL* if Area or *H* is unavailable. For instance, *H* is assumed to equal 3 m for one-story, and 5.5 m for two-story; see Chan et al. (2012) for more details. Of the 134,000 single-family detached homes with estimates of *NL*, 26,000 were new homes built since 2000. Note that the definition of *NL* has been modified slightly in ASHRAE Standard 62.2 (2012) since the analysis presented here: the exponent is changed from 0.3 to 0.4. This change has a negligible effect on the results presented in this paper.

Duct System Air Leakage

Duct leakage is commonly measured following E-1554 (ASTM 2007). A calibrated fan delivers air into the duct system to pressurize it to either 25 Pa or 50 Pa, with all registers closed. For measuring duct leakage, 25 Pa is commonly used to represent a pressure difference that more closely resembles the condition during system operation. Some building codes and energy efficiency guidelines scaled the duct system leakage with respect to floor area (e.g., $Q_{d,25}$ = cfm25 per 100 ft^2 of conditioned floor area). Most of the duct system air leakage measurements in ResDB are provided in units of cfm25, and so $Q_{d,25}$ is the metric used in the analysis of approximately 11,000 homes. In an additional 8,000 homes, duct leakage was measured by pressurizing the house with a blower door to the same pressure as the duct system during the test. The duct leakage to-outside, $Q_{d,25,\text{to-outside}}$, is the flow required to equalize the house and duct pressures. In this analysis, $Q_{d,25,\text{to-outside}}$ is scaled to 100 ft^2 of conditioned floor area, in the same way as $Q_{d,25}$.

California, Florida, Nevada, Texas, and Washington are states with the most number of duct system air leakage measurements in ResDB. In Washington, some of the duct leakage measurements were collected at 50 Pa pressure difference. Those data are converted to 25 Pa assuming a pressure exponent n of 0.6 (Walker 1998) as follows:

$$Q_d \propto (\Delta P)^n$$
$$\frac{Q_{d,25}}{Q_{d,50}} = \left(\frac{25}{50}\right)^{0.6} \quad (2)$$

For estimating the energy consumption and delivery efficiency of thermal distribution systems, as in ASHRAE Standard 152 (2004), the duct system leakage as a percentage of the system fan airflow is needed as an input parameter. Unfortunately, duct leakage as a percentage of fan airflow can only be computed in about 800 homes because relatively few homes in ResDB provided the fan airflow rates. The percentages of fan airflow data are collected mostly by weatherization and other retrofit programs from existing homes. Because those data are typically from older homes built before 2000, they will not be discussed here.

ANALYSIS OF NORMALIZED LEAKAGE DATA

Measurements of building envelope air leakage in California (Offermann 2009; Proctor et al. 2011) and in Minnesota (Nelson 2012) suggest that homes built since 2000 met the IECC 2009 airtightness threshold of 7 ACH50, especially in colder climates where the state energy code tends to be more stringent (e.g., Minnesota energy code is <1.5 ACH50 in 2000). Figure 1 shows the *NL* of homes built since 2000 available in ResDB from 14 states. The median *NL* is 0.3, which corresponds to approximately 5 ACH50. Even though this data set is not a statistically representative sample of the US housing stock built since 2000, it includes homes that are located in many climate zones, ranging from cold areas like Alaska and Wisconsin, to warmer areas like Florida and Texas.

It is important to note that despite the large number of data depicted in Figure 1, the data are likely skewed towards being more airtight than the typical homes. This is because roughly one-third of the homes shown in Figure 1 are rated for energy efficiency. Many of these homes are rated following ENERGY STAR® guidelines for new homes. The current ENERGY STAR guidelines, version 3, specify ACH50 to be less than 3 to 6 (EPA 2012), depending on the climate zone. Consequently, there is a selection bias in the data shown in Figure 1 towards better-than-average airtightness. The energy-efficiency rated homes shown in Figure 1 likely followed earlier versions of such guidelines (versions 1 and 2 were adopted in 1995 and 2007, respectively), or their equivalent, which had less stringent airtightness guidelines. Nonetheless, the regression analysis by Chan et al. (2012) found that energy-efficiency rated homes are 30% lower in *NL* compared to conventional homes in ResDB, regardless of which ENERGY STAR guidelines these homes most likely followed. Note that the 30% describes an overall difference between energy-efficiency rated homes and conventional homes from all available data in ResDB, and not just the subset of the data that is shown in Figure 1.

