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INDOOR AIR QUALITY

Building Tightness Guidelines: When Is a House Too Tight?

by George Tsongas

When it comes to weatherization, what's good in Arkansas may be bad in Maine. New guidelines will help blower door users tailor air tightness levels to the house and its setting—preserving air quality and energy savings.

After more than a decade of training and field experience, low-income weatherization crews are substantially increasing the air tightness of homes. That's positive from an energy-use point of view, but in many cases it's causing over-tightening, which can lead to indoor air quality problems. Blower doors are increasingly used to measure air tightness. They depressurize a house and measure air flow through it when the pressure between the inside and the outdoor air is set at a difference of 50 Pascals (a metric unit of pressure). The flow through the fan typically is measured in cfm (cubic feet per minute) and is usually referred to as "cfm_{50}." Yet serious questions plague blower door users, such as "How tight is too tight?" and "What factors affect the answer?" "Is there a difference if two elderly people live in a house or if eight people live there?" "What difference does house size have?" "What if smokers live there?" Crews want answers and specific guidelines!

New Basis for Tightness Guidelines

Building tightness limits (BTLs) have been developed in some states. BTLs are guidelines based on estimates of the minimum air exchange rate of a building necessary to provide enough fresh air to maintain satisfactory health of the occupants and durability of the structure. They are increasingly important to the Department of Energy's Weatherization Assistance Program.[1] Utilities also are struggling to develop such guidelines.

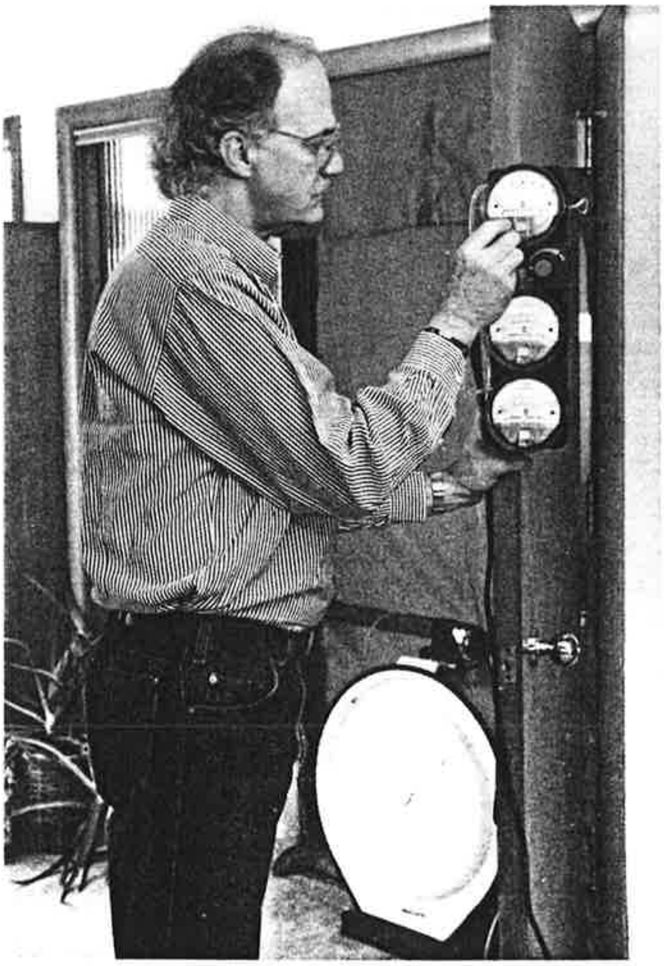
BTLs usually specify a building's minimum air leakage rate—cfm_{50}min—for comparison with the measured value of cfm_{50}. A few years ago, based on the recommendations of 15 cfm of outdoor air per person in a building set out in ASHRAE (American Society of Heating, Refrigerating, and Air Conditioning Engineers) Standard 62-1989, Minnesota and Wisconsin adopted cfm_{50}min values of 1,200 and 1,500, respectively. These single values were never intended for use by other states, yet they have been adopted because using a single number is simple. They were adopted for conditions in Minnesota and Wisconsin—conditions which are not likely to be the same elsewhere.

Blower doors measure a building's tightness (essentially its leakage area), and the natural infiltration rate of a house is estimated from that value based on a number of parameters. A single BTL does not incorporate factors like climate, a building's wind exposure, building size, or the number of occupants. Air exchange rates can vary widely depending on such factors.

