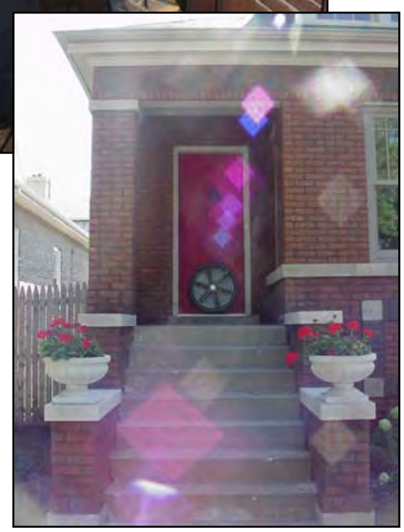
Midwest Weatherization Best Practices Field Guide

Weatherization Works



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We help people enjoy a more comfortable home, a home that costs less to live in, a home that is safer and a home that is healthier. We help people – that is what the Weatherization Assistance Program is all about. Saving people money, improving the environment, saving energy and helping the economy are the results of our efforts.

The Midwest is the center of Weatherization activity in the nation. One-third of the U.S. Department of Energy's program is operated in the eight states that comprise the Midwest Region. These eight states provide some of the highest quality service and innovative approaches available to addressing the energy needs of the low-income community.

Since the 1970's, when the Weatherization Program began, our efforts were often not as effective as they are today. We would put storm doors and windows on most homes, blow some insulation in the attic and caulk any crack we could find. Those early efforts were well meaning, but we always believed we could do better.

Today, the Weatherization crews throughout the Midwest are setting the standard for effective energy efficiency investments in the housing sector. They are also leading the housing sector overall in testing and implementing efficiency measures that are the result of more than 25 years of regional cooperation. Many of the techniques developed by Weatherization programs in our region are now standard practice in all building efficiency work. They are a foundation for affordable housing and building science applications.

This field guide is another step in that evolution. It provides a single source for the best of what we do and how to do it, not only for our eight states, but for others around the country who are striving to implement high quality programs. It is the result of the strong partnerships and cooperation that our eight states share on a regular basis as we work throughout the region.

We applaud all of the men and women of the Weatherization program who not only helped develop this guide, but who spend a good portion of every day striving to provide quality services to our clients, our neighbors and our communities. We encourage you to use the Guide, to apply it to your work and to share it with others who are working to make our homes and communities as energy efficient as possible. Your efforts are improving the lives of millions of Americans and laying a strong foundation for a healthy, energy efficient future.

Peter Dreyfuss
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Midwest Regional Weatherization Project Manager

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The Weatherization Assistance Program (WAP) of today bears little resemblance to the one that began in 1976. Those who have some history in WAP would hardly recognize that early Program from today's systematic approach. The early practioners became skilled at installing storm doors and plastic storm windows while weatherstripping everything that moved and caulking everything that didn't. Weatherization was focused toward saving energy for those who could least afford to pay for it and doing it with the "best available information" at the time.

The focus has remained the same, but the "best available information" has not. Who would have thought that those early weatherization measures would evolve into blower door guided air-sealing, zone pressure diagnostics and dense-packing building cavities, just to mention a few of the many weatherization practices now commonly employed throughout the country. And who would have thought that the mission of saving energy would expand to encompass occupant health and safety and building durability?

The intent of the *Midwest Weatherization Best Practices Field Guide* is to capture the currant "best available information" and transform it into recommended best practices for the midwest weatherization programs. It is a voluntary standard that individual state weatherization programs can use and adopt as their programs continue to evolve to provide better and more effective services to their clientele.

This document was produced under Weatherization *Plus* as part of the "advanced technology capability" effort and represents the combined efforts of the eight states in the region. Representatives from each of the states and the Midwest Regional Office formed a working group to guide and provide input to the document. The standards of all of the states in the region were reviewed (as were state standards from outside the region). Strengths, weakness and "holes" were identified. This information was combined with the thoughts and ideas of the working group members and the authors to determine where weatherization practices currently are and in what direction they should be moving.

This *Best Practices Field Guide* is by no means cast in stone; it is an evolving document, changing as our understanding evolves about the dynamics of building systems and the occupants interaction with those systems. Mold, for example, is merely one example that falls in a long line of issues such as asbestos, knob-and-tube wiring, and lead-based paint that have affected the course of the Weatherization Program. Mold was just a "blip" on the weatherization radar screen when work on this document began in late 2002. What will the next "mold" be for weatherization in the coming years and how will it affect the focus of the Weatherization Assistance Program?

The *Best Practices Field Guide* represents a snap-shot in time. Users of this document are encouraged to submit their comments and ideas to the Midwest Regional Office or to the authors. Just as today's weatherization practioners might get a chuckle if they were to review a “Best Practices Field Guide” produced in 1980, weatherization practioners reviewing this document 25 years from now may also get a chuckle – but it is our hope it will be just a slight one.

“So what’s the Best Practice?”

Acknowledgements

Producing the *Midwest Weatherization Best Practices Field Guide* has been a long and arduous journey, and a journey not to be taken alone. When first approached about developing this document, I knew that Don Michael Jones would be the perfect traveling companion. His technical expertise was nationally recognized and he was a key player in the evolution of the Weatherization Program. Don single-handedly brought many weatherization practioners (some kicking and screaming) into the blower door age of weatherization. But Don’s personality and easy-going teaching ability made this change palpable to even the most suspicious of weatherization staff. Don was a rare individual who knew both the technical side and the practical art of weatherization. Don’s loss was not only a tremendous loss for those who knew him, but for the entire weatherization program as well.

Rick Karg was asked to step-in to help fill the void left by Don. He brought renewed energy to the project at a very difficult time. His background and experience in weatherization proved invaluable. Rick also has that unique gift of transforming difficult technical subjects into easy-to-understand language that was needed in producing this document. Working with Rick has been truly a wonderful and enlightening experience. I’m glad he said “Yes” when asked to work on this project.

John Krigger, Saturn Resource Management, deserves credit for his work in developing weatherization field guides over the past number of years. These field guides particularly those developed for some of the states in the Midwest Region, served as a resource on which this document was able to build.

The project was managed by Eddy Haber with the Office of Energy Assistance at the Illinois Department of Health Care and Family Services. The document was originally scheduled to be completed in March 2004. His patience and understanding through difficult times was remarkable, particularly in dealing with bureaucratic paperwork for contract extensions. He has been the strongest supporter of this document and provided encouragement on almost a weekly basis.

Rob deKieffer with Boulder Design Alliance provided a review of the document from a national perspective. Rob brings a unique, energetic and refreshing approach to weatherization. He asks the right questions that also happen to be the difficult ones. It is that kind of thinking that keeps weatherization true to its spirit.

Finally, I would like to thank all of the members of the Best Practices Working Group. Their comments, insights and support kept things in perspective.

- Paul Knight

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Midwest Weatherization Best Practices Recommendations

111 Blower Door Tests

- State weatherization programs should examine the implications of adopting ASHRAE Standard 62.2-2004, *Ventilation and Acceptable Indoor Air Quality in Low-Rise Residential Buildings,* in place of using Building Tightness Limits (BTL).
- Depressurization Tightness Limits (DTL) should be estimated for homes where BTL or BTLa is used. The greater of the two should be used as the minimum ventilation rate.
- In homes that are tighter than the minimum ventilation rate as determined by BTL, BTLa or DTL, air sealing work should be limited to sealing attic bypasses and where air sealing work is necessary to correct a health and safety condition.

112 Zone Pressure Diagnostics

- Zone pressure diagnostics (ZPD) are not recommended for every home. The use of ZPD is recommended when additional information is needed regarding the relative and absolute leakage of pressure boundaries when the following conditions are found;
    - Indoor air quality concerns (tuck-under garages, crawl spaces or other zones are present that may have an adverse effect on indoor air quality),
    - Moisture problems in attics, and
    - Air leakage remains high after air sealing.
- Both pressure and flow readings should be determined when using ZPD in primary zones.

113 Duct Leakage Tests

- Pressure-pan testing is recommended:
    - On ducts located in unconditioned spaces (attics, behind knee walls, tuck-under garages, for example),
    - When basement return ducts are suspected of creating a hazardous venting condition, or
    - When basement return ducts may be contributing to indoor air quality problems, such as elevated interior moisture levels associated with wet basements.
- Measuring duct leakage to the outside with a Duct Blaster™ fan is recommended when:
    - The ducts are substantially outside the building envelope, and
    - The ducts are accessible and can be repaired.
- Pressure pan tests should always be conducted on mobile home ducts.

114 Duct-Induced Room Pressures

- Provide pressure relief when pressures are + or -3.0 Pa between a room and the main body of the house with the air handler operating.

121 Furnaces and Boilers

- A combustion efficiency test should be performed for an adequate appraisal of the operation and efficiency of the heating system.
- The following tests should also be conducted to help assess existing condition of heating system.
  - CO test,
  - Draft test under worst-case draft conditions,
  - Gas leak test (gas-fired systems),
  - Temperature rise (forced-air furnaces), and
  - Clocking the meter (gas-fired systems).

122 Water Heaters

- The following tests should be conducted to help assess existing condition of water heaters.
  - Draft test under worst-case draft conditions,
  - CO test, and
  - Gas leak test (gas-fired systems).

123 Worst-Case Draft Testing

- A worst-case draft test should be performed near the end of each work day in appropriate dwellings.
- The worst-case draft test should include:
  - Determination of the worst-case condition in the dwelling.
  - Testing each vented combustion appliance for spillage under worst-case conditions.
  - Testing each vented combustion appliance for adequate draft under worst-case conditions.
- Any appliance that fails the worst-case test before or after all weatherization work is completed should be made non-operational until the hazardous condition is corrected.

124 Gas Range Testing

- The following should be completed in dwellings with gas ranges.
  - Inspect the gas range top burners and oven burners for proper maintenance and operation.
  - Measure the range top burners for CO emission levels (as-measured).
  - Measure the oven bake burner for CO emission levels (air-free).
  - Educate the client about gas range use and maintenance.

130 Health & Safety

- Existing smoke alarms should be inspected for proper location and operation and replaced or relocated if necessary.
- Existing CO alarms should be inspected for proper location and operation.

- All homes should received exterior and interior inspections for previous or existing moisture problems. Weatherization staff should understand the mechanics of moisture movement, the impact that excess moisture has on occupant health and building durability and the impact that weatherization may have on solving or creating moisture problems in homes.
- Existing bathroom and kitchen exhaust fan systems should be examined for actual flow rates, vent condition, exterior termination and controls.
- Dryer vents should be examined for proper vent material, exterior termination and connections.
- Recommended weatherization activities must be done within the context of lead-safe work practices.
- It is the State's responsibility to ensure insulation installed around knob-and-tube wiring be in conformance with applicable codes in the jurisdiction where the work is being performed.

211 Air Sealing

- The primary objective of air sealing is to establish an effective air barrier at the thermal boundary of the home.
- The benefits of air sealing must be balanced with maintaining acceptable indoor air quality and ensuring proper draft of combustion appliances.
- Blower door tests should be performed during air sealing activities to help guide those tasks.