Comparison with IECC Airtightness Guidelines

Many states have adopted the airtightness guideline of 7 ACH50 following IECC 2009 or have building codes that are more stringent in the range of 3 to 5 ACH50, similar to the levels specified in IECC 2012. Equation 3 is used to convert the air leakage data shown in Figure 1 from units of *NL* to ACH50 for comparison with these airtightness guidelines, so that we can evaluate if homes built since 2000 in ResDB are meeting these IECC levels.

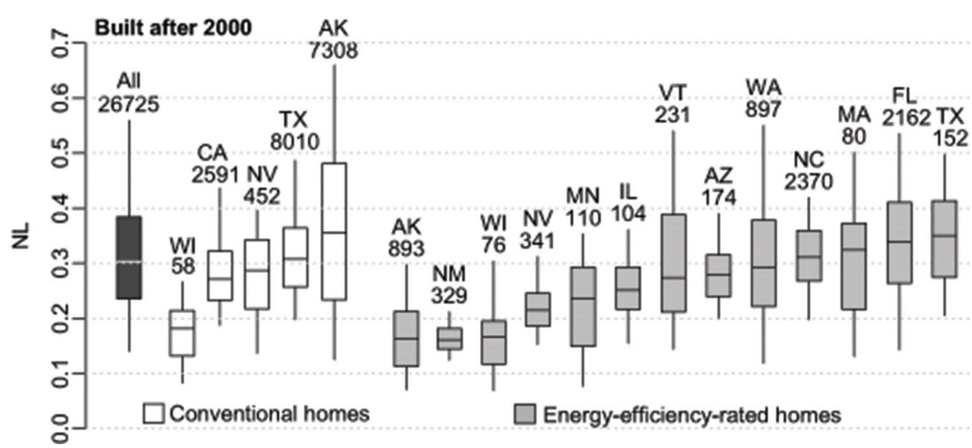

Figure 1 *Whole-building envelope air leakage of homes in ResDB built after 2000. Each box plot shows the median and interquartile range, and the whiskers show 5th and 95th percentiles, of the* NL *of homes from different states. The number shown beneath each state is the house count.*

$$\text{ACH50} = \frac{NL}{\frac{1000}{3600}\left(\frac{\sqrt{\frac{\rho}{2(4\text{ Pa})}}\left(\frac{4\text{ Pa}}{50\text{ Pa}}\right)^n}{2.5\text{ m}}\right)\left(\frac{H}{2.5\text{ m}}\right)^{0.3}} \quad (3)$$

Figure 2 shows the cumulative percentiles of ACH50 computed using Equation 3. Overall, 81% of all the homes, regardless of their climate zones, met the IECC 2009 airtightness guideline of 7 ACH50. The IECC 2012 airtightness guideline of <5 ACH50 for climate zones 1 and 2 (i.e., some parts of Florida and Texas) are met in 29% of the homes. But just 10% of the homes in the other climate zones 3–8 meeting the most stringent guideline of 3 ACH50. Altogether, only 12% of the homes met IECC 2012 guidelines. These statistics suggest that an airtightness level of <7 ACH50 is often achieved across the US. Figure 2 also shows that about 40% of the homes built in the past ten years are already sufficiently airtight to reach <5 ACH50. Reaching <3 ACH50 is not an unattainable goal, but it is a challenge. Consequently, only a small fraction of the homes (12%) built since 2000 reached that level of airtightness specified in IECC 2012.