In response to the need for BTLs that factor in such variables, tables have been developed by this author for each of the four climate zones in the United States based on the work of Max Sherman of the Lawrence Berkeley Laboratory (see "Infiltration: Just ACH_{50} Divided by 20?" *HE*, July/Aug. '86). The tables (see p. 21) account for the number of occupants, the number of stories of the building, and its wind shielding characteristics. The factor in the Sherman method which accounts for the type of leaks (large or small) is not included because even highly trained professionals have difficulty identifying them.

These tables assume that the only concern is with providing adequate fresh air for occupants, that there is little or no mechanical ventilation, and that there are no unusual air pollutant generation rates. They also assume that the issues of combustion safety and makeup air for exhaust fans and combustion appliances will be dealt with separately. The tables include a U.S. map, divided into four climate zones. Weatherization personnel can use the map to find their particular zone and then select the appropriate table with the correct cfm_{50}min values. The BTL tables ease the tension between saving energy and preserving indoor air quality. Using them is straightforward.

George Tsongas is a professor of Mechanical Engineering at Portland State University in Oregon, and the head of George Tsongas & Associates. He regularly presents training workshops on blower doors and indoor air quality issues in weatherization.



Brent Schauer

Blower doors, such as the one that the author is installing, are an important tool in estimating building air infiltration rates before and after energy conservation measures. But how far can the air infiltration rates fall before indoor air quality problems arise?

The Number of Occupants

If the number of occupants is not known, a rule of thumb for determining it is to double the number of bedrooms. However, a minimum of five people in a residence is assumed to account for potential changes in occupancy after weatherization. This assures that if additional people move into a house after weatherization, there's ample fresh air. If more than eight occupants live in a residence, add to the eight occupant cfm_{50}min value for each additional resident an amount determined by multiplying 15 cfm by the LBL correlation factor N in the tables.

The Stack Effect

Warm air exfiltrates out of the top of the building as a result of the stack effect much like a hot air balloon rises. The tables account for the stack effect as expressed through the number of stories of the building. The taller the building, the greater the stack effect. Confusion in selecting the appropriate number comes when deciding how to deal with basements. It helps to remember that the number of stories refers to the average height of the volume of heated air in the house that has stack effect-induced air leakage. Since there is little infiltration except through the top portion of basements, generally they should *not* be included in the number of stories.

There are exceptions. A partial daylight basement exposed on one side but not on the opposite side might be counted as a half story. A split-level house with half of the lower level being bedroom space and the other half unheated garage space might have the lower level counted as a half story. A heated attic room of, say, 600 ft^2 might be counted as a half a story if the main living space below was 1,200 ft^2.

Precautions

There are situations where no tightening should be performed or where it should at least be put off until certain tests or measures are undertaken, particularly if the house has an indoor air quality problem that can not be remedied or the house has an unvented space heater that can not be replaced—for example an oven that is used as the main space heater in the house. Products of combustion, including carbon monoxide and oxides of nitrogen as well as water vapor, are emitted directly into a living space by such space heaters. They already can be extremely hazardous. Air tightening can make them even more dangerous.

One of the most important considerations should be combustion safety. Two aspects impact air sealing. The first is the possible existence of elevated levels of carbon monoxide (CO) in the indoor air from combustion appliances such as furnaces, water heaters, stoves or ovens, and even gas clothes dryers. The CO can get into the ambient air by direct venting of the combustion products, including CO, or by indirect leakage through a defective furnace heat exchanger, or by backdrafting or spillage. Testing for CO in the ambient air and in the undiluted flues or vents of all combustion appliances is essential.[2]

- If any combustion appliances exist, no air tightening should be undertaken until the undiluted flue gases are monitored for CO and found to be less than 50 parts per million (PPM). If levels above 50 PPM are found, no air tightening should proceed until the combustion appliance is fixed and the CO level is below 50 PPM.
- If flame change is noted in the furnace when the furnace fan comes on, the heat exchanger may be cracked and introduce undesirable combustion products into the living space. No air tightening should be undertaken until the problem is fixed.

