Are Your Houses Too Tight?

by Gary Nelson, Robert Nevitt, and Gary Anderson

In the past, builders rarely thought about ventilation for the houses they built. Standard practice resulted in houses that kept out big, uncomfortable drafts, but that still allowed in plenty of fresh air. Today, builders are routinely producing houses that are much tighter — often without even realizing it (see illustration, next page). It is clear from recent research that builders can no longer rely on air leakage alone to provide enough ventilation.


CAROLYN BATES/ENERGY RATED HOMES OF VERMONT

A blower door sets up quickly and gives a precise reading of a home's level of tightness.

Evidence of lower ventilation rates has been seen in numerous studies done across the U.S. and Canada. A study of 64 randomly selected new houses built in 1984 in Minnesota showed that 80% failed to meet recognized minimum ventilation standards. A more recent and extensive investigation of 472 new homes in the Pacific Northwest found that more than half failed to meet current ventilation guidelines, even after accounting for operation of bath and kitchen exhaust fans.

The effects of lower ventilation rates can frequently be seen in cold climates in the form of excessive condensation on windows and other cold surfaces. Moisture-related problems are made worse by the common use of hot tubs, whirlpools, and saunas. Higher humidity levels create an ideal environment for molds and the less obvious dust mites, which live in carpeting and other fabrics. Both molds and dust mites are suspected as a leading cause of increasingly common respiratory problems and allergies.

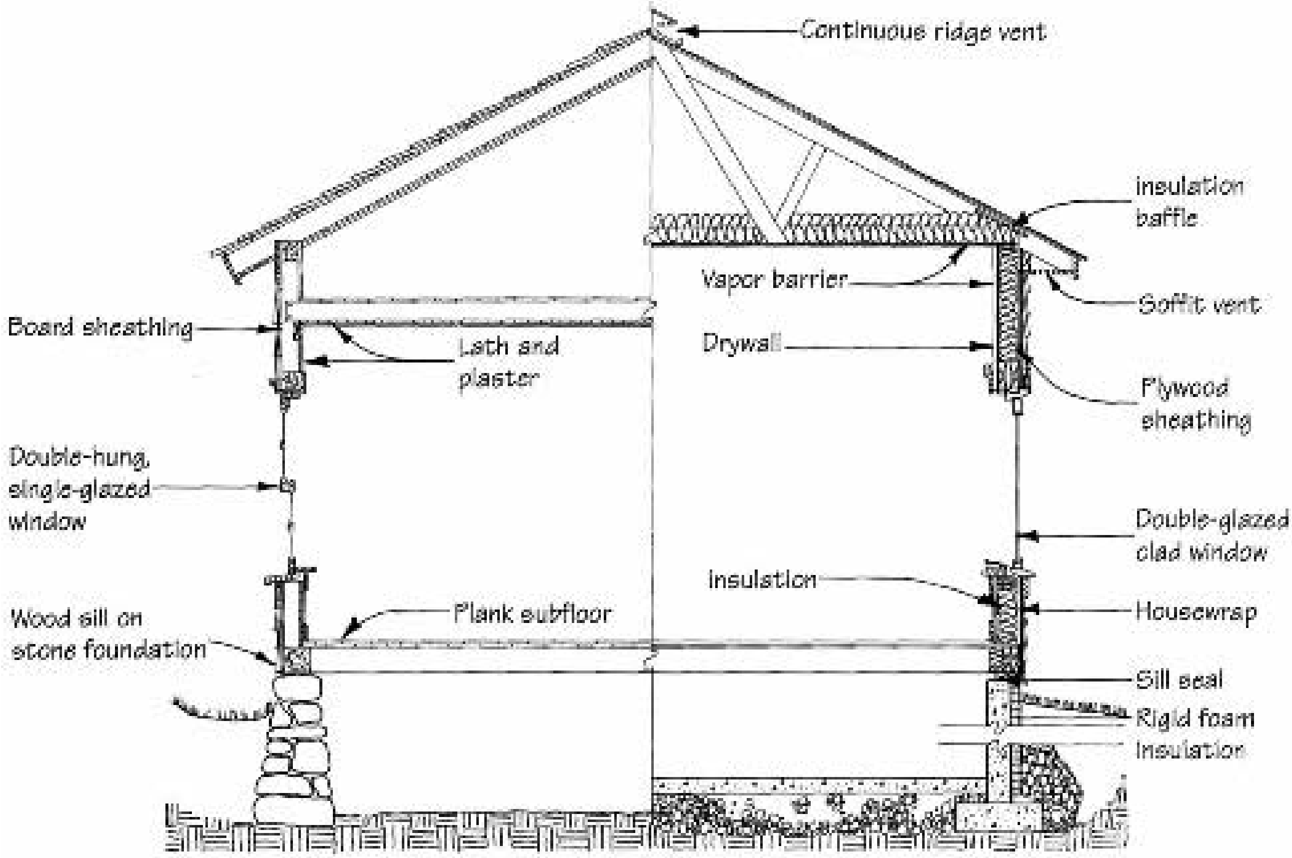
Plugging the leaks in a building's envelope saves energy, but it can also create serious air quality problems

