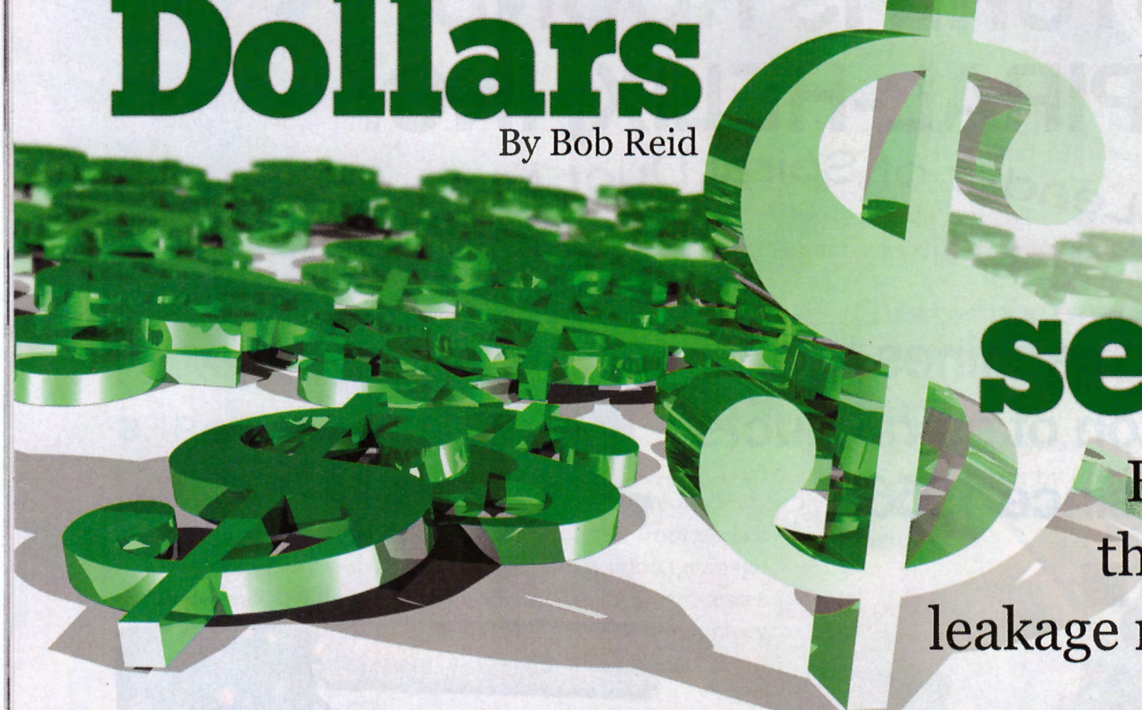
Dollars and sense

By Bob Reid



Figuring out the cost of air leakage no easy task

Duct systems leak. HVAC construction contractors, duct manufacturers and sheet metal products manufacturers have always acknowledged that duct systems are not 100 percent airtight.

Common opinion was that "this is just air." A little bit of leakage from an HVAC market system wouldn't harm anyone. From a health and safety standpoint it's a bit hard to argue with that logic. But the industry was overlooking two important things: Most people didn't realize how much air actually leaked from a typical system. And this leakage was causing harm — to the building owner's pocketbook.

Almost 25 years ago, reports were published that said the typical commercial HVAC market systems were leaking 10 percent to 30 percent of the air produced by fans. Many of these same reports hinted that leakage in residential systems could be much higher. At the same time, ducts for universities and hospitals were being installed and tested to perform at 0.5 percent leakage and at 1.5 times the system operating pressure.

It seemed logical to pass the reports of leaky ducts off as the work of unscrupulous or poorly trained HVAC sales installers. After all, leakage does come down to component choices and workmanship. The surprising fact is even those "half of 1 percent" leakage ducts were part of systems that leaked at much higher rates. If you look at how a leakage test is typically performed you can see how the majority of duct system leakage remains unmonitored.

A duct system to be tested will usually be installed using higher-quality components — spiral duct or rectangular ducts with flanged transverse connectors. Duct sealants are used liberally on the joints and side seams. The ducts would be capped off and tested. But what was not being tested? A typical duct-leakage test never included any components. Access doors were excluded. Duct sections were always capped off prior to fire dampers so they were not part of the test. Sound attenuators were not tested. Typically, the trunk ducts were tested but the caps were placed on the T taps, so round run-outs to variable-air-volume boxes were not included.

