A Million Miles of Ducts: Duct Sealing Update

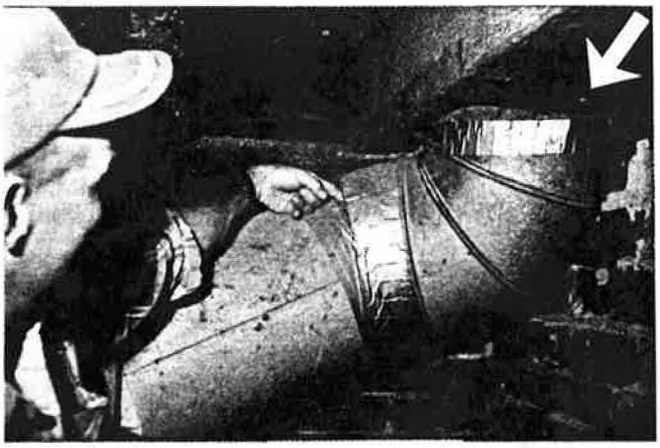
by Brian Coyne

The verdict is in: forced-air systems promote air infiltration, and air sealing efforts should focus on ducts first. But the science of duct sealing is still evolving.

In the past few years, the emphasis in air sealing has shifted from the building shell to forced-air distribution systems. And right fully so: "the infiltration, ventilation, and energy impacts of duct leaks (are) far more significant than those of building envelope leaks," concludes Mark Modera, staff scientist at Lawrence Berkeley Laboratory (LBL) in a recent study.[1] An estimated two-thirds of the million miles of ducts in homes throughout the United States are leaky, causing forced air systems to exacerbate infiltration and indoor air pollution. Researchers and retrofitters are beginning to put together a better picture of how duct systems work and how to test and seal them. This article will summarize results of recent research throughout the country and discuss techniques for diagnosing and repairing duct leakage. It relies heavily on a new training manual, *Duct Doctoring: Diagnosis and Repair of Duct System Leaks*, developed by Jim Cummings of Florida Solar Energy Center (FSEC) and John Tooley and Neil Moyer of Natural Florida Retrofit.[2]

How Leaky is Leaky?

To get a feel for the magnitude of duct leakage, blower door testing has shown that ducts often contribute 10–15% to the total leakage area of a home. The Sheet Metal and Air-Conditioning Contractors National Association (SMACNA) standards for fibrous glass ducts call for a maximum leakage rate of 2 cubic feet per minute at 50 Pascals (cfm_{50}) per 100 ft^2 of duct. For a house with 400 ft^2 of duct area, this would allow 8 cfm_{50} of duct leakage. Yet Cummings reports an average of 320 cfm_{50} of leakage in



Mike Keyes/COAD

Duct tape was never meant to be structural. Stronger connections are needed to avoid such "catastrophic" leaks as these.

Florida homes, with a range of 200–500 cfm_{50}. And Bruce Davis, manager of Home Comfort in Fayetteville, Ark., in a 1991 study[3] found an average of 621 cfm_{50} duct leakage, with a range of 200–1,300 cfm_{50}. Houses with duct leakage in excess of 600 cfm_{50} most likely have "catastrophic" leaks, with disconnected ducts or missing sections—but these are not uncommon.

But the leakage area is only the tip of the iceberg. In contrast to standard building shell leaks, the leakage area of ductwork doesn't give a rough idea of the air exchange rate through those leaks, due to the "forced air infiltration" of the distribution fan. Measured infiltration rates typically double or triple when the distribution fan is running.[4,5] For example, fan use nearly tripled the infiltration rate in the California homes Modera tested; an average 0.24 air changes per hour (ach) measured leakage rate mushroomed to 0.69 ach. Simply closing interior doors while the fan was running caused infiltration rates to triple again—to nine times the natural infiltration rate—in some Florida homes with inadequate return air systems.[6] The largest study of residential infiltration rates to date, a compilation of data from 472 homes in the Northwest, found that overall, "forced air distribution systems increase infiltration rates by 15% to 36%, depending on the amount of exterior ductwork."[7]

