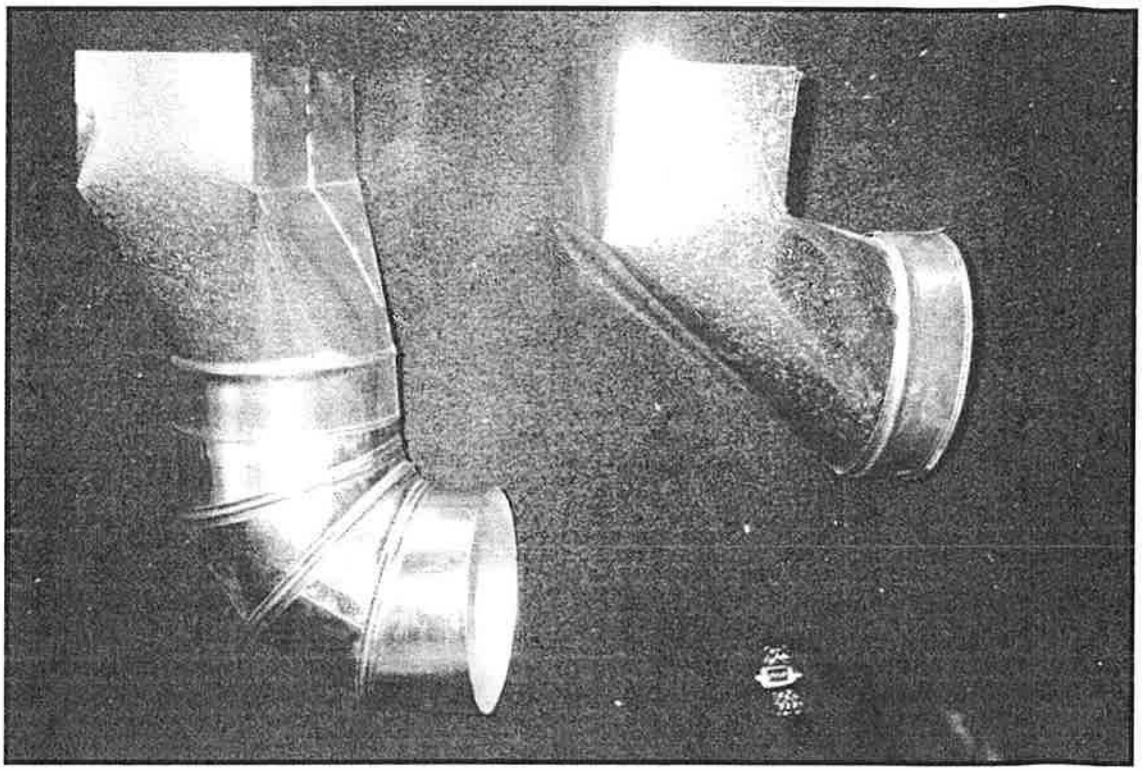
The Energy Penalty of Poor Duct Design

by Bill Hylton



BILL HYLTON

My company, Energy Master Home Incorporated, recently renovated a duct system for an energy association officer who had tried to build a model energy-efficient home for himself and his family. He had taken pains to follow every recommendation of a well-known energy guru. His house was tight and well insulated—although not as well insulated as he thought—and there was little we could do to reduce his heating and cooling loads. But, his ducts were a different story.

The ducts were delivering 1,493 CFM of conditioned air from a two-stage, 5-ton geothermal heat pump (when it was operating at high speed). Since 400 CFM are needed to effectively deliver each ton of cooling capacity, the ducts were essentially strangling the air conditioner. It was delivering only 80% of what it could produce. As it turned out, ACCA *Manual J* load for the house was 4 tons. As the ducts were delivering almost 4 tons of conditioned air, the customer and his family were not unduly uncomfortable.

A home with a poor duct system can't be energy efficient no matter how tight or well-insulated it is.