Improvement in Airtightness of Homes Built Since 2000

There are other attributes of the homes also known to be associated with *NL* (Chan et al. 2012), such as climate zone, floor area, and so on. By first removing the influences of these other attributes, we can evaluate if the data from ResDB show continuing improvement in the airtightness of US houses in the past ten years since 2000. In Equation 4, the expected values of *NL* are computed using regression estimates from Chan et al. (2012), where the coefficient estimate βs are reproduced in Table 1. After adjusting for all the relevant attributes, the model residuals $\ln(NL_{obs}) - \ln(NL_{pred})$ are regressed with respect to year built of the homes, as shown in Equation 5.

$$\ln(NL_{\text{pred}}) = \beta_{CZ} \cdot I_{CZ} + \beta_{\text{post-2000}} + \beta_{\text{area}}\text{Area} + \beta_H H + \beta_e \cdot I_e \quad (4)$$

$$\ln(NL_{obs}) - \ln(NL_{pred}) = \beta_{\text{year}} \cdot (2005 - \text{Year}) \quad (5)$$

In Equation 4, *NL* is adjusted by climate zone (*cz*), floor area, house height, and if the home is rated for energy efficiency (*e*) or not. The *I*s in Equation 4 are indicator variables:

Table 1. Regression Coefficients Used in Equation 4 to Compute NL_{pred}

Variable	Coefficient
Climate Zone Humid (A) Zone 1, 2	$\beta_{A\text{–}1,2} = 0.473$
(A) Zone 3	$\beta_{A\text{–}3} = 0.253$
(A) Zone 4	$\beta_{A\text{–}4} = 0.326$
(A) Zone 5	$\beta_{A\text{–}5} = 0.112$
(A) Zone 6, 7	$\beta_{A\text{–}6,7} = 0$
Dry (B) Zone 2, 3	$\beta_{B\text{–}2,3} = -0.038$
(B) Zone 4, 5	$\beta_{B\text{–}4,5} = -0.009$
(B) Zone 6	$\beta_{B\text{–}6} = 0.019$
Marine (C) Zone 3	$\beta_{C\text{–}3} = 0.048$
(C) Zone 4	$\beta_{C\text{–}4} = 0.258$
Alaska (AK) Zone 7	$\beta_{AK\text{–}7} = 0.026$
(AK) Zone 8	$\beta_{AK\text{–}8} = -0.512$
Year Built (homes built after 2000)	$\beta_{\text{post-2000}} = -1.058$
Floor Area	$\beta_{\text{area}} = -0.00208\ (\text{m}^{-2})$
House Height	$\beta_H = 0.064\ (\text{m}^{-1})$
Energy-Efficiency Rated Homes	$\beta_e = -0.384$

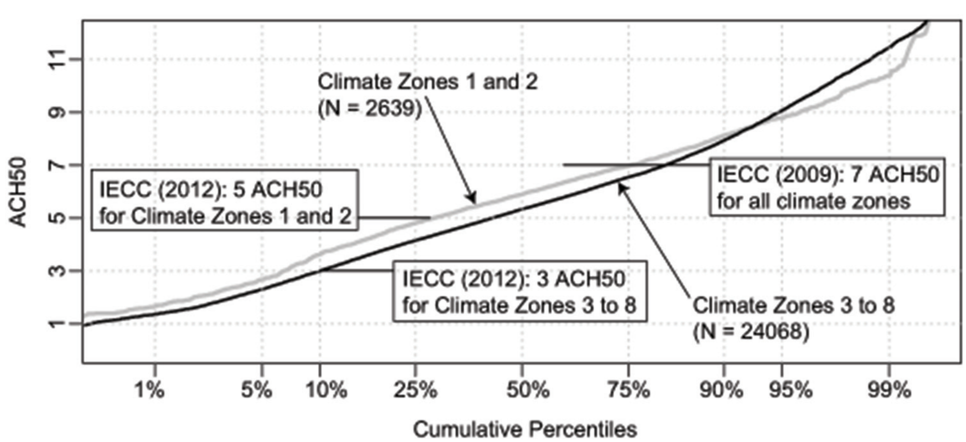

Figure 2 *Cumulative percentiles of building envelope air leakage of homes in ResDB built after 2000, shown separately for climate zones 1 and 2 and climate zones 3 to 8 (N = house count).*

$I = 1$ if the condition is true, and $I = 0$ if not. The coefficient $\beta_{\text{post-2000}}$ is a constant used to describe all homes built since 2000 (as opposed to homes built in 1990–99, 1980–89, etc. that are part of the regression analysis by Chan et al. [201]), but are not considered here in this paper). Other coefficients estimated by Chan et al. (2012) are excluded because they do not apply to the subset of data considered here (i.e. none of the homes considered here participated in a weatherization assistance program, and too few data are available on foundation type and duct system location to account for their influences on *NL* in this analysis).