In the mix

Flexible ducts and most importantly, their connections to metal ducts and mixing box connections, were not tested. The mixing boxes themselves were not checked for leakage, nor were any components connected to them like coils and heaters. Downstream of the mixing box was a whole different type of duct — unmonitored and often dismissed as irrelevant in leakage.

Industry groups and contractors would say, "It doesn't leak much. It's low pressure" and that testing for leakage in these systems would not be cost-effective.

Research performed at Lawrence Berkeley National Laboratory on installations just like a typical "low pressure" duct system show that these leakages are not irrelevant. These systems often use no sealants at all. The ducts are smaller so you see rectangular ducts with S-and-drive connections instead of flanged ends. You would see components like spin-in taps used with dampers that pivoted on a peg stuck through a 3/8-inch open hole. Adjustable elbows seldom had seams sealed. Longitudinal seams of rectangular ducts and snap-lock pipes were not sealed.

Flexible ducts were installed on crimped duct ends and

Continued on page 16

Leaks

Continued from page 14

too-short grille collars — with no profile to prevent pull-off —with, if anything, duct tape used to seal the connection. An unsealed "low pressure" duct system can easily leak 10 percent of the supply fan flow.

One case study by Semco titled "Efficient Duct System Design" illustrates the problem. In a very typical VAV duct system, there was almost 50 percent more square footage of surface area in the "low pressure" duct system versus the "medium pressure" duct system. We classify leakage as "Cubic feet per minute per square footage of duct surface area." There were eight times as many transverse connections in the low-pressure duct. There was more than three times the length of seams that should have been — but often were not — sealed.

'Wasted'

Looking at the total duct system, you could see that even a tightly sealed medium-pressure duct system would only partially affect "system" leakage. Any air that leaves the "duct system" between the fan and the grille is leakage — and is wasted. All system components have their own leakage and contribute to what usually becomes a substantial amount.

In 2002 a study was produced by Tiax LLC called "Energy Consumption Characteristics of Commercial Building HVAC Systems." It sought to identify the top building energy-wasting faults in commercial buildings and where potential operation savings could be accomplished.

Another paper, called "Building Commissioning: A Golden Opportunity for Reducing Energy Costs and Greenhouse Gas Emissions" referenced this study and put some actual energy costs with it. The author ranked duct leakage as the single largest energy inefficiency in commercial buildings — with an annual cost 50 percent higher than the next leading inefficient practice, "HVAC left on when space unoccupied" and 70 percent higher than the third-place inefficiency, "Lights left on when space unoccupied." Using fairly conservative costs he estimated duct leakage to consume the electricity equivalent of 28.6 billion kilowatt hours per year at a cost of $2.9 billion dollars annually.

It's easy to stop right there and go "Wow. We should do something about that." But then we would be overlooking another big component of the cost of duct leakage: system overdesign. Design engineers are charged with creating buildings for occupant comfort. A lot of research has gone into what amount of conditioned air delivered in what way makes for happy occupants. A substantial portion of this design process, however, has relied on feedback and adjustments to what happens in the "real world." Over time they have gotten used to designing systems around substantial duct system leakage.

An oversize problem

So what happens when we get used to 30 percent air leakage? Fans are oversized to produce 30 percent more air than required for occupant comfort. It doesn't really matter where in the system the air leaks. The fan still needs to produce a sufficient quantity to the room. You generally can't use the same equipment. If you try to use the same fan for 10,000 cfm of air and try to make it work for 13,000 cfm of air — 30 percent leakage — the rotations per minute would increase 30 percent, the static pressure would increase 69 percent and you would need 120 percent more brake horsepower. For the rest of the system, chiller and boiler capacity would have to be increased to condition 30 percent more air. Duct sizes need to increase.

You might typically design a duct at 36 inches round for 10,000 cfm and 40-inch round at 13,000 cfm. That results in a 10 percent increase in surface area — 10 percent more steel, insulation and installation labor. The same air volume delivered through rectangular duct with typical height restrictions — say, 24 inches — would give us a 54-by-24 duct instead of a 44-by-24 duct, a 15 percent increase in surface area, material, insulation and installation labor.

In this particular example, you get off light because you can make these ducts with the same gauges for 10,000 or 13,000 cfm.

But what happens when the size increase causes you to cross a line in the Sheet Metal and Air-Conditioning Contractors' National Association duct-construction tables and you have to increase the gauges? Twenty-two-gauge steel weighs 22 percent more than 24-gauge steel. Eighteen gauge weighs 30 percent more than 20 gauge. You not only have a substantial material increase, but your labor increases by about the same amount since much of the industry still calculates installation labor based on duct weight.

