ASHRAE Standard 152 & Duct Leaks in Houses

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small building applications

Do ducts in houses leak? Tests have shown that in most houses the answer is yes, and most of those ducts leak enough to merit sealing. Duct leaks create uncontrolled airflows with consequences that include low pressure zones, increased infiltration that can increase or decrease humidity, nonuniform temperatures, and energy/capacity losses for the HVAC system.

This article discusses data collected from thousands of houses around the country and also discusses ANSI/ASHRAE Standard 152–2004, *A Method of Test for Determining the Design and Seasonal Efficiencies of Residential Thermal Distribution Systems.*

The standard quantifies how much energy and HVAC equipment capacity duct leaks actually waste. In addition, it calculates the energy and capacity implications of where the ducts are located (attic vs. crawlspace vs. basement, as well as Miami vs. Minneapolis), of the insulation level of those ducts, of the flow through those ducts, and of the type of HVAC equipment to which they are connected. In addition, the standard allows comparison of the efficiency of using hydronic baseboards vs. installing a duct system in a new house.

Duct Performance Data

Over the past decade or so, increasingly more groups have measured field performance of residential HVAC systems.[1–7] The previously unreported data presented here was collected by residential HVAC dealers as part of a diagnostic test to determine whether a particular customer's house required duct improvement services, as well as while the dealer was performing duct improvement services in houses that needed them.

Dealers performed a house pressure test, which measures the change in house pressure associated with turning on the HVAC system fan. The test distinguishes houses that really need duct sealing, those that might benefit from sealing, and houses in which the cost of sealing is probably not justifiable.

Supply leaks to the outdoors cause the house pressure to decrease when the fan is turned on, while return leaks increase house pressure. As a result, the house

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pressure test detects leakage only to outside—to or from a vented attic or crawlspace.

The situation becomes more complicated when both supply and return ducts are leaking. In this case the pressure change is proportional to the difference between the two leakage rates, not the sum of the leakage rates (e.g., the pressure change would be zero if they are both leaking the same amount, even if the leakage flows are very large).

To distinguish tight ducts from equally leaky ducts, the house pressure test includes a second step: partially blocking the return grilles, increasing the pressure differences across the return leaks and decreasing the pressure differences across the supply leaks. If the ducts are tight, changing their pressures does not affect the house pressure. However, if supply leakage was masking return leakage, the return-blocked test will make the return leaks more prominent.

One complication is that the leakage of the shell of the house determines the magnitude of the pressure change associated with a given duct leakage flow. For that reason, this test is not a precise measurement of duct leakage, but an indicator that only gives one of three answers, as shown in *Figure 1*.

Figure 1 shows results of approximately 1,000 house pressure tests in Sacramento, Calif., and Austin, Texas. Both regions are predominated by attic duct installations of flex-duct systems. *Figure 1* demonstrates two interesting points: 1) between 60% and 85% of the houses in these regions would benefit from duct sealing, and 2) the distribution of results is remarkably similar in the two regions (we also found similar consistency between dealers in each region).

Another important aspect of duct performance is how much air actually is delivered to the rooms being conditioned. *Figure 2* shows results of another diagnostic test performed by the HVAC dealers to measure the airflow delivered by each grille in a house. The results in *Figure 2* represent the sum of each house's register flows divided by the nominal cooling capacity of the HVAC equipment. These results can be compared to a nominal flow of 400 cfm/ton (54 L/s per kW), which is where most residential air conditioners are rated for efficiency and capacity.