212 Attic Insulation

- Attics should be thoroughly inspected for safety and moisture related issues. Such issues should be addressed prior to installing attic insulation.
- Effective R-value of existing attic insulation should be determined taking into account age, settling, gaps and voids and uniformity of coverage.
- Unfinished Attics
    - Blown insulation is recommended for unfinished attics cavities and should be installed to a uniform depth according to manufacturers' specifications for proper coverage.
- Cathedral ceilings should be dense-packed with insulation.
- Finished Attics
    - Collar beams and outer ceiling joists should be insulated as per unfinished attics.
    - Sloped ceiling should be dense-packed with insulation.
    - Knee walls should be insulated to the maximum R-value as allowed by stud cavity depth. A vapor permeable air barrier should be used to enclose the back-side of the knee wall cavity.
- Attic ventilation should be part of an overall strategy for controlling attic air temperatures and should be considered an optional measure.

213 Sidewall Insulation

- Dense-packing sidewalls utilizing the one-hole method and tubes is recommended.

214 Foundation Insulation

- Basements should generally be considered part of the conditioned space of a home.
- Foundation walls of crawl spaces containing mechanicals should generally be considered the thermal boundary.
- Foundation wall insulation should be a minimum R10.
- Floor joist cavity insulation should be the maximum R-value structurally allowable or highest SIR value in cases where the floor above the crawl space is the thermal boundary.
- Properly installed ground covers are recommended for crawl spaces, regardless of the thermal boundary location.
- Crawl space vents should be sealed where the foundation walls form the thermal boundary.
- Band joists should be both air sealed and insulated.

215 Window Measures

- Window measures should be governed by cost effectiveness or the individual home's need for window repair. Window measures to solve minor comfort complaints should be avoided.
- Window measures should be accomplished using lead-safe weatherization practices.
- Replacement windows should be ENERGY STAR® rated.

216 Door Measures

- Door measures should be governed by cost effectiveness. Door related security and durability issues should be addressed within the overall budget context. Door measures to solve minor comfort complaints should be avoided.

221 Clean & Tune - Gas & Oil Fired Furnaces & Boilers

- Heating systems should be cleaned and tuned to ensure that they are operating in a safe and efficient manner.
- Shell retrofits should not be done until health and safety issues, such as gas leaks, high CO readings or venting problems are corrected.
- Comprehensive testing protocols should be adopted to ensure proper operation, venting and combustion air supply for gas- and oil-fired space heating appliances.

222 Heating System Retrofits

- The following heating system retrofits are recommended for the Midwest Region;
  - Automatic setback thermostat,
  - Intermittent ignition device and vent damper,
  - Boiler pipe insulation, and
  - Flame retention head burner.
- Heating system retrofits should be considered based on cost effectiveness, condition and life expectancy of heating system and client being served.

223 Heating System Replacement

- Every effort to repair and retrofit heating appliances should be made prior to replacement. Heating appliances that are non-operational or non-repairable should be replaced.
- Replacement heating systems must be sized according to accepted calculations such as the *Residential Load Calculation* (Manual J) or approved computerized load calculation software. Sizing should account for lower heating loads resulting from insulation and air sealing work. Sizing calculations must be included as a permanent part of the client file.
- Replacement heating appliances should meet the guidelines and efficiency ratings as shown in the table below or be ENERGY STAR® rated unless shown not to be cost-effective or if existing conditions are not appropriate for their installation.

Natural Gas/LP Furnaces	90%, direct vent sealed combustion
Oil Furnaces	83%
Gas and Oil Boilers	85%

- Weatherization work shall not be done in any home with an unvented space heater where client does not permit its removal.

224 Water Heater

- Water heaters should be cleaned and tuned to ensure that they are operating in a safe and efficient manner.
- The following water heater measures are recommended for the Midwest Region;
    - Water heater temperature setting,
    - Tank insulation,
    - Pipe insulation, and
    - Replacement
- Mechanically vented, direct vent and tankless water heaters should be considered as replacement units based on cost-effective and appropriateness of existing conditions.

225 Masonry-Chimney Liners

- A flue may be left unlined if the appliance is not to be replaced and the flue and chimney appear to be in good condition.
- Rebuilding a chimney, lining or relining should be considered for unlined chimneys, when existing liners are in poor condition or if the cross-sectional area of the chimney is oversized for the appliance(s).
- It is recommended flues be properly lined for solid-fuel appliances that are used as a primary or frequent secondary space heating source.

226 Heat Pumps and Air Conditioners

- All air-source heat pumps with electric auxiliary must be served by a control system – thermostat(s) – to minimize the operation of the electric heaters.

- Clients should be informed about routine maintenance and operation of heat pumps and air conditioners.
- When a heat pump requires more than simple maintenance, a professional service technician should be hired to check coil air flow, inspect for refrigerant leaks and charge, inspect and adjust controls, and perform other specialized testing and adjustment.
- Replacement heat pumps and air conditioners should be sized properly and ENERGY STAR® rated.

227 Duct Improvements

- Ducts located in unconditioned areas must be sealed and insulated.
- Duct system airflow should be checked and corrected if necessary in response to client comfort complaints.

230 Baseload

- Fluorescent lamps used for replacement should be ENERGY STAR® rated.
- Low-flow showerheads should be included as part of weatherization services.
- Measuring kWh or referring to http://www.waptac.org/sp.asp?id=68 should be used to determine electrical consumption for refrigerators being considered for replacement.
- Replacement refrigerators should be ENERGY STAR® rated.

240 Health & Safety

- At least one smoke alarm should be installed in each weatherized home.
- Fire extinguishers should be given to each weatherization client if they do not already have one.
- At least one CO alarm should be installed in each weatherized home having combustion appliances, when the home has an attached or tuck-under garage or when assessors believe that there are other health and safety situations related to CO.
- CO alarms should also be installed when weatherization services must be deferred due to unsafe combustion appliances.
- Whole house ventilation should be added to homes that are below the BTL or BTLa ventilation rates.
- Consideration should be given to providing whole house ventilation in all homes according to ASHRAE Standard 62.2-2004, *Ventilation and Acceptable Indoor Air Quality in Low-Rise Residential Buildings*.
- Exhaust fan ducts should be sized according to ASHRAE 62.2-2004.
- Disconnected or improperly vented clothes dryers should be corrected as part of weatherization.
- Missing or damaged gutter systems should be repaired or replaced if causing an indoor moisture problem.
- Weatherization staff should be knowledgeable of mold remediation procedures and outside funding sources available to remediate moldy surfaces in clients' homes.

300 Mobile Homes

- Air sealing should be limited to sealing ductwork and large holes needed to hold insulation in place until all insulation measures have been completed and a blower door test has been conducted.
- Cost effectiveness of insulating floors, sidewalls and roof cavities should be examined by State Weatherization Programs. If cost effective, actions should be taken to increase local agency capacities to include these measures as part of production.
- Replacement windows should be double-glazed.
- Pressure-pan testing should be done in all mobile homes.
- Replacement water heaters should be done with HUD approved units.

400 Final Inspection Tests

- Blower door tests should be done when all weatherization work has been completed to evaluate effectiveness of air sealing work. If this test was not done, it must be completed during the final inspection.
- Homes should be visually inspected for evidence of effective air sealing work. Zone pressure diagnostics may be helpful to evaluate air sealing activities when "hidden" air sealing has occurred (bypass sealing under attic insulation, for example).
- Visual inspection and duct testing should be done during the final inspection to verify work results when duct repair and sealing has been specified.
- If a worst-case draft test was not done after weatherization work was completed, it must be completed during the final inspection.
- If a steady-state combustion efficiency test for gas- and oil-fired appliances was not done and thoroughly documented following completion of heating system work, it must be completed during the final inspection.
- If gas range inspection and testing was not done and thoroughly documented during the weatherization work, it must be inspected and tested during the final inspection.

111 Blower Door Test

Best Practice Recommendations:

- State weatherization programs should examine the implications of adopting ASHRAE Standard 62.2-2004, *Ventilation and Acceptable Indoor Air Quality in Low-Rise Residential Buildings*, in place of using Building Tightness Limits (BTL).
- Depressurization Tightness Limits (DTL) should be estimated for homes where BTL or BTLa is used. The greater of the two should be used as the minimum ventilation rate.
- In homes that are tighter than the minimum ventilation rate as determined by BTL, BTLa or DTL, air sealing work should be limited to sealing attic bypasses and where air sealing work is necessary to correct a health and safety condition.

A blower door measures total leakage rate of a home, indicates the potential for air leakage reduction in a home, provides an estimate of the natural infiltration for a home and assists in finding air leakage locations.

The blower door measures air flow at a pressure difference of 50 Pascals (Pa) between the house and outside, producing a number (CFM_{50}) that is used to compare the leakiness of homes. The blower door also creates pressure differences between rooms in the house and buffer zones like attics and crawl spaces that can give clues about the location and size of a home's air leaks.

Only air sealing work that significantly reduces air leakage or mitigates indoor air quality hazards should be performed. Air sealing should be directed by blower door diagnostics at every opportunity. The primary goals of air sealing are to:

- Reduce heat loss resulting from air leakage,
- Avoid moisture migration into building cavities,
- Save energy by protecting insulation's thermal resistance, and
- Increase thermal comfort.

All weatherization workers should understand how to perform a blower door test properly.

1111 Preparation

A walk-through of the house should be done prior to conducting a blower door test. Items listed in sections 11111 through 11116 should be reviewed prior to conducting a blower door test.

Setting up the blower door for a depressurization test

11111 Depressurization Test

A depressurization test is recommended as it is the standard test in the low-income weatherization program because it is easier to perform than a pressurization test. If there are concerns about doing a depressurization test, perform a pressurization test or gradually depressurize the house to 50 Pa while checking the condition of the suspect areas.

11112 Pressurization Test

A pressurization test should be done, rather than a depressurization test, if one of the following conditions is present in the home:

- Drip-pot heating appliance operating,
- Wood or coal fired heating appliance operating,
- Animal or bird feces is found in the attic that may be a health hazard,
- Interior wall or ceiling finishes might be pulled in or down by a depressurization test,
- An open sump in basement,
- Open sewer line in the home,
- Harmful pollutants could be introduced into the home by the operation of the blower door, or
- Friable asbestos is found in the basement or in another area within the thermal boundaries of the dwelling.

11113 Blower Door Test Cannot Be Done

There may be instances when a depressurization or pressurization test cannot be performed. If so, reasons for not doing a blower door test must be documented and included in the client's file. When blower door testing cannot be performed, air sealing work is limited to:

- Attic bypass and key juncture sealing.
- Glass replacement, and
- Up to one work hour of comfort sealing[1].

11114 Blower Door Set-Up

Follow set-up procedures in blower door manufacturer's instruction manual for depressurization and pressurization tests.

11115 House Set-Up

Preparing the house for a blower door test involves putting the house in its heating or cooling operating condition with all conditioned zones open to the blower door. See Section 11116, "Basements", for guidance as to whether the basement should be considered conditioned space.

- Identify location of the thermal boundaries and house zones that are conditioned.
- Deactivate all vented combustion appliances by turning the thermostat down or the appliance off.

