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Blower Door Guidelines for Cost-Effective Air Sealing

by Jeff Schlegel

Caulking and weatherstripping have long been the unquestioned staple of weatherization programs. But since evaluations have proven that air-sealing is often excessive, a new method has evolved to provide on-site feedback about the safety and cost-effectiveness of each increment of air sealing. It's the latest trend in blower-door use.

Blower doors have become a widely-used diagnostic tool in weatherization. They have been effectively used to measure building leakage rates and to locate leaks. Until recently, however, crews and contractors had to rely solely on guesswork or their own experience to decide when to stop tightening a building. Sometimes this worked, particularly with well-trained, experienced crews. More often it was either wasteful or potentially dangerous, as inexperienced crews with or without blower doors sealed houses too tight.

To remedy this problem, several organizations have begun to develop procedures and guidelines designed to: 1) improve the cost-effectiveness of infiltration reduction in weatherization programs, and 2) ensure proper ventilation in buildings that are weatherized. With the new procedures, retrofitters use a blower door to guide their air-sealing work. The blower door is still used to find leaks and measure the building leakage rate. In addition, measurements from blower door tests are compared to site-specific guidelines to assist the crew or contractor in the field and provide feedback on the effectiveness of their work. These guidelines and recommended practices answer three basic questions often asked by field personnel:

- When should I stop air sealing because it is not worth my effort (not cost-effective)?
- When should I stop air sealing because the building is tight enough?
- Which leaks should I seal and why?

We at Wisconsin Energy Conservation Corporation (WECC) have calculated guidelines now being practiced in Wisconsin, Pennsylvania, and New York. This article will explain how we derived them and how they can be adapted to various climates.

Why Guidelines?

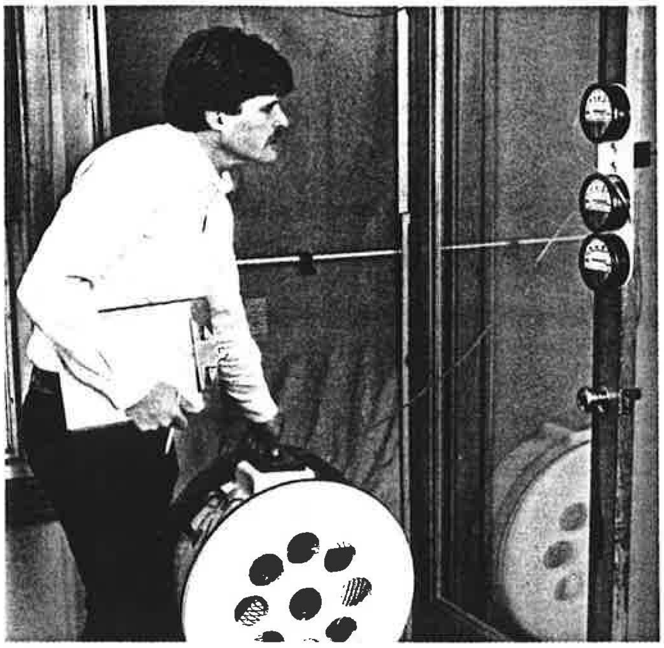
Several studies have demonstrated the increased cost-effectiveness of blower-door-guided air sealing and have recommended that blower doors be incorporated in weatherization programs. Early experimentation with blower doors indicated that they could be used effectively by crews to locate leaks. However, there were still problems with most crews and contractors; many of the problems were the same ones the field personnel had before they started using blower doors. The problems included:

- Spending too much money on buildings that were already tight;
- Making some buildings too tight;
- Sealing relatively unimportant leakage areas while missing major, high volume leaks; and
- Not targeting their efforts and expenditures to those buildings and leakage areas where they could attain cost-effective reductions in leakage rate.

Old habits were hard to break. While additional training helped in some cases, standardized procedures were obviously necessary to guide the crews on every building in the field. WECC developed these procedures and guidelines to provide the essential site-specific feedback.

Diagnostic procedures to address health and safety issues such as indoor air quality, ventilation, and backdrafting of heating systems have been incorporated in the infiltration reduction procedures. The integration of infiltration reduction—and concern for indoor air quality—in one set of procedures implemented by one crew ensures the complete, thorough, and safe treatment of a building while increasing the crews' understanding of these issues.

