Designing & Testing FORCED-AIR SYSTEMS

Most of our company's work consists of installing and maintaining forced-air systems. We also consult with builders and homeowners to test and balance new hvac systems. This balancing work has led us to the conclusion that the vast majority of residential forced-air systems are poorly designed and installed. Even new homes often suffer from oversized equipment, oversized or undersized ducts, and leaky duct connections.

whom are equipped and qualified to do performance testing on forced-air equipment and are ready to provide the results directly to the homeowner.

There are several steps you can take to minimize problems with forced-air systems in your homes: Learn as much as you can about the best practices for system design and equipment start-up, develop an understanding of proper installation techniques, and — perhaps most important — develop a good set of forced-air specs.

Rules of thumb are no substitute for proper equipment sizing, duct design, and airflow balancing

by Bryce Johnson

Most builders leave the design of their forced-air systems to their subcontractor. But it's the builder who is ultimately responsible for the performance of the forced-air equipment. If the equipment has been oversized or was never properly commissioned at start-up, liability for any mechanical problems falls on the builder's shoulders. One additional factor in builder liability is the increasing role of home inspectors, many of

Equipment Sizing

Improper sizing of equipment and ducts occurs when contractors ignore the fundamentals: load calculations and duct design. When it comes to sizing furnaces and air conditioners, bigger is not better. When builders use rules of thumb to estimate costs, some hvac subs are tempted to oversize a system — especially if the sub is paid so many dollars per ton of cooling. Sometimes an oversized furnace, air conditioner, or air handler is installed to mask problems with poor duct design. Oversized equipment is expensive to buy, expensive to run, and subject to premature wear from short cycling.

To size equipment accurately, a contractor needs to perform an accurate load calculation, according to the Air Conditioning Contractors of America (ACCA) *Manual J — Residential Load Calculation*. *Manual J* calculations will provide a design airflow for each room of a house, measured in cfm. Knowing each room's design airflow is essential, because these numbers allow the performance of the installed system to be assessed.

Sizing the Ducts

Proper duct sizing is essential for today's energy-efficient furnaces and air conditioners. To reduce electrical usage, blower motors no longer include extra capacity, but are instead designed to be just large enough to meet government-mandated efficiency standards. These smaller motors are less able to overcome inefficiencies in duct design and installation. Similarly, undersized ducts force a variable-speed blower motor to operate at higher speeds. A variable-speed motor can contribute to energy savings only when the ducts are properly sized.

The problem of leaky ducts has gotten a lot of attention lately, and rightly so. But duct sizing is even more important than duct sealing (see Figure 1, next page). If ducts are incorrectly sized, overall airflow will be unbalanced, and some rooms may get less airflow than required, even if the ducts are perfectly sealed. Although a Duct Blaster test will tell you whether your duct system is leaky or tight, it will not tell you whether your duct system was properly designed. To ensure that ducts are sized right, insist that your hvac contractor size the ducts according to the ACCA *Manual D — Residential Duct Systems*.

Keeping down the noise. Ducts can be too big as well as too small. When oversized ducts provide too much air to a register, the result is excessive noise. Using *Manual D* assures you that the face velocity of the moving air at registers and grilles will be low enough to avoid noise complaints. Moreover, low air velocities enhance the effectiveness of filters, improving indoor air quality.

Figure 1. Because the interior of flex duct is corrugated, it offers more resistance to airflow than smooth-walled duct. This added resistance needs to be taken into account when a duct system is designed.

Figure 2. Crimps in flex duct not only restrict airflow but may also attract a red flag from a code official.

Flex Duct Installation

Pinched, sagging, and loopy flex duct is all too common (Figure 2). Poorly installed flex duct is not only inefficient, it may also be a code violation. Two important provisions for the installation of flex duct are found in the 1997 *Uniform Mechanical Code*, Appendix A, Standard 6-3, Part B — Flexible Ducts, Section 6.307 — Suitable Installation:

- "Install duct fully extended; do not install in the compressed state or use excess lengths" (Section 6.307.2.1).
- "Flexible duct shall be supported at manufacturer's recommended intervals, but at no greater distance than 4 feet. Maximum permissible sag is $^1/_2$ inch per foot of spacing between supports" (Section 6.309.1).

Equipment Commissioning

Every hvac system needs to be commissioned on start-up. Unless your specifications include commissioning requirements, you won't have any idea whether the installed system meets the design requirements.

One of the most important steps in commissioning a forced-air system is measuring the airflow at each supply register and return grille (Figure 3).

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Figure 3. An airflow hood (left) measures the airflow at a supply register or return grille in cfm. If the register is in a difficult-to-access location, a funnel-like device, TSI's Air Flow Horn (above), can be used in conjunction with a hot-wire anemometer to measure airflow.

These airflow measurements are essential to balancing and verifying the performance of the duct system.

Measuring airflow. At most registers and grilles, airflow can be measured using an airflow hood (also called a flow hood or capture hood). An airflow hood ($1,800 to $2,500) fits over a register, captures the air, and measures the airflow in cubic feet per minute by means of an anemometer. We buy our airflow hoods from TSI.