The regression shown in Equation 5 gives $\beta_{\text{year}} = -0.016$ (95% C.I. –0.014 to –0.017), suggesting that there is an overall reduction in *NL* all through the years since 2000 at approximately 1.6% per year (Figure 3). But R^2 of the regression is only 0.02, meaning that besides the year built, there may be other factors that contribute to the variability in *NL*. Nonetheless, this regression found a relationship between *NL* and the year built, and it estimates that homes built in 2011 are 20% more airtight than those built in 2000, all else held equal. Our finding suggests that recent attention paid to airtightness, likely in response to tightening of building codes, has led to persisting reduction in building envelope air leakage. This agrees with the recent findings in California homes. Proctor et al. (2011) found a median ACH50 = 4.7 (range min–max: 2.0–8.2) in 40 single-family homes that were first occupied in 2007. Offermann (2009) found a median ACH50 = 4.8 (3.6–8.4) in 108 homes built between 2002 and 2004. Hoeschele et al. (2002) found an average ACH50 = 5.5 (2.6–8.7) in 30 new homes tested in 1999 and 2001. These levels are more airtight than an earlier study cited in Offermann (2009): a median of 8.6 (6.2–13.2) in 13 homes built before 1987.

DUCT SYSTEM AIR LEAKAGE

There are fewer duct system air leakage data in ResDB and as a result, the available data are not as representative of the US housing stock. The vast majority of duct leakage data are from homes built after 2000, which are shown here. The western states (e.g., California and Washington) are well represented, but less so for the US overall, as shown in Figure 4. Because there are significant differences in the heating and cooling systems used in the different parts of the US, the discussions here are limited to areas that are represented by the duct leakage data in ResDB.

Figure 5 shows the distribution of the total duct leakage and compared the data with IECC duct systems airtightness guidelines. The median total duct leakage $Q_{d,25}$ of homes built since 2000 in ResDB is 3.5 cfm25 per 100 ft^2 of conditioned floor area, meaning that over half of the homes would meet the IECC 2012 total duct leakage guideline of <4 cfm25. Nearly all the homes (greater than 90%) met IECC 2009 total duct leakage guideline of <12 cfm25. These data show significant improvements in duct systems airtightness compared to the analysis by Neme et al. (1999) that found an average of 270 cfm25, or about 20 cfm25 per 100 ft^2 of conditioned floor area for a typical 1500 ft^2 house, from 19 studies of duct leakage and its effects on electric HVAC efficiency.

Duct Leakage To-Outside

Duct leakage to-outside $Q_{d,25,\text{to-outside}}$ was measured in a small number of states. Figure 6 shows the ratio of the duct leakage to-outside and total duct leakage, $Q_{d,25,\text{to-outside}}/Q_{d,25}$, for the Florida data shown in Figure 4 and for a few other states. The Florida data has a median ratio of 0.36, with 90% of the data range between 0.16 and 0.64 (Figure 6(a)). This

