Getting the Most From

MECHANICAL COOLING

We're in an attic in Phoenix, directly over the closet that holds the air handler. With a flashlight and smoke pencil, which makes the air stream visible, we watch hot attic air being sucked into return duct fittings and down the interior partition walls into the air-handler's platform plenum below. Later, while inspecting the crawlspace, we see chilled air leaking out of supply branch lines where they exit the trunk line. With attic temperatures averaging more than 20°F higher than outdoor temperatures it's no wonder the occupants are disappointed with their air conditioner's performance. After all, it's trying to cool 120°F attic air while losing cooled air to the crawlspace.

The preceding scenario is unfortunately the rule rather than the exception. And leaks in the duct system are just part of the problem when it comes to air conditioning. The other chief energy wasters are (1) low air flow through the inside (evaporator) coil; (2) improper refrigerant charge; and (3) oversized air conditioners.

Field studies across the nation indicate that residential air conditioners are running far below their rated efficiencies because of these problems. One extensive study found that duct leakage alone raised the average cooling load in new homes by about 23%. Duct leakage is the largest loss, followed by improper charge, air flow problems, and oversizing.

The time to fix these problems is during design and construction, when small improvements will yield big payoffs in efficiency. Retrofitting at a later date, however, when many of the problems are buried behind drywall and finished floors means less gain for more money. In addition to saving the homeowner a lot of money, a better job up front means fewer callbacks for the contractor — for the electric bill that's "twice as high as my neighbors" or the unit that won't stop running but still leaves the owners uncomfortable.

Throw away your duct tape *and smear on water-based mastic instead, if you want a long-lasting seal against duct leakage. Duct mastic has the consistency of mashed potatoes and is applied by hand or with a cheap paint brush.*

The biggest energy thief is leaky ductwork — but also make sure the refrigerant charge, air flow rate, and sizing meet the manufacturer's specs

By Michael Uniacke & John Proctor

Duct Leakage

Because of standard installation practices, duct leakage plagues almost all forced-air heating and cooling systems. While only 10% to 15% of the total air leakage in a home is located in the duct system, duct leaks are under pressures 10 to 20 times higher than other building leakage whenever the air handler runs. The result is that when the air handler is running, duct leaks can double or triple the total air leakage in a home. And this typically happens when you least want it — at the hottest or coldest times of the year.

So where do the leaks occur? Disconnected ducts and framing cavities are the largest leakage sites (Figure 1). It is not unusual to find ducts that have either been accidentally disconnected by another trade, such as plumbers or electricians, or that were never connected in the first place. The take-offs and collars where branch lines exit the trunk are notoriously leaky (Figure 2, page 23). Basically, there are leaks wherever there is a joint or a seam in the system (one exception is the snap-lock joints along the length of a straight section of duct). Even the cabinets that house the units are leaky.

Another big problem is the widespread use of framing cavities as part of the air supply and return system. This includes platform plenums, and panned joist and stud cavities (Figure 3, page 25). Typically, the hvac contractor says it's the contractor's, drywaller's, or framer's responsibility to seal up framing cavities; whereas the contractor points the finger at the hvac sub. Even if the contractor does a thorough job of sealing these cavities, they may not

Figure 1. ***Prime leakage sites include:*** *connections where flex ducts join junction boxes (left), disconnected ductwork (center), and poorly installed boots at grilles and registers (right). Leaky ductwork can spoil the performance of an otherwise tight, well-insulated home.*

A BALANCING ACT

Leaky ductwork and household exhaust fans can unbalance air pressures — leading to poor air quality, moisture problems, and backdrafting

by Frank Vigil

If you blow air into a well-sealed room, the room will be positively pressurized, like an inflated balloon. If you draw air out of a room, it will be under negative pressure, like a vacuum-packed jar. The tighter a house, the more easily it is pressurized or depressurized — and the more likely it is to face pressure related problems.

What Causes These Pressures?