Jeff Schlegel is director of Research and Development for Wisconsin Energy Conservation Corporation, a non-profit energy services company.



The Energy Conservatory

Gary Anderson of the Energy Conservatory adjusts the blower door to take a reading at cfm$_{50}$, to check whether the next increment of air sealing will be cost-effective.

Wisconsin's Weatherization Assistance Program is using the procedures and guidelines developed by WECC statewide. The procedures are also used by several utilities in Pennsylvania and New York, and by the Pennsylvania Weatherization Assistance Program. Similar guidelines have been developed and implemented in Minnesota. Other states and utilities are also implementing guidelines to improve the cost-effectiveness of their programs as well.

The procedures consist of two building-specific guidelines, which use the leakage rate measurement obtained from the blower door test, combined with recommended air sealing practices and health and safety diagnostics.

The Guidelines

The two guidelines used in the infiltration procedures are:

- Cost-Effectiveness Guideline: Cost-effective leakage rate reduction per person-hour (or per $100 spent)
- Minimum Ventilation Guideline: Minimum leakage rate necessary to ensure proper ventilation

The cfm$_{50}$ reading from the blower door test, a measurement of the air leakage rate, is used in the guidelines. cfm$_{50}$ represents cubic feet per minute at 50 Pascals (50 Pa) pressure difference between the inside and the outside of the house. cfm$_{50}$ is used in the guidelines rather than ACH$_{50}$ (air changes per hour at 50 Pa) because it is not volume dependent, can be measured easily, and works well with ventilation standards. Using cfm$_{50}$ instead of ACH$_{50}$ is fast becoming standard practice in the Midwest.

Cost-Effectiveness Guideline

The Cost-Effectiveness Guideline tells the crew the minimum reduction in leakage rate that should be attained in order for their work to remain cost-effective. It is used to determine when the crew should stop doing work because it is no longer cost-effective. The guideline can be stated in the following ways:

- cfm$_{50}$ reduction / person-hour in the field
- cfm$_{50}$ reduction / $ 100 expenditure (labor & materials)
- $ expenditure / 100 cfm$_{50}$ reduction

WECC prefers the first option because it provides feedback to the crews in the manner they are most familiar with: how much reduction in cfm$_{50}$ do they need to get for every person-hour they work.

To check on progress the building is periodically tested, and the measured reduction in leakage rate (cfm$_{50}$) is compared to the guideline. If the measured reduction in cfm$_{50}$/person-hour exceeds the guideline, then the work was cost-effective. Blower door tests should be completed periodically (every hour or so) since the Cost-Effectiveness Guideline is used to determine whether the next leak is worth sealing, rather than to determine if the work on average is cost- effective.

To calculate a Cost-Effectiveness Guideline for your area use the equations in the box, "Calculating the Guidelines." As an alternative, Figure 1 can be used to provide a quick estimate of the guideline for buildings that reasonably match these assumptions:

- LBL conversion factor: 18
- Degree day correction factor (C_d) = 0.8 (Equivalent to a reference temperature of 60°F for Madison, Wisc.)