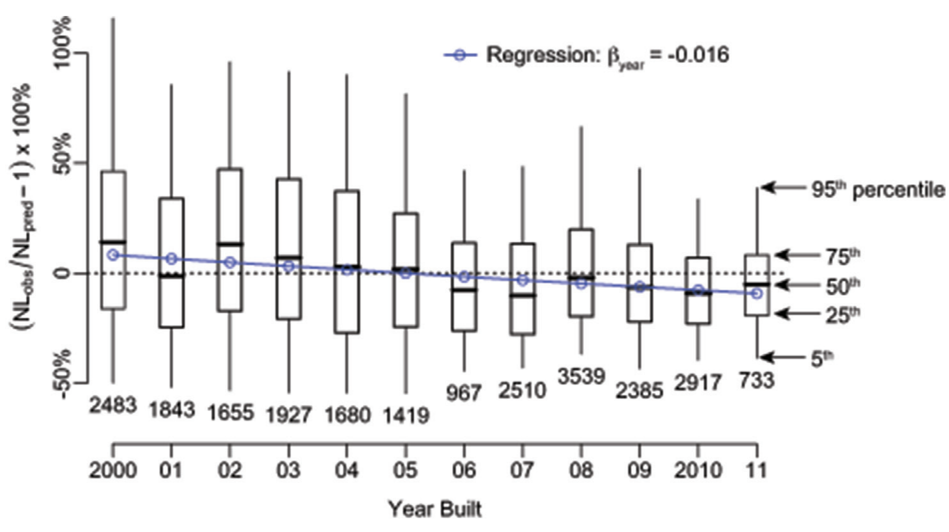

Figure 3 *Relationship between* NL *and year built, where* NL *has been adjusted by first accounting for other attributes that influence air leakage, as described in Equation 4. Each box plot shows the median and interquartile range, and the whiskers show 5th and 95th percentiles. The regression line determined via Equation 5, as shown here as circles with lines through them, describes this relationship.*

ratio is computed from paired data only, where $Q_{d,25,\text{to-outside}}$ and $Q_{d,25}$ were measured in the same house. Figure 6(b) shows this ratio from two other sources of data in ResDB where the ratio of $Q_{d,25,\text{to-outside}}/Q_{d,25}$ can be calculated. The study teams that were part of the Department of Energy Building America Program collected most of these measurements. The other source of data, also included in Figure 6(b), is from Proctor et al. (2011) who measured the duct systems air leakage and conducted other diagnostic tests in 40 California homes.

Figure 6(b) shows that the ratio of $Q_{d,25,\text{to-outside}}/Q_{d,25}$ varies significantly by region: median = 0.072 in Connecticut, Illinois, and Minnesota, 0.44 in Florida and Texas, and 0.74 in Arizona, California, and Nevada. Hoeschele et al. (2002) measured this ratio in 30 California homes and found an average value of 0.81, which agrees with the range shown in Figure 6(b). The differences between states are due to the locations where ducts are commonly placed in the house. Placing the duct system inside the conditioned space means a lower ratio, which is more common in states with colder climate; whereas placing the duct system in vented attic or crawlspace would tend to result in a higher ratio, as found in states with more temperate climate.

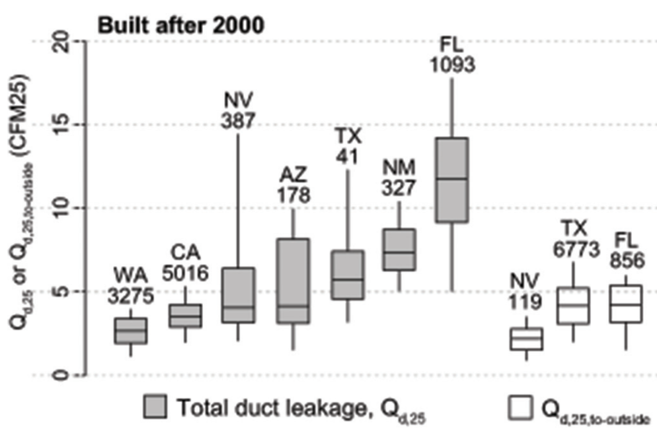

Figure 4 *Duct system leakage of homes in ResDB built after 2000, where the total duct leakage* $Q_{d,25}$*, and the total duct leakage to-outside* $Q_{d,25,\text{to-outside}}$*, are in units of cfm25 per 100 ft*^{2} *of conditioned floor area. Each box plot shows the median and interquartile range, and the whiskers show 5*th *and 95*th *percentiles. The number shown beneath each state is the house count.*

Regression of Duct Leakage and Year Built

Similar to building envelope air leakage, continuing improvement in airtightness is also observed from the duct leakage data collected over the past decade. Approximately 3,000 total duct leakage measurements shown in Figure 4 also provided the exact year built of the house (other year built data in ResDB are categorical, i.e., built between certain years). These include data mostly from California (60%), about 10% each from New Mexico, Nevada, and Florida, and the remaining 10% from 16 states. Equation 6 is the linear regression used to see if there is a relationship between duct leakage and year built. For this regression, the total duct leakage data $Q_{d,25}$ is log-transformed to more closely resemble a normal distribution. Further, 2005 is subtracted from the year built to give meaning to the intercept term such that exp(k) equals $Q_{d,25}$ of homes built in 2005 as estimated by the regression model.