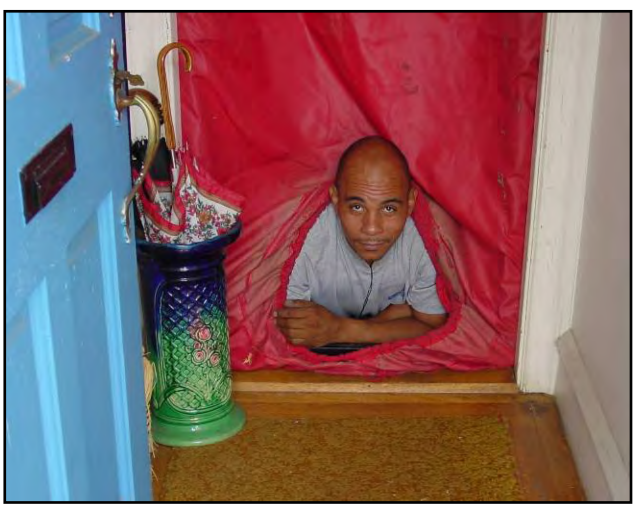
[1] Comfort sealing is air sealing work that targets drafts, directed primarily by the occupant and is limited to 1 labor hour.

- Prevent ashes of wood/coal burning units from entering the living space by closing/sealing doors and dampers or by cleaning out ashes.
- Inspect house for loose or missing hatchways, paneling, ceiling tiles or glazing panes. Secure any items that may become dislocated during the test and seal any missing hatchways.
- Remove one ceiling tile on suspended ceilings to relieve pressure, if necessary.
- Close all primary windows, self-storing storm windows, exterior doors and latch them as they normally would be found during the winter.
- Open interior doors so that all indoor areas within the thermal boundary are connected to the blower door.
- Temporarily seal appropriate intentional fresh air openings (air ducted from the outdoors to the furnace, for example). Do not seal intentional exhaust air openings, such as combustion appliance flues, dryer vents or exhaust fans.
- Ensure children, pets, manometer hoses, and power cords are at a safe distance from fan blades.

11116 Basements

Basements may be used as living space. Furnaces and boilers and their respective distribution systems, water heaters and washers/dryers are often located in the basement. Heat from these items as well as heat from the space above helps condition basements during the winter. Therefore, basements are usually considered conditioned space and basement doors should be open during the blower door test unless of one the following conditions are present (even if the basement door is generally closed during the winter):

- None of the above mentioned appliances are located in the basement,
- It is clear that the occupants do not use the basement on a regular basis; for example, access to the basement is through an exterior door or hatch, or
- Moisture problems in the basement that weatherization work cannot solve.



Has anyone seen my blower?

1112 Existing Leakage Rate

The following procedure is based on The Energy Conservatory's Minneapolis Blower Door, Model 3.

Perform a one-point blower door test at 50 Pa or the highest achievable house pressure if unable to reach 50 Pa. If wind seems to be affecting the test results, take several one-point tests and average the results.

Record existing CFM_{50} leakage rate and determine cost effective air sealing standard (see section 1115, "Air Sealing Guidelines").

11121 Air Density Correction Factors

The CFM_{50} rate can be adjusted for greater accuracy based on differences in air density caused by air temperatures.

Air Density Correction Values
Table 110-1

Outdoor Temp	CFM_{50}
90°F	4360
70°F	4280
20°F	4073
-10°F	3944

The CFM_{50} rate read at the blower door is measuring the air flow from the house out through the blower door (depressurization test). It is generally assumed that this flow rate is equal to that coming into the home through air leaks. However, when the inside and outside temperatures are different, the air flow through the fan is actually different from the air flow back into the building due to differences in air density. In some case, the differences in air flow can be as much as 10%. This may be especially important when climatic conditions have changed between the initial air leakage test taken during the assessment and the air leakage test taken during the final inspection.

Table 110-1 demonstrates the variation in CFM_{50} numbers based on different outdoor air temperatures and an indoor temperature of 70°F.

Refer to tables in the blower door manual for the appropriate correction factors. Note that separate tables are used for depressurization and pressurization tests.

11122 "Can't Reach 50" Multipliers

If the blower door cannot achieve -50 Pa house pressure, re-inspect the home to assure that all windows and doors are closed.

Can't Reach 50 Factors
Table 110-2

House Pressure	CRF
45	1.1
40	1.2
35	1.3
30	1.4
25	1.6
20	1.8
15	2.2
10	2.8

If the blower door still cannot depressurize the house to -50 Pa, get the house pressure to the highest multiple of five (25, 30, 35, 40, or 45 Pa). Multiply the flow rate (CFM) by the "Can't-reach-fifty (CRF)" multiplier listed in Table 110-2.

For example, a house can only be depressurized to -25 Pa. The CFM reading is 4600. Converting to -50 Pa, the house leakage is 7360 CFM_{50} (4600 CFM_{25} x 1.6 = 7360 CFM_{50}).

11123 Fan Rings

The blower door is generally operated with the fan open (no rings). Ring A or ring B may be added to the fan for tight or small dwellings. If the measured fan pressure is less than 25 Pa, install a ring to increase accuracy. Note that this is fan pressure, not house pressure.

For example, a house pressure of -50 Pa has been achieved with the fan open. The fan pressure is 20 Pa. Ring A should be installed since the fan pressure is less than 25 Pa. The manometer must be reset to indicate the presence of ring A. Another indication that a ring may be required is when the fan doesn't sound like it's working very hard with a house pressure of -50 Pa.

11124 Approximate Leakage Area

The CFM_{50} measurement may be converted into square inches of total leakage area to help visualize total leakage area in the home. The simplest way to convert CFM_{50} into an approximate leakage area (ALA) is to divide CFM_{50} by 10. This approximation may be used with the fan open or if rings were used on the fan.

$$ALA = CFM_{50} \div 10$$

11125 Existing Leakage Rate Greater than the Building Tightness Limit (BTL)

The Building Tightness Limit (BTL) is discussed in section 1113. If the existing leakage rate is above the home's BTL, see section 1115, "Air Sealing Guidelines" to determine the extent of cost-effective air sealing work.

11126 Existing Leakage Rate Less than the BTL

If a home's existing leakage rate is below its BTL, air sealing work might still be appropriate. Conductive heat loss measures, heating system work, duct sealing and balancing, along with ventilation assessment and corrective actions should still be accomplished (see section 123, "Worst-Case Draft Test").

Air sealing work should be limited to sealing attic bypasses and circumstances where air sealing work is necessary to correct a health and safety condition. A home may be tightened beyond its BTL if continuously operating mechanical ventilation is provided.

Bathroom and kitchen exhaust fans should be checked for proper operation with an Exhaust Fan Flow Meter®, if possible. If these fans are non-operational or not present, they should be repaired or new fans installed. Exhaust fans vented into attics or crawl spaces should be ducted to the outside.

Don't do this! Four small holes in the fan flow sensor ring must be unobstructed and regularly cleared of dust accumulation

11127 When Air Sealing Should be Deferred

Air sealing should be done in all homes; however, air sealing work should be deferred until the following conditions are corrected.

- Presence of unvented space heaters (whether used for primary or secondary heating),
- Depressurization tightness limit exceeded (see section 1114, "Depressurization Tightness Limits"),
- Measured drafts of combustion appliances do not meet standards under worst-case conditions,
- Carbon monoxide levels exceed suggested action levels,

- Evidence of serious mold issues (an area of mold greater than 10 ft^2), or
- The building CFM_{50} tightness level is lower than the Building Tightness Limit (see section 1113, "Building Tightness Limit") and mechanical ventilation cannot be provided.

11128 Post-Blower Door Test

The following items should be checked prior to leaving the home following a blower door test.

- Inspect all pilot lights of combustion appliances to ensure that blower door testing did not extinguish them.
- Reset thermostats of heaters and water heaters that were turned down or off for testing.

1113 Building Tightness Limits (BTL)

Establishing a building tightness limit (BTL) is intended to prevent the creation of an indoor air quality problem (IAQ). A building tightness limit must be determined for every home and may be established by one of three methods as specified by the state;

- BTL, Basic Calculation based on ASHRAE Standard 62-2001.
- BTLa, Advanced Calculation based on ASHRAE Standards 62-2001, 119-1988, and 136-1993.
- 62.2, based on ASHRAE Standard 62.2-2004.

In addition, a Depressurization Tightness Limit (DTL) should also be determined for each home (see section 1114, "Depressurization Tightness Limits"). The DTL is used to develop a tightening limit for safe combustion appliance venting and is not related to other IAQ issues.
The DTL becomes the minimum tightness level if it is greater than the BTL.

11131 Building Tightness Limit (BTL method), Basic Calculation

This method is based on ASHRAE 62-2001. Both of the requirements of this Standard – fresh air at the rate of 15 CFM/person and 0.35 air changes per hour – must be satisfied. These numbers form the basis for determining BTL in units of CFM_{50}.

BTL should be calculated using for both occupancy and house volume. The method that yields the greatest CFM_{50} is the BTL for the house. See Appendix A for information on how BTL is calculated based on occupancy and house volume.

11132 Building Tightness Limit (BTLa method), Advanced Calculation[2]

This method for determining acceptable indoor air quality is based on ASHRAE 62-2001 with the fresh air requirements of 15 CFM/person and 0.35 air changes per hour. It also

[2] A survey conducted in 2001 for the Chicago Regional Diagnostic Working Group, *Survey of Tightness Limits for Residential Buildings*, concluded that the BTLa method was more accurate than the BTL method. This conclusion was based on the opinions of the surveyed experts. See www.karg.com/btlsurvey.htm.

utilizes two other ASHRAE standards for the calculation procedure, making it more accurate than the basic BTL method.[3]

The complexity of this calculation requires the use of a computer or programmed calculator. For the advanced BTLa method, these values must be entered into the computer or programmed calculator. See Appendix A for additional information about the BTLa method.

11133 ASHRAE Standard 62.2-2004 (62.2 method)

ASHRAE Standard 62.2-2004 – *Ventilation and Acceptable Indoor Air Quality in Low-Rise Residential Buildings* – is significantly different from ASHRAE Standard 62-2001 and, as its title makes clear, is for residential buildings only. The next time Standard 62-2001 is revised (probably in 2005), all requirements for residential buildings will be removed and it will address only commercial buildings. When this happens, any weatherization program using the current BTL or BTLa methods, will be basing their procedures for ensuring acceptable indoor air quality on an obsolete standard.

DG-700 digital manometer from The Energy Conservatory

Some significant differences between ASHRAE 62-2001 and 62.2-2004 include:

- Ventilation fans – whole building ventilation – are required in more houses under 62.2-2004.
- The required CFM of whole building ventilation under 62.2-2004 is usually less than that required by 62-2001. This is primarily because 62.2-2004 allows an "infiltration credit", but 62-2001 does not.
- Local mechanical exhaust in bathrooms and kitchens is required by 62.2-2004, but not by 62-2001.
- The 62.2-2004 Standard recognizes the potential hazards of air leakage paths between living areas and garages.