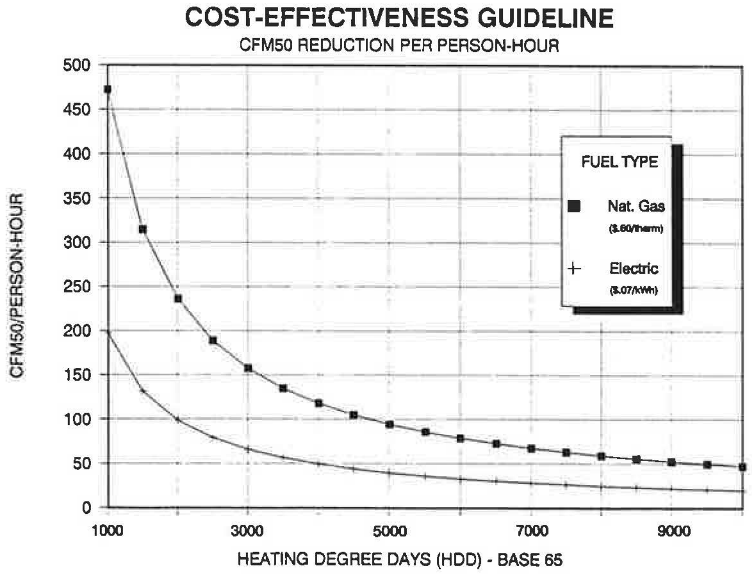


Figure 1. For a quick and dirty estimate of a cost-effectiveness threshold for any climate, follow the verticle axis up from the degree days. The first curve is the level of tightness at which the crew should stop tightening in electrically heated homes; the second is the cost-effectiveness level for gas-heated homes.

- Natural gas fuel cost = \$8.57/million Btu (\$0.60/therm at 70% efficiency)
- Electricity fuel cost = \$20.51/million Btu (\$0.07/kWh at 100% efficiency)
- Benefit cost ratio cutoff (BCR) = 1.2
- Discount rate = 5%
- Energy conservation measure lifetime = 10 years
- Hourly installation rate (labor and materials) = \$30

For example, let's imagine a building with a leakage rate of 3,500 cfm_{50} and apply a Cost-Effectiveness Guideline of 100 cfm_{50}/person-hour. A two-person crew begins work, starting with the leaks that are most worthwhile to address: these can be either the largest leaks or the leaks that are easiest (i.e., least expensive) to treat. In the first hour the crew reduces the cfm_{50} leakage rate from 3,500 to 2,900. This exceeds the guideline (100 cfm_{50} x 2 crew members = 200 cfm_{50}/crew hour) so they continue working. They continue air sealing until they can no longer meet or exceed the guideline. In their last hour they only get 150 cfm reduction, so it is time to stop.

Table 1.

Status	cfm_{50}	cfm_{50} Reduction	Cost-Effectiveness Guideline
Start:	3,500	—	—
After 1 Hour:	2,900	600	200
After 2 Hours:	2,500	400	200
After 3 Hours: (Stop)	2,350	150	200

Note that the average cfm_{50} reduction per person-hour should be significantly larger than the guideline. The guideline is a minimum, not an average. In this example the average is 192 cfm_{50}/person-hour, compared to the guideline of 100 cfm_{50}/person-hour.

Three issues about the use of the Cost-Effectiveness Guideline need to be clarified. First, setup time (including time for the pre-, post-, and interim blower door tests) is not included in the leakage rate reduction time period. The actual time spent finding and treating leaks is the only crew time used when comparing measured cfm_{50} reduction/person-hour to the guideline.

Second, the Cost-Effectiveness Guideline should not be used as an excuse for doing little or no infiltration reduction work. A crew should first check to make sure that they are not overlooking other important leakage areas before leaving a building, leaks that cause uncomfortable drafts (which could cause residents to turn up their thermostats).

Third, it's very important that the crew members start with the leaks that are most cost-effective to address. Ideally a crew should get their best reduction in cfm_{50} during the first hour of work, and the cfm_{50} reduction/person-hour should decline after each additional hour until the guideline is reached. This hierarchy of leakage areas is critical, and should be emphasized during training. After using the guidelines and procedures in the field, the crews become quite skilled at determining which leaks are most cost-effective to address. The constant feedback from comparing measured cfm_{50} reduction to the Cost-Effectiveness Guideline gives them valuable experience that can be used in future buildings; the past experience helps them determine which leakage areas should be treated first. This process increases the speed of the crew's work, making it even more cost-effective, and is one of the key benefits of using this feedback tool.

Minimum Ventilation Guideline

The Minimum Ventilation Guideline (MVG) is used to suggest a point at which the crew should stop tightening a building to ensure that proper ventilation is maintained. The guideline is based on minimum ventilation rates of 15 cfm per person recommended by ASHRAE (ASHRAE Standard 62-1989). The 15 cfm/person is converted to cfm_{50} using the LBL conversion factor. The Minimum Ventilation Guideline usually ranges between 1,500 and 2,500 cfm_{50}, depending on the number of occupants, number of smokers, etc. See box. (For a 15,000 ft³ house, 1,500 cfm_{50} is equivalent to a leakage rate of 6 ACH_{50}. However, it is 15 ACH50 for a 6,000 ft³ mobile home.) This should be increased above the calculated value if there are indoor air quality or moisture problems, such as formaldehyde from construction materials, that require additional ventilation. The crew periodically measures cfm_{50} as work is being performed to ensure that the house