With exhaust equipment, the answer is fairly straightforward. For example, a range-top exhaust fan rated at 600 cfm will exchange all the air in a 15x18-foot kitchen every three and a half minutes. For every cubic foot of air that is drawn out of a room, one cubic foot of makeup air must enter. This creates a negative pressure in the room, relative to the outside of the house. This same principle applies for all exhaust equipment — be it bathroom fans or clothes dryers.

Leaky ductwork is another strong source of negative or positive pressures. In a balanced duct system, the air flow drawn into the return side matches the flow delivered via the supply side. Leaks in the supply ducts to unconditioned spaces such as attics and crawlspaces "starve" the return for air and cause negative pressures. Leaks in the return side from outside spaces have the opposite effect — and the house becomes pressurized.

Due to the large size of the air handler fan (about 400 cfm per ton), these pressures can increase the air infiltration rate in a house by 300% or more every time the air handler kicks on. And this happens at the worst time of the day — when it is hottest or coldest outside.

Powered attic exhaust fans can also create large negative pressures in a house. Studies have shown that soffit, gable, and ridge vents often cannot supply enough makeup air when the fans are running. The resulting negative pressure causes air from the house to be pulled into the attic through leaks in the ceiling, putting all or part of the house under negative pressure.

Another important cause of house pressures is the simple closing of interior doors. Since most new homes use only one return (sometimes two) for the air distribution system, contractors generally undercut bedroom and bathroom doors about an inch. In theory, this allows free movement of air back to the return. But studies by John Tooley and Neil Moyer of Natural Florida Retrofit in Montverde, Fla., show that this theory rarely works. Many times, the undercut is blocked by the carpeting. And even without carpeting, the undercut often overly restricts the return air flow, which pressurizes the closed-off room and depressurizes the rest of the house.

Why All the Concern?

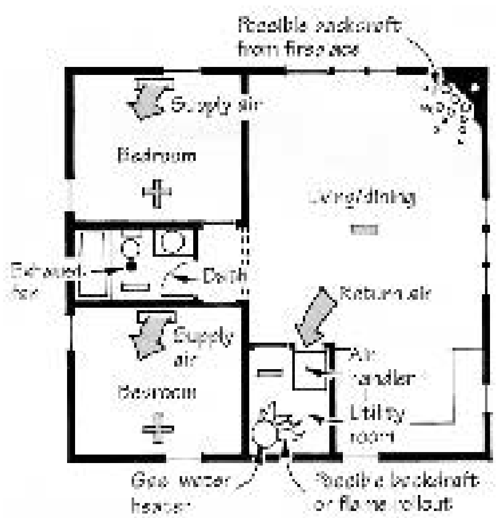
In addition to raising infiltration rates and energy bills, these pressures can also harm the occupants and the house itself.

When a house is under negative pressure, unless the contractor provides controlled makeup air, it will leak in from the easiest sources. Quite often, these sources include flues for water heaters, furnaces, and fireplaces. Since flue gas pressures are very small, it doesn't take much reverse pressure to cause spillage and even backdrafting.

Tests in hundreds of homes across the nation demonstrate that simply closing interior doors can often cause such hazards. For example, it is not uncommon for a family to go to bed, close their bedroom doors, and leave a fire smoldering in the fireplace. A smoldering fire produces carbon-monoxide gas and will not sustain a draft as the chimney cools. Gas spillage and backdrafting are likely in this case.

Add in the depressurization caused by leaky ductwork or a kitchen range hood or bathroom exhaust fan, and the negative pressures may be strong enough to cause flame roll-out in a gas-fired water heater or furnace. In flame roll-out, the initial burst of flame is drawn out from the appliance by the negative pressures, possibly igniting surrounding materials.

Closed Door Effect



Something as simple as closing doors can cause backdrafting. In this house, the furnace fan will pressurize the bedrooms and depressurize the main living area — possibly reversing the flue gases in a water heater or smoldering fire.