The ZipTest Pro[2] software for the Texas Instruments TI-86 programmable calculator calculates whole building ventilation needs required by ASHRAE 62.2-2004. For information, see www.karg.com/software.htm. The Energy Conservatory software TECTITE 3.1 will also calculate the whole building ventilation needs based on this standard. For information, see www.energyconservatory.com.

[3] The BTLa method is based on ASHRAE Standard 62-2001,*Ventilation for Acceptable Indoor Air Quality;* Standard 119-1988, *Air Leakage Performance for Detached Single-Family Residential Buildings*; Standard 136-1993, A *Method of Determining Air Change Rates in Detached Dwellings*.

1114 Depressurization Tightness Limit (DTL)

Weatherization agencies currently use BTL, BTLa or ASHRAE 62.2-2004 for determining ventilation guidelines in homes. Depressurization tightness limits should also be checked as a screening process to identify potential backdrafting problems. If the depressurization tightness limit is greater than the BTL or BTLa, then the depressurization tightness limit should be used as the ventilation guideline.

Worst-case draft testing (Section 123) should always be done regardless of the method used to determine the ventilation guidelines.

The depressurization tightness limit (DTL) is the CFM_{50} value (leakage rate) at which the appliances in the house that exhaust air are likely to cause vented combustion appliances to backdraft. Appliances that exhaust air include bathroom and kitchen exhaust fans, vented dryers, and furnace air handlers. The more air sealing done in a house, the greater the negative pressure each of these exhaust appliances produces.

The DTL method is based on estimating the exhaust potential of all devices located in the home. These devices are defined as mechanical equipment or combustion appliances that exhaust through a vent connected to the outside of the envelope and that draw air from the living space. This method allows the inspector to determine when the minimum CFM_{50} at which backdrafting may occur.

Locate and record all devices located in the building. Use Table 110-3 to record the effective flow of the devices. If possible, it is always best to measure actual exhaust flow rates. Sum the effective flows for the home.

ESTIMATED EXHAUST RATES
Table 110-3

Device	Approximate Duct/Flue Size (inches)	Typical Nominal Flow CFM	Average Actual Flow CFM
Bathroom and Range Hood Fans	3 3¼x 10 4 7 8	85 85 106 212 318	53 53 64 127 223
Exterior Mounted Kitchen Fans	10 10	424 636	297 445
Clothes Dryer	4	85-127	106
Central Vacuum			117
Jenn- Air or similar Range or counter Top/ext.vent	5 6 3¼ x 10	800 800 800	300 500 600
Wood Burning Fireplace			300
Open Wood Stove			65
Airtight Wood Stove			50
Atmospheric gas oil or Propane Appliances (Water heaters, Boilers, Furnaces)	3 4 5 6		21 38 47 72

Select the appropriate building depressurization limit from Table 110-4. If more than one appliance is located in a combustion appliance zone (CAZ), use the appliance Pa limit most likely to backdraft. For example, an appliance with a rating of -2 Pa is more likely to backdraft than an appliance rated at -5 Pa.

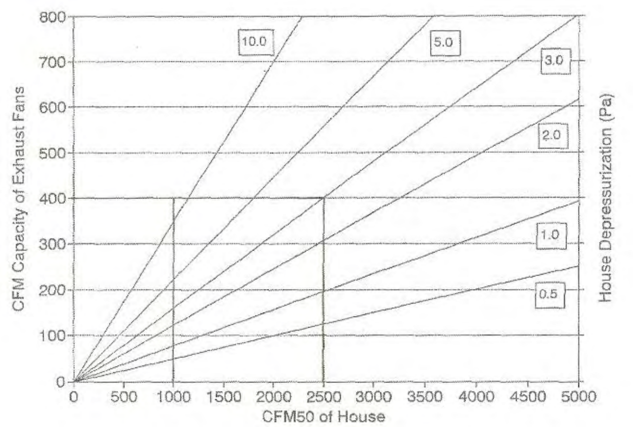
Building Depressurization Limits for Various Appliance Types
(Used to calculate the Depressurization Tightness Limit)
Table 110-4

Appliance Type	***Building Depressurization Limit, Pascals***
Atmospheric water heater only (separately vented from furnace)	-2
Atmospheric water heater and atmospheric furnace common vent	-3
Furnace or boiler, gas atmospheric or fan assist., Category I[4]	-5
Oil or gas unit with power burner	-5
Induced draft appliance (fan at point of exit at wall)	-5
Direct-vent, sealed combustion appliances	-25

[4] Category I appliances are defined as "An appliance which operates with a non-positive vent static pressure and with a vent gas temperature that avoids excessive condensate production in the vent". For additional information, see NFPA54-2002, "Vented Appliance Categories" under Definitions.

Locate the effective flow on the Y-axis on the House Depressurization Chart (Figure 110-1). Locate the appropriate building depressurization diagonal line in Figure 110-1. Read down to the X-axis at the intersection of the effective flow and building depressurization limit to find the minimum CFM_{50} value.

Since the DTL is an estimate of exhaust potential and could overestimate the exhaust, there is some flexibility in this method. When the DTL is approached while air sealing, a worst case draft test should be performed (see section 123). If no problems exist, further air sealing is possible.



House Depressurization Chart
Figure 110-1

If the DTL is greater than the BTL, the DTL should be used rather the BTL as the weatherization tightness limit for the home. Otherwise, the BTL remains as the weatherization tightness limit.

1115 Air Sealing Guidelines

Guidelines for cost-effective air sealing work should be established. The guidelines may take the form of cost limit per 100 CFM_{50} reduction or may be based on the existing CFM_{50} leakage rate.

A cost-effective guideline per 100 CFM_{50} reduction should be established based on climate, fuel costs, material and labor costs for air sealing and heating system efficiency. CFM_{50} needs to be measured on a periodic basis as the air sealing is done. The cost of the CFM_{50} reduction achieved is compared to the cost-effectiveness of achieving it. If actual air sealing costs are less than the cost-effective guideline per 100 CFM_{50}, additional air sealing may continue. If actual air sealing costs exceed the guideline, air sealing work should cease. See Appendix A for additional information regarding cost-effective air sealing guidelines.

If a cost-effective guideline per 100 CFM_{50} is not established, target CFM_{50} levels based on a range of existing leakage rates may be used. Target CFM_{50} levels relate existing CFM_{50} leakage rates to expected post-weatherization leakage rates. The premise is that homes with high leakage rates have a potential for a larger cost-effective leakage reductions than tighter dwellings. Example target CFM_{50} levels are shown in Table 110-5.

Target CFM_{50} Levels
Table 110-5

Existing CFM_{50}	**Target CFM_{50} Levels**	**Example**
less than BTL	see 11146, "Existing Leakage Rate Less than the MVR"	
BTL to 1560	CFM_{50} not to drop below BTL	
1560 to 2750	80% of existing CFM_{50}	Existing CFM_{50} = 2600 .80 x 2600 = 2080 Target CFM_{50} = 2080
2750 to 4250	70% of existing CFM_{50}	Existing CFM_{50} = 3600 .70 x 3600 = 2520 Target CFM_{50} = 2520
4250 to 5500	60% of existing CFM_{50}	Existing CFM_{50} = 5000 .60 x 5000 = 3000 Target CFM_{50} = 3000
5500 to 7500	55% of existing CFM_{50}	Existing CFM_{50} = 6800 .55 x 6800 = 3740 Target CFM_{50} = 3740
> 7500	50% of existing CFM_{50}	Existing CFM_{50} = 8100 .50 x 8100 = 4050 Target CFM_{50} = 4050

The most cost-effective air sealing involves addressing the largest leakage paths first and sealing leaks in the top part of the home. Confirm effectiveness of air sealing strategies by performing interim blower door tests.

Air seal a home until further tightening is no longer cost-effective or to achieve the target CFM_{50} level. Air sealing may be done beyond the target if air sealing work remains cost effective and the building has not been sealed below its BTL.

11151 Air Sealing Exceptions

Because of structural conditions or other factors, some homes may not reach the target CFM_{50} level. Exceptions for not reaching the target are:

- The weatherization installers made every reasonable attempt to reach the target, or
- Further air sealing is not cost effective, or
- The home is at or below the BTL.

A reasonable attempt to reach the target CFM_{50} level should be made in every home. Note that conditions may prevent air sealing levels from being achieved. In all cases the client's file must provide clear and adequate documentation of the installer's efforts to reach the target, and the reason(s) the standard could not be achieved.

1116 Mobile Homes

Mobile homes should be treated similarly to single-family homes when determining the Building Tightness Limit and air sealing level. See section 310, “Air Leakage”, in chapter 300, “Mobile Homes”.

1117 Recording

All homes must have a blower door test performed during the audit and again at the final inspection. The BTL, the DTL and the initial and final blower door tests must be listed on the audit input form. Reasons for not performing a blower door test must be listed in the client file.

1118 Post-Weatherization Blower Door Test

If post-weatherization CFM_{50} is less than the BTL, remedial action should be considered that could include client education, mechanical ventilation or combustion air supply. See section 411, “Blower Door”, for Post-Weatherization blower door testing procedures.

112 Zone Pressure Diagnostics

Best Practice Recommendations:

- Zone pressure diagnostics (ZPD) are not recommended for every home. The use of ZPD is recommended when additional information is needed regarding the relative and absolute leakage of pressure boundaries when the following conditions are found;
    - Indoor air quality concerns (tuck-under garages, crawl spaces or other zones are present that may have an adverse effect on indoor air quality),
    - Moisture problems in attics, and
    - Air leakage remains high after air sealing.
- Both pressure and flow readings should be determined when using ZPD in primary zones.

The blower door can be an effective tool at finding direct leaks by depressurizing the house and looking or feeling for airflow through leaks. However, leaking air often takes a path through two surfaces that have a space, or zone, between them. These zones can include attics, basements, garages, knee-wall areas, or attached porch roofs. These leakage sites may be difficult to find because they are in unconditioned spaces or hidden within the framing systems of a house. Once found, these leaks may be the largest and easiest leaks to seal.

A blower door is required for zone pressure diagnostics

Zone pressure diagnostics can be used to measure the size of the leakage paths to various house zones and the extent to which those holes are leaking. Measurements may be taken that indicate the amount of air leakage between the house and zone and zone and outside, both in terms of CFM_{50} flow and square inches of leakage area. Following weatherization work, zone pressure diagnostics can quantify the effectiveness of air sealing efforts.

1121 Zones

A "zone" is an enclosed space that separates a heated space from the outdoors. Typical zones include attics, crawl spaces and attached garages. The inner boundaries of these zones are building components such as walls, ceilings, or floors that separate these zones from the conditioned space. The outer boundaries of these zones are the walls, roofs, and foundation walls that separate a zone from the outdoors.

The building component that separates the conditioned space from the outdoors should be the primary pressure boundary. The pressure boundary is often thought of as being the building's air barrier and is where air sealing should be done during weatherization. The thermal boundary is defined by the placement of insulation. In order to maximize the effectiveness of the thermal boundary, the pressure boundary must be aligned with it. In other words, it's very important that the pressure boundary be part of the thermal boundary. If the insulation and the air barrier are not aligned; that is, located in different building components, air is allowed to pass around or through the thermal boundary, making the insulation less effective.