To compound these problems, the rate of natural ventilation — air infiltration from outside — can vary dramatically from one season to another. For example, many new houses have poor ventilation during the spring and fall — the so-called "swing" seasons. During these seasons, heating appliances may still be operating and windows may still be closed, but there is less difference in temperature between inside and outside. That means the "stack effect" forces less cold, fresh air through the holes in the building envelope.

Combustion Safety

The consequences of the problems we have described so far are relatively long term. Although condensation

Airtightness: Old vs. New Construction



The average house built today is much tighter than houses built in the past — in large part because energywise building products like sill seals, housewraps, and weathertight windows have become standard. In some cases, new materials have had an unintentional tightening effect — such as the replacement of board sheathing with plywood.

and mold may show up in the first few months after a house is built, rot and respiratory problems may take years to develop. But there is also a more immediate problem that many builders aren't aware of. As houses are made tighter, it becomes easier for exhaust devices such as range hoods and clothes dryers to create large negative pressures in a house. This can cause spillage and backdrafting of natural-draft combustion appliances like furnaces, water heaters, and fireplaces. Combustion appliances can introduce carbon monoxide and other pollutants, such as carbon dioxide, water vapor, and nitrogen oxides directly into the house. Also, coals from a smoldering fire in an open fireplace produce a lot of carbon monoxide, which can be drawn into the house.

Most builders assume that codes ensure adequate makeup air for safe combustion. We are discovering, however, that many typical new houses — even those with combustion air inlets — still have backdrafting problems when one or more exhaust appliances are operating. In most cases, this just adds some extra moisture and pollutants to the indoor air. But in cases where significant amounts of carbon monoxide spill into the house, the result has been serious illness and even death.

In one recent case in the Twin Cities area, a family of four was hospitalized for near life-threatening carbon monoxide poisoning. The problem was a gas fireplace that was exhausting enough air to cause a natural-draft gas furnace to backdraft. The homeowners had previously complained of headaches, and the gas company had checked the furnace on four occasions — but never while the gas fireplace was operating.

Leaky Ducts Part of the Problem

One factor that can make the problem more difficult to diagnose is that a forced-air heating or cooling system often functions as an exhaust appliance. It would be impossible to cover this subject completely in this article (see "Getting the Most From Mechanical Cooling," 8/93), but the following example will give you a general understanding of this relationship.

Suppose a house has its supply ducts running through attic — common in many areas of the country. The air handler, located inside the house, draws air from the living space (through the return ducts) and blows it back into the house through the supply ducts. If all the ducts and their connections to the air handler and registers are airtight, the house pressure remains balanced (zero) as far as the forced-air system is concerned. But if one of the attic supply ducts becomes disconnected from its register — believe it or not, this is common — then all the air going through that duct is coming from inside the house and escaping outside through the attic. This depressurizes the house, making it harder for a combustion

Testing for Tightness

Despite the growing importance of house airtightness, few builders actually know how tight they are building their houses. Until recently, the building community has tended to rely on subjective estimates of airtightness. Unfortunately, it is impossible to accurately estimate the tightness level of houses by visual inspection alone. And without knowing house airtightness, it is difficult to assess the need for, or to design an effective approach to, ventilation for good indoor air quality.

When discussing these issues, it is important to distinguish between two terms — *airtightness* and *natural ventilation*. The airtightness of a house is related directly to the cumulative size of all the holes and penetrations in the exterior building envelope. The natural ventilation rate is determined by the forces driving air in or out through the leaks in the envelope.

The easiest way to measure house airtightness is with a diagnostic tool called a blower door. This device consists of a powerful, calibrated fan that is temporarily sealed into an exterior doorway of a house. The fan blows air out of the house to create a slight pressure difference between inside and outside. House airtightness is determined by the amount of air flow that it takes to maintain a 50 Pascal (0.2 inches of water column) depressurization of the house. The tighter the house, the less air you need to exhaust in order to maintain the pressure.