Any device that exhausts air from a tight house (exhaust fans, clothes dryers, furnace fans, furnace and water heater vents, fireplaces) can compete with the normal venting of combustion products from combustion appliances. This can lead to backdrafting and spillage (see "Backdrafting Causes and Cures" *HE*, May/June '91, p. 30). In tight houses, exhaust devices can cause so much depressurization inside the house that the normal chimney or flue flow of combustion products from furnaces and water heaters reverses. This can cause minor moisture damage or even death. Tightening a house can create this situation or increase it where it already exists.

- If any combustion appliances exist, backdraft/spillage and draft testing should be performed before and after

Building Tightness Limits ($cfm_{50}min$)

Using the BTL Tables: An Example

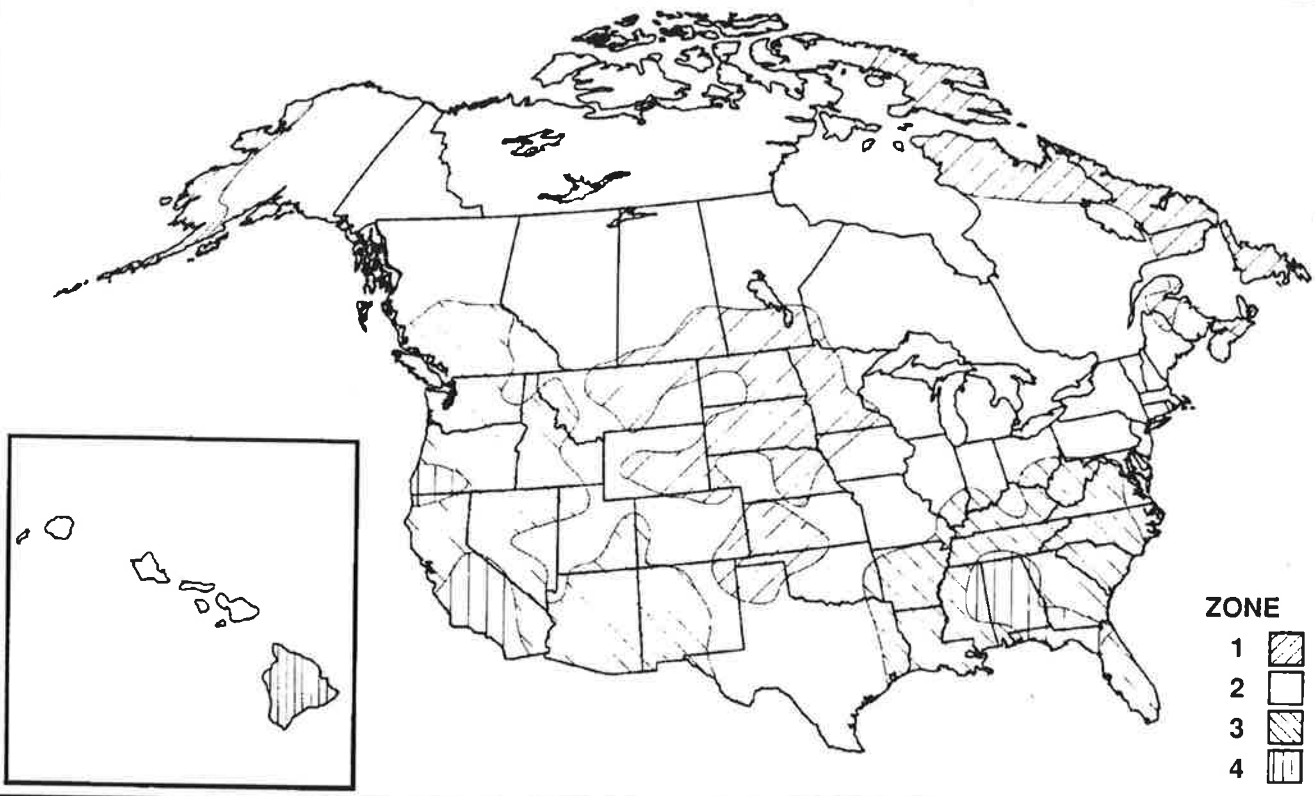
Consider a single story house with an unheated basement and four occupants in Rochester, N.Y. With the map, it is determined that the house is in Zone 2; From the table for that zone, the number of stories is "1," wind exposure is "normal," and the number of occupants is in the "five or less" category. The resultant Building Tightness Limit value is 1,390.