As you can see, the cost of duct leakage becomes the sum of two costs. There is "first cost" — the increased cost of the building from providing equipment and components that are larger than they need to be. Second, there is an increased operating cost that will go on as long as the

Leaks

Continued from page 16

building is in use. But what is this cost? If we have a water leak we know what our cost per gallon is because we buy water. But if we measure leakage and air produced as "cfms," how much does a cfm cost?

Since we are manufacturing that cfm of air and not buying it, the answer has been surprisingly hard to find. The typical answer for several years of HVAC market professionals asked that question has been "It depends."

It's a very important number to know, because knowing the real cost of duct leakage — the ongoing cost beyond the building's first cost — is necessary in justifying what most people think is an increased cost of construction for producing duct systems that leak less. Owners and contractors undoubtedly need to know more about this cost, but in asking the question we have started to see a range of what different groups see as the cost to produce a cfm of air and the related cost of air leakage.

Almost 25 years ago reports were published that said the typical commercial HVAC market systems were leaking 10 percent to 30 percent of the air produced by fans.

The numbers tend to range from $1.50 to $2 per year per cfm. Location and projected life of the building and equipment affect the number as well, but a median cost of $1.75 per cfm per year is reasonable. In checking with the American Society of Heating, Refrigeration and Air-Conditioning Engineers' Standard 90.1 subcommittee, which made the 2010 changes that greatly affect duct construction and leakage class, they used a slightly higher figure in their cost justification of the change.

What do we do with this number, the cost of leaked air? If owners and operators know the cost of operating a system using what, in the past, was typically leaky duct, they would more readily agree with a little more upfront cost to build the system right in the first place. Some of the studies reference industry estimates of as little as 20 cents per building square foot to seal a duct system properly. Awareness of duct leakage costs could form the basis of a retrofit industry where existing "leaky" systems could be sealed for better performance (though it should be noted that the "cost" numbers above depend on "right-sized" equipment as a component of the savings).

Perhaps the best use of the cost-per-cfm is in choosing where to spend money on fixing leaky air systems. Better installation workmanship is considered key in reducing duct system leakage, but how do we know the quality of workmanship without testing? Compliance and commissioning costs can be justified if overall amounts are reduced. However, owners most willing to pay for compliance testing

Article references

The studies and reports cited in this article include:

American National Standards Institute/ASHRAE/Illuminating Engineering Society Standard 90.1-2013: Energy Standard for Buildings Except Low-Rise Residential Buildings.

2012 ASHRAE HVAC Systems and Equipment Handbook, Chapter 19, Duct Construction

2013 ASHRAE Fundamentals Handbook, Chapter 21, Duct Design

2008 California Green Buildings Standards Code, Title 24, Part 11 , California Building Standards Commission

"Building Commissioning: A Golden Opportunity for Reducing Energy Costs and Greenhouse Gas Emissions," Evan Mills, Ph.D., Lawrence Berkeley National Laboratory, report prepared for: California Energy Commission Public Interest Energy Research, July 21, 2009

"Duct Leakage Impacts on VAV System Performance in California Large Commercial Buildings," Craig P. Wray and Nance E. Matson, Environmental Energy Technologies Division, Indoor Environment Department, Lawrence Berkeley National Laboratory, October 2003

"Duct Work Leakage & Leak Testing," R.V. Simha, Air Conditioning and Refrigeration Journal, the Magazine of the Indian Society of Heating, Refrigerating and Air Conditioning Engineers, October-December 2003

"Energy Consumption Characteristics of Commercial Building HVAC Systems Volume III: Energy Savings Potential," Roth, et.al., and TIAX LLC for building technologies program, July 2002

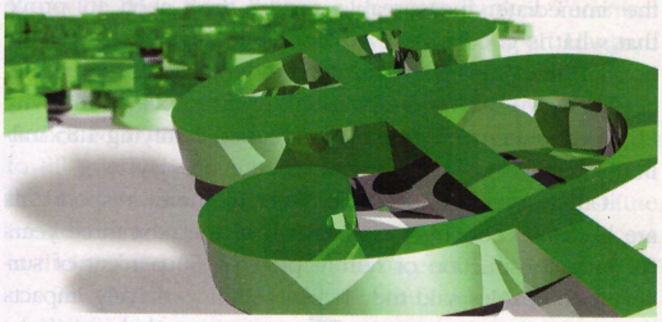
"Energy Impact of Commercial Building Controls and Performance Diagnostics: Market Characterization, Energy Impact of Building Faults and Energy Savings Potential," Roth, et.al., and TIAX LLC for U.S. Department of Energy, November 2005

"Duct System Performance and Energy Losses in Large Commercial Buildings," Xu, et.al., Indoor Environment Department, Lawrence Berkeley National Laboratory

"Tech Brief: Duct Testing," Pacific Gas and Electric Co. (revised October 2007)

"A Roadmap to Successful Duct Air Leakage Testing," Gabriel Alejandre, TBE, article appearing in the TAB Journal of the Associated Air Balance Council, Spring 2011

Efficient Duct System Design: Why Spiral Duct Should Be Your First Choice, Semco LLC, 2015



and commissioning are probably already requiring some level of it and are getting the best performing current systems. Some studies recommend promoting better installation techniques and products that facilitate good duct installations, improving the likelihood of reduced duct leakage.