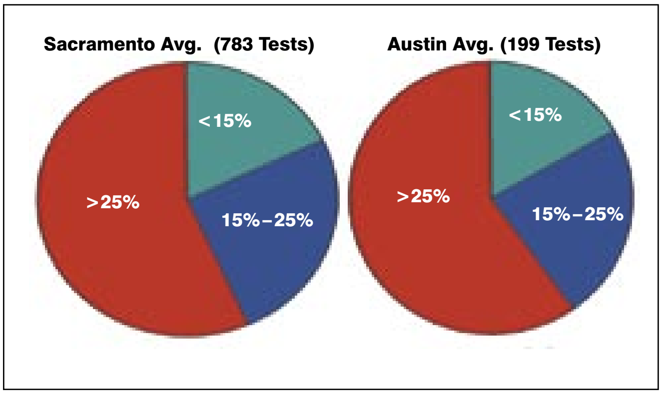
The significant difference between the actual flows in *Figure 2* and 400 cfm/ton (54 L/s per kW) stems predominantly from two effects: 1) supply duct leakage, and 2) excessive resistance to airflow. The particularly low register flows in the Illinois data are most likely due to the larger quantity of leaks in the rectangular sheet-metal duct systems typically found in that region (see *Figure 4* and associated discussion).

As noted earlier, fan flow, duct leakage and duct insulation all impact the temperature of the air leaving the grilles. *Figure 3* shows the results of register temperature measurements in almost 2,000 houses. The data presented are based upon temperature measurements at all supply and return grilles.

The percentage loss in sensible capacity at any supply grille is calculated by dividing the temperature difference between that grille and the best supply grille, by the temperature difference between the best supply grille and the average of the return grilles (*Equation 1*).

$$\%\ \text{Thermal Loss} = (T_{best\text{-}grille} - T_{grille}) / (T_{best\text{-}grille} - T_{return\text{-}average}) \times 100 \qquad (1)$$

This procedure estimates the sensible capacity using the difference between the average return temperature and the best supply temperature, which in most cases is an underestimation due to leakage and conduction losses between the return grille and the air handler, and between the HVAC equipment and the best supply grille. These results are striking, as they indicate that, on average, between a quarter and a third of the registers



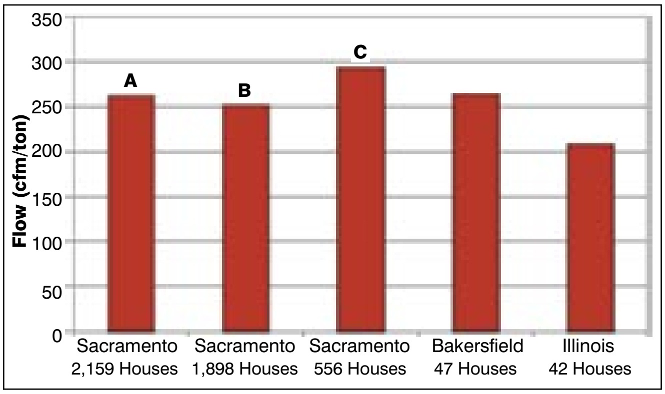
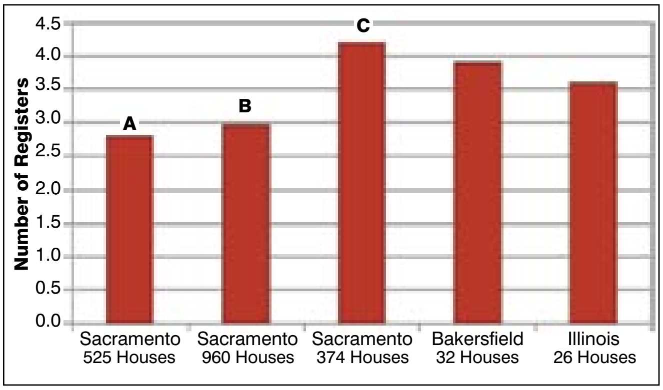


Figure 1 (left): Distributions of house pressure test results, where percentages are combined supply and return duct leakage as a fraction of HVAC fan flow. Averages are for all participating dealers in the region. Figure 2 (right): Register flow measurement results. A, B, and C refer to different dealers.