Measuring zone pressures during a blower door test indicates whether the thermal and pressure boundaries are aligned. The pressure measured across either the inner boundary of a zone – house with reference to (wrt) the zone – or the outer boundary of a zone (zone wrt outside) can indicate the relative leakiness of each of the boundaries.

Depending on zone pressure measurements alone can be misleading, however. For example, a house-to-attic pressure measurement of -45 Pa (-5 Pa wrt outside) indicates that the ceiling is tighter than the roof. However, it does not indicate how much air is flowing through the roof and the ceiling or how many square inches of holes are in each. For example, the attic floor structure could have 40 or 400 square inches of leakage area.

11211 Primary Zones

Primary zones are spaces that can be physically accessed and inspected. Typical primary zones include attics, crawl spaces, basements, and attached garages. Because temporary openings can be created to the house and/or to the outdoors from these primary zones, an air leakage rate (CFM_{50}) between the house-to-zone and zone-to-outside can be determined. These flows can be converted to leakage areas simply by dividing them by 10. This information provides the assessor and air sealing team with information regarding the extent of air sealing work required and a method for evaluating the effectiveness of air sealing work.

11212 Secondary Zones

Secondary zones are spaces that cannot be physically accessed. Secondary zones include:

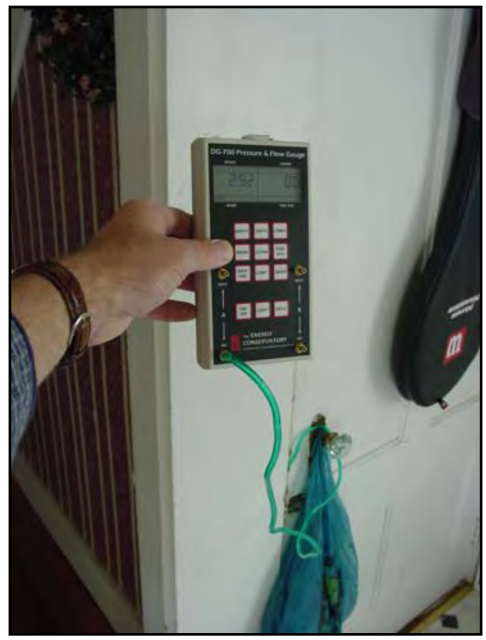
- Dropped soffits and other ceiling height changes,
- Open joist cavities (beneath knee walls in finished attics),
- Cantilevered floor joists,
- Floor joists over tuck under garages, and
- Porch ceilings or living space floor cavities along the porch ceiling.

Temporary openings usually cannot be made between the house and secondary zones or between the zone and the outdoors. Consequently, flow rates and leakage areas cannot be measured. However, pressure readings can be taken if a pressure probe can be inserted into the secondary zone. This pressure reading is used to determine how well connected (or disconnected) the secondary zone is from the house.

1122 Zone Pressure Diagnostics – Recommendations

Zone pressure diagnostics are recommended when additional information is needed regarding the relative and absolute leakage of pressure boundaries. Specifically, zone pressure diagnostics is recommended when the following situations are encountered.

1. Indoor Air Quality concerns - Zone pressure diagnostics should always be done in houses with attached or tuck-under garages, crawl spaces and other spaces where pollutants, moisture and soil gases can enter a home through air leaks.
2. Moisture-related problems in attic - this might be the case if:
    a. The attic has obvious moisture problems,
    b. There is evidence of high relative humidity in the home during winter, or
    c. Ice dams are a concern.
3. Air leakage/energy loss concerns - If the leakage rate of the house remains high after initial tightening of large leaks, zone pressure diagnostics can help identify less obvious air leakage sites in the attic floor, house walls, or basement and crawl space walls.



Zone pressure test to basement with blower door depressurizing house to -50 Pascals

Zone pressure diagnostics is most valuable on homes of moderate air leakage, rather than on homes with very high or very low air leakage rates. There are probably very obvious air leakage sites in homes where a pressure difference of -50 Pa cannot be achieved with the blower door. Sealing these obvious leaks is likely the most cost-effective measure that can be done in these homes. Likewise, identifying and sealing leaks between unconditioned zones and the living space in tight homes (less than 150% of the BTL) is probably not cost-effective. However, zone pressure diagnostics in tight homes is recommended when conditions as discussed above in items 1 and 2 are found.

1123 Zone Pressure Diagnostics - Preparation

Identify primary and secondary zones that will be tested.

Install a pressure probe or tube into the zones to be measured. Avoid pinching the tube. The tube/probe should be well above any insulation and not in any direct airflow.

Set-up the house and blower door for a typical air leakage test. The tube used to measure the pressure difference between the house and outside for the blower door test can also be used to measure the zone-to-outside pressure. Ensure that this hose will not be affected by the blower door airflow.

1124 Measuring Zone Pressures

11241 Zone-to-Inside/Outside Pressures

Depressurize the house to -50 Pa. If the house cannot be depressurized to -50 Pa see section 11242, “Zone Pressures when the House Cannot be Depressurized to -50 Pa”. Note that flow rates and leakage areas cannot be determined unless the house can be depressurized to -50 Pa unless software for advanced zone pressure diagnostics is being used (see section 11251, “Software Calculations”).

Connect the hose coming from the zone to the “input” tap on the manometer. This will be the zone with reference to inside pressure. Record the pressure.

With the zone hose still connected to the “input” tap, connect the hose from the outside to the “reference” tap. This will be the zone-with-reference-to-outside-pressure. Record the pressure.

The two pressures should add up to the house wrt outside pressure of -50 Pa. For example, if the zone-to-outside pressure is -5 Pa, the zone-to-house pressure should be 45 Pa if the blower door is at -50 Pa.

11242 Zone Pressures when the House Cannot be Depressurized to -50 Pa

If the house cannot be depressurized to -50 Pa, zone pressures can still be measured. However, measuring a CFM_{50} flow and air leakage area between the zone and house cannot be done unless the house can be depressurized to -50 Pa.

Depressurize the house to the highest multiple of 5. Measure the zone pressure and use the adjustment value found in Table 112-1 to determine the corresponding CFM_{50} Pa pressure reading.

For example, the house can only be depressurized to -35 Pa. The attic-to-outside pressure reading is -7 Pa. The corresponding CFM_{50} pressure reading is -9.8 Pa or (-7 Pa x 1.4 = -9.8 Pa).

Zone Pressure Adjustment Factors

Table 112-1

House Pressure	-10 Pa	-15 Pa	-20 Pa	-25 Pa	-30 Pa	-35 Pa	-40 Pa	-45 Pa
Zone/House	2.9	2.2	1.8	1.6	1.4	1.3	1.2	1.1
Zone/Outside	5	3.3	2.5	2	1.6	1.4	1.2	1.1

11243 Interpreting Zone-to-Inside/Outside Pressures

Pressure readings between the zone and the inside/outside indicate whether the pressure boundary is aligned with the thermal boundary. In all cases, both the pressure boundary and thermal boundary should be in the same construction assembly.

Generally, the thermal boundary should be between the conditioned space and an unconditioned space or outdoors. The thermal boundary must always be between the conditioned space and a tuck-under or attached garage.

For an attic, zone-to-outside readings of 0 Pa to -24 Pa (or zone-to-inside readings of 50 Pa to 26 Pa) indicate that the pressure boundary between the living space and attic is tighter than the boundary between the attic and outside (for example, the ceiling is tighter than the roof of an unfinished attic). Pressure numbers closer to 0-wrt-outside (or 50-wrt-inside) generally indicate that the pressure boundary is aligned with the thermal boundary. However, flow readings should be taken to determine the amount of CFM_{50} leakage between the house and zone and to determine the amount of air-sealing needed.

Zone-to-outside readings of -26 Pa to -50 Pa (or zone-to-inside readings of 0 Pa to 24 Pa) indicate that the pressure boundary between the zone and outside is tighter than the pressure boundary between the living space and zone. For example, the crawl space foundation walls are tighter than the floor between the crawl space and conditioned area. If it is determined that the crawl space foundation walls should be the thermal boundary, holes in the foundation wall should be sealed. Flow readings between the house and crawl space can be helpful in determining the amount of air sealing needed.

House-to-zone pressures in secondary zones such as framing cavities within the living space should be relatively low since they are supposed to be within the pressure boundary of the house. If the pressures are elevated, this normally means that one end or the other of that framing component is connected to a source of air leakage to the outdoors.

Zone-to-outside readings of -25 (zone-to-inside readings of 25 Pa) indicate that the air barrier between the zone and conditioned space and the air barrier between the zone and outside are equally leaky. This can make the tasks of defining conditioned space and where to do air sealing more difficult. Determining CFM_{50} flow readings can be an important tool for making such a decision.

Pressure readings between primary zones and living spaces indicate the location of the best air barrier and its relative leakiness. However, it is often important to have an estimate of the leakage area for purposes of air sealing. Using either calculator/computer based programs or the tables explained below can help accomplish this estimate.

1125 Measuring Flows and Leakage Areas

Air leakage flow in units of CFM_{50} between the zone and the living space and between the zone and the outside can be calculated with the methods described below. An opening, or hole, is added to the zone, either between the zone and house or zone and outdoors. Pressures are read before and after the temporary opening is created. The size of the hole is measured. Flow rates and leakage areas between the house and zone and zone and outside can then be determined. Additionally, the total path flow can be calculated. This represents the combined flow or Total Path, in units of CFM_{50}, taking into account the resistance of *both* of the pressure boundaries.

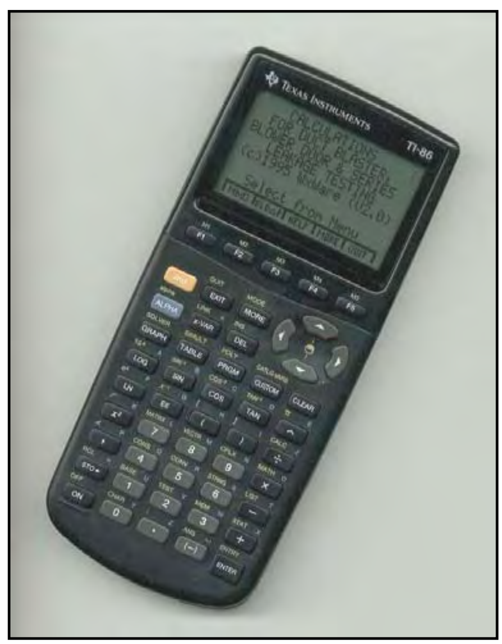
An operable hatch or door to the zone, or from the zone to the outside, is required to determine these flow values. Therefore, flow rates and leakage areas can only be measured for primary zones.

Flow rates and leakage areas between zones and the house can be calculated with software or manually with the use of tables. See the software users' manual for their recommended procedures. Additional information about flow values is provided in section 1126, "Manually Calculating Flow Rates (CFM_{50})".

11251 Software Calculations

Using software calculations to calculate flow rates and leakage areas is easier and more accurate that manually using tables. Software calculations should be used whenever possible.