When a register is located where use of an airflow hood is impossible — for example, in a toe kick — then a handheld hot-wire anemometer can be used to measure airflow. A hot-wire anemometer ($500 to $1,800) is a measuring tool with a probe designed to be inserted in a hole drilled in a duct (Figure 4). It measures air velocity using an electrically heated wire. When moving air cools the wire, the changing resistance of the wire is measured and converted into an air velocity reading in feet per minute.

EXTECH INSTRUMENTS

Figure 4. When an airflow hood is unavailable, or in locations where an airflow hood cannot be used, airflow can be measured with a hot-wire anemometer. Most hot-wire anemometers, like this model 407123 from Extech, can record both air velocity and air temperature.

Airflow measurements are the first step required when performing air balancing. To balance a system, the airflow to each room is adjusted if necessary by the use of dampers located in each branch duct.

Static-pressure test. This test measures whether ductwork is restricted or filters are clogged. To perform a static-pressure test, measurements are taken at two locations: on the return side, between the filter and the equipment (where a typical negative pressure reading is -0.2 inch of water column), and on the supply side, between the outlet of the furnace or air handler and the coil (typically, 0.3 inch of water column). The closer these measurements are to zero, the better the duct system. The greater the deviation from zero, the more resistance there is in the duct system. Most modern high-efficiency systems do not tolerate much resistance in the duct system. The sum of the absolute values of these two readings should not exceed the manufacturer's recommendations — generally, not more than 0.5 inch of water column.

Static pressure can be measured with a simple magnehelic gauge ($50 to $100), or with a more expensive digital manometer ($250 to $750) (Figure 5).

Calculation of Btu performance. Once the airflow at each register and grille has been measured, it's important to measure the temperature and humidity of the supply air and return air. With

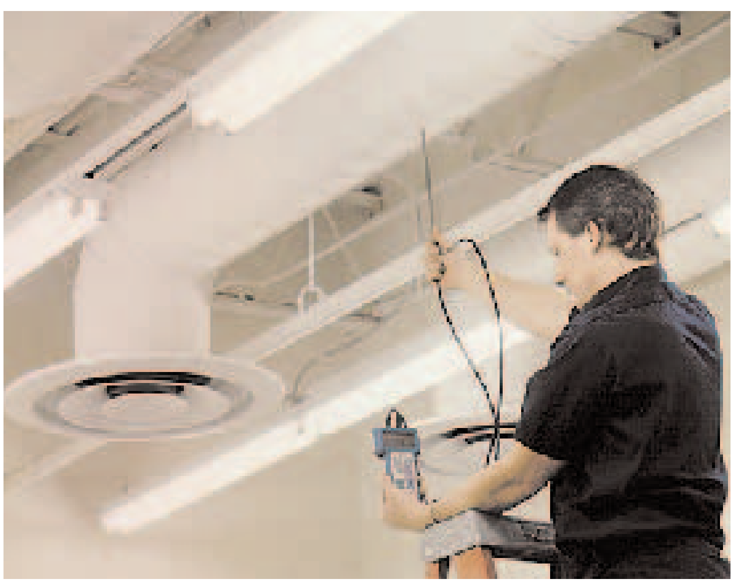

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Figure 5. Static pressure can be measured with a simple magnehelic gauge or with a sophisticated digital manometer like the DP-Calc from TSI, shown here.

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Figure 6. A flue gas analyzer, like the CombuCheck from TSI, measures levels of oxygen and carbon monoxide in the flue gas of a combustion appliance.

Specifications for Forced-Air Systems

1. ACCA *Manual J* load calculations and *Manual D* duct design calculations shall be performed, documented, and implemented.
2. All equipment shall be installed according to manufacturers' recommendations.
3. Metal ducts and flex ducts shall be sealed with UL-181 mastic. Fiberglass ducts shall be sealed with UL-181 heat-sensitive tape.
4. Flex ducts shall be installed according to the 1997 *Uniform Mechanical Code*, Appendix A, Standard 6-3, Part B — Flexible Ducts, Section 6.307 — Suitable Installation.
5. Ducts in unconditioned spaces shall be equipped with insulation equal to R-4.2 or greater.
6. Each branch duct shall be equipped with a balancing damper, located near the takeoff where the branch duct connects to the main trunk.
7. No room containing a combustion appliance shall have a measurable negative pressure while the appliance is operating.
8. Combustion appliances shall produce less than 100 ppm carbon monoxide (CO) measured at the flue prior to mixing with dilution air. Measured oxygen percentage in the flue gas shall be in accordance with the BPI National CO Protocol.
9. A carbon monoxide detector with a warning level no higher than 10 ppm shall be installed near the ceiling at each level of the building, preferably near bedroom areas.
10. The following procedures shall be performed as part of equipment commissioning: air balancing of the distribution system; measurement of air velocity at all supply registers and return grilles; measurement of delivered airflow to each room; a static-pressure test; and a calculation of Btu performance of the system based on measurements of overall airflow, temperature, and humidity.
11. The combined duct and mechanical-equipment leakage shall be no more than 5% of the total design cfm.
12. Delivered air to each room shall be within 10% of the load calculation and design.
13. The face velocity of air at any return-air grille with a filter shall not exceed 300 feet per minute. The face velocity of air at any return-air grille without a filter shall not exceed 500 feet per minute.
14. The face velocity of air at any supply register shall not exceed 600 feet per minute.
15. Static pressures shall not exceed manufacturer's specifications.
16. Btu performance of heating and cooling equipment shall be within 10% of the manufacturer's stated load capacity.
17. Commissioning at equipment start-up shall include adjusting refrigerant charge to within 5% of manufacturer's specifications (superheat and subcooling method).
18. Commissioning at furnace start-up shall include measurement of temperature rise across the heat exchanger and shall meet manufacturer's specifications.
19. Air temperature readings in all rooms shall be within 3°F of the thermostat setting.