A blower door operator adjusts the fan speed to maintain a house depressurization of 50 Pascals.

It takes about 20 minutes to set up a blower door and do a test to document the airtightness of the building envelope. An experienced operator can use the blower door to get other important information about a house, such as an estimate of duct leakage or leakage between the living space and an unconditioned attic, as well as the location of air leaks in the building envelope. This information can help you assess the potential for backdrafting caused by exhaust fans.

In addition to knowing the airtightness of the envelope, it's also good to know the natural ventilation rate, because this is what determines how much indoor pollutants are diluted. While it doesn't measure this directly, the blower door test provides us with a measure of the total hole size in the exterior envelope. And that information can be used along with a simple mathematical model to provide useful estimates of the average annual natural infiltration rate of the house. This ventilation estimate can then be compared with published ventilation guidelines to help determine if additional mechanical ventilation may be needed.

appliance, like a gas water heater, to vent properly.

Leaky ducts in the basement can also cause the basement area to become depressurized, leading to backdrafting. In a study of eight randomly selected new Minnesota houses, we found one house where a continuously operating furnace fan depressurized the basement by 5 Pascals (see "Exhaust Fans and Depressurization: Crunching the Numbers," next page) due to leaks in the return-air ductwork. This was enough to cause complete and continuous backdrafting of the natural-draft gas water heater — adding carbon monoxide to the supply air and creating a serious air quality problem.

How much an air handler changes the house pressure, and whether it pressurizes or depressurizes, depends on many factors, including the relative sizes of supply leaks and return leaks and how much of the leakage is to or from the outside. The important point, however, is that the tighter the building envelope gets, the more imbalances and leaks in the forced-air distribution system are likely to change house pressure.

Recommendations For New Construction

If, like many builders, you've made a conscious effort to tighten the houses you're building, you're probably wondering how to make sure those houses are also well ventilated and safe. There are some concrete steps you can take:

Have a blower door test done on one of your typical houses (see "Testing for Tightness," above). This generally costs between $50 and $100 (probably more for a complete energy audit) and will provide you with valuable information. Your state or local energy office can refer you to someone with the necessary equipment and expertise. After getting an accurate measure of the airtightness of your houses, you can then decide how much and what kind of additional ventilation to provide. The blower door technician should be able to help you make an assessment, or point you to someone who can help.

Avoid natural-draft combustion appliances — they are prone to backdrafting in tight houses. Use sealed-combustion units or units with fan-assisted draft. As long as sealed-combustion appliances are used, an occasional intermittent high negative pressure — such as might be caused by