$$\ln(Q_{d,25}) = k + \beta_{d,\text{year}} \cdot (\text{Year} - 2005) \qquad (6)$$

The regression analysis found a negative relationship between year built and duct system air leakage, where $\beta_{d,\text{year}}$ = –0.068 (95% C.I. = –0.063 to –0.073), and exp(k) = 5.21 cfm25 per 100 ft^2 of conditioned floor area (95% C.I. 5.10 to 5.31 cfm25). The regression has a R^2 of 0.20, meaning that the year built explains some of the variability in duct leakage, but there are other factors that matter as well. Together, these coefficients estimated a 50% improvement in

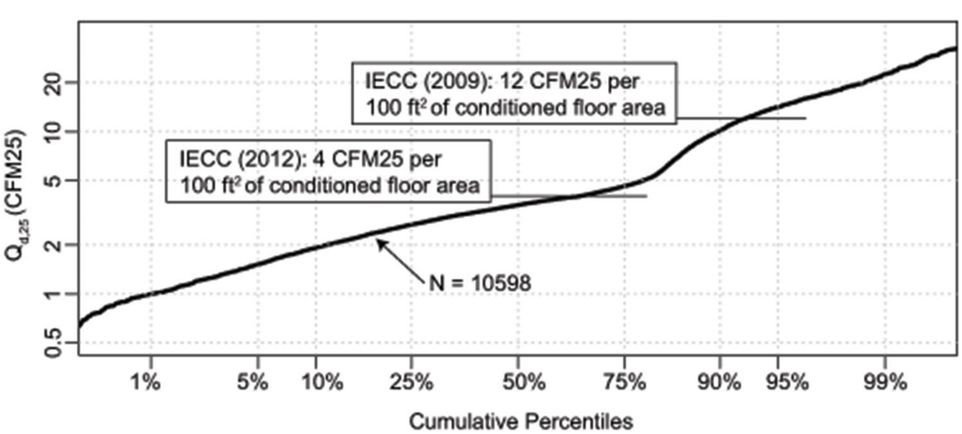

Figure 5 *Cumulative percentiles of total duct leakage* $Q_{d,25}$ *in units of cfm25 per 100 ft*^{2} *of conditioned floor area, of homes in ResDB built after 2000 (N = house count).*

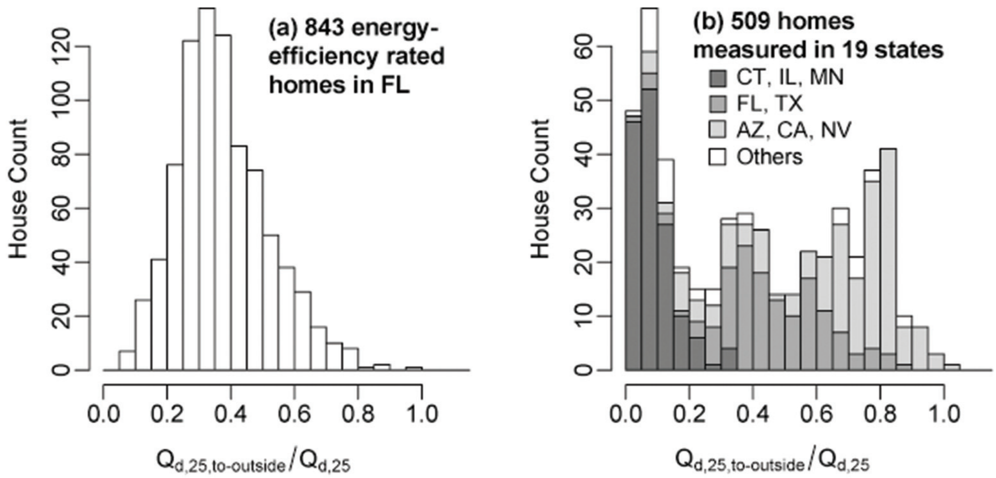

Figure 6 *Ratio of duct leakage to-outside and total duct leakage of homes built after 2000 in ResDB. Data are plotted separately by sources: (a) all Florida homes contributed by an energy rating company, (b) data from many states collected by Building America project teams.*