Values for cfm_{50} can be converted to ACH_{50} values (air changes per hour at a 50 Pascals (Pa) pressure difference across the house envelope) by multiplying cfm_{50} by 60 and dividing by the heated house volume. In our sample home, if the measured cfm_{50} value was 2,000 and the house volume was 10,000 ft^3, then the ACH_{50} value would be:

$$2{,}000 \times 60/10{,}000 = 12.$$

The tabulated values of the Lawrence Berkeley Laboratory (LBL) correlation factor N can then be used to estimate the natural infiltration rate ACHnat by dividing the ACH_{50} by N. In the example, the tabulated value of N is found to be 18.5, and the resultant ACHnat value is:

$$12/18.5 = 0.65.$$



NOTES:

Max ft²

Persons	Total cfm (15 cfm × Persons)	Max. ft²
5	75	1,610
6	90	1,930
7	105	2,250
8	120	2,570

- If house area exceeds Max ft², do *not* use tabulated values. Calculate:

$$cfm_{50}min = 0.35 \times (\text{Volume}) \times \frac{N}{60}.$$

$$\text{ACHnat} = \frac{cfm_{50} \times 60}{\text{Volume} \times N}$$

- For each occupant greater than 8, add 15N.
- Consider adding another occupant or two for each person who smokes.
- Regardless of the above limits, air sealing shall not be undertaken if the house has an indoor air quality problem that has not been fixed or can not be remedied.

Wind Shielding Factors

Well Shielded	Urban areas with high buildings or sheltered areas. Buildings surrounded by trees, bermed earth, or higher terrain.
Normal	Buildings in a residential neighborhood or subdivision setting, with yard space between buildings. 80–90% of houses fall in this category.
Exposed	Buildings in an open setting with few buildings or trees around. Buildings on top of a high hill or ocean front, exposed to winds.

Building Tightness Limits ($cfm_{50}min$)

	Number of stories		1	1.5	2	3
ZONE 1	Five occupants	Well shielded	1,395	1,255	1,115	975
		Normal	1,165	1,045	930	815
		Exposed	1,045	940	835	730
	Six occupants	Well shielded	1,675	1,505	1,340	1,170
		Normal	1,395	1,255	1,115	975
		Exposed	1,255	1,130	1,005	880
	Seven occupants	Well shielded	1,955	1,760	1,560	1,365
		Normal	1,630	1,465	1,300	1,140
		Exposed	1,465	1,320	1,170	1,025
	Eight occupants	Well shielded	2,230	2,010	1,785	1,560
		Normal	1,860	1,675	1,490	1,300
		Exposed	1,675	1,505	1,340	1,170
	LBL correlation factor (N)	Well shielded	18.6	16.7	14.9	13.0
		Normal	15.5	14.0	12.4	10.9
		Exposed	14.0	12.6	11.2	9.8
ZONE 2	Five occupants	Well shielded	1,665	1,500	1,330	1,165
		Normal	1,390	1,250	1,110	970
		Exposed	1,250	1,125	1,000	875
	Six occupants	Well shielded	2,000	1,800	1,600	1,400
		Normal	1,665	1,500	1,330	1,165
		Exposed	1,500	1,350	1,200	1,050
	Seven occupants	Well shielded	2,230	2,100	1,865	1,630
		Normal	1,945	1,750	1,555	1,360
		Exposed	1,750	1,575	1,400	1,225
	Eight occupants	Well shielded	2,665	2,400	2,130	1,865
		Normal	2,220	2,000	1,775	1,555
		Exposed	2,000	1,800	1,600	1,400
	LBL correlation factor (N)	Well shielded	22.2	20.0	17.8	15.5
		Normal	18.5	16.7	14.8	13.0
		Exposed	16.7	15.0	13.3	11.7
ZONE 3	Five occupants	Well shielded	1,935	1,740	1,550	1,355
		Normal	1,615	1,450	1,290	1,130
		Exposed	1,450	1,305	1,160	1,015
	Six occupants	Well shielded	2,320	2,090	1,860	1,625
		Normal	1,935	1,740	1,550	1,355
		Exposed	1,740	1,565	1,395	1,220
	Seven occupants	Well shielded	2,710	2,440	2,165	1,895
		Normal	2,260	2,030	1,805	1,580
		Exposed	2,030	1,830	1,625	1,420
	Eight occupants	Well shielded	3,095	2,785	2,475	2,165
		Normal	2,580	2,320	2,065	1,805
		Exposed	2,320	2,090	1,860	1,625
	LBL correlation factor (N)	Well shielded	25.8	23.2	20.6	18.1
		Normal	21.5	19.4	17.2	15.1
		Exposed	19.4	17.4	15.5	13.5
ZONE 4	Five occupants	Well shielded	2,205	1,985	1,765	1,545
		Normal	1,840	1,655	1,470	1,285
		Exposed	1,655	1,490	1,325	1,160
	Six occupants	Well shielded	2,645	2,380	2,115	1,850
		Normal	2,205	1,985	1,765	1,545
		Exposed	1,985	1,785	1,590	1,390
	Seven occupants	Well shielded	3,085	2,780	2,470	2,160
		Normal	2,575	2,315	2,060	1,800
		Exposed	2,315	2,085	1,850	1,620
	Eight occupants	Well shielded	3,530	3,175	2,820	2,470
		Normal	2,940	2,645	2,350	2,060
		Exposed	2,645	2,380	2,115	1,850
	LBL correlation factor (N)	Well shielded	29.4	26.5	23.5	20.6
		Normal	24.5	22.1	19.6	17.2
		Exposed	22.1	19.8	17.6	15.4