The Energy Conservatory (www.energyconservatory.com/) offers a free zone pressure diagnostic (ZPD) utility program that calculates both flows and leakage areas. A Windows-based computer is required to run this program. This program utilizes advanced ZPD calculations.



Texas Instruments TI-86 calculator loaded with ZipTest Pro[2] building diagnostics software

Pressure readings between the zone and outside (or zone and inside) are taken with the house depressurized to -50 Pa. An opening is made between the house and zone (or zone and outside). Pressure readings are adjusted and the area of the opening is measured. The ZPD program then calculates the estimated flow and bypass area between the house and zone.

The Zip Test Pro™ (basic ZPD calculations) and Zip Test Pro2™ (basic and advanced ZPD calculations) software utilizes a hand held Texas

Instruments TI-86 calculator that calculates flows. This tool is used in the field and will provide immediate answers. Information about this software may be found at www.karg.com/software.htm.

Measuring pressures and determining flow rates either manually or using basic ZPD calculations can only be done if the house can be depressurized to -50 Pa. However advanced ZPD calculations allow use of pressures of less than 50 Pascal difference between the house and outdoors.

1126 Manually Calculating Flow Rates (CFM_{50})

Flow rates and leakage areas may be calculated manually with the use of tables. These procedures are described in Appendix 112.

113 Duct Leakage

Best Practice Recommendations:

- Pressure-pan testing is recommended:
  - On ducts located in unconditioned spaces (attics, behind knee walls, tuck-under garages, for example),
  - When basement return ducts are suspected of creating a hazardous venting condition, or
  - When basement return ducts may be contributing to indoor air quality problems, such as elevated interior moisture levels associated with wet basements.
- Measuring duct leakage to the outside with a Duct Blaster™ fan is recommended when:
  - The ducts are substantially outside the building envelope, and
  - The ducts are accessible and can be repaired.
- Pressure pan tests should always be conducted on mobile home ducts.

Duct leaks can lead to many problems in a dwelling, the most common one being wasted energy. Other problems can include hazardous combustion venting, thermal discomfort and substandard indoor air quality.

Ductwork leakage can take place within the confines of the conditioned envelope of the building or to and from the outdoors.

Duct leakage to or from the outdoors may waste more energy than leakage within the confines of the thermal envelope. Mobile home ducts and site-built homes with ductwork in crawl spaces or attics are susceptible to leakage to and from the outdoors.

Although duct leakage within the conditioned envelope usually does not have a significant energy impact, it might cause comfort problems or may impose a hazard to occupant health by causing poor indoor air quality or backdrafting of combustion appliances.

Two types of duct leakage tests are discussed in this section; pressure-pan and duct blower.

1131 Pressure-Pan Test Description

The pressure-pan test is a duct leakage diagnostic tool that is used with the blower door and digital pressure gauge to identify duct leakage to the outdoors. A gasketed pan is placed over each register or grille with the air handler fan off and the blower door depressurizing the house to -50 Pa. A pressure measurement between a duct and the room where the duct register or grille is located provides an indication of whether duct leakage to the outdoors exists.

Pressure-pan testing is recommended when ducts are found in:

- Unconditioned spaces (attics, behind knee walls, tuck-under garages, for example), or
- Basements when return leaks are suspected of creating a hazardous venting condition.

Pressure pan and digital monometer, both from The Energy Conservatory

Pressure pan tests should always be conducted on mobile home ducts (see section 34042, "Duct Leakage Standards").

Pressure-pan testing may also be done on basement ducts when the ductwork is suspected of causing a thermal comfort or indoor air quality problem.

1132 Duct Blower Test

A duct blower test measures the air tightness of forced air duct systems. Duct leakage to the outdoors of a home can be measured or total duct leakage to both the interior and exterior of a home can be measured. This section addresses only the measurement of duct leakage to the outdoors. A duct blower and blower door are required for this test. The duct blower used in the following description is The Energy Conservatory Duct Blaster™.

The Duct Blaster™ fan is connected directly to the duct system at a central return or at the air handler cabinet. With all the registers and grilles temporarily sealed, the duct system is either pressurized or depressurized. When the Duct Blaster™ is used with the blower door, duct leakage to the outside can be measured. Total duct leakage to the outside should be measured when the ducts are substantially located outside the building envelope.

Duct blower (Duct Blaster) from The Energy Conservatory

1133 Importance of Duct Location

11331 Ducts Located in Conditioned Spaces

Perform a house-to-zone pressure and flow test to determine if the space in question is conditioned in terms of its pressure boundaries (see section 112, "Zone Pressure Tests"). The house-to-zone pressure should be 20 Pascals or less (or zone-to-outside pressure 30 Pascals or greater).

Visually inspect the conditioned space to ensure that the shell is properly insulated and air sealed. If it is determined that weatherization work should be done to the shell of the conditioned space that houses the ducts, perform a house-to-zone pressure and flow test before and after the work to quantify the effectiveness of the air sealing work.

Always repair disconnected ducts. Sealing the shell of the space rather than sealing the duct joints will maximize energy savings. Sealing the duct joints may correct a combustion venting problem, increase thermal comfort or improve an indoor air quality problem, but will do little to save energy.

11332 Ducts Located in Unconditioned Spaces

If possible, permanently convert the unconditioned space where the ducts are located to a conditioned space, making sure the air and thermal barriers are installed effectively. Demonstrate the effectiveness of this weatherization work by performing a house-to-zone pressure and flow test before and after converting the unconditioned space to a conditioned space (see section 112, "Zone Pressure Diagnostics").

Always repair disconnected ducts in unconditioned spaces. If the unconditioned space is impossible or impractical to convert to a conditioned space:

- Make all necessary ductwork repairs, seal all ductwork joints with mastic, and
- Add R8 insulation to uninsulated ducts.

Examples of unconditioned spaces that may be impractical to convert to conditioned space include some crawl spaces, unconditioned basements, attics, attached or tuck-under garages, and exterior walls.

1134 Duct Leakage Standards (Site-Built Homes)

11341 Pressure-Pan Testing for Ducts in Conditioned Spaces

Pressure-pan testing is not recommended for ducts located within conditioned spaces. Rather, air sealing leaks to the outdoors in the space in which the ducts are located is recommended.

11342 Pressure-Pan Testing for Ducts in Unconditioned Spaces

Pressure-pan testing is recommended for ducts located within unconditioned spaces in site-built homes. Pressure-pan tests are also recommended for mobile home ducts (see section 34042, "Duct Leakage Standards").

If the ducts themselves or the space in which they are located is perfectly sealed to the outdoors, no pressure difference will be read during a pressure-pan test. The higher the pressure reading in ducts, the more connected the ducts are to the outside. This connection means leaks and leaks lead to wasted fuel.

- Following weatherization work, no more than three registers shall have pressure-pan readings greater than 2.0 Pa. No readings shall be greater than 4.0 Pa.
- If all readings are under 1.5 Pa, no duct sealing is needed.
- Pressure pan readings in excess of 4.0 Pa indicate a serious breach in the duct system. Locate and seal holes in duct.

Inspect the boot connections behind registers measuring more than 4 Pa. Re-attach or seal boots if necessary.

11343 Standards for Duct Blower-Measured Leakage to the Outdoors

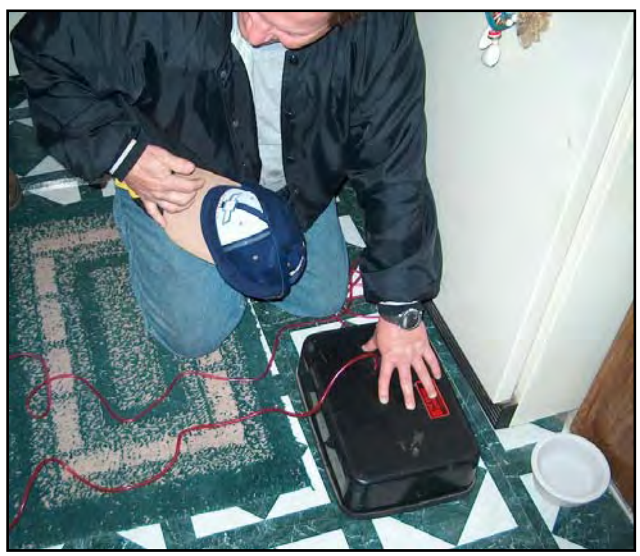
Total duct leakage to the outside should be measured when the ducts are substantially located outside the building envelope. Duct leakage to the outdoors, as measured with the Duct Blaster™ fan[5] and blower door, should be no more than 5 percent of conditioned floor area. For example, if the conditioned floor is 1,300 ft^2, duct leakage to the outside should be no more than 65 CFM.

1135 Pressure-Pan Test

11351 Duct Leakage to the Outdoors

Pressure-pan duct testing can help identify leaky or disconnected ducts that are leaking to or from the outdoors. Testing before and after duct sealing gives an indication of the effectiveness of sealing efforts. Pressure-pans do not read duct leakage directly; they infer leakage to the outdoors by reading the pressure at individual registers.

Pressure-pan readings are taken at each supply and return register served by ducts running through unconditioned spaces with the house depressurized by the blower door to -50 Pa. Pressure-pan readings close to 0 Pa indicate no leakage to the outside. Pressure-pan readings greater than -4 Pa indicate a significant leak to the outside.



Pressure pan test (operating blower door not pictured)

Duct boot connections should be inspected at registers measuring more than 4 Pa. Boots that have dropped-down or have holes in

[5] At 25 Pa; see section 1136, “Duct Leakage to the Outside”.

the corners should be re-attached and sealed. Another pressure-pan reading should then be taken. Inspect the duct if the pressure-pan reading remains elevated.

Special attention should also be given to registers attached to stud cavities or panned joists used as return ducts. These wood framed ducts are often very leaky to the inside and outside of a dwelling.

11352 Duct Leakage to Conditioned Spaces (Basements/Crawl Spaces)

Basements are most often considered part of the conditioned space of a home. Therefore, it is recommended that the door between the basement and living space be **closed** during pressure-pan testing. If pressure-pan readings are taken on ducts located in basements with basement doors open, the pressure readings are likely to be very small, despite the fact that large holes in the basement ducts may be present and visible.

When pressure-pan tests are taken with the basement door open, low pressure readings indicate little duct leakage to the outside, although there may be significant duct leakage to the basement. Basement leaks may cause discomfort, indoor air quality and combustion venting problems. Leaks in the return system may become apparent during the worse case draft test. However, location of these leaks with a pressure pan may become quite apparent when the basement is connected to the outdoors by opening basement windows.

To check for leakage to the basement from basement ducts with the pressure-pan, place the basement outside the conditioned space. Close the basement door between the house and basement. Open basement windows and/or the basement door to the outside. Seal supply and return registers in the basement. Seal filter slot as well. Measure the pressure pan readings in the main floor ducts.

Air sealing the foundation walls will likely reduce pressure-pan readings for ducts located in conditioned basements and crawl spaces. Unless duct leakage is causing a hazardous combustion venting problem, creating a comfort problem or causing an indoor air quality problem in the main body of the house, it is always preferable to air seal the foundation walls before duct sealing (see section 11331, “Ducts Located in Conditioned Spaces”).