Exhaust Fans and Depressurization: Crunching the Numbers

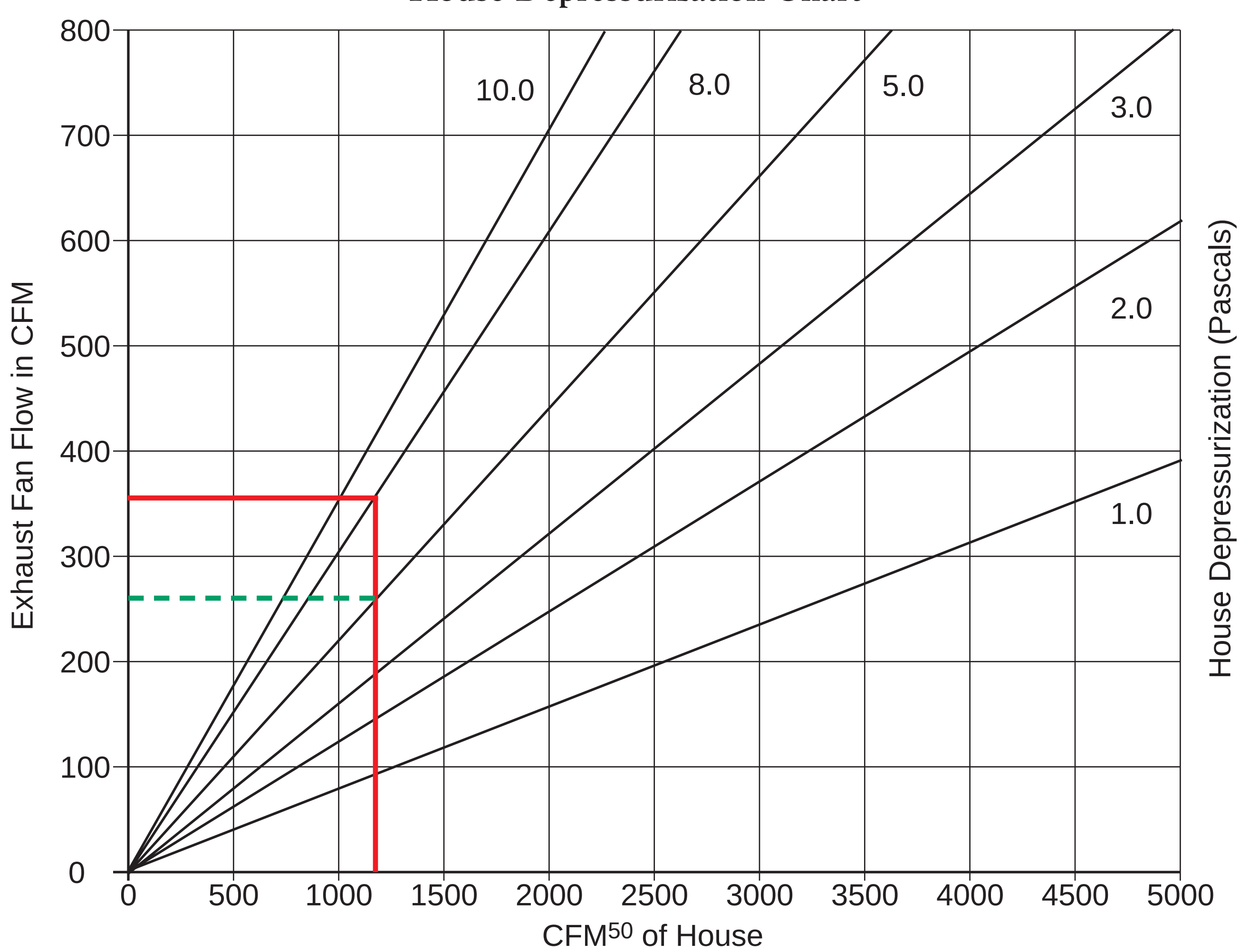
Exhaust fans, such as those found in bathrooms and above kitchen ranges, blow air out of the house. This can have the effect of depressurizing the house relative to the outside. Small bath fans — those in the 50- to 75-cfm range — are turned on for short periods of time and generally cause no problems. However, some range hoods — those with 200-cfm or larger blowers — may cause problems.

The level of negative pressure in a house is usually the main factor that causes backdrafting in natural-draft combustion appliances. Studies done for the Canadian Mortgage and Housing Corporation (CMHC) have found that typical natural-draft furnaces, boilers, and water heaters begin to have venting problems if negative pressures exceed about 5 to 7 Pascals. (A Pascal is a measure of air pressure equal to 0.004 inches of water column as measured by a manometer. A Pascal is equal to about .02 pounds per square feet.) Conventional fireplaces were found to start having problems at only 3 Pascals. In the summer, we see problems with backdrafting on natural-draft appliances at negative pressures of 3 Pascals.

How much negative pressure is caused by exhaust equipment, such as kitchen and bath exhaust fans, depends on the tightness of the envelope and the flow rate of the fan. The graph below is a useful tool for understanding the relationships between house pressure, tightness, and flow rate. The horizontal axis gives house pressure in cfm_{50}, as determined by a blower door (see "Testing for Tightness," previous page). This is the flow rate, in cubic feet per minute, necessary to depressurize the house by a pressure of 50 Pascals, and is a common standard for blower door testing. The vertical axis gives exhaust fan flow in cfm. The diagonal lines represent various levels of house depressurization measured in Pascals.

Suppose we have a well-insulated new house that has been measured with a blower door to have a cfm_{50} value of 1,200 (including leakage through the code-required combustion air inlet). This is about average for a typical new Minnesota house. We want to know if there might be a problem with the natural-draft gas water heater if we install a downdraft

House Depressurization Chart



NEIL MOYER/NATURAL FLORIDA RETROFIT

Crunching the Numbers Continued

kitchen range fan rated at 350 cfm. We draw a vertical line up from 1,200 cfm_{50} and a horizontal line from 350 cfm on the fan flow scale (in red on the chart). The diagonal line closest to the intersection of these two lines gives the depressurization level that would be caused by the operation of the downdraft exhaust fan in this particular house. In this case, we get about 8 Pascals of depressurization — clearly a problem for the operation of the water heater, according to the work by CMHC. If some interior doors are closed, the part of the house that is open to the exhaust fan could be depressurized even more.