duct airtightness overall in the past ten years, from $Q_{d,25}$ = 7.3 cfm25 in 2000, to $Q_{d,25}$ = 3.7 cfm25 in 2010. Based on this analysis, the average new homes that are built nowadays would meet the IECC 2012 guideline of 4 cfm25. Again, this analysis also concludes that new homes built in the US since 2000 had more success in meeting IECC duct system airtightness guidelines than the whole-building envelope airtightness, where only 10% of the homes met the 2012 IECC guideline.

CONCLUSION

A large fraction of the homes built since 2000 from ResDB have airtightness that met the IECC 2009 guidelines, both for building envelope and duct systems. This is perhaps not surprising because parts of the US already have energy codes that are equivalent or more stringent than the requirements of IECC 2009. Moreover, many of the homes considered in this analysis from ResDB are built to meet certain energy efficiency targets. Even so, compliance with state building code is not guaranteed, especially because air leakage testing was not mandatory for example, in IECC until 2009 for duct systems and 2012 for building envelope. The adoption rate of state energy code by local jurisdictions also varies across the US (Cort and Butner 2012). Thus, it is an important finding that the 26,000 measurements of building envelope air leakage, and 11,000 measurements of duct system leakage, which together represent many US states, collectively show airtightness that is at the IECC 2009 level.

Over half of the homes built since 2000 from ResDB would meet the IECC 2012 total duct leakage guideline. On the other hand, only a small fraction of the homes met the IECC 2012 building envelope airtightness guidelines. This is important because mandating building envelope airtightness is part of many states' energy efficiency strategy. Moving forward, in order to reach these energy efficiency goals, building envelope airtightness must continue to improve such that more homes would meet tighter guidelines. Logue et al. (2012) estimated that there are substantial energy savings from air sealing of the building envelope to IECC 2012 levels, which shows the importance of airtightness as part of the energy efficiency strategy in the US residential sector.

By pooling together existing data that were collected by various sources, ResDB provides the quantity of data needed to evaluate the state of airtightness of single-family detached homes in the US. Trends such as the gradual changes over time, for example, are often difficult to observe in small data sets because of this large variability in a housing stock. Analysis of residential consumption data over the years has found energy savings as state-level building codes are being adopted (Aroonruengsawat et al. 2012). Potentially, energy savings would increase by setting even more stringent airtightness limits on new homes. Yet another opportunity to realize these energy savings is by implementing policies that can enhance conformance to airtightness guidelines and, by doing so, reduce the variability in airtightness in the new homes being built. Still, what remains to be proven is how persistent is airtightness as the homes are being occupied. If building envelope and duct systems soon lose their airtightness, this may adversely impact the home energy performance over time.

ACKNOWLEDGMENTS

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NOMENCLATURE

ACH50	=	air changes (h^{-1}) at 50 Pa pressure difference
Area	=	house floor area (m^2)
β	=	regression coefficient estimates
CFM50	=	blower door airflow (ft^3/min) at 50 Pa pressure difference
ELA_4	=	effective leakage area (m^2) at 4 Pa pressure difference
H	=	house height (m)
I	=	indicator variables (–)
k	=	linear regression intercept
n	=	pressure coefficient (–)
NL	=	normalized leakage (–)
ΔP	=	pressure difference (Pa) across building envelope or duct system
Q_{50}	=	building envelope leakage airflow (ft^3/min) at 50 Pa pressure difference
$Q_{d,25}$	=	duct system leakage airflow (ft^3/min) at 25 Pa pressure difference per 100 ft^2 of conditioned floor area
$Q_{d,25,\text{to-outside}}$	=	duct system leakage airflow (ft^3/min) to outside at 25 Pa pressure difference per 100 ft^2 of conditioned floor area
ρ	=	air density 1.2 kg/m^3
Year	=	house year built

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