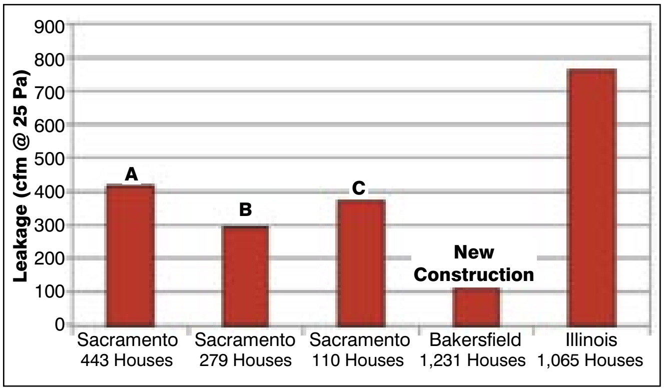


Figure 3 (left): Results of register temperature measurements (registers with greater than 25% thermal loss are within a given house). A, B, and C refer to different dealers. Figure 4 (right): Results of fan-pressurization tests of duct leakage. A, B, and C refer to different dealers.

are losing more than 25% of the sensible capacity provided by the equipment. Moreover, whether the loss is caused by leakage, low flow, or poor insulation, these calculated losses represent only the thermal conduction loss on the supply side, which would apply to the flow being delivered after the supply leakage has been subtracted.

The data presented in *Figures 1* through *3* was obtained during diagnostic services, while *Figure 4* presents the results of fan pressurization tests of total (i.e., supply plus return) duct leakage performed just prior to sealing in almost 3,000 houses.

As compared to the house pressure test, these results are more precise and repeatable, although they represent a different leakage characteristic, namely the flow through all supply and return leaks at a fixed reference pressure. The unit, cfm at 25 Pa (0.1 in. w.g.), represents the leakage flow at a reference pressure differential of 25 Pa (0.1 in. w.g.) (considered representative of the average pressures across leaks during normal operation) created by the duct pressurization fan.

It also represents a combination of SI and I-P units, and unfortunately has become the typical unit of reporting. To compare these leakage values with house pressure test results, they must be combined with measured operating pressures and measured fan flows to calculate duct leakage as a fraction of fan flow. Also the house would need to be simultaneously pressurized to the same pressure as the ducts to isolate duct leakage flows to/from outside the house.

Figure 4 suggests some interesting trends. First, the three dealers in Sacramento all measured approximately the same level of leakage, which one would hope to find. This is consistent with the house pressure test results. Second, the leakage levels in new Bakersfield, Calif., construction are considerably lower than the data from existing houses in Sacramento. This also is consistent with the assumptions within the California Energy Efficiency Standards about duct leakage in new vs. existing buildings. However, the same dealer installed the duct systems being sealed, and, therefore, had an incentive to minimize leakage introduced during the installation process.

The other key trend in *Figure 4* is that the data from Illinois shows significantly higher leakage levels, which is consistent with other studies of rectangular sheet-metal duct systems in basements.*

This type of duct construction has much more extensive

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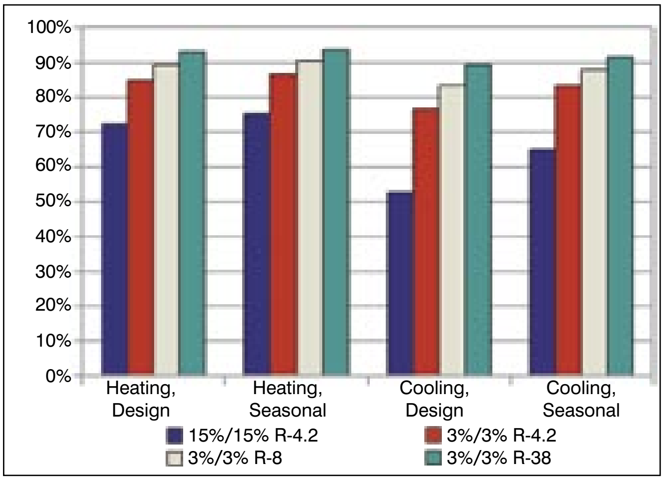
*A comparison of the leakage data in Strunk, et al., 1996, with Jump and Modera, 1994, shows that the floor-area-normalized duct leakage flow at 25 Pa (0.1 in. w.g.) was more than three times as much in the basement houses.