We can also calculate the size of the fresh air inlet hole that would be necessary to limit depressurization to, say, 5 Pascals, a level we might feel comfortable with. Starting at the intersection of the 5 Pascal line and the 1,200 cfm_{50} vertical line, draw a horizontal line (in green on the chart) over to the fan flow scale. This tells us that at 5 Pascals of depressurization, this house would leak at about 260 cfm. Therefore, in order to maintain 5 Pascals' depressurization while the exhaust fan is operating, we would have to add 90 cfm of makeup air (350 – 260 = 90).

It turns out that an unrestricted hole between the outside and inside will leak at a rate in cfm approximately equal to the area of the hole in square inches times the square root of the pressure difference (in Pascals). So

$$90 = \text{Area of vent} \times \sqrt{5}$$

$$\text{Area of vent} = 90 \div \sqrt{5} = 40 \text{ sq. in.}$$

This means that you would have to cut a 7-inch-diameter hole in the house to provide makeup air for the exhaust fan — hardly a practical solution. A better solution is to install a draft-assist fan on the water heater.

a clothes dryer or kitchen exhaust fan running — is not usually a problem. Some fan-assisted draft appliances may backdraft under large enough negative pressures. Ask your supplier to provide you with information on appliances that aren't prone to backdraft under the negative pressures you expect to find in the houses you build.

Warn your customers about the dangers of fireplaces, which produce large amounts of carbon monoxide whenever the fire smolders. In tight houses, fireplaces can be deadly. If your clients insist on having one, steer them toward a manufactured unit that has been tested for operation in a negative-pressure environment. (Increasingly, the manufactured fireplace industry is concerned about negative-pressure problems, so a good manufacturer ought to be able to provide you with this information.) Manufactured units have very tight-fitting glass doors and draw combustion air from outside to ensure that they don't spill combustion gases into the house.

Make sure forced-air heating and cooling systems are installed properly, with minimal leakage. You can even have the ductwork pressure-tested for leakage at installation, probably by the blower door contractor.

Provide exhaust fans in all kitchens and baths to take care of moisture and odor problems. We recently installed a humidistat-controlled 100-cfm exhaust fan in a room with a large whirlpool that was having major condensation problems; the fan immediately cured the problem. In another case, a client came to us complaining of lingering musty odors in her home. She had also been suffering asthma symptoms. After we installed a small continuously operating fan to the master bath, the symptoms and the musty smells disappeared — suggesting excess moisture and mold were the culprits.

Try to minimize other indoor pollution sources, such as carpet outgassing or formaldehyde from wood paneling and particleboard products. Unfortunately, common minimum ventilation standards (such as the .35 air changes per hour set by ASHRAE) do not account for such sources of indoor air pollution. Likewise, if there is a large moisture source in a house (such as improper site drainage of rainwater runoff), you will very likely still have a moisture problem despite meeting a minimum ventilation guideline.

The best advice we can give is to build tight houses, and install some form of mechanical ventilation. This is the only way to assure adequate fresh air in mild weather without excessively ventilating in extreme weather conditions. Mechanical ventilation does not have to be complex or expensive — something as simple as a continuously operating 50-cfm bathroom fan, such as the Panasonic FV-05VQ (Panasonic, 1 Panasonic Way, 4A-4, Secaucus, NJ 07094; 201/348-7231), can be enough. In other cases in cold climates, an air-to-air heat exchanger might be justified; in houses with electric heat, we might recommend an exhaust air heat pump. (See "Simple Ventilation for Tight Houses," 5/91, and "Heat-Recovery Ventilators," 3/94.)

Most experts agree that continuously operating, low-level ventilation that requires little occupant attention is best. Studies indicate that homeowners often turn off or permanently disable mechanical ventilation for a variety of reasons, so you may need to consider strategies that minimize the ability of homeowners to turn them off. One of the biggest reasons that mechanical ventilation gets shut off is the noise, but with expert installation this shouldn't be a problem. One of the reasons we like the Panasonic fan is that it's rated at .5 sones — you can hardly hear it when it's on, making it ideal for continuous use. With larger systems, there are several installation strategies that minimize noise, such as remote-mounting the fan and using insulated ductwork. The bottom line is that if homeowners can't hear the ventilation system running, it has the best chance of getting used. ■

Gary Nelson and Gary Anderson founded The Energy Conservatory (TEC) in 1982. TEC is a Minneapolis-based building science research and consulting firm, and a manufacturer of blower doors and other diagnostic tools. Robert Nevitt joined The Energy Conservatory in 1990, bringing experience in single-family and multi-family energy conservation programs .