Negative or positive pressures can create other problems as well, including poor indoor air quality and moisture damage. In northern climates, a house that is positively pressurized in winter will force warm, moist interior air into the exterior walls, where it can cause mildew and rot. In the hot and humid South, a house under negative pressure during the summer will draw hot, humid outdoor air through walls, where it can cause similar problems.

Leaky ductwork can also draw in pollutants directly from the outside. For instance, ductwork with return leaks located in the crawlspace may draw in toxic termite sprays, radon, moisture, or mold and mildew spores. Leaky return ductwork in the attic can draw in loose insulation particles, another potential health hazard.

What Can You Do?

Builders should include pressure balancing strategies as an integral part of their planning process. Consult with a reputable, trained hvac contractor or engineer on ways to pressure-balance the house.

One solution is to install over-the-door transom grilles, common in older homes. Another option is transfer grilles, which have a high grille on one side of a wall and low grille on the other side (thus connecting the stud bay to both sides of the wall). These offer the same pressure relief with more privacy. Even better are cross ducts, sometimes called "jumper" ducts. These consist of a grille installed in the ceiling of one room, connected via a short length of duct to another grille in the main body of the house. The best way to reduce pressures caused by ductwork — but also the most costly — is to install individual returns in each room.

To minimize backdrafting hazards, builders should use only sealed-combustion appliances. Furnaces, water heaters, fireplaces, and even kitchen stoves are now available in sealed-combustion models.

Even if you typically install your ductwork within the heated space, you're not immune to pressure imbalance problems. Quite often, the chase used for the duct is not airtight either to the outside or to the house. And even if the ductwork is truly inside the heated space, return leaks can cause localized negative pressures strong enough to cause problems.

The solutions are not overly complex or expensive. With proper training and attention to detail, builders can provide houses that are truly healthy, durable, comfortable, and energy efficient.

Frank Vigil is senior project manager with North Carolina Alternative Energy Corp., a nonprofit corporation promoting energy efficiency. He was instrumental in developing voluntary standards for pressure balancing.

survive the work of plumbers and electricians. Regardless, most framing lumber shrinks as it dries and new cracks will appear. Our conclusion is that the building industry must get away from using building cavities as part of the air distribution system.

If you are skeptical, we suggest you examine one of your duct systems as it is being installed. Pop off a return grille on a panned joist return and scrutinize all the seams. Examine where supply lines branch from trunk lines. If you have the opportunity, look down a trunk line while it is being installed. You will most likely see light coming in every 48 inches where the sections connect. A flashlight and an inspection mirror are handy for this.

Sealing the ducts. Fortunately, duct leakage is simple to eliminate during new construction if you know where to look for leaks and how to seal them. Depending on the complexity of the system, sealing can cost from $150 to $350. Research has shown that the payback period on this added cost ranges from less than a year to about three years. And there are important health and safety benefits as well (see "A Balancing Act").

The product of choice for duct sealing is water-based mastic accompanied by a fiberglass mesh on larger holes. Two good duct mastics are Glencoat (I.M. Distributors, 5061 24th St., Sacramento, CA 95822; 916/381-1800) and RCD #6 (RCD, P.O. Box 547606, Orlando, FL 32854; 407/422-0089). These mastics have the consistency of mashed potatoes and can be easily spread over joints in the ductwork with an inexpensive paint brush or one's gloved hand. On cracks and gaps wider than 1/4 inch, place a section of 2-inch-wide fiberglass mesh tape in the bed of mastic to reinforce the seal. The beauty of water-based mastic is that it provides a long-term durable seal and cleans up with water.

The traditional duct tape approach doesn't work. Because of the extreme temperature conditions that ducts are subjected to, the tape eventually fails. Mastic is actually less labor intensive than a "good" taping job.