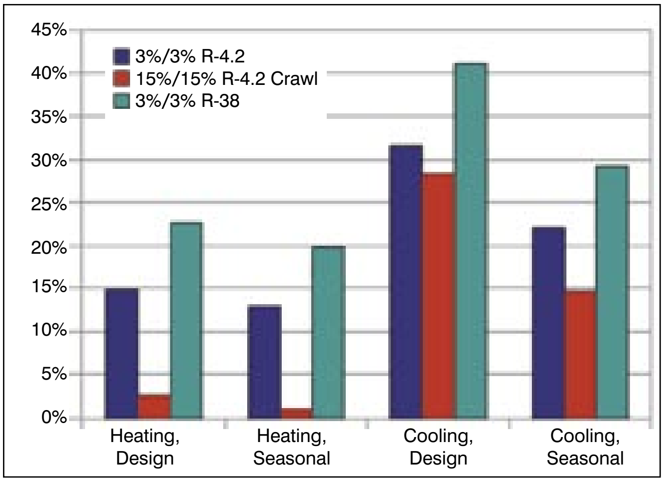


Figure 5 (left): Application of Standard 152 to an attic flex-duct system in Sacramento shows the attic duct efficiency. Figure 6 (right): Savings calculated with Standard 152 for changes to an attic flex-duct system in Sacramento.

return duct systems and many more joints as compared to plastic flex-duct systems; common practice in residential basement construction does not include sealing those joints.

In addition, a small fraction of the Illinois houses had building cavity returns, which generally have higher leakage as compared to sheet-metal systems. One caution relative to all of the data in *Figure 4* is that some measurements include both supply and return leakage, whereas other measurements include only one side of the fan. Based upon conversations with the dealers who took the data, the Illinois data contains many more single-sided measurements. This suggests that the ratio of leakage areas between rectangular sheet-metal basement ducts and attic flex-duct systems is underestimated by this data.

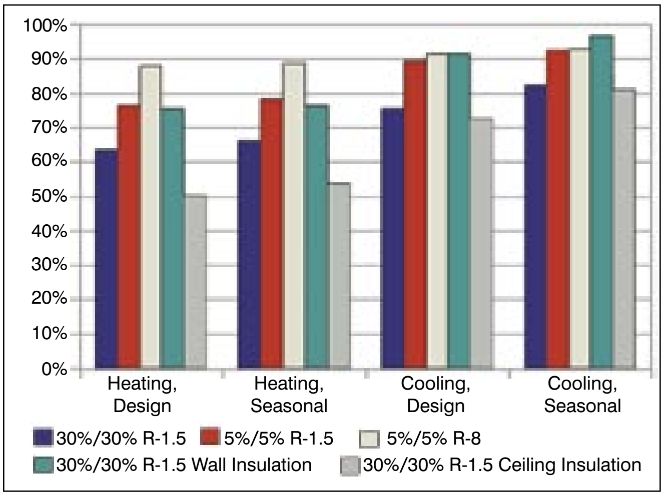


Figure 7: Application of Standard 152 to a basement system in Chicago shows the basement duct efficiency.

Something else to keep in mind when comparing attic and basement construction is that the pressure differentials seen by the leaks in basement systems are typically smaller than those in attic systems. The net result is that a reasonable estimate of leakage for attic flex-duct systems is 15% to 20% of fan flow on each side of the fan,[3] while rectangular sheet-metal duct systems have more like 25% to 30% leakage on each side of the fan.

ASHRAE Standard 152

As duct leakage and temperature loss data began to appear in the early 1990s, concerns quickly arose about how to interpret that data. These concerns led to the formation of a standards project committee in 1993 that ultimately developed Standard 152.

Standard 152 was developed to provide a means for rating the performance of different thermal distribution systems. Its scope was limited to air systems, hydronic systems, and electric systems.

Minimum inputs for rating a duct system are:

- Duct leakage (supply and return);
- Duct location (e.g., attic, crawlspace, basement);
- Duct insulation level;
- House location (from a list of cities); and
- HVAC equipment characteristics (type [e.g. heat pump], capacity, fan flow).

The outputs are:

- Heating design efficiency;
- Heating seasonal efficiency;
- Cooling design efficiency; and
- Cooling seasonal efficiency.