The 2010 revision to the ASHRAE 90.1 standard was a game-changer for the HVAC construction industry in dictating how it deals with duct leakage. It mandates that all ducts, regardless of pressure class, be sealed to a Class A standard with all transverse connections, longitudinal seams and duct penetrations sealed. Only spiral lock seams are exempted from sealing. Dampers now have to have bearings and bushings. While only ducts outside the building and a representative sample of ducts operating above 3-inch water gauge are required to be leak tested, all ducts are required to be installed in accordance with a Class 4 leakage standard (4 cfm leakage per 100 square feet surface area at 1-inch water gauge).

Virtually all duct specifications reference the latest version of Standard 90.1 and at the time of this writing, virtually all local building codes should incorporate at least the 2010 version of ASHRAE Standard 90.1 in their mandatory requirements.

So now the industry knows it is going to have to start reducing duct system leakage, whether the owners and engineers truly understand the cost or not. That cost per cfm becomes a valuable number along with a second number — how much particular joints and components leak. The 2008 California green buildings standards code and others make it an even more simple numbers game. They require no more than 6 percent duct system leakage

Let's say our previous duct systems have been leaking 30 percent. In the case of our 10,000-cfm HVAC construction duct design we had to provide 13,000 cfm of air at the fan. Now we need to provide a system that requires only 10,600 cfm at the fan while delivering 10,000 cfm at the grilles. Assuming a cost of $1.75 per year per cfm, that additional 2,400 cfm was going to cost the owner $4,200 per year. To meet code, the owner will need to expect some increase in first cost, but with a substantial decrease in operating costs later.

A lot of the HVAC construction duct changes mandated by Standard 90.1 will substantially decrease leakage while making some duct components impractical or in violation. With bearings and bushings required for all dampers, the old peg-type hardware protruding through an open 3/8-inch hole can no longer be used. The cost of sealing old components, such as adjustable elbows, could make them non-competitive against other elbow types such as pressed, pleated or spiral elbows that don't require such sealing.

Spiral duct manufacturers will gladly tell you that since most duct leakage occurs at the joints, the easiest way to cut your leakage in half is to use ducts that are twice as long (10-foot and 20-foot standard spiral duct lengths versus 5-foot standard transverse duct connections rectangular lengths). Major VAV box manufacturers already offer low-leakage models. There is a noticeable cost difference between those and the regular models, but low-end VAV boxes with coils can easily leak in the range of 3.5 percent of fan flow — more than half of your "leakage budget" under codes like California's. Fixing the box leakage is probably more cost-effective than fixing most other parts of the system, and worth the extra money. For the duct, round and flat-oval ducts have commonly been expected to leak half of what comparative rectangular systems leaked.

Recent innovations like gasketed joints may cost a little more, but they are often not as expensive as the labor of sealing the same joint with mastics. All of these items move the industry toward the recommendations of the building energy use studies: "Better installation techniques and products that facilitate good duct installations, improving the likelihood of reduced duct leakage."

The industry can no longer ignore or dismiss duct leakage. Standards and codes have already changed and we will start to see compliance enforced. Smart contractors will seize on the potential benefit. They can and should get paid more for less leaky systems. Contractors that do not meet codes and standards should be penalized for noncompliance. With cost-per-cfm, we have a way of selling the owner on the benefit of systems that save him operating expense in the future.

Better systems come from contractors with better workmanship and knowledge of the benefits of particular system choices. Finally, building owners have started showing a willingness to change design choices and even spend more money in the name of energy efficiency. That could be frightening to those in the ductwork fabrication industry, because many of those emerging technologies are described as ductless.

Bob Reid has 38 years of experience in ductwork fabrication, HVAC sales and design. He is the northeast regional manager for duct and acoustical products with Semco. He is also the company's chief engineer for air distribution systems. He is vice chairman of the ASHRAE 5.2 duct design and construction technical committee, and technical director for the Spiral Duct Manufacturers Association.