this information, it's possible to calculate the overall Btu performance of a system. Poor Btu performance can be an indication of problems with ducts — for example, uninsulated ducts in a hot attic will lower the Btu performance of a cooling system.

Flue gas analysis. To perform this test, a hole is drilled into the flue pipe of the combustion equipment, and the probe of a combustion analyzer is inserted into the flue (Figure 6, previous page). A good combustion analyzer (about $750 to $850) tests for levels of both oxygen and carbon monoxide in the flue gas. The Building Performance Institute (BPI) has established a protocol for flue gas testing. The oxygen level in the flue gas should be between 6% and 9%, and the CO level should be less than 100 ppm measured prior to mixing with dilution air. We have had good success with combustion analyzers from Bacharach.

If you're writing the specs for your hvac sub, it's up to you to decide who should be responsible for start-up testing and balancing. Most small residential builders leave the commissioning to their subs. With a skilled and reputable hvac installer, this can work. There are two alternatives: Either the builder can receive training in air balancing, allowing him to verify the sub's work; or the builder can hire a third-party air-balancing company. Since third-party commissioning adds between $400 and $800 to the cost of mechanical work, this option is rarely chosen for residential work. But third-party commissioning is well worth the investment.

Regardless of who commissions the equipment, a builder should learn as much as possible about balancing and equipment start-up, to help assess the quality of his subcontractor's work.

Specifications

A forced-air system will be only as good as the specifications you provide to your hvac sub. We have developed a set of forced-air specifications that will help a builder achieve a quality system (see "Specifications for Forced-Air Systems" at left). The best hvac contractors routinely conform to these specifications, but in many parts of the country, few residential hvac contractors perform work at this level.

Although some builders and remodelers may feel that these specifications are too stringent for residential work, evidence is increasing that, when it comes to the performance of forced-air systems, most builders set the bar too low. Even if you don't want to integrate all of these specifications into your own contracts, you may be able to work with your sub to raise the bar on hvac performance, using these specs as a springboard for discussion. Fortunately, there are several excellent resources available for hvac contractors looking for more training in balancing and equipment commissioning (see "For More Information" below). Most of the installers at our company have received training and certification from the National Comfort Institute or the Building Performance Institute.

The bottom line is that a well-designed, balanced forced-air system is not hard to achieve, as long as the system is conscientiously designed, installed, and commissioned. The final result will be a comfortable homeowner with no complaints.

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For More Information

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703/575-4477
www.acca.org
Publisher of ACCA Manual D *and* Manual J

Building Performance Institute Inc.
126 State St., 3rd floor
Albany, NY 12207
518/207-4545
Training and certification programs for carbon monoxide analyst and heating specialist

National Comfort Institute
228 Miller Rd.
Avon Lake, OH 44012
440/930-7095
www.nationalinstitute.com
Training and certification for residential and light commercial contractors in air balancing and forced-air diagnostics

Sources for Testing Equipment

Airflow Technical Products Inc.
23 Railroad Ave.
Netcong, NJ 07857
800/247-8887
www.airflow.com
Anemometers, manometers, digital thermometers, ductwork leakage testers

Alnor
7555 North Linder Ave.
Skokie, IL 60077-3223
800/424-7427
www.alnor.com
Airflow hoods and other testing equipment for air-balancing work

Bacharach Inc.
625 Alpha Dr.
Pittsburgh, PA 15238
412/963-2000 or 800/736-4666
www.bacharach-inc.com
Combustion-testing instruments

Davis Instruments
4701 Mount Hope Dr.
Baltimore, MD 21215
800/368-2516
www.davisontheweb.com
Air velocity meters, hot-wire anemometers, temperature and humidity meters

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285 Bear Hill Rd.
Waltham, MA 02451
781/890-7440
www.extech.com
Airflow meters, humidity meters, hot-wire anemometers

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Lake Forest, IL 60045
888/361-8649
www.grainger.com
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