Based upon the inputs, Standard 152 first calculates the fraction of the conditioning produced by the HVAC equipment that is delivered at the supply registers. The standard calculates this fraction, called the delivery effectiveness, using fixed algorithms to calculate the temperatures in each duct zone using the local climate conditions.

The local climate conditions are ASHRAE Handbook design values for the design efficiencies, while the seasonal climate conditions are based upon load-weighted seasonal averages of hour-by-hour climate data. The zone-temperature algorithms include effects such as the presence of a radiant barrier in an attic, and the location of wall and ceiling insulation in basements. For example, Standard 152 temperatures for a well-vented attic are T_{design} + 22°F at design conditions, and $T_{seasonal}$ + 13°F for seasonal efficiency calculations.

Standard 152 then calculates the overall distribution efficiency, adjusting the delivery effectiveness by the fraction of energy losses that are recovered into the conditioned space. The regain factors are based upon the ratio of the thermal conductance between the duct zone and the conditioned space, to the overall thermal conductance of the duct zone. Typical regain values are 10% for a vented attic, 50% for an uninsulated basement, 75% for a basement with insulated walls, and 30% for a basement with an insulated ceiling.

Standard 152 also accounts for interactions between HVAC equipment and ductwork, including the effect of ductwork losses on equipment operating mode, as well as the effect on equipment efficiency of low fan flows. For example, the equipment interaction factor (which multiplies the delivery effectiveness) for a heat pump is:

$$F_{equip} = 0.44 + 0.56 \times (\text{Delivery Effectiveness}) \qquad (2)$$

which accounts for the fact that the extra load associated with duct losses increases the use of electric resistance heating by a heat pump. At a delivery effectiveness of 0.75, the equipment interaction factor reduces the distribution efficiency by 14%.

Example Applications of Standard 152

Some examples of efficiencies calculated with Standard 152 are illustrated in *Figures 5* through *7*. *Figure 5* shows distribution efficiency results for Sacramento at different levels of duct leakage and insulation. It shows that efficiencies for a duct system with R-4.2 duct insulation and the leakage levels observed in the field for existing houses (15% supply, 15% return) range from 53% for cooling under design conditions to 75% for the average value over the heating season. *Figure 5* also shows that sealing the duct leakage has the largest impact, and that the combination of sealing and super-insulation of the ducts (e.g., burying them in loose-fill insulation) can bring all efficiencies above 90%.

Figure 6 compares the savings that can be achieved by different duct system improvements in Sacramento and demonstrates that moving the ducts from the attic to the crawlspace has little impact on heating, but produces cooling savings similar to those achieved by sealing the attic ducts. *Figure 6* also illustrates the

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dramatic impacts of duct improvements on cooling efficiency at design conditions, which translates to comparable impacts on overall cooling system capacity at design conditions.

Figure 7 presents duct efficiencies for basement ducts in Chicago. At typical unsealed leakage levels of 30% supply and 30% return for an uninsulated metal duct system in an uninsulated basement, cooling efficiencies still are considerably higher than for attic ducts in Sacramento, due to the coolness of the basement.[8] *Figure 7* also shows the impacts of duct sealing and insulation, as well as the impacts of basement insulation and location.

Measurement Procedures in Standard 152

In addition to standardizing calculation procedures, Standard 152 also specifies two procedures for measuring duct leakage and two procedures for measuring HVAC system fan flow. The two duct leakage test procedures both include calibrated-fan pressurization of the duct system. The first procedure pressurizes the house with a blower-door fan to the same pressure as the duct system and measures duct leakage to outside. The second procedure pressurizes the ducts only, thereby measuring total duct leakage. The standard only allows the second procedure to be applied to duct systems having leakage levels of less than 10% of fan flow. For either test, to adjust fixed-pressure duct leakage flows to the specific systems being tested Standard 152 also specifies procedures for measuring the duct system operating pressures.

The two procedures within Standard 152 for measuring fan flow are: 1) a method that involves substituting a calibrated-plate for the system filter, and 2) a method that involves substituting a calibrated fan for the return ductwork. Method 2 works by adjusting the calibrated fan speed to produce the same supply plenum pressure as found during normal operation.

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