This situation presents an all-too-common dilemma for the whole-house auditor. Strangely, the inefficiency of the duct system was compensating for oversized equipment. Renovating the duct system could result in a cooling system that was oversized in reality as well as in theory—in this case 25% oversized. It could have other ill effects as well. An improved duct system could leave moisture in a tight house, and it could result in short cycling, which could offset any energy savings.

However, this customer's previous investment in two-stage equipment resolved that dilemma. We did renovate the duct system. We completely reconstructed his return, doubling the triangular chase by making it square and extending it to the ceiling to make room for a second filter grille (see Figure 1), and installing two 18-inch galvanized steel return ducts. On the supply side, we straightened out the kinks in the flex ducts and replaced the

90° mitered boots with straight boots and elbows (which will be usable when the flex duct falls apart and has to be replaced).

After the renovation, the ducts delivered 127% of their previous levels—more than 1,900 CFM—or nearly a full 5 tons of conditioned air. With efficient ducts, the equipment now operates more hours in the low stage and goes to high-stage operation only during high-load hours.

This case makes a strong argument for taking the time and paying what it costs to plan and design duct systems properly. This customer's ducts could have been properly built for less additional cost than the duct renovation cost him. And he would not have had to give up part of a cupboard closet to make room for an enlarged return.

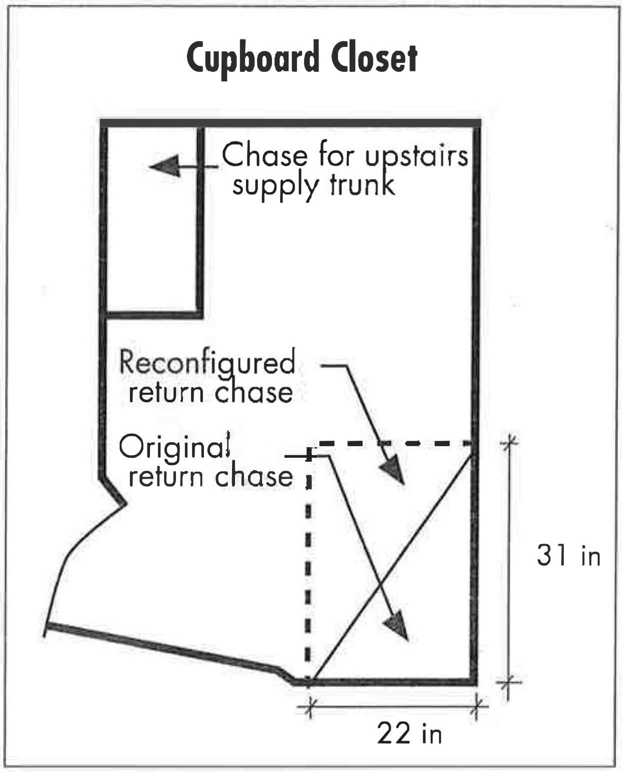


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Figure 1. Originally, the return chase was only high enough to accommodate an 18-inch x 40-inch filter grille. We extended it to the ceiling and installed a second 18-inch x 40-inch grille.

Ignorance of Proper Duct Design Is Not Bliss

A duct system can do no more than deliver all of the conditioned air the equipment can produce—but it can do significantly less. When it does less, the equipment compensates, or tries to compensate, by running for a longer time. The homeowner is then penalized with higher utility bills, and society is penalized by unnecessary use of electricity and fossil fuels.

Table 1. Duct Sizing Chart

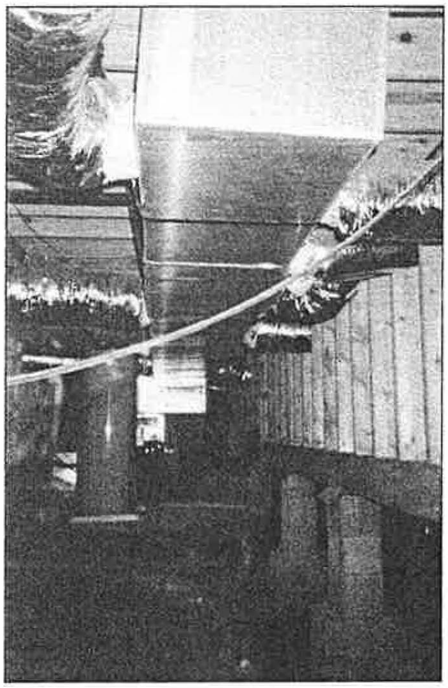
Equipment Size (Tons)	Duct Size (In)
1.5	14
2.0	16
2.5	18
3.0	20
3.5	One 14 and one 16
4.0	Two 16
5.0	Two 18