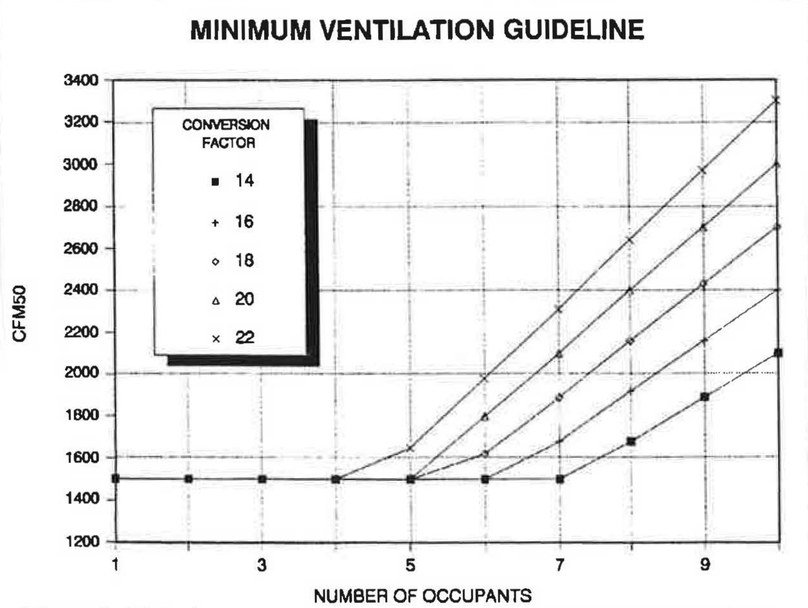


Figure 2. This chart gives a rough idea of the minimum natural ventilation a home should have, given the number of occupants and the climate (as measured by the conversion factor).

Calculating the Guidelines

Cost-Effectiveness Guideline

The key information needed to calculate the Cost-Effectiveness Guideline is an estimate of the first year energy savings (FYS) from the reduction in leakage rate in the building. The FYS calculation estimates the annual energy savings in million Btu provided by each cfm_{50} reduction in air leakage. The FYS per cfm_{50} reduction is calculated using the following equation.

$$FYS = \frac{1\ cfm_{50}}{CF} \times DD_{Tb} \times Cp \times \frac{\frac{60\ min}{hr} \times \frac{24\ hr}{day}}{\frac{10^6\ Btu}{million\ Btu}}$$

Where:

FYS = First year estimated energy savings per cfm_{50} reduction (in million Btu)

CF = LBL conversion factor

DD_{Tb} = Annual heating degree days calculated from a reference temperature (T_b) using a variable-base degree day model.

Cp = Heat capacity of air (0.018 $Btu/ft^3 \times °F$)

The LBL conversion factor (CF) in the above equation is used to convert cfm_{50} to natural cfm and is estimated using the Lawrence Berkeley Laboratory infiltration model (see *HE*, July/Aug '86). Degree days (DDTb) are calculated from a reference temperature base (Tb) of 60°F in Wisconsin. Another option would be to use degree days from a 65°F base and a correction factor (Cd). (See *ASHRAE Handbook of Fundamentals*, 1989, 28.2.)

The FYS value is used to calculate the Cost-Effectiveness Guideline (CEG) in the following equations. Two methods of assessing cost-effectiveness are provided: simple payback and benefit-cost ratio (BCR). WECC prefers the BCR method because it accounts for the lifetime of the infiltration reduction work and the time value of money, if these are known. In both methods the cfm_{50} reduction/person-hour calculation is listed first since this is the most useful number for field personnel.