any air sealing is undertaken. If spillage, backdrafting, or insufficient draft exists, no air sealing should be undertaken until the problem is remedied.[2]

Observations Concerning Tabulated Values

The wide variation (730–3,530) indicates that a single value is not appropriate. Barring extenuating circumstances, no house in the United States should be tightened below 730 cfm_{50}. For homes with BTL values below 1,200, tightening to the limit reduces air leakage, yielding greater energy savings. On the other hand, there are numerous conditions where cfm_{50}min values exceed 1,200, especially in Zone 4. Thus many agencies using a single value may likely be over tightening and exacerbating indoor air quality problems.

There are clear trends in the tables. There's an increase in cfm_{50}min values with increasing climate zone number, which correlates with less severe weather. In milder climates there is less natural infiltration, and thus larger cfm_{50}min values are necessary to maintain satisfactory indoor air quality. Houses with more stories have greater natural infiltration, and hence lower cfm_{50}min values are allowed. Finally, increasing the building's wind exposure decreases the cfm_{50}min values. An exposed house has a greater natural infiltration rate than a shielded house. Therefore it can be tighter.

Adjusting the Values—or Not

In some cases, it may be necessary to adjust the BTL values to account for factors such as large buildings, smokers, and heating and ventilation system types.

Building Size

If the heated area of a house exceeds the maximum noted in the tables, the table values of cfm_{50}min should not be used. That is because the tabulated values, based on 15 cfm per person, are lower than the values based on a minimum natural air change rate for a building of 0.35 ACH. ASHRAE Standard 62-1989 specifies that the larger of the two values should be used.

For such "large" buildings the appropriate cfm_{50}min values need to be calculated using the equation:

$$cfm_{50}min = 0.35 \times (\text{House Volume}) \times N/60.$$

The factor N is the LBL correlation factor shown in the tables. For example, suppose a one story house in New York (Zone 2) with normal exposure (average N = 18.5) and four occupants has a total living space of 2,500 ft^2 and 8 ft ceilings. The calculated value of $cfm_{50}min = 0.35 \times (2{,}500 \times 8) \times 18.5/60 = 2{,}160$. That's higher than the tabulated value of 1,390 cfm_{50}min and *should be used.*

Smokers

When there are smokers, additional air exchange may be needed. The 15 cfm per person of fresh outdoor air recommended by ASHRAE Standard 62-1989 accounts for smoking. A safe approach is to add the equivalent of one or two persons for each smoker.

Combustion Air

Some suggest that cfm_{50}min values should be adjusted upward to reflect the air needs of natural gas or propane appliances. Another common approach is to simply install combustion air inlets in all houses being weatherized, with no adjustments to BTL values. Unfortunately, neither of these approaches adequately addresses the complicated interactions between house, airtightness, and combustion safety.

What Affects Air Tightness The Most?

- **A broken window and a leaky or no fireplace damper are obvious leaks.**
- **Blowing insulation into walls usually increases tightness substantially.**
- **Duct leaks—especially in mobile homes—are often significant.**
- **Attic bypasses typically constitute a major fraction of the house's leakage area.**
- **Houses are often tight enough after blowing insulation into walls and sealing ducts and bypasses, without any caulking or weather-stripping.**

Dedicated combustion air is often thought to prevent the appliance from being air starved and/or to provide pressure relief in the combustion appliance room to prevent backdrafting or spillage. In fact, the air requirements of a combustion appliance are fairly small and typically are met easily with basement or house air. An exception would be if the appliance is located in a small, airtight room.