11353 Pressure-Pan Test Procedures[6]

Identify ducts that are in unconditioned zones of the house. It is not necessary to take pressure-pan readings on ducts located in conditioned spaces unless ducts located in basements are suspected as causing a thermal comfort or indoor air quality problem (see section 11352, “Duct Leakage to Conditioned Spaces”).

Install the blower door and set-up the house for winter conditions. Open all interior doors, including door to basement.

[6] Pressure-pan standards for mobile homes are located in section 34042, “Duct Leakage Standards”.

Make sure the furnace burner and air handler are off and will not start during the testing. Remove the furnace filter. Ensure that all grilles, registers, and dampers are fully open in the conditioned space of the house[7].

Temporarily seal any outside fresh-air intakes to the duct system. These are usually ducted to the return side of the ductwork. If supply ducts are located in a garage or other unconditioned space, seal these registers so that the register opening does not show up as a duct leak.

Open zones that contain the ducts as possible to the outside. These zones include attics, crawl spaces and garages.

A blower door is needed for the duct blower test to determine leakage to the outdoors

Connect the hose between the pressure pan and the input tap on the digital manometer. The reference tap to the house should be open.

Depressurize the house to -50 Pa. Place the pressure pan completely over a grille or register to form a tight seal. Record the reading. Note that only one register is sealed with the pressure-pan at a time.

If unconditioned spaces in which ducts are located are not well connected to the outdoors or have very large connections to the house, then the unconditioned space will be at a pressure between the outside and inside house pressure during the blower door test. In this case, the pressure-pan reading will show an artificially low number. To correct this misleading number:

- With the house at -50 Pascals, measure the pressure difference between the house and the unconditioned space. (For example, the house-to-zone pressure is 10 Pascals and the pressure pan reading is 2.0 Pascals).

- Multiply the pressure pan reading by the multiplier in Table 113-1 to get the adjusted reading. (For example, multiply the pressure pan reading of 2.0 Pascals by 5, resulting in a pressure pan reading of 10 Pascals).

If you are testing a house with a very leaky building shell and are not able to create a 50 Pa pressure difference with the blower door, perform pressure-pan

[7] Before fully opening or changing the position of balancing dampers, mark their position so that they can be returned to that position after the pressure pan testing.

tests with the house at the highest achievable pressure. Interpret pressure-pan readings carefully. Compare the measured pressure-pan reading with the maximum possible reading.

Pressure Pan Multipliers
Table 113-1

se/Zone Pressure	***Pressure Pan Multiplier***
50	1.0
45	1.1
40	1.25
35	1.42
30	1.66
25	2.0
20	2.5
15	3.5
10	5.0
5	10.0

Repeat the test for each register and grille on ducts located in unconditioned spaces in a systematic fashion.

If a grille is too large or supply register is difficult to access (under a kitchen cabinet, for example), seal the entire grille or register with duct-mask tape. Insert a pressure probe through the duct-mask tape and record reading. This is more time consuming than using the pressure-pan, but it gives an accurate reading.

When two registers or grilles are closely connected to the same duct run (for example, two registers on opposite sides of the same partition wall), seal one and use the pressure-pan on the other unsealed register or grille.

1136 Duct Leakage to the Outside

In some cases, especially where the ducts are substantially outside the building envelope, it can be useful to quantify the amount of air leakage that is occurring through the ducts to the outside. This test can provide a clear picture of the amount of leakage between the ducts and unconditioned zones and should only be done if the ducts are accessible and can be repaired.

A Duct Blaster™ fan is used in combination with the blower door to measure air leaks to the outside in the duct system. The blower door neutralizes duct leakage to the indoors. Only CFM leakage to the outdoors not neutralized by the blower door is measured.

11361 Duct Leakage to the Outside Procedures

Put the house into a winter condition with all interior doors open. The basement door is to remain open if the basement is conditioned.

Cover all supply and all returns with an air impermeable material (plastic bags work well as do magnetic panels and 3 inch masking tape). Make sure all major openings to the inside of the house are covered (i.e., basement, toe kick, closet registers and the front and back of any open filter slots). Remove the furnace filter prior to sealing the filter slot.

Locate a large unobstructed opening into the return side of the distribution system. This may be a large return register (remove the grill covering before installing the Duct Blaster™ fan), but is usually the access panel to the fan compartment of the furnace. Cover/tape the opening of the return access with a sheet of rigid material (cardboard, rigid insulation, etc) with an opening cut in it sized to fit the Duct Blaster™ fan. Attach the fan to the rigid covering with the intake side of the fan (flow reducer side) facing the house. Place a restriction plate on the fan opening (Ring 2; 48 to 340 CFM is the best to start with). Install the fan and covering in a way that minimizes the amount of fan opening restriction by the circuit board present in newer furnaces.

On the digital manometer, install one hose into the supply side of the distribution system (in other words, the opposite side of the heat exchanger from the fan) and attach it to the reference tap of the pressure gauge's Channel A. Install a second hose to the pressure tap located on the fan housing and attach it to the input tap of Channel B. Since this is a pressurization test the flow conditioner is not required.

Select a level of pressure to measure the duct leakage. The most common pressure used for this test is 25 Pa. Switch the blower door fan to the pressurization mode and pressurize the house to the desired duct measurement level. Be sure the pressure gauge is out of the fan flow since air will be drawn in through the fan at a significant rate. There is no need to determine the CFM_{50} of the house; just pressurize the house to 25 Pa.

Note the pressure across the ducts produced by the duct leaks in the system. Slowly increase the Duct Blaster™ fan speed until the duct system pressure is decreased to a 0 (neutral) Pascal pressure. Check the fan pressure/flow. If the fan pressure is too low (<10 Pa) the flow restriction plate should be replaced with a smaller plate (Ring 3; 20-140 CFM). If the pressure across the ducts cannot be neutralized, a larger sized restriction plate should be installed or use the open fan (Ring 1; 124 to 878 CFM or Open Fan; 330 to 1696 CFM).

When the leakage is neutralized and a measurable fan pressure is attained, check the house pressure produced by the blower door to make sure it is still at 25 Pa and make any needed adjustments to the blower door and/or Duct Blaster™ fan speed. Using either a conversion chart or the fan flow calculation mode on the pressure gauge, find the CFM_{25} fan flow needed to neutralize the duct leaks in the system at 25 Pa

The previous procedure details a test where both the house and duct system are pressurized. Duct leakage to the outside may also be done by depressurizing both the house and duct system. One advantage of depressurizing is not having to switch the blower door to the pressurization mode. Also, it may be difficult to keep the tape or plastic on the registers during a pressurization test. Depressurizing the ducts tends to make the covering over the registers tighter. Check the Duct Blaster™ fan manual for additional information on depressurizing the ducts.

114 Duct-Induced Pressures

Best Practice Recommendation:

- Provide pressure relief when pressures are + or -3.0 Pa between a room and the main body of the house with the air handler operating.

An improperly balanced air-handling system can cause comfort, impact building durability, and contribute to indoor air quality problems. An imbalance between the supply and return sides of the distribution can be caused by duct leakage to the outside, restricted/inadequate returns, the restriction of supply flow back to the main living spaces of the house and/or pressure driven exfiltration.

1141 Whole House Dominant Duct Leakage

This test identifies the side of the distribution system that has the strongest connection to the unconditioned spaces of the dwelling or to the outdoors.

1. Set-up the house for winter conditions. Close all windows and exterior doors. Turn off all exhaust fans.

2. Open all interior doors, including the door to basement if it is a conditioned space.

3. On the manometer, place a hose from “reference” tap to the outside.

4. Measure the house pressure with reference to the outside. This is the baseline pressure created by natural pressure forces (stack-effect air leakage).

5. Turn on the air handler (high speed, if two-speed fan).

6. Measure the house pressure with reference to the outside.

Note the difference between the baseline pressure and the duct-induced pressure. If the house pressure with reference to (wrt) the outside is negative, it indicates that the dominant duct leakage to the outdoors is on the supply side of the distribution system. If it is positive, the dominant duct leakage to the outdoors is on the return side.

1142 Duct-Induced Room Pressures

This test identifies the restriction of supply flow to the main living space by measuring pressure differences between the main body of the house and each room, including the combustion appliance zone (usually the basement).

1. Set-up the house for winter conditions. Close all windows and exterior doors. Turn off all exhaust fans.

2. Close all interior doors, including the door to basement.

3. Turn on the air handler (high speed, if two-speed fan).

4. On the manometer, place a hose from “input” tap under the door of the room being tested. Leave “reference” tap open to main body of house.

5. Read and record measurement for each room, including the basement.

6. With the doors still closed and the air handler operating place the hose outside and measure the pressure between the main body of the house and the outside. This will identify if door closure is producing a negative pressure across the main body of the house and how strong that pressure is.

The blower door is NOT used for this testing

11421 Interpreting Duct-Induced Room Pressures

If the pressure difference is more than + or -3.0 Pa with the air handler operating, pressure relief is necessary. To estimate the amount opening for adequate pressure relief, slowly open the door until pressure difference drops between +3.0 Pa and -3.0 Pa. Measure and calculate the area of the door opening. This is the area required to provide pressure relief by undercutting the door or installing a door grille.

Alternately, transfer grilles may be mounted in a partition wall (one high on the wall and one low on the opposite side), a jumper duct may be installed across the ceiling between the room and the hallway, a door louver may be installed or the door may be undercut.

Correcting most significant pressure differences will require a larger opening than a door undercut can provide and the door louver sacrifices a certain amount of privacy. The wall and ceiling mount relief strategies are usually the most effective. It is also important to remember that the door opening measured is a gross opening and so the size of the transfer grilles must be adjusted for the restriction of those grilles.

Additional information about calculating the area required for pressure relief may be found in Appendix 114.

Adding return air ducts (or enlarging existing return air ducts) may also correct pressure balance problems.

121 Furnaces and Boilers

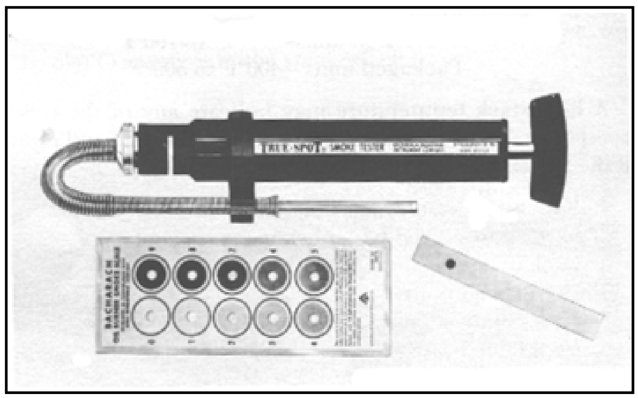
Best Practices Recommendations:

- A combustion efficiency test should be performed for an adequate appraisal of the operation and efficiency of the heating system.
- The following tests should also be conducted to help assess existing condition of heating system.
  - CO test,
  - Draft test under worst-case draft conditions,
  - Gas leak test (gas-fired systems),
  - Temperature rise (forced-air furnaces), and
  - Clocking the meter (gas-fired systems).