The last step in the sealing procedure is to test to make sure your hvac contractor got it right. You can use either a blower door and flow hood or the newest arrival — the Duct Blaster (The Energy Conservatory, 5158 Bloomington Ave. S., Minneapolis, MN 55417; 612/827-1117). With proper training, these diagnostic tools are fairly simple to use (Figure 4, page 26). The goal is to have no more than 25 cfm of leakage at .10 inches of water column in smaller homes and no more than 50 cfm leakage in larger homes. This is achievable, but it takes a lot more attention to detail than most hvac contractors are accustomed to.

The testing has several benefits. First, when an hvac contractor knows his work will be tested, he's more likely to get it right the first time. Second, diagnostic tools turn up leaks that are virtually undetectable by visual inspection. And third, the test teaches the participants where to seal better next time, as well as making believers out of skeptics.

Improper Charge

The second most important problem with mechanical cooling systems involves the refrigerant charge. Over half the homes we evaluated in one study had the wrong charge. For the most common systems (capillary tube), a 10% overcharge results in a 10% loss in efficiency. When undercharged by 20%, the same system loses 16% of its designed efficiency. Incorrect charge also reduces capacity and may shorten compressor life.

An undercharge causes the compressor to run longer and hotter, while an overcharge causes the compressor to work harder and can lead to compressor failure. In the case of an undercharge, less heat is removed from the indoor air as it passes through the coil, so the unit has to run longer.

Technicians typically use guesswork to determine if the charge is correct. One common but unreliable technique is to feel the suction line. If the temperature to the compressor "feels right," then the charge is assumed to be correct. The accurate way to check the charge is straightforward for a trained person and takes less than an hour. The process involves first checking the air flow and then either the *superheat* or *subcooling*, depending on system design.

Low Air Flow

The third major problem with mechanical cooling is low air flow over the indoor coil. The indoor coil, or evaporator, is where heat and moisture are removed from warm indoor air. Most manufacturers recommend that air flow across the coil should be 400 cfm per ton. When the air flow drops below 350 cfm, the unit's efficiency drops off.

In simple terms, lower air flow means less heat is transferred to the refrigerant, so the unit has to run longer to remove the same amount of heat. Another effect of low air flow is that the coil may begin to freeze, which further reduces efficiency and can cause the compressor to fail.

A study we conducted of 175 newer homes revealed that 24% of the homes had air flow of 350 cfm per ton or less, some as low as 196 cfm per ton. The average efficiency loss was 8%.

Reduced air flow has many causes. The most common cause is poor duct design and installation (see Figure 5, next page). Closed registers also reduce the air flow. If the air distribution system relies on a filter grille at the return, return leaks can suck dust and insulation into the duct system, which accumulates on the coils and reduces air flow. A dirty air filter has a similar effect. Even without duct problems, it is important to inspect both the indoor coil and air filter on a regular basis.

Unfortunately, the indoor coil is often installed in an inaccessible location. If the supply plenum has to be dismantled to gain access to the coil, chances are it will never be inspected. If, on the other hand, an access panel is incorporated into the supply riser and only a handful of sheet metal screws have to be backed out, the service technician can make a visual inspection as part of the annual service.

The best way to measure air flow is with the Duct Blaster, described above. For efficient performance, the flow should be within 5% of manufacturer's specs.

Oversizing

The majority of air conditioners are oversized by 25% or more. When duct leakage, low air flow, and improper charge have been addressed, this oversizing becomes apparent. An oversized unit is more expensive to run, compromises comfort, and can be a source of callbacks. Once again, the penalty for this problem involves more than just a higher utility bill.

An oversized system will "short cycle," meaning the unit cycles on and off rapidly instead of running steadily. A capillary tube system takes over five minutes to reach 95% of its operating capacity. Short cycles never allow the equipment to perform to its designed capacity.