Even those who take a whole-house approach to energy efficiency too often overlook the significance of duct design. When assessing a home's energy efficiency, the whole-house auditor or energy rater should never assume that the duct system was properly designed. It probably wasn't. Most duct systems are built by the lowest bidder, whose profits decrease with any increase in the quality of the ducts, and whose work by and large remains hidden from the view of all but the most inquisitive. These generalizations will be readily acknowledged by any efficiency-oriented HVAC contractor.

According to research recently reported by the Arkansas Energy Office, the average new home in Arkansas has a cooling system that is 49% oversized when compared to its *Manual J* cooling load. Although I know of no published study to support my conclusion, my experience tells me that this abominable situation results from a distrust of *Manual J* (when it is used at all) and an unwillingness to master *Manual D*. The typical contractor in this area knows from bitter experience that *Manual J*–sized equipment won't work for the customer. If this contractor follows *Manual J* and installs a 4-ton system but, failing to follow *Manual D*, then connects it to a 3-ton duct system, the customer will not be comfortable.

Any given air conditioner comes rated in Btu per hour and, with a matching air handler, can deliver to the duct system the stated Btu in the stated time. If the ducts are properly sized, the stated Btu (less duct heat loss and gain, which should be considered in the load sizing) will be delivered to the conditioned space in the stated time. However, the stated Btu can't be delivered through a soda straw.

The soda straw effect occurs most often in the return system, which usually consists of a single duct and rarely consists of more than two ducts. The sizing of that duct (or ducts) is critical. If the duct is too small, the system will not be able to deliver the stated Btu in the stated time. Building chases that act as part of the return duct system greatly complicate matters. It does little good to install a properly sized return duct over (or under) a chase that is half the duct's size.



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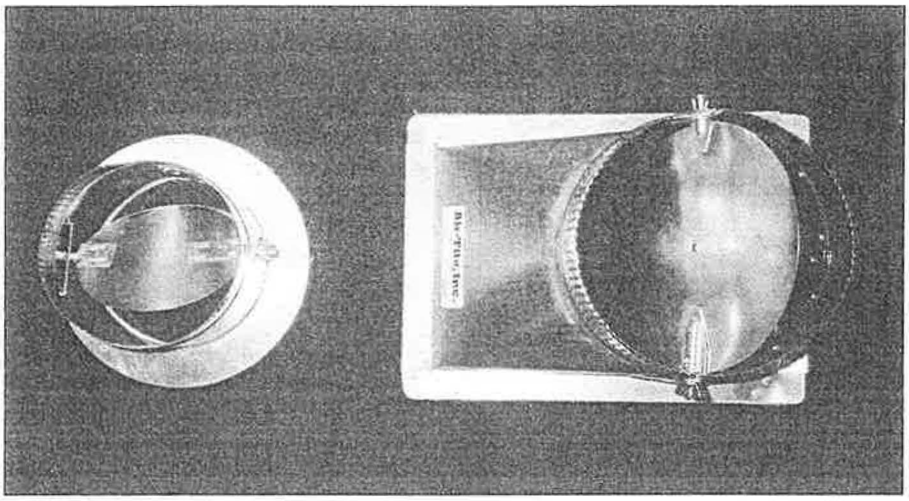
After a duct system renovation, these supply trunks and flex duct from a 5-ton geothermal heat pump were able to deliver a full 5 tons of conditioned air.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Replacing a standard collar take-off *(left)* with a tapered take-off *(right)* can increase duct system efficiency.