What does this mean for energy savings potential? John Proctor, in the Appliance Doctor Project in California, found that duct leaks increased heating and cooling loads by 16% and 25%, respectively (see "An Ounce of

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Mobile Home Ducts (or Lack Thereof)

Mobile homes ducts are much more accessible than those in site-built homes, giving them greater potential for sealing. None of the ducts run through walls, and the return systems—often not ducts but building cavities—can merit complete overhaul. In contrast to the 60%–65% duct leakage reductions crews achieve in site-built homes, we at Corporation for Ohio Appalachian Development aim for a 100% reduction in mobile home duct leakage, with 70% a bare minimum.

In field situations, we quantify the duct system leakage with a blower door. A normal blower door pre-test is taken first, then all the registers (both supply and return) are sealed with masking tape, and then another blower door test is taken. The difference in the two cfm_{50} readings provides a good working estimate of the total air leakage in the duct system. This number can be important from a program standpoint because it can be used as the basis of a performance-based pay system for duct-sealing work.

Bruce Davis

Accumulated dirt in furnace room return air grilles can be one cause of poor air circulation.

In site-built homes, retrofitters normally begin duct sealing at the plenum area and work outward. When sealing mobile home duct systems, however, we find that reversing the procedure makes the most sense since the mobile home boot and register connections (often called the register boot) are almost always quite loose. Crews use inspection mirrors and flashlights to get an indication of the condition of the main duct run. Should a problem be discovered somewhere in the duct run, it's usually necessary to go under the mobile home and gain access to the damaged area by cutting into the belly board or rodent barrier. Once access is gained, the leaky area is sealed with a latex mastic product such as Foster's 38–00 (Aqua-fas), with reinforcing fiber-glass mesh wrapped around any point having more than ¼-in. wide gap. In some cases we will also use butyl-backed tapes, mainly around register openings where the temperature is not high enough to cause product failure. It's important to remember not to reinstall the registers until the mastic sets up, or the registers will be sealed in place forever!

One situation that requires special attention is when the belly of the mobile home serves as the return air system for the heating unit. If the belly is to be insulated, the return air "duct" will be filled with insulation, so a new return system must be designed. We do this first by sealing off the base of the furnace with flashing or some other durable material. Then, we permanently seal all return openings inside the mobile home. This procedure changes the design of the system, and new returns must be added, generally by installing louvered grills into the furnace closet door. The supply ducts are sealed by the usual techniques.

When a belly return system is eliminated, rooms with closed doors will be under positive pressure, which increases exfiltration and could possibly cause structural damage due to moisture migration into the walls. Relieve pressure by undercutting the doors or installing transom vents. Make sure to test for spillage, and educate customers concerning closed doors if pressure differences remain.

We do not consider the air leakage reduction created by redesigning the return system as part of the duct sealing reduction, as that would give a false indication of the effects of the duct sealing. For example, a mobile home we recently worked on had a blower door pre-test of 3,844 cfm_{50}. By eliminating the belly as an air return, the volume was reduced to 2,625 cfm_{50} without any duct sealing having yet been done. So, in cases where the belly is serving as the air return, we isolate and tape off only the supply registers and find out the leakage in the truly ducted portion of the system. In the case cited, sealing the supply ducts revealed leakage of 1,330 cfm_{50} in the ducts.

Once the duct sealing process is thought to be completed, we take another blower door test. The cfm_{50} reading attained should ideally equal the reading attained when the registers were taped off. Matching the two readings means that you got 100% of the leaks sealed. A performance-based pay system for duct sealing is a good incentive for thorough sealing of ducts because payment is on a per cfm_{50} reduction basis. A less-than-thorough sealing job would result in a lower payment, and a job that fails to attain at least 70% of the total might result in a callback.

— G.H. Runevitch

Prevention," *HE*, May/June '91, p. 23 and "Heat Pumps," Mar/Apr '91, p. 29).

Davis tested an air sealing procedure that reduced an average of 21.8% in heating energy usage (31.3% in heat pump systems, 19.7% in natural gas furnaces). The Arkansas homes he studied began with measured leakage rates 10–12 times as great as "properly installed systems might have," Davis reported. The process sealed 74% of the duct leakage in homes with accessible ducts outside of the conditioned space.

Diagnostics

Most researchers favor the flow hood method for duct leakage testing, where the house is depressurized to 50 Pa with the blower door (air handler off), and all supply and return registers are sealed, except for the largest return, which is fitted with a flow hood. (See box, "Mobile Home Ducts (or Lack Thereof)" for an approach to mobile home testing and retrofitting.)

An alternative method of measuring duct system leakiness, called the "subtraction method," is to take two whole-house blower door readings at 50 Pa depressurization, one with all registers are covered and one without. The difference between the two readings yields an estimate of the duct leakage.

Davis compared the flow-hood test method with the subtraction method, noting that the latter is tougher to use when most duct leakage has been eliminated.

DUCT SEALING

Mike Keyes/COAD

The flow hood measures duct air leakage, helping auditors determine how much duct sealing is necessary and where.

Davis also devised a devilishly simple technique for measuring pressure differentials at each register (see box, "Pressure Pan Takes the Cake"), which helps locate the leakiest ducts.

Aside from Davis' pressure pan technique, most leaks are detected by visual inspection of accessible duct runs, and by using a smoke pencil and inspection mirror at registers with the house pressurized by the blower door (air handler off). With the house depressurized, the technician can feel leaking air pulled into the room through registers or can squirt smoke into suspected duct leaks from outside the conditioned space. Proctor feels a blower door is absolutely necessary during the leak-seeking process; he has found that the crews are less effective without it.

The use of building cavities in lieu of ducts is a major factor in distribution system leakage. For example, panned floor joists, interior or exterior wall cavities, and closet ceiling cavities used as ducts all offer diffuse leak sites, especially when they are also used as chaseways for plumbing or wiring. Is this problem limited to older homes? "Unfortunately," says Proctor, "more and more building spaces are being used as returns," and he finds returns "communicating" with the attics in new construction. The growing popularity of open truss systems for second-story floors has greatly increased this type of leakage.

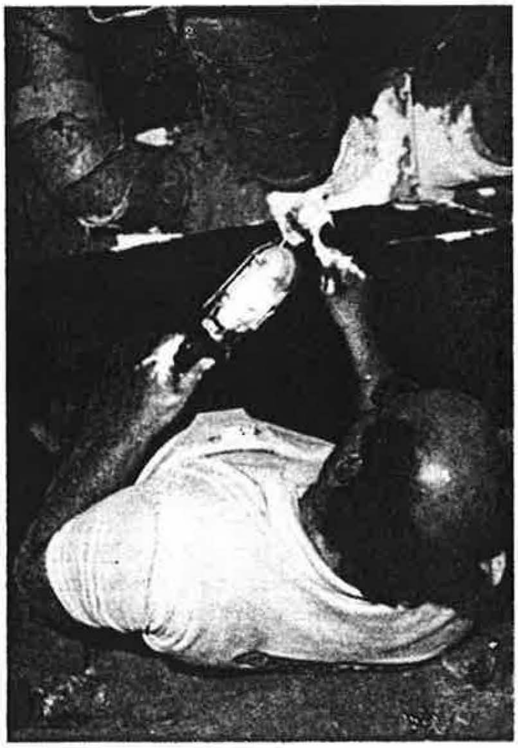
Returns are usually leakier than supply ducts, the *Duct Doctoring* manual explains, primarily because supply leaks are more noticeable (supply air shoots out of the duct rather than being drawn in, and is either warmer or cooler than the ambient air), and so more likely to be sealed. Returns also suffer from poor design: mobile homes often use the belly as the return and many single-family homes have only one return register. The imbalanced duct systems mean portions of the house may be pressurized while others are depressurized.

Health and Safety Considerations

Cummings, Tooley, and Moyer have extensively investigated the dynamic nature of pressures within the conditioned space resulting from occupants closing interior doors (for example, in bedrooms with supply registers and no returns). They have found that when doors are closed and the distribution fan is on, negative pressures in some areas of the home often cause or exacerbate combustion appliance backdrafting, drawing deadly carbon monoxide into the house. Meanwhile, positive pressures in other rooms may cause exfiltration, moisture damage, and comfort problems. (See "Air Handler Fan: A Driving Force for Infiltration," *HE*, Nov/Dec '89, p. 11.) The researchers suggest retrofitters test pressure differentials within the home to avoid such problems.

Because ducted distribution systems can have such a dramatic impact on pressure differentials in the home, it is essential that the technician understand and anticipate possible problems resulting from the duct sealing itself. For example, sealing supply leaks in the vicinity of a combustion appliance may eliminate its source of make-up air and increase the likelihood of exhaust gas backdrafting. Sealing return leaks in one area of the home while ignoring return leaks near the furnace may have the same result.

Researchers unanimously stress the importance of checking combustion appliance draft before and after



Mike Keyes/COAD

Duct sealing often puts retrofitters in "sticky" situations.

Pressure Pan Takes the Cake

When Bruce Davis of Home Comfort ran into John Tooley at a weatherization conference, Tooley showed him his latest invention: a bread pan with a few attachments, which he was using to measure pressure differentials between a room and its wall cavity. Upon his return to Arkansas, Davis quickly set about creating his own version of the "pressure pan." He took an ordinary 10 in. × 14 in. aluminum cake pan; drilled a hole, stuck a length of blower door gauge hose in it, and sealed it in place with some mastic; put some gasket material around the rim, and attached a handle. He hooked up this low-tech cover, large enough to place over most supply registers, to a high-tech electronic micromanometer (a pressure gauge from a blower door would also work).

With this tool, Davis and his crew take quick pressure readings at each register with the blower door depressurizing the house to 30 Pascals. Where the register is too large, they cover the opening with paper, and insert the gauge hose through a hole. Davis soon discovered how useful the pressure pan would be for his study of duct leakage problems.

Joe Kuonen of Energy Rated Homes of Little Rock, Ark., tries out Bruce Davis's pressure pan.

What do the pressure pan readings mean? The tested register-pressure differential does not measure or correlate with the overall leakage from the duct because the pressure differential is affected by the friction throughout the duct. The length of the duct section being tested, the location of the leaks (closer or further from the register), and the leakage level all affect the pressure differential. Davis admits, "I know some people say that this doesn't measure anything, and that may be true—but it tells you everything you need to know." It tells you, in relative terms, the extent the portion of the duct near each register "communicates" with unconditioned air. The registers with higher readings are closer to the big leaks. This helps identify the leakiest ducts. "The pressure pan is a tremendously exquisite prioritizing tool and it quickly lets you know if you were effective in sealing," Davis says.

Figure 1 shows the pre- and post-repair pressure measurements at the supply and return registers in one Arkansas house from the study (taken with the house depressurized to 30 Pa.). Duct sealing reduced register pressure readings to 1.1 Pa or lower, and most were reduced to 0.3 Pa. Davis also measured the whole house leakage before and after the retrofit, with the house depressurized to 50 Pa. Sealing reduced duct leakage from 661 cfm$_{50}$ to "0" cfm$_{50}$ (the blower door is not sensitive enough to measure such low leakage rates). Interestingly, duct leakage declined not only in ducts that were repaired, but also in the other ducts in the system.

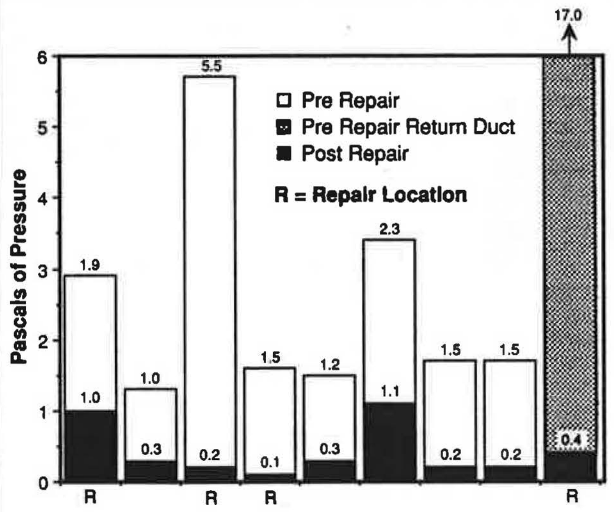
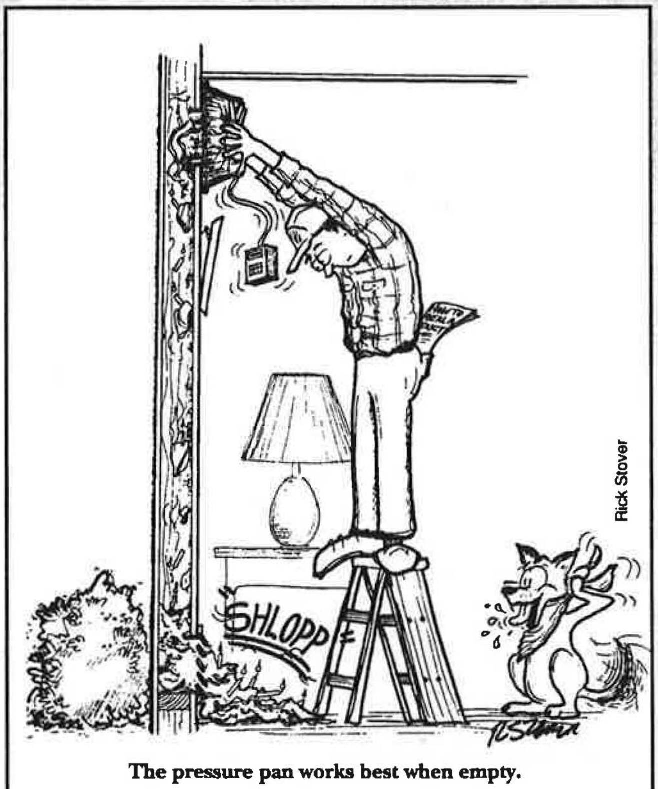


Figure 1. This chart shows measured reductions in pressure pan readings (furnace fan off, house depressurized to 30 Pa. with blower door) in one Arkansas home after repairing just the four leakiest ducts. Bruce Davis



The pressure pan works best when empty.

Besides finding leaks, other possible uses of the pressure pan are code enforcement and certification of distribution systems for home energy ratings, Davis suggests. He invites others to join in and contribute to the evolution of the pressure pan as a diagnostic tool.

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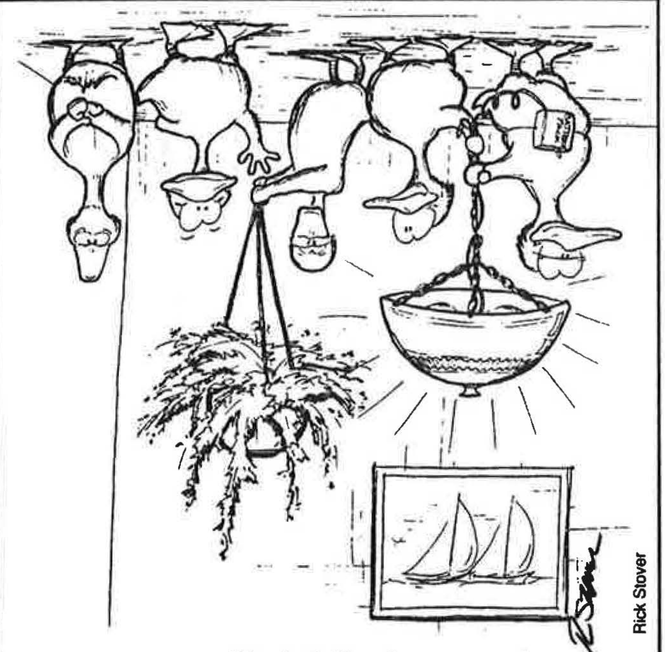

Rick Stover

"Duck Ceiling."

duct sealing. (In fact, this may not be a bad policy in any home with combustion appliances, regardless of whether it has forced air or not. How many well-intentioned crews have encountered an unvented clothes dryer, and vented it to the outdoors without considering the effect it might have on the chimney draft of the furnace and water heater in the same utility room?) Further, they warn, a system that seems to vent properly after duct sealing may experience spillage or backdrafting when the fireplace is used, interior doors are closed, or exhaust appliances are on. Spillage testing should simulate "worst case" scenarios: with doors closed; kitchen and bathroom exhaust fans running; furnace, dryer, and water heater running; and distribution fan on—all at once.

Attention should be paid as well to balancing the leakiness of supply and return systems, and making sure doors to rooms without return registers have sufficient door undercuts to avoid excessive pressurization and exfiltration.

Various materials may be used to seal the leaks themselves; gone are the days when duct tape was the panacea. (See box, "Sealants: Mastic vs. 'May Stick'") Whole sheets of sheetrock or sections of new ductwork may be needed. A well-stocked truck is ideal.

Mike Keyes/COAD

Caulking a register boot between the air intake and the floor reduces the substantial air leakage often found there.

Effects on System Performance

In addition to increasing air infiltration and backdrafting dangers, duct leaks also affect heating and cooling equipment performance. One house cited in the *Duct Doctoring* manual was found to be taking over 50% of its return air from the attic, due to missing sheetrock in the plenum that allowed air to be drawn from the attic through an interior partition wall. The owner was unable to get the house cool during the daytime, so he ran the air conditioning only at night. After sealing the plenum and the ceiling cavity, the system operated and cycled normally.

Figure 2 shows the magnitude of the reduction in air conditioner performance due to supply leaks, according to the *Duct Doctoring* manual. Supply leaks of 15% of the air through the system will reduce efficiency and capacity of a 10 SEER air conditioner by about 33% when the leakage comes entirely from outdoors (95°F), and by about 50% when two-thirds of the leakage comes from a 120°F attic (not unusual on a hot day in Florida).

Heat pump efficiency is similarly degraded by duct leakage, though it is more complex. If heat pump demand

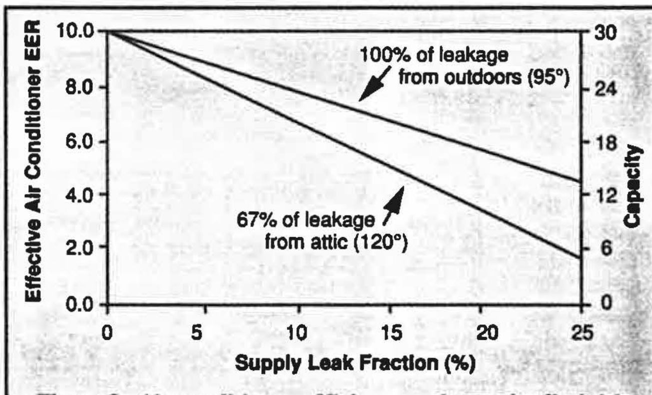

Figure 2. Air-conditioner efficiency and capacity diminish rapidly with an increasing proportion of supply leaks. This graph assumes a 2.5-ton air conditioner with 10 EER. As more of the duct leakage is drawn from the attic, the slope gets steeper. It is even possible for an air conditioner to *heat* a house, if attic air overloads capacity so much that the air conditioner can't cool the distribution air lower than the house air. FSEC

Sealants: Mastic vs. "May Stick"

Mike Keyes/COAD

This return system is well-sealed with mastic and mesh tape, a permanent sealing system.

We have all had the experience of viewing gray cloth duct tape applied where it shouldn't, wouldn't, and couldn't stick. I've seen it used on flue pipes, Kraft-backed duct insulation, floor joists, and window screens. Fortunately, in most cases alternatives exist that are more durable and more effective.

Even for sealing ducts, the Florida researchers prefer mastic. When used in combination with glass fabric mesh, mastic can create a durable, airtight seal. Its chief advantage is its suitability for a variety of applications—new ducts or old, sheet metal seams, or ductboard/flex duct interface. It can be brushed, trowelled, or hand-dipped (wearing rubber gloves) onto a surface.

Of course, all mastics are not created equal. Some have a long curing period, and are better suited to new construction. Water-based mastics clean up more easily than petroleum-based versions. As with any product, installers should check the safety warnings on the Material Safety Data Sheet, which program managers are obliged by law to provide.

Quality metallic duct tape can be used to seal areas where accessibility must be maintained (e.g., the blower compartment panel).

Here are a handful of products the experts have found worthwhile:

Mastic:			Fiber Mesh:	Tape:
RCD	Glencoat	Foster Products Corp.	Cain Mfg. Co.	Alumi-GRIP
P.O. Box 547606	I.M. Distributors	3200 LaBore Rd.	P.O. Box 848	Hardcast
Orlando, FL 32854-7606	5061 24th St.	Vadnais Heights, MN 55110	Pelham, AL 35124	903 W. Kirby
(407)422-0089	Sacramento, CA 95822	(612)481-9558	Self-adhesive fiber-glass duct sealer membrane; sold in 150-ft rolls 3-in. wide	Wylie, TX 75095
#6 mastic; sold in tubes, 1-, 2- and 5-gallon tubs	(916)736-9060	Aqua-fas (38-00)		(214)442-6545
				Sold in 50-ft rolls 3-in. wide

exceeds capacity, back-up electric resistance heat kicks in and the coefficient of performance (COP) drops sharply. For example, a system with a 30% supply leak may see the efficiency drop from 2.2 to 0.7 COP, according to Florida Solar Energy Center calculations. Cummings stresses the implications of duct leakage repair for electric utility demand-side management. Improving system performance will reduce the use of backup electric heat in winter and air conditioning in summer, saving energy *and* reducing peak demand.

Recommendations

The researchers represented here were unanimous in one sentiment: It is absolutely critical that anyone seeking to repair ducts be aware of, and consider, the interactions among components of the house. Combustion appliance venting, indoor air quality, moisture, comfort, and occupant behavior must all be factored in. As Cummings warns, "This is not 'Find a leak, seal a leak.'" Proper training is essential, and repair work must proceed with caution to avoid "solutions" causing problems of their own.

Duct leakage diagnosis is a science, but it is far from exact. Researchers are the first to acknowledge that we do not have all the answers yet. Standard practice today might be cast aside next year or next week in favor of a better approach. Still, a few guidelines emerge from the research:

1) Duct sealing should be a major component of air sealing retrofits.
2) Homes should be screened for duct leakage. The leakage varies greatly from house to house (Modera found standard deviations of 50–100% in his leakage measurements), so programs should measure leakage before retrofitting to identify the houses with the greatest potential.
3) Properly trained crews should aim to reduce total system leakage to about 100–150 cfm_{50}. They should be able to eliminate 60–65% of the measured duct leakage in single-family, site-built homes and more than 70% in mobile homes.
4) Pressure differentials and spillage should be tested before and after sealing ducts, to pinpoint the right leaks first, and to leave the home safe and healthy.
5) Sealants should be durable and provide a good, airtight seal.

Recognition of the enormity of the problem of duct leakage is only the beginning; the greater challenge is to correct the problem for the benefit of our homes, our health, and our environment, indoors and out. ■

Endnotes

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