Oversizing can also degrade comfort in hot, humid climates, because the unit's ability to dehumidify (latent cooling) is reduced. The unit

Where to Seal Ducts

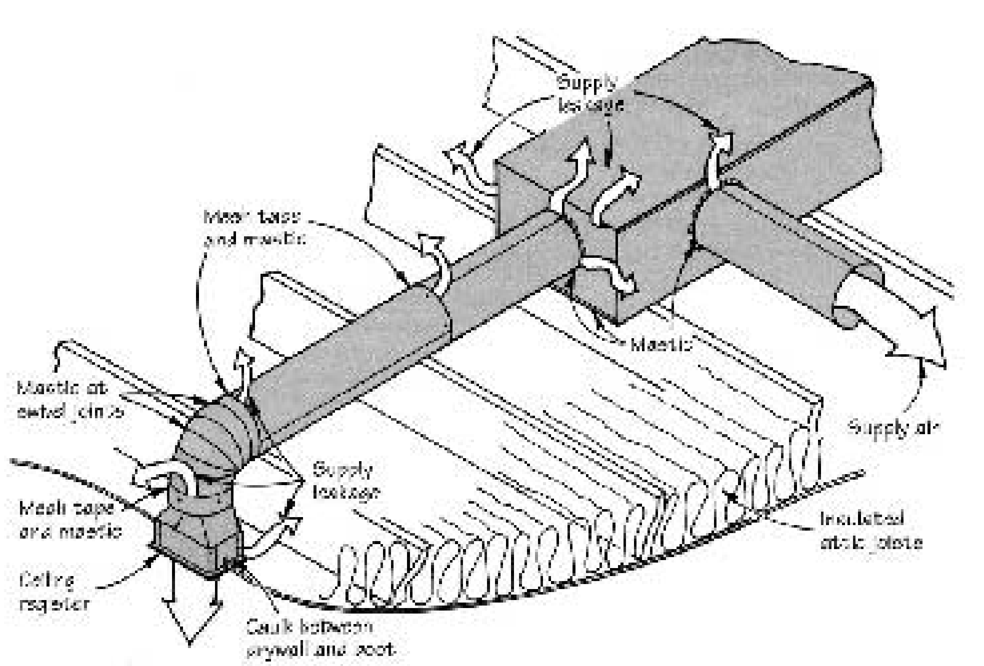


Figure 2. ***To control metal duct leaks*** *in attics and other unconditioned spaces, seal all joints with mastic except lengthwise snap-lock joints, which are relatively tight. With flex duct, seal the inside liner to the metal collar with a plastic tie, then apply mastic and fibermesh.*