All elements of the return should be carefully measured to determine whether they are restricting air flow.

The Fix

The friction rate of a length of duct represents the dissipation rate—in inches of water column per 100 feet of pipe—of the air handlers available static pressure. Static pressure is "still" pressure, the same pressure that compressed air exerts on the walls of its tank (even with the compressor off). The static pressure produced by a compressor would be less on a large tank than on a small tank, and a one-inch round hole in the small tank would blow more air than the same hole in the larger tank.

The criteria for sizing duct returns are fairly simple and straightforward. *Manual D* sizes ducts using the longest-duct friction rate, but there is a qualifier. If that design criterion produces an air velocity in any duct that is higher than the manuals velocity limits, then that duct should be resized using the velocity criteria. On the supply side, an inappropriately high air velocity translates into noisy system operation, uncomfortable blasts of air, and unnecessary energy use to create the high CFM.

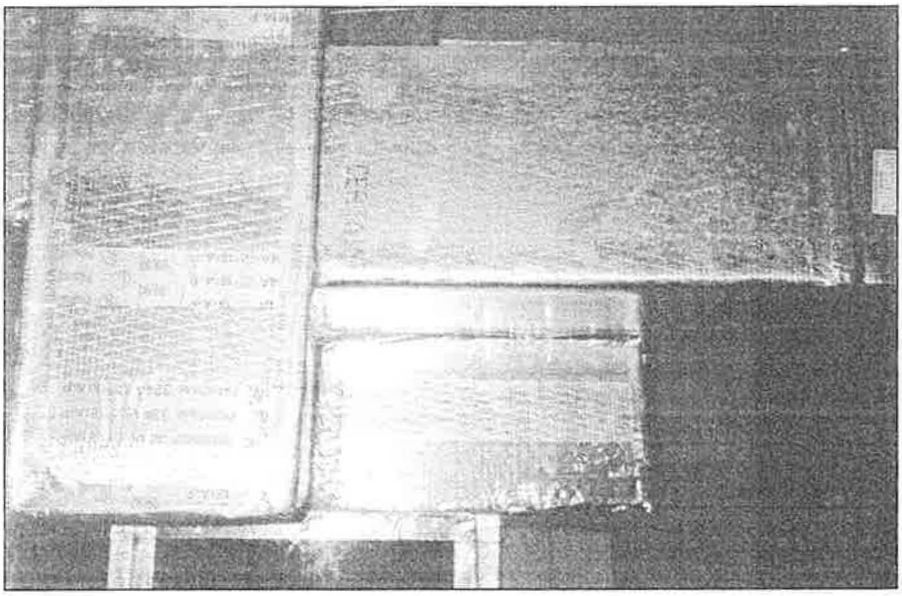
The velocity criteria will always apply to return ducts unless the friction rate is absurdly low—that is, below about .03. The velocity recommended by *Manual D* for return ducts is 600 ft per minute, with a maximum of 700 ft per minute. A few minutes with a duct calculator will produce the results shown in Table 1.

Flex duct should be sized even larger than the sizes listed in Table 1, to compensate for its greater resistance to air flow. Square and rectangular ducts and building chases should be evaluated by using the ACCA duct calculator's "rectangular size for 'round duct' friction rate" window. Don't assume, because a chase has a cross-sectional area equal to a 20-inch round duct, that it has equal air-carrying capacity. The 20-inch round duct has 63 inches of wall surface for every inch of linear distance to create friction for the conditioned air, while the square duct with an equivalent cross-sectional area has 71 inches of wall surface per linear inch. Rectangular shapes have even more wall surface, and that wall surface will increase as the rectangle aspect increases. For instance, a 2-inch x 10-inch rectangle has more wall surface than a 4-inch x 5-inch rectangle.