Benefit-Cost Ratio (Present Value) Method

In these equations a benefit-cost ratio (BCR) cutoff is used to ensure that a minimum BCR is maintained. The State of Wisconsin weatherization program uses a BCR cutoff of 1.2.

$$CEG\ \frac{cfm_{50}}{person\text{-}hour} = \frac{BCR}{PV \times \frac{FYS \times FC}{SE}} \times HIR$$

$$CEG\ \frac{cfm_{50}}{\$100} = 100 \times \frac{BCR}{PV \times \frac{FYS \times FC}{SE}}$$

$$CEG\ \frac{\$}{100\ cfm_{50}} = \frac{\frac{100}{BCR}}{PV \times \frac{FYS \times FC}{SE}}$$

Where:

CEG = Cost-Effectiveness Guideline

BCR = Benefit-cost ratio cutoff

PV = Present value calculation of term in parenthesis (see note below)

FYS = First year energy savings per cfm_{50} reduction (in million Btu)

FC = Fuel cost per million Btu

SE = System efficiency

HIR = Hourly installation rate including labor and materials

Note: Present value (PV) is calculated using the following formula:

$$PV\ of\ FYS\ in\ \$ = \frac{FYS \times FC}{SE} \times \frac{1-(1+i)^{-n}}{i}$$

Where:

i = Discount rate

n = Term (retrofit life)

Editor's note: two troubles with the benefit-cost ratio are: it assumes the price of energy will be constant and energy savings will be the same each year (materials will not degrade until the lifetime is up).

Simple Payback Method

$$CEG\ \frac{cfm_{50}}{person\text{-}hr} = \frac{HIR}{\frac{FYS \times FC}{SE} \times SPP}$$

$$CEG\ \frac{cfm_{50}}{\$100} = \frac{100}{\frac{FYS \times FC}{SE} \times SPP}$$

$$CEG\ \frac{\$}{100\ cfm_{50}} = 100 \times \left[\frac{FYS \times FC}{SE} \times SPP\right]$$

Where:

CEG = Cost-Effectiveness Guideline

HIR = Hourly, per-person installation rate including labor and materials

FYS = First year energy savings per cfm_{50} reduction (in million Btu)

FC = Fuel cost per million Btu

SE = System efficiency

SPP = Simple payback period

Minimum Ventilation Guideline

The following equations are used to calculate the Minimum Ventilation Guideline. In the first equation the minimum ventilation rate is determined by using 15 cfm per occupant, plus another 15 cfm per smoker and converting these values to cfm_{50}.

The second equation uses a minimum number of occupants in the formula to account for any substantial changes in occupancy (i.e., eight people move into a house where one person lived before). This ensures a reasonable minimum ventilation rate if an occupancy change takes place after weatherization. Gary Nelson of the Energy Conservatory and WECC recommend using five occupants as a minimum in the second equation. WECC also recommends that a more conservative minimum ventilation rate of 1,500 cfm_{50} be maintained in all single family homes in Wisconsin (third equation). This is because several weatherization agencies in Wisconsin have observed more moisture problems (resulting in callbacks) in buildings where the leakage rates have been reduced below 1,500 cfm_{50}.

The higher of either the calculated value (first equation) or 1,500 cfm_{50} is used as the Minimum Ventilation Guideline (MVG) in Wisconsin. In Minnesota the higher value from either the first or second equation is used.

MVG = 15 cfm x (# Occupants + # Smokers) x conversion factor

or

MVG = 15 cfm x 5 people x conversion factor

or

MVG = 1,500 cfm_{50}

These guideline calculations can be incorporated in the program for the pocket computers (such as the Sharp PC-1,262) supplied with many blower doors. Calculating the guidelines on the blower door computers will help to minimize on-site calculations, effectively deal with more variables (fuel costs, system efficiencies, degree days, conversion factors, etc.), and enhance accuracy. WECC has modified computer programs for several types of blower doors. These programs are in use in Wisconsin, Pennsylvania, and New York.

remains above the Minimum Ventilation Guideline. If a building starts below the guideline, no air sealing work should be done unless proper ventilation and indoor air quality can be ensured (through source reduction or mechanical ventilation, for example).

The equations in the box, "Guidelines for a Sample Building," are used to calculate the Minimum Ventilation Guideline. Figure 2, based on WECC's calculations, can provide a quick estimate.