1211 Smoke Testing

A combustion smoke test should be performed on all oil-fired heating systems *before* a steady-state efficiency test is done. This smoke test is not required on natural gas- or propane-fired systems.

If the measured smoke reading of the combustion emissions is 2 or less, the steady-state efficiency test may be performed. If the smoke test shows a reading higher than 2, the system must be cleaned and tuned before a steady-state efficiency test is performed.



Bacharach True Spot® Smoke Test kit used for oil-fired systems only

This standardized smoke test measures the amount of carbon in the flue gases by pulling a measured amount of these combustion gases through a special filter paper. The smoke dot on the filter paper is then matched with one of ten smoke density samples numbered from 0 to 9 on a sample card.

The most common device for measuring smoke on an oil-fired system is the Bacharach True-Spot® Smoke Test Kit. This is a pump-type device with a slot for filter paper. While the burner is operating and when the system has reached steady-state (stable flue gas temperature), insert the probe for the calibrated pump into a hole in the breech of the vent connector and then manually operate the pump according to the instructions to pull combustion gases through the filter paper. Match the smoke spot on the filter paper with one of the ten choices on the sample smoke card.

1212 Combustion Efficiency Testing

A combustion efficiency test should be performed by the assessor or a heating system specialist for an adequate appraisal of the operation and efficiency of the heating system. This test must always be performed during steady-state conditions. This means that the burner must be operating and the flue gas in the vent connector must reach a stable temperature. If the burner stops firing during a steady-state efficiency test, the test must be aborted and started again.

12121 Information Needed for Test

To determine the steady-state efficiency of a heating system, the net stack temperature and the amount of excess air in the flue gas must be measured.

The net stack temperature is the temperature of the combustion supply air (room temperature) subtracted from the temperature of the combustion gases in the vent connector. Older combustion analyzers measure the gross stack temperature. The combustion supply air, which is usually the room air temperature of the space in which the heating appliance is located, must be subtracted from the gross stack temperature to find the net stack temperature.

The Testo 325 combustion analyzer measures steady-state efficiency and carbon monoxide emissions

Newer digital combustion analyzers automatically subtract room air temperature from stack temperature for their calculation of efficiency. Make sure that the room temperature is recorded by the analyzer so that it calculates the efficiency correctly. The lower the net stack temperature, the higher the efficiency of the heating system.

In order to determine the amount of excess air is in the combustion gases, the oxygen (O_2) or carbon dioxide (CO_2) percentage in the combustion gas is measured. Digital combustion analyzers always read O_2 with an oxygen sensing cell. These newer digital units are sometimes referred to as dry-type analyzers. The older wet-type analyzers determine the percentage of CO_2 in the flue gas by pumping the combustion gases through a special liquid (potassium hydroxide) that absorbs CO_2. As the CO_2 is absorbed the volume of the liquid increases.

12122 Where to Test

The temperature and O_2 or CO_2 must always be measured before any room air is allowed to dilute the combustion gases. For a gas boiler, the measurements must be taken before the draft hood or draft diverter. For some older gas-fired boilers, room dilution air enters through an opening in the underside of the vent connector at the point it connects to the heating unit. For these older systems, the temperature and O_2 or CO_2 readings are taken by inserting the instrument probe into the vent connector opening (drilling a hole is not necessary) and holding the probe in a position that will not be affected by room dilution air.

For an atmospheric gas furnace, the readings must be taken just before the emissions are diluted by room air at the draft diverter.

For oil-fired units, the readings must be taken at the breech before the barometric damper.

12123 Conducting the Test

With the heating unit operating, insert the sampling probe of a combustion analyzer into the appropriate location of the vent system. Measure the temperature of the flue gases to determine when steady-state condition is reached. This will be when the flue gas temperature stabilizes (steady-state condition).

The Bacharach Fyrite Pro combustion analyzer measures steady-state efficiency and carbon monoxide emissions

Measure and record the net stack temperature (room temperature subtracted from steady-state stack temperature) and O_2 or CO_2. Determine whether the readings are within the acceptable limits listed in Table 121-1, “Acceptable Combustion Test Analysis Values”.

If the burner shuts down while conducting the test, start the test again. Turning up the thermostat so that the burner runs longer may be helpful. Other temporary adjustments will ensure that the burner runs for longer periods, but it is important to follow state program recommendations when making such adjustments.

Return the thermostat(s) and other modified controls to their original settings when the test is complete.

Always be aware of health and safety during combustion testing. If any of the following conditions are present during an efficiency test, shut down the heating system and take remedial action:

- If significant draft reversal occurs, filling the combustion appliance zone with combustion gases.
- If ambient carbon monoxide levels reach 10 ppm.
- Flame rollout.

- Hazardous heat exchanger defects.
- Obvious electrical or system control problems.
- Any other hazardous malfunction of the heating unit or distribution system.

Acceptable Combustion Test Analysis Values
Table 121-1

Heating Unit Type	*Oxygen (O_2)*	*Carbon Dioxide (CO_2)*	*Net Stack Temp.*	*Smoke Test*
Gas				
Atmospheric	4 - 9%	Natural 9.6 - 6.8% LPG 11.2 - 7.8%	300-600º F	NA
Fan-assisted	4 - 9%	Natural 9.6 - 6.8% LPG 11.2 - 7.8%	300-480º F	NA
Condensing	See man. Info.	See man. Info.	See man. Info.	NA
Standard Power Burner	4 - 9%	Natural 9.6 - 6.8% LPG 11.2 - 7.8%	300-650º F	NA
Oil (No. 1 & 2)				
Oil gun burner	4 - 9%	12.5 - 8.8%	325-600º F	2 or less
Flame Retention Burner	4 - 7%	12.5 - 10.3%	325-600º F	2 or less

1213 Carbon Monoxide Test

With the heating unit operating and in steady-state condition, insert the sampling probe into the appropriate spot in the vent system (before any room dilution air has entered the vent system). The CO test is always done in the same vent system location as the steady-state efficiency test.

Measure and record the amount of carbon monoxide in the flue gas, either as-measured or air-free. The measured CO emissions level must be equal to or less than that listed in Table 121-2. If cleaning and tuning does not adequately lower the CO emissions, consider replacement of the heating unit (see Section 223, "Heating System Replacement", for other criteria related to replacing existing heating appliances).

The best time to measure for CO emissions is during worst-case conditions. Please refer to Section 123 for more information.

Carbon Monoxide (CO) Action Levels and Allowable Levels
Table 121 -2

Appliance	*Allowable CO Level*	*Comments*
Gas Furnace / Boiler	100 ppm / 200 ppm	as-measured / air-free
Oil Furnace / Boiler	100 ppm	as-measured

1214 Draft Testing

All heating system units should be tested for draft at the time of the efficiency test, during a cleaning and tuning, and under worst-case conditions (see Section 123, "Worst-Case Draft Testing"). Exceptions to this requirement include:

- Condensing furnaces and boilers.
- Direct-vent, sealed combustion appliances.
- Heating units with vent connectors under positive pressure.

Under all conditions, including worst-case, heating units must demonstrate a minimum draft strength corresponding to the values in Tables 121-3 and 121-4. Notice that typical oil-fired units have two draft values – overfire and breech. In addition, notice that draft readings for oil-fired units are not dependent on outdoor temperature – as atmospheric gas-fired units are – because the barometric damper on oil units automatically adjusts for differences in temperature.

Draft readings are often taken at a different location in the vent connector than combustion efficiency or carbon monoxide readings. Make sure that the draft reading is always taken at the proper location.

Atmospheric Gas Appliances Only
Acceptable Draft Test Readings for Various Outdoor Temperature Ranges
Table 121-3

ºF	<20	20-40	41-60	61-80	>80
Pascals	-5	-4	-3	-2	-1
Water Column inches	-.02	-.016	-.012	-.008	-.004

Power Oil Burners
Acceptable Draft Readings Overfire and at Breech
Table 121-4

Draft Reading Location	**Acceptable Draft**
Overfire Draft	-0.01 to -0.02 inches or -2.5 to -5 Pascals
Vent Connector or Breech	-0.04 to -0.06 inches or -10 to -15 Pascals

1215 Gas Leak Testing

Gas leak testing should be done for all natural gas and propane appliance lines and connections. Because propane is heavier than air and natural gas is lighter than air, hold the combustible gas detector probe just below a propane gas line and just above a natural gas line. All identified gas leaks should be referred to appropriate persons for repair or replacement.

1216 Temperature Rise

The temperature rise of a furnace distribution system should be measured before and then after any significant heating unit or distribution system repairs or modifications.

The measured temperature rise should be between 40^o and 70^oF or within the manufacturer's specified range. The specified temperature rise is almost always included on a nameplate on the furnace.

If the temperature rise is too high, it could be due to:

- Low air handler fan speed or broken fan belt.
- Obstruction in the return or supply ductwork, including a dirty filter.
- Inadequate or restricted return ductwork.
- Overfired burner.
- Dirty or defective blower.

If the temperature rise is too low, it could be due to:

- Air handler fan speed is too high.
- Excessive duct leakage.
- Underfired burner.

With the heating unit and blower operating, measure the temperature in a duct within 12 inches of the supply and return plenums. In a mobile home, measure the supply temperature at the supply register closest to the furnace.

If the temperature rise is out of range, take action to correct the cause.

1217 Clocking the Gas Meter

Clock the gas meter to measure gas input. Ensure that other gas appliances (water heater, dryer, range) do not fire when clocking the meter. Refer to table 121-5 for input rates based on clocking the gas meter. Use the following formula if the gas meter does not have a ½ ft^3 or 1 ft^3 dial:

1,000 Btuh = (dial type * 3600)/time for revolution

For example, a there is a 2 ft^3 dial on the gas meter and it takes 50 seconds to make one revolution. The metered gas input is 144,000 Btuh.

1,000 Btuh = (2 x 3600)/50 seconds = 144

Clocking the Gas Meter

Table 121-5

Using a watch, measure the number of seconds for either the ½ ft^3 or the 1 ft^3 to make one complete revolution. Read the corresponding input rate in 1,000 of Btus/ft^3.

Seconds for One Revolution on the Dial	½ ft^3	1 ft^3	Seconds for One Revolution on the Dial	½ ft^3	1 ft^3
10	180	360	40	45	90
11	164	327	41	44	88
12	150	300	42	43	84
13	138	277	43	42	84
14	129	257	44	41	82
15	120	240	45	40	80
16	112	225	46	39	78
17	106	212	47	38	77
18	100	200	48	37	75
19	95	189	49	37	73
20	90	180	50	36	72
21	86	171	51	35	71
22	82	164	52	35	69
23	78	157	53	34	68
24	75	150	54	33	67
25	72	144	55	33	65
26	69	138	56	32	64
27	67	133	57	32	63
28	64	129	58	31	62
29	62	124	59	30	61
30	60	120	60	30	60
31	58	116	62	29	58
32	56	113	64	29	56
33	55	109	66	29	54
34	53	106	68	28	53
35	51	100	70	26	51
36	50	100	72	25	50
37	49	97	74	24	48
38	47	95	76	24	47
39	46	92	78	23	46