With respect to pressure relief, combustion room depressurization is frequently found, even after code-approved combustion air inlets are installed. This is because passive combustion air inlets do not provide sufficient air flow to relieve negative pressure caused by large or numerous exhaust appliances or forced air distribution system imbalances. Furthermore, under certain wind conditions, a combustion air inlet may actually increase combustion room depressurization.

So what do we do to address pressure-induced combustion safety problems? Most importantly, comprehensive combustion safety testing, including worst case depressurization tests, must be performed on all houses with natural draft combustion appliances. This should be done after air tightening and pressure balancing of forced air distribution systems. If testing reveals a potential pressure-induced spillage or backdrafting problem, installation of combustion air is warranted. If the addition of combustion air does not relieve the problem, additional measures will be necessary.

Stoves and Fireplaces

There is no need to adjust the BTL value for a home with an airtight wood stove or fireplace insert. They typically require only about 10–15 cfm. Air leakage in even the tightest home will provide considerably more than that. However fireplaces require more combustion air, often 200–400 cfm. Such large exhaust flows can cause considerable depressurization, especially in tight houses, and subsequent backdrafting of furnaces, boilers, or water heaters.

At a minimum, depressurization in the combustion appliance area(s) should be measured with a fire in the fireplace. A depressurization of 3 Pascals or more can lead to backdrafting. This kind of testing is difficult and seldom done. Yet serious backdrafting can lead to sickness and even death. One option is not to tighten homes with fireplaces. Another is to replace a natural draft furnace, boiler, or water heater with a new induced draft or power-vented model, the ultimate solution for all backdrafting problems. Or a power venter kit, or a high-flow, fan-assisted combustion air inlet system can be installed. If one of those approaches is taken, there is no need to alter the BTL value because the value is based on providing fresh air for occupants rather than for combustion appliances. Cracking a window when the fireplace is in use may or may not help, depending on wind speed and direction.

Forced Air Heating Systems

The tables do not differentiate between types of space heating systems, such as ducted versus non-ducted. A house with a forced air system will tend to have higher pressure differentials between the inside and outside air and therefore higher leakage. Tests on new homes in the Pacific Northwest indicate that the average natural infiltration rate for ducted homes is significantly higher than for non ducted homes. Thus, in principle, BTLs should be lower for houses with forced air systems. Deciding how much lower is difficult, especially for older, low-income housing.

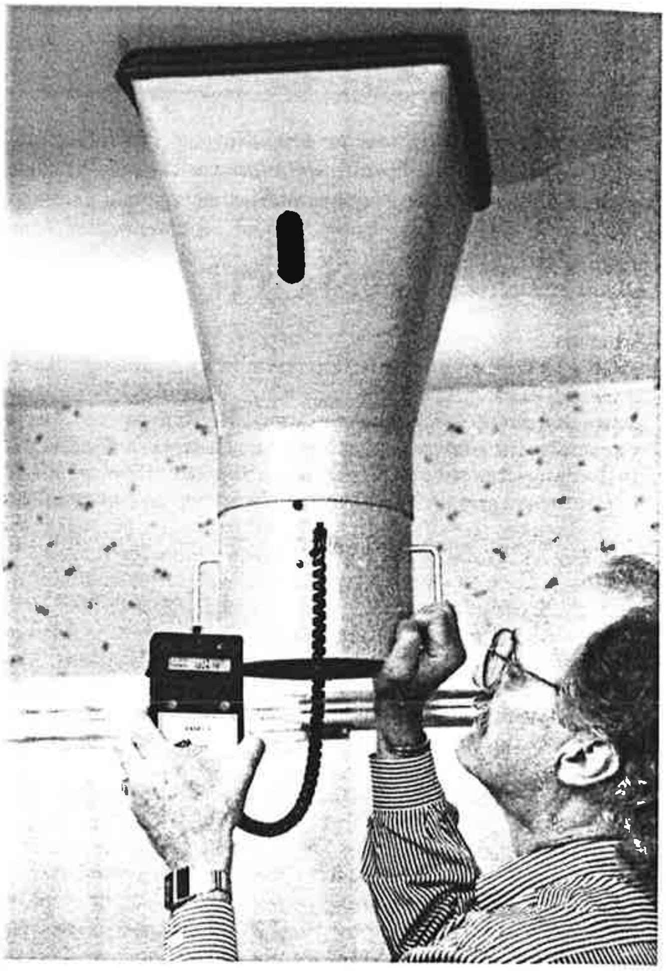
The best policy, however, is to reduce the pressure differentials caused by closed interior doors and duct leaks. Once these are fixed, there's no need to modify the BTL values. Since most indoor air quality problems occur during mild weather when the heating system runs the least, there may not be a need to modify the BTL values anyway.

Attic Moisture Problems

It may be necessary to seal attic bypasses, and so air tighten, even in cases where the tightening will reduce the house's measured cfm_{50} value below the BTL. Solving a serious attic moisture problem may create an indoor moisture problem or other indoor air quality problem since the air sealing will likely raise the humidity. One option is to over-tighten and install mechanical ventilation.

Bathroom and Kitchen Exhaust Fans

No changes should be made in the BTL values based on whether a bathroom or kitchen fan exists and is used. They help control moisture, but generally do not affect the overall ventilation rate. They are not always used, and do not run very long. There are no clear guidelines for whether a bathroom exhaust fan (or general ventilation) should be installed if none exists and the house is over tightened. The best approach is to carefully inspect for an indoor air pollution problem. If one is found, a fan may be warranted. Portable dehumidifiers can also provide good results.



Brent Schauer

The flow hood, used here on an exhaust fan, is another useful air measurement tool. Used in bathrooms and kitchens, flow hood measurements can provide some idea of air flow rates and ventilation inside a building.

Use Common Sense

Since the tables do not indicate whether any or all of the air sealing is cost effective, before and during air tightening, cost effectiveness should be determined.[3] Furthermore, if a house is already close to the BTL, it makes little sense to spend lots of time looking for large leaks. There's also no point in caulking small cracks in a leaky building when the budget may not allow for fixing all of the bigger holes. It's best to go after the big leaks first.

The BTL guidelines are a reasonable and relatively easy way to help avoid indoor air quality problems when weatherizing existing homes. Keep in mind, though, they *do not* guarantee satisfactory air quality, especially from large pollutant sources. An alternative approach is to tighten the building as much as economically possible—often well below the tightness limits presented here—and then install a controlled mechanical ventilation system. A lack of practical experience and relatively high costs limit this option at present. Dehumidification may also be required, especially in small dwellings with a large number of occupants during mild weather.

The author would like to thank the Montana Department of Social and Rehabilitation Services for supporting the initial development of these building tightness guidelines. Special thanks

go to Dave Legg of MassSave for providing the first BTL tables used in Massachusetts. Finally, the author is indebted to Gary Nelson of The Energy Conservatory in Minneapolis who years ago developed the first BTL tables and helped with the initial development of these guidelines for Montana, and whose consultation and advice has been invaluable. ■

Endnotes

1. DOE's 1992 grant guidance document in its Health and Safety section (IV. Policy, Program Guidance, and Regulatory Changes) states that grantees must have in their programs procedures to determine the minimum number of air changes that will occur in dwellings following weatherization. Support offices are asked to encourage grantees to include in the state plans information that describes their target level for minimum air change rates and how subgrantees will test to determine that level.
2. An invaluable, detailed, step-by-step procedure for all necessary combustion safety tests is provided in the October 1992 *Minneapolis Blower Door Manual*, available from The Energy Conservatory, 5158 Bloomington Ave. S., Minneapolis, MN 55417. Tel: (612)827-1117; Fax: (612)827-1051. Another good source of information on this subject is the *Chimney Safety Tests Users' Manual*, 2nd ed., prepared for Canada Mortgage and Housing Corp. by Scanada-Sheltair Consortium Inc., 1988. It is available free from C.M.H.C., Publications Section, Montreal Rd., Ottawa, ONT K1A 0P7. Tel: (613)748-2367.
3. Methods for determining whether a particular air sealing weatherization action is cost-effective are presented in the *Minneapolis Blower Door Manual*. (Also, see "Blower Door Guidelines for Cost-Effective Air Sealing," *HE*, Mar/Apr '90, p. 34.)