Health and Safety Issues

In addition to the Minimum Ventilation Guideline, we take other steps to ensure indoor air quality. We train crews and contractors to diagnose and recommend remedies for moisture and ventilation problems. The crews use diagnostic procedures to assess existing combustion venting and to measure pressure differences resulting from combustion appliances, mechanical ventilation, and forced air distribution systems. Infiltration crews identify, assess, and recommend remedies for poor combustion venting or excessive positive or negative pressurization, which can lead to spillage, backdrafting, or other indoor air quality problems. (For an explanation of these pressure differences, see *HE*, Nov/Dec '89, p.11.)

Recommended Air Sealing Practices

In order to get a cost-effective reduction in air leakage, crews must address the right leakage areas. They should be trained to address major, high volume leaks located in areas of high pressure difference that are quick and easy to seal.

The air sealing work follows five basic rules:

- Seal big leaks (high volume)
- Seal leaks that are inexpensive to fix
- Seal leaks in areas of high pressure difference
- Minimize pressure differences
- Educate the occupants

Much of the air sealing work consists of treating attic bypasses and large foundation leaks. Routine weatherstripping and caulking are discouraged except in situations where they could improve occupant comfort (i.e., reduce a draft on a person's back). This approach, if implemented properly, results in reductions in heat loss due to infiltration, not just reductions in cfm_{50}. It is designed to minimize the difference between predicted savings (reduction in cfm_{50}) and measured savings (reduction in fuel usage).

Field Experience

The use of the guidelines and procedures in Wisconsin's program have had a significant impact. The program encouraged the use of blower doors statewide beginning in 1985. As of January 1, 1989 the use of blower doors and the guidelines were required on all single family buildings. "The guidelines really helped to target our infiltration reduction work," according to Cathy Ghandehari, weatherization program manager for the State of Wisconsin. "Before, crews had difficulty determining when to stop air sealing. The blower door really helped to locate leaks, but we still found people spending lots of time in buildings doing work that probably wasn't cost-effective." WECC observed that even with the blower door, air sealing work was done in some buildings that were tight enough already, indicating the need for a Minimum Ventilation Guideline.

Several studies demonstrate how Wisconsin's program has improved. In 1984, Wisconsin was spending an average of $570 on labor and materials per house for infiltration reduction. A study in 1985 found no significant reduction in the average air leakage rate following the installation of typical air sealing measures (caulking and weatherstripping—no blower door was used). A recent study found that the program is now spending $285 per house for infiltration reduction. This figure includes setup time for the pre-, post-, and interim blower door tests, and often includes gross air sealing measures such as replacing broken panes of glass. The average cfm_{50} reduction was 23%. (Note: Wisconsin has some of the tightest low-income housing stock in the country. The average pre-retrofit leakage rate was 2,890 cfm_{50}.)

"Before using this approach, we had crews spending 1 to 2 days in a building, just doing infiltration work," according to Ghandehari. "Now the crews spend about half a day in the average building. The reduction in infiltration expenditures has helped the program concentrate on other major measures such as wall and attic insulation, and heating system repair and replacement."

Training is very important for the successful implementation of blower doors and guidelines in weatherization programs. Training sessions should be well-planned and should build on previous experiences or knowledge. Field-based training is critical, and using the blower door and guidelines is the best way to learn. A follow-up session in the field within 2 to 6 weeks after the initial training session is also very helpful as it reinforces the early training and positive field experiences. ■

Guidelines for a Sample Building

Below are the guidelines for a sample Wisconsin building with the following parameters:

- Volume: 15,000 ft^3
- Leakage rate: 4,700 cfm_{50}
- LBL conversion factor: 18
- Heating degree days: 7,642 (6,114 DD_{60}—equivalent to using Cd = 0.8)
- Fuel type: natural gas
- Fuel cost: $6/million Btu
- System efficiency: 70%
- Benefit-cost ratio cutoff: 1.2
- Hourly rate (labor & materials): $30/person
- Occupants: 3
- Smokers: 0

Cost-Effectiveness Guideline:

- $\frac{61.8\ cfm_{50}}{\text{person-hour}}$
- $\frac{206.0\ cfm_{50}}{\$100\ \text{expenditure}}$
- $\frac{\$48.54}{100\ cfm_{50}}$

Minimum Ventilation Guideline:

- 1,500 cfm_{50}