On the supply side, duct designers and retrofitters should pay close attention to the myriad details associated with the fittings that go into making a duct system. For example, a tapered take-off has an equivalent length 25 ft shorter than a standard collar. A mitered floor boot (where the sheet metal makes a sharp right angle on the inside of the turn) has an equivalent length 40 ft longer than a straight, vertical boot coupled to a three-seam elbow, with a radius to diameter ratio of .75 (where the inside radius of the elbow's curve is three quarters of the diameter of the duct).

Reducing a duct's equivalent length will increase its efficiency and increase the amount of air it can deliver. It will also raise the friction rate, and herein lies an apparent anomaly of the ACCA duct-sizing method. The higher the friction rate, the more air a duct can deliver. Common sense would seem to dictate otherwise—that a duct with a higher friction rate is less effective. A glance at the duct calculator will indeed show that as the friction rate rises, so does the CFM of any given duct. For instance, a 14-inch duct will deliver 700 CFM at .05 friction rate and 1,000 CFM at 0.1 friction rate.

Similarly, if an air handler can produce 0.1 inches of water column pressure on the walls of a 100-ft long, 14-inch duct, it can produce only half that in a 200-ft long, 14-inch duct. The less pressure it exerts, the less air will escape at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Reducing a duct's equivalent length will increase its efficiency and the amount of air it can deliver.

any given opening, including the main opening in the duct—the boot.

So high-friction ducts are shorter ducts that deliver more air, which brings us full circle to the point made above. Use more efficient fittings to make ducts as short as possible. But don't misplace boots to shorten ducts. Place the boots where they will achieve the necessary air circulation in the space being served. For ducts, as for all other air conditioning equipment, bigger isn't better. To guess at duct sizes, no matter how experienced the hired hand doing the guessing, is to do a disservice to all the people who will occupy the house over many decades.

Bill Hylton is sales manager for Energy Master Home Incorporated in Little Rock, Arkansas. E-mail: bill@energymasterhome.com. Tel: (501)821-2570; Fax: (501)821-5349. Energy Master Inc. 2080 Colonel Glenn Road, Little Rock, AK 72210.

For more information:

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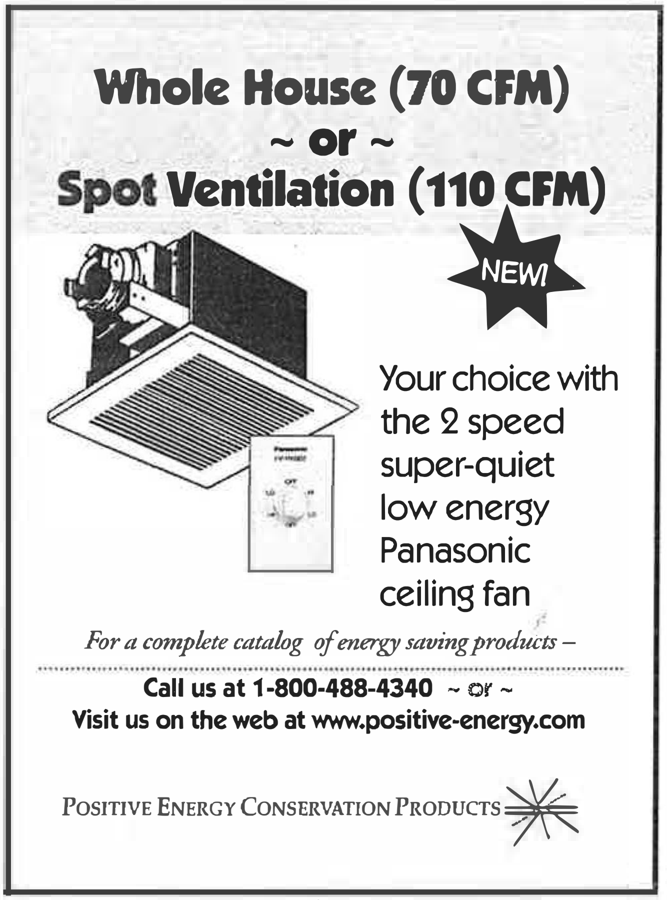

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