Using Building Cavities as Ducts

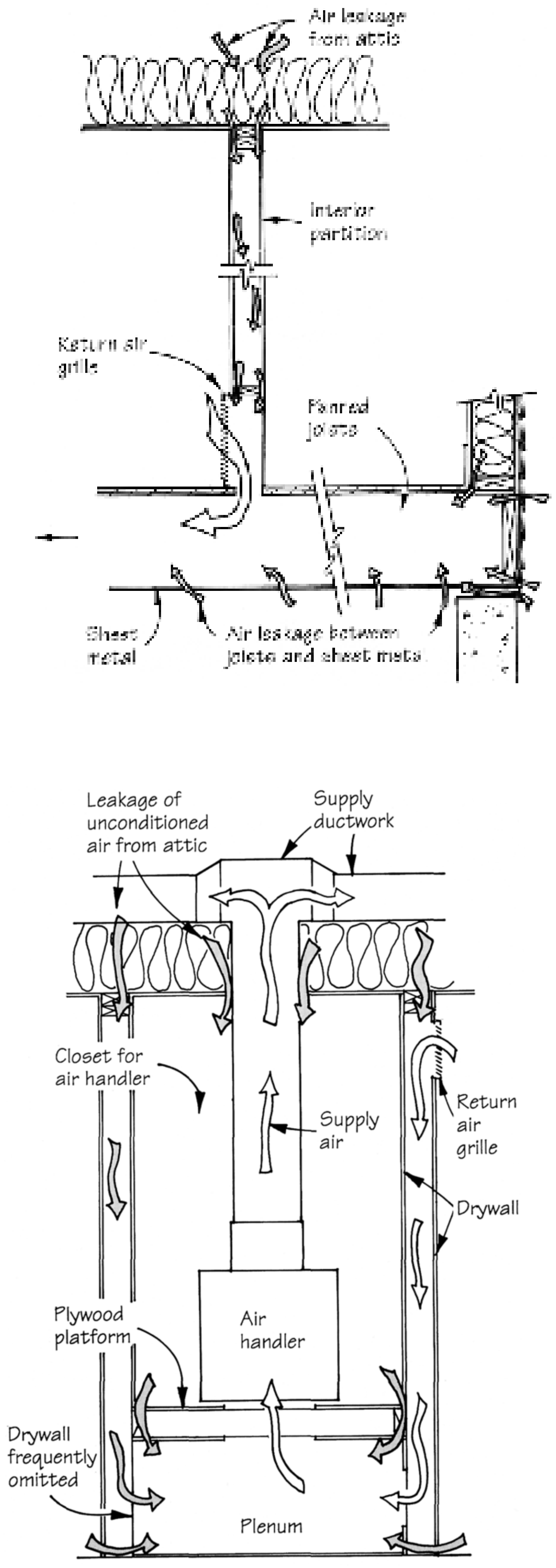


Figure 3. ***Stud and joist bays*** *make handy return ducts, but are a major source of leakage (top). Air handlers set on raised platforms (above) suffer from similar leaks. The author's recommendation: Use ductwork instead of building cavities.*

Figure 4. ***Measuring duct leakage*** *takes under half an hour using the new Duct Blaster, a portable calibrated fan. Used as a powered flow hood, it can also accurately measure air flow through the duct system.*

Figure 5. ***Too many twists and turns*** *in the duct runs create excess resistance to flow. This lowers system performance and can freeze up the evaporator coil.*

cools the air so quickly that it kicks off before the indoor coil removes an adequate amount of moisture. The indoor humidity remains high, preventing a person's body from keeping cool through natural evaporation from the skin.

The result is that the air ends up cool and clammy, and occupants respond by turning down the thermostat further, driving up energy use. For example, turning the thermostat down from 75°F to 70°F can easily increase the cooling load by 25%.

Ask your hvac contractor how he sizes equipment. Most rely on rules of thumb based on the square footage of the house. Window orientation, levels of conservation, and occupant load are often not taken into consideration.

The solution is Manual J, which is a simple method for sizing heating and cooling loads. Manual J becomes fairly easy to navigate once you've waded through it a couple of times. A companion manual, Manual D, is for sizing duct work. The manuals cost $24 each from the Air Conditioner Contractors Association, (1513 16th St. NW, Washington, DC 20036). Both procedures are also available on computer software called Wright J and Wright D (Wright Associates, 394 Lowell St., Lexington, MA 02173). With the software, an experienced estimator can do a run on a simple 1,800-square-foot home in about an hour — compared to about three hours manually.

The time it takes to correctly size a cooling system is well spent. A properly sized unit will often reduce the initial cost of the system, run more efficiently, last longer, and enhance the comfort level in the home. If your hvac contractor isn't already sizing systems correctly, encourage him to learn how to use Manual J and Manual D.

Summary

It's safe to say that over 95% of new air-conditioned homes being built today will suffer from one or more of the problems discussed in this article: duct leakage, low air flow, improper refrigerant charge, and oversizing. To correct these problems, builders and designers need to start using detailed specifications that require quality installations. The payback period for eliminating these problems is typically less than three years, not counting the benefits of better comfort and indoor air quality, as well as fewer callbacks. ■

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For More Information

Professional training in duct doctoring is offered by the Florida Solar Energy Center (300 State Rd. 401, Cape Canaveral, FL 32